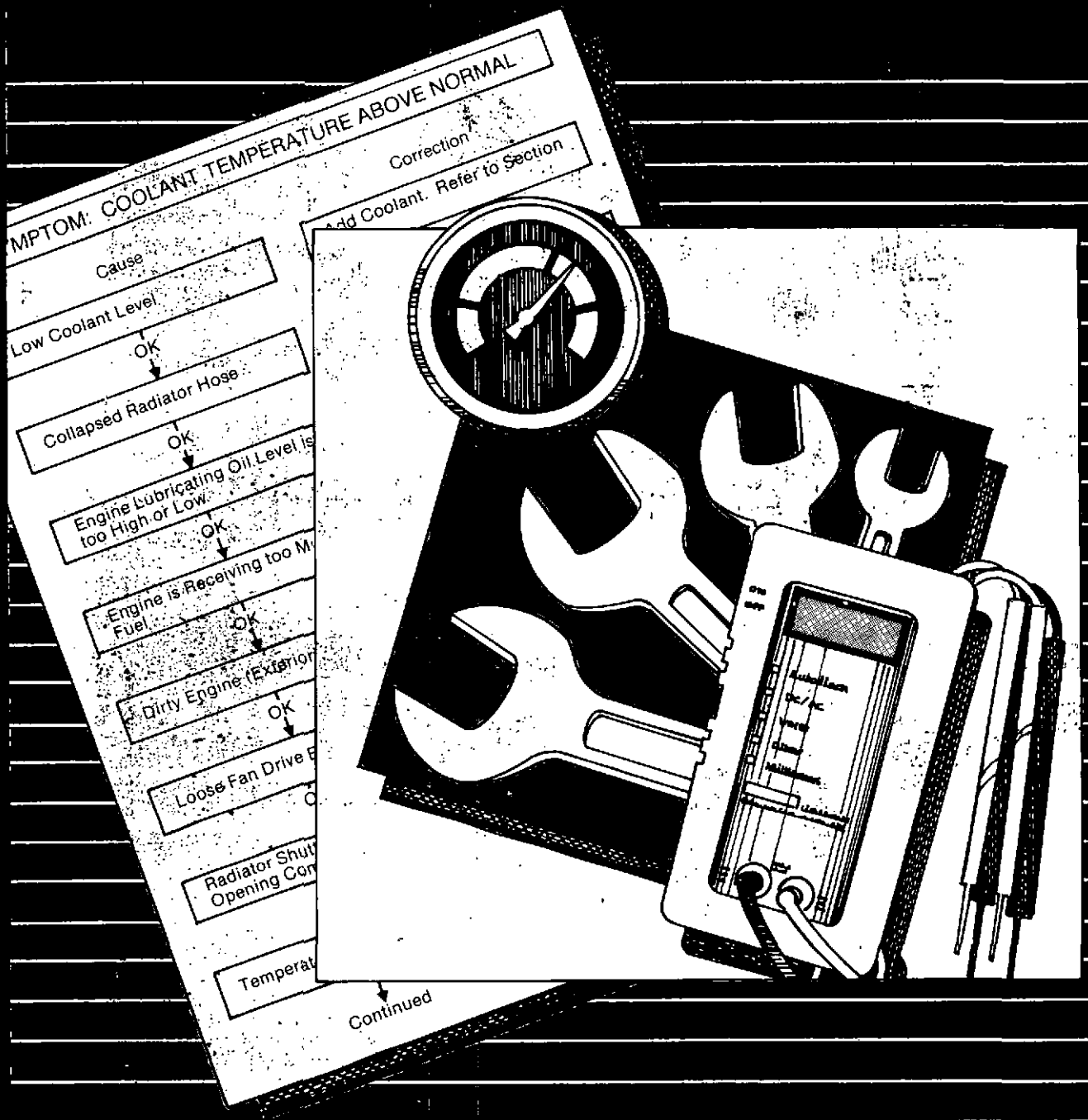
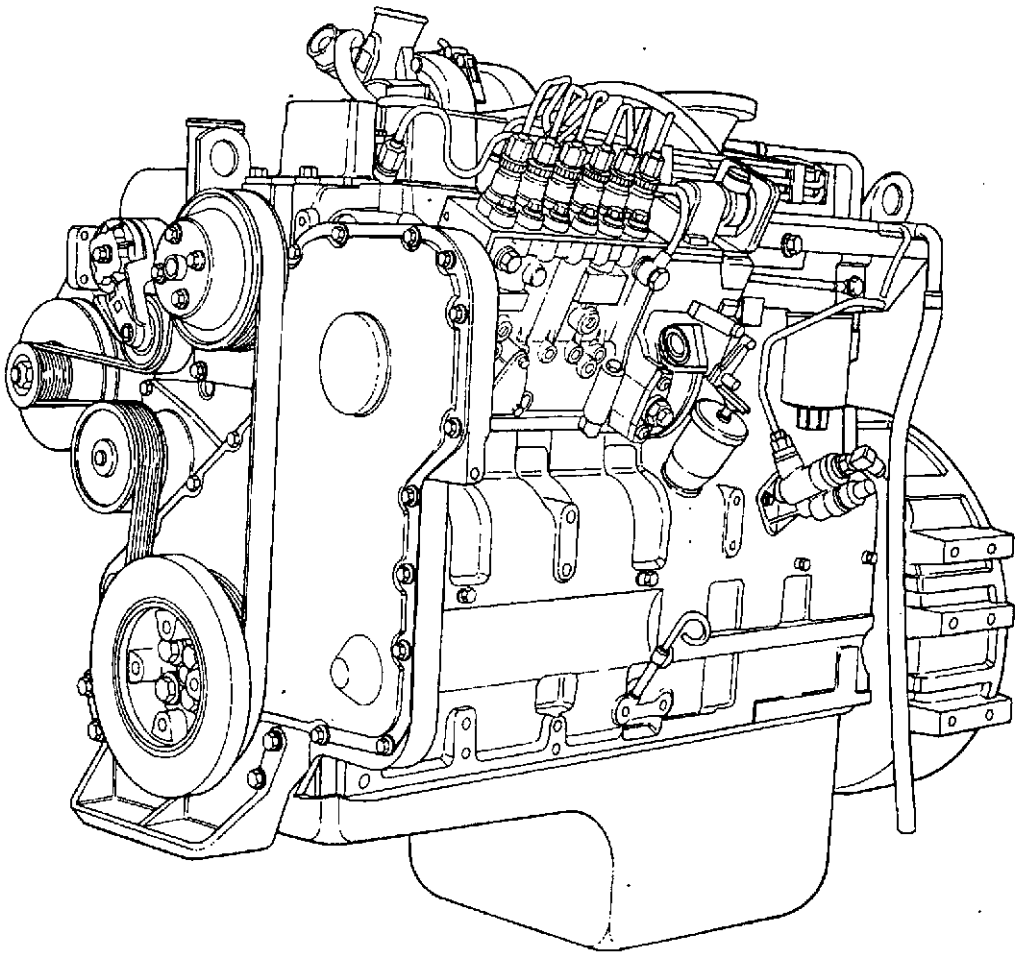
Troubleshooting and Repair Manual C Series Engines 1991 and 1994 Certification Levels



Troubleshooting and Repair Manual C Series Engines



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Foreword

This manual provides instructions for troubleshooting and repairing the C Series Engine in the chassis. Component and assembly rebuild procedures are provided in the C Series Engine Shop Manual. Refer to Page i-2 in the Introduction for instructions on how to use this manual.

The manual is organized to guide a service technician through the logical steps of identifying and correcting problems related to the engine.

This manual does **not** cover vehicle or equipment problems. Consult the vehicle or equipment manufacturer for repair procedures.

A series of specific service manuals (Shop, Specifications, Alternative Repair, and so on.) are available and can be ordered by filling out and mailing the Literature Order Form located in the Service Literature Section L.

The repair procedures used in this manual are recommended by Cummins Engine Co., Inc. Some service procedures require the use of special service tools. Use the correct tools as described.

Reporting of errors, omissions, and recommendations for improving this publication by the user is encouraged. Please use the postage paid, self-addressed Literature Survey Form in the back of this manual for communicating your comments.

The specifications and rebuild information in this manual is based on the information in effect at the time of printing. Cummins Engine Company, Inc. reserves the right to make any changes at any time without obligation. If differences are found between your engine and the information in this manual, contact a Cummins Authorized Repair Location, a Cummins Division Office, or the factory.

The latest technology and the highest quality components are used to manufacture Cummins engines. When replacement parts are needed, we recommend using only genuine Cummins or ReCon® exchange parts. These parts can be identified by the following trademarks:

Cummins

Cummins ReCon

HOLSET®

Fleetguard®

Premium Blue®

Table of Contents

Section i - Introduction

Section Contents

About the Manual

This C Series Troubleshooting and Repair Manual is intended to aid in determining the cause of engine-related problems and to provide recommended repair procedures. The manual is divided into sections by system. Each section provides general information, specifications, diagrams, and service tools, where applicable. The specific repair procedures are referenced in the Troubleshooting Logic Charts. The procedures in this manual were developed for the in-chassis environment.

How to Use the Manual

The manual is organized to provide an easy flow from problem identification to problem correction. A list of troubleshooting symptoms containing the most common engine problems is on Page T-2 in the Troubleshooting Section. Complete the following steps to locate and correct the problem:

(STEP 1.) Locate the symptom on the list.

Reference is made to the procedure number where the "Troubleshooting Logic Chart" is found.

(STEP 2.) The left column of the "Troubleshooting Logic Chart" indicates a probable cause, starting at the top with the simplest and easiest to repair, and continuing downward to the most difficult.

The right column provides a brief description of the corrective action with the reference number for the repair.

(STEP 3.) Locate the probable cause in the left column, and then turn to the procedure number in the right column.

The repair procedures are listed by system (Cooling, Lubricating Oil, Combustion Air, Compressed Air, Fuel, Electrical, and Base Engine Components).

(STEP 4.) The Troubleshooting Logic Charts are based on the following assumptions:

1. The engine has been installed according to the manufacturer's specifications.
2. The easiest repairs are done first.
3. "Generic" solutions to cover problems with the most common applications and Original Equipment Manufacturers (OEM's).

Symbols

The following symbols have been used in this manual to help communicate the intent of the instructions. When one of the symbols appears, it conveys the meaning defined below:

WARNING - Serious personal injury or extensive property damage can result if the warning instructions are **not** followed.

CAUTION - Minor personal injury can result or a part, an assembly, or the engine can be damaged if the caution instructions are **not** followed.

Indicates a **REMOVAL or DISASSEMBLY** step.

Indicates an **INSTALLATION or ASSEMBLY** step.

INSPECTION is required.

CLEAN the part or assembly.

PERFORM a mechanical or time **MEASUREMENT**.

LUBRICATE the part or assembly.

Indicates that a **WRENCH or TOOL SIZE** will be given.

TIGHTEN to a specific torque.

PERFORM an electrical **MEASUREMENT**.

Refer to another location in this manual or another publication for additional information.

The component weighs 23 kg [50 lb] or more. To avoid personal injury, use a hoist or get assistance to lift the component.

Simbolos

Los símbolos siguientes son usados en este manual para clarificar el proceso de las instrucciones. Cuando aparece uno de estos símbolos, su significado se especifica en la parte inferior.

ADVERTENCIA - Serios daños personales o daño a la propiedad puede resultar si las instrucciones de Advertencia **no** se consideran.

PRECAUCION - Daños menores pueden resultar, o de piezas del conjunto o el motor puede averiarse si las instrucciones de Precaución **no** se siguen.

Indica un paso de **REMOCION** o **DESMONTAJE.**

Indica un paso de **INSTALACION** o **MONTAJE.**

Se requiere **INSPECCION.**

LIMPIESE la pieza o el montaje.

EJECUTESE una **MEDICION** mecánica o del tiempo.

LUBRIQUESE la pieza o el montaje.

Indica que se dará una **LLAVE DE TUERCAS** o el **TAMAÑO DE HERRAMIENTA.**

APRIETESE hasta un par torsor específico.

EJECUTESE una **MEDICION** eléctrica.

Para información adicional refiérase a otro emplazamiento de este manual o a otra publicación anterior.

El componente pesa 23 kg [50 lb] o mas. Para evitar dano corporal empleen una cabria u obtengan ayuda para elevar el componente.

Symbole

In diesem Handbuch werden die folgenden Symbole verwendet, die wesentliche Funktionen hervorheben. Die Symbole haben folgende Bedeutung:

WARNUNG - Wird die Warnung **nicht** beachtet, dann besteht erhöhte Unfall- und Beschädigungsgefahr.

VORSICHT - Werden die Vorsichtsmassnahmen **nicht** beachtet, dann besteht Unfall- und Beschädigungsgefahr.

AUSBAU bzw. **ZERLEGEN.**

EINBAU bzw. **ZUSAMMENBAU.**

INSPEKTION erforderlich.

Teil oder Baugruppe **REINIGEN.**

DIMENSION - oder **ZEITMESSUNG.**

Teil oder Baugruppe **ÖLEN.**

WERKZEUGGRÖSSE wird angegeben.

ANZUG auf vorgeschriebenes Drehmoment erforderlich.

Elektrische **MESSUNG DURCHFÜHREN.**

Weitere Informationen an anderer Stelle bzw. in anderen Handbüchern.

Das teil weigt 23 kg [50 lb] oder mehr. Zur vermeidung von koerperverletzung winde benutzen oder hilfe beim heben des teils in anspruch nehmen.

Symboles

Les symboles suivants sont utilisés dans ce manuel pour aider à communiquer le but des instructions. Quand l'un de ces symboles apparaît, il évoque le sens défini ci-dessous:

AVERTISSEMENT - De graves lésions corporelles ou des dommages matériels considérables peuvent survenir si les instructions données sous les rubriques "Avertissement" **ne** sont **pas** suivies.

ATTENTION - De petites lésions corporelles peuvent survenir, ou bien une pièce, un ensemble ou le moteur peuvent être endommagés si les instructions données sous les rubriques "Attention" **ne** sont **pas** suivies.

Indique une opération de **DEPOSE.**

Indique une opération de **MONTAGE.**

L'INSPECTION est nécessaire.

NETTOYER la pièce ou l'ensemble.

EFFECTUER une **MESURE** mécanique ou de temps.

GRAISSER la pièce ou l'ensemble.

Indique qu'une **DIMENSION DE CLE** ou **D'OUTIL** sera donnée.

SERRER à un couple spécifique.

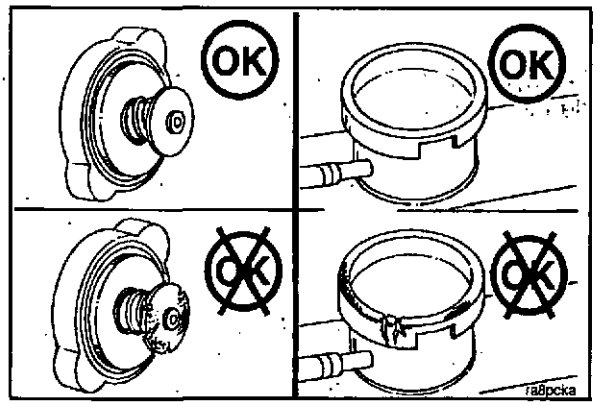
EFFECTUER une **MESURE** électrique.

Se reporter à un autre endroit dans ce manuel ou à une autre publication pour obtenir des informations plus complètes.

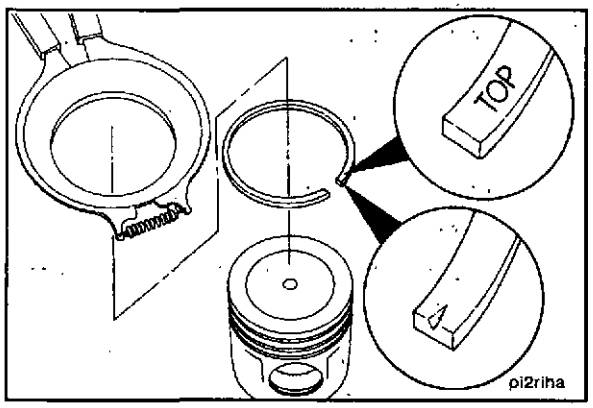
Le composant pese 23 kg [50 lb] ou davantage. Pour eviter toute blessure, employer un appariel de levage ou demander de l'aide pour le soulever.

Illustrations

The illustrations used in the "Repair Sections" of this manual are intended to give an example of a problem and to show what to look for and where the problem can be found. Some of the illustrations are "common" and might **not** look exactly like the engine or parts used in your application. The illustrations contain symbols to indicate an action required and an acceptable or **not** acceptable condition.



The illustrations are intended to show repair or replacement procedures with the engine "in-chassis." The illustration can differ from your application, but the procedure given will be the same.



Definition of Terms

AFC	Air Fuel Control
API	American Petroleum Institute
ASA	Air Signal Attenuator
ASTM	American Society of Testing and Materials
C	Celsius
CARB	California Air Resources Board
C.I.D.	Cubic Inch Displacement
Cm	Centimeter
CPL	Control Parts List
cSt	Centistokes
DCA	Diesel Coolant Additive
ECM	Electronic Control Module
E.C.S.	Emission Control System
EPA	Environmental Protection Agency
EPS	Engine Position Sensor
F	Fahrenheit
ft-lb	Foot Pound
GVW	Gross Vehicle Weight
Hg	Mercury
HP	Horsepower
H_2O	Water
in-lb	Inch Pound
kg	Kilograms
km	Kilometers
km/l	Kilometers per Liter
kPa	Kilopascal
l	Liter
m	Meter
mm	Millimeter
MPa	Megapascal
MPH	Miles Per Hour
MPQ	Miles Per Quart
N•m	Newton-meter
OEM	Original Equipment Manufacturer
ppm	Parts Per Million
psi	Pounds Per Square Inch
PTO	Power Takeoff
RPM	Revolutions Per Minute
S.A.E.	Society of Automotive Engineers
STC	Step Timing Control
VS	Variable Speed
VSS	Vehicle Speed Sensor

General Safety Instructions

Important Safety Notice

⚠ WARNING ⚠

Read and understand all of the safety precautions and warnings before performing any repair. This list contains the general safety precautions that **must** be followed to provide personal safety. Special safety precautions are included in the procedures when they apply.

- Make sure the work area surrounding the product is safe. Be aware of hazardous conditions that can exist.
- **Always** wear protective glasses and protective shoes when working.
- Do **not** wear loose-fitting or torn clothing. Remove all jewelry when working.
- Disconnect the battery and discharge any capacitors before beginning any repair work. Disconnect the air starting motor if equipped to prevent accidental engine starting. Put a "Do **Not** Operate" tag in the operator's compartment or on the controls.
- Use ONLY the proper engine barring techniques for manually rotating the engine. Do **not** attempt to rotate the engine by pulling or prying on the fan. This practice can cause serious personal injury, property damage, or damage to the fan blade(s) causing premature fan failure.
- If an engine has been operating and the coolant is hot, allow the engine to cool before you slowly loosen the filler cap and relieve the pressure from the cooling system.
- Do **not** work on anything that is supported ONLY by lifting jacks or a hoist. **Always** use blocks or proper stands to support the product before performing any service work.
- Relieve all pressure in the air, oil, and the cooling systems before any lines, fittings, or related items are removed or disconnected. Be alert for possible pressure when disconnecting any device from a system that utilizes pressure. Do **not** check for pressure leaks with your hand. High pressure oil or fuel can cause personal injury.
- To prevent suffocation and frostbite, wear protective clothing and ONLY disconnect liquid refrigerant (freon) lines in a well ventilated area.
- To avoid personal injury, use a hoist or get assistance when lifting components that weigh 23 kg [50 lb] or more. Make sure all lifting devices such as chains, hooks, or slings are in good condition and are of the correct capacity. Make sure hooks are positioned correctly. **Always** use a spreader bar when necessary. The lifting hooks **must not** be side-loaded.
- Corrosion inhibitor contains alkali. Do **not** get the substance in your eyes. Avoid prolonged or repeated contact with skin. Do **not** swallow internally. In case of contact, immediately wash skin with soap and water. In case of contact, immediately flood eyes with large amounts of water for a minimum of 15 minutes. IMMEDIATELY CALL A PHYSICIAN. KEEP OUT OF REACH OF CHILDREN.
- Naptha and Methyl Ethyl Ketone (MEK) are flammable materials and **must** be used with caution. Follow the manufacturer's instructions to provide complete safety when using these materials. KEEP OUT OF REACH OF CHILDREN.
- To avoid burns, be alert for hot parts on products that have just been turned OFF, and hot fluids in lines, tubes, and compartments.
- **Always** use tools that are in good condition. Make sure you understand how to use them before performing any service work. Use ONLY genuine Cummins or Cummins Recon® replacement parts.
- **Always** use the same fastener part number (or equivalent) when replacing fasteners. Do **not** use a fastener of lessor quality if replacements are necessary.

General Cleaning Instructions

Solvent and Acid Cleaning

Several solvent and acid-type cleaners can be used to clean the engine parts. **Cummins Engine Company, Inc. does not recommend any specific cleaners. Always** follow the cleaner manufacturer's instructions.

Experience has shown that the best results can be obtained using a cleaner that can be heated to 90 to 95 degrees Celsius [180 to 200 degrees Fahrenheit]. A cleaning tank that provides a constant mixing and filtering of the cleaning solution will give the best results.

Remove all the gasket material, o-rings, and the deposits of sludge, carbon, etc., with a wire brush or scraper before putting the parts in a cleaning tank. Be careful **not** to damage any gasket surfaces. When possible, steam clean the parts before putting them in the cleaning tank.

Warning: The use of acid can be extremely dangerous to personnel, and can damage the machinery. Always provide a tank of strong soda water as a neutralizing agent.

Rinse all of the parts in hot water after cleaning. Dry completely with compressed air. Blow the rinse water from all of the capscrew holes and the oil drillings.

If the parts are **not** to be used immediately after cleaning, dip them in a suitable rustproofing compound. The rustproofing compound **must** be removed from the parts before installation on the engine.

Steam Cleaning

Steam cleaning can be used to remove all types of dirt that can contaminate the cleaning tank. It is a good way to clean the oil drillings.

Warning: Wear protective clothing to prevent personal injury from the high pressure and extreme heat.

Do **not** steam clean the following parts:

1. Electrical Components
2. Wiring
3. Injectors
4. Fuel Pump
5. Belts and Hoses
6. Bearings

Glass or Plastic Bead Cleaning

Glass or plastic bead cleaning can be used on many engine components to remove carbon deposits. The cleaning process is controlled by the size of the glass or plastic beads, the operating pressure, and the cleaning time.

Caution: Do not use glass or plastic bead cleaning on aluminum piston skirts. Do not use glass bead cleaning on aluminum ring grooves. Small particles of glass or plastic will embed in the aluminum and result in premature wear. Valves, turbocharger shafts, etc., can also be damaged. Follow the cleaning directions listed in the procedures.

NOTE: Plastic bead blasting media, Part No. 3822735, can be used to clean aluminum ring grooves. Do **not** use any bead blasting media on pin bores or aluminum skirts.

Follow the equipment manufacturer's cleaning instructions. The following guidelines can be used to adapt to manufacturer's instructions:

1. Bead size:
   - Use U.S. size No. 16-20 for piston cleaning with plastic bead media, Part No. 3822735.
   - Use U.S. size No. 70 for piston domes with glass media.
   - Use U.S. size No. 60 for general purpose cleaning with glass media.
2. Operating Pressure:
   - Glass: Use 620 kPa [90 psi] for general purpose cleaning.
   - Plastic: Use 270 kPa [40 psi] for piston cleaning.
3. Steam clean or wash the parts with solvent to remove all of the foreign material and glass or plastic beads after cleaning. Rinse with hot water. Dry with compressed air.
4. Do **not** contaminate the wash tanks with glass or plastic beads.

General Repair Instructions

This engine incorporates the latest diesel technology; yet, it is designed to be repaired using normal repair practices performed to quality standards.

- **Cummins Engine Company, Inc. does not recommend or authorize any modifications or repairs to engines or components except for those detailed in Cummins Service Information. In particular, unauthorized repair to safety-related components can cause personal injury. Below is a partial listing of components classified as safety-related:**

  Air Compressor
  Air Controls
  Air Shutoff Assemblies
  Balance Weights
  Cooling Fan
  Fan Hub Assembly
  Fan Mounting Bracket(s)
  Fan Mounting Capscrews
  Fan Hub Spindle
  Flywheel
  Flywheel Crankshaft Adapter
  Flywheel Mounting Capscrews
  Fuel Shutoff Assemblies
  Fuel Supply Tubes
  Lifting Brackets
  Throttle Controls
  Turbocharger Compressor Casing
  Turbocharger Oil Drain Line(s)
  Turbocharger Oil Supply Line(s)
  Turbocharger Turbine Casing
  Vibration Damper Mounting Capscrews

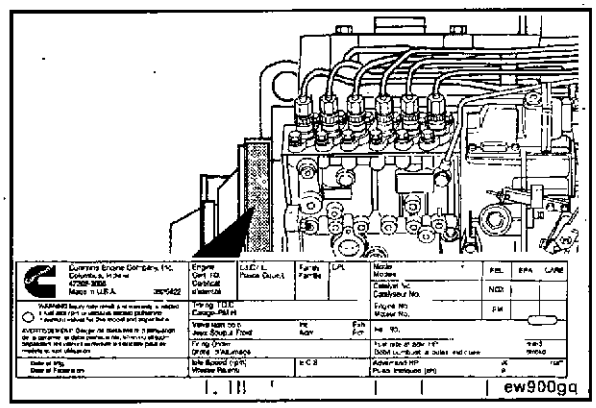
- **Follow All Safety Instructions Noted in the Procedures.**
  - Follow the manufacturer's recommendations for cleaning solvents and other substances used during the repair of the engine. **Always** use good safety practices with tools and equipment.
- **Provide A Clean Environment and Follow the Cleaning Instructions Specified in the Procedures**
  - The engine and its components **must** be kept clean during any repair. Contamination of the engine and components will cause premature wear.
- **Perform the Inspections Specified in the Procedures.**
- **Replace all Components or Assemblies Which are Damaged or Worn Beyond the Specifications**
- **Use Genuine Cummins New or ReCon® Service Parts and Assemblies**
  - The assembly instructions have been written to use again as many components and assemblies as possible. When it is necessary to replace a component or assembly, the procedure is based on the use of new Cummins or Cummins ReCon® components. All of the repair services described in this manual are available from all Cummins Distributors and most Dealer locations.
- **Follow The Specified Disassembly and Assembly Procedures to Avoid Damage to the Components.**

Complete rebuild instructions are available in the shop manual which can be ordered or purchased from a Cummins Authorized Repair Location. Refer to Section L, Literature, for ordering instructions.

NOTES

Section E - Engine Identification

Section Contents

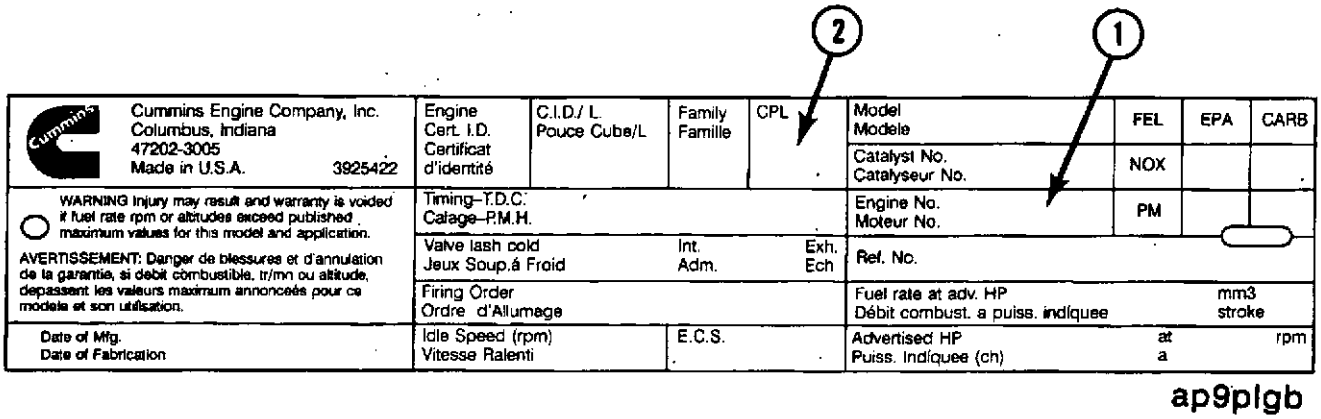


Engine Identification

Engine Dataplate

The engine dataplate shows specific information about your engine. The engine serial number (1) and Control Parts List (CPL) (2) provide information for ordering parts and service needs.

NOTE: The engine dataplate **must not** be changed unless approved by Cummins Engine Company, Inc.



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The model name for engines in automotive applications provides the data shown in the following example:

Example

C 8.3-275

- 275 — Rated Horsepower
- 8.3 — Displacement in Liters
- C — Engine Series

The following example shows a model name of an engine for non-automotive applications:

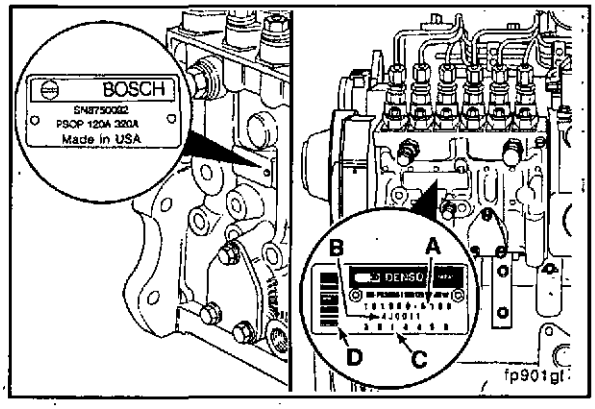
Example

6 C T A 8.3

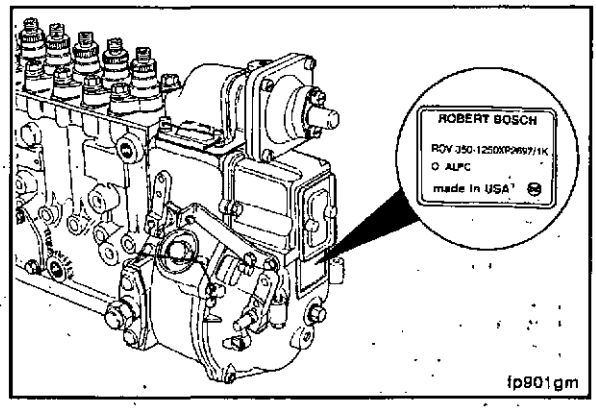
- 8.3 — Displacement in Liters
- A — Aftercooled
- T — Turbocharged
- C — Engine Series
- 6 — Number of Cylinders

Fuel Injection Pump Dataplate

The Bosch and Nippondenso fuel injection pump dataplate is located on the side of the injection pump. It provides information for fuel pump calibration.



The Cummins part number for the fuel pump-governor combination is located on the governor dataplate.



General Engine Specifications

General Engine Data

Bore ..... 114 mm [4.49 in]

Stroke ..... 135 mm [5.32 in]

Displacement ..... 8.27 liters [504.5 in^3]

Compression ratio

- 6C8.3 ..... 16.4:1
- 6CT8.3 ..... 17.3:1
- 6CTA8.3 ..... 16.5:1
- C8.3*
  - High Torque 17.3:1
  - Low Torque 18:1

Firing order 1-5-3-6-2-4

Valve clearance

- Intake ..... 0.30 mm [0.012 in]
- Exhaust ..... 0.61 mm [0.024 in]

Engine rotation (viewed from front of engine) ..... Clockwise

Aspiration

- 6C8.3 ..... Naturally Aspirated
- 6CT8.3 ..... Turbocharged
- 6CTA8.3 ..... Turbocharged and Aftercooled
- C8.3* ..... Charge Air Cooled (CAC)

Engine weight (with standard accessories)

- Dry weight ..... 603 to 612 kg [1330 to 1350 lb]
- Wet weight (with engine fluids) ..... 635 to 658 kg [1400 to 1450 lb]

Lubrication System

Oil pressure

- At Idle (minimum allowable) ..... 69 kPa [10 psi]
- At rated speed (minimum allowable) ..... 207 kPa [30 psi]

Regulating valve opening pressure ..... 518 kPa [75 psi]

Differential pressure to open oil filter bypass valve ..... 138 kPa [20 psi]

Oil flow at rated speed (less flow through pressure regulator) ..... 57 rpm [16 gpm]

Oil temperature at rated speed ..... 98.9° to 126.6°C [210° to 260°F]

Oil temperature thermostat

- Fully open ..... 116°C [241°F]
- Close ..... 104°C [219°F]

Oil pan capacity (all engines) (high - low) ..... 18.9 to 15.1 liters [20 to 16 U.S. Qts.]

Total system capacity

- 6C8.3 ..... 23.6 liters [25.0 U.S. Qts.]
- 6CT8.3 ..... 23.8 liters [25.2 U.S. Qts.]

Cooling System

Thermostats

- Begins to open ..... 81°C to 83°C [178°F to 182°F]
- Fully open ..... 95°C [203°F]

Top tank temperature

- Maximum allowable ..... 100°C [212°F]
- Minimum recommended ..... 70°C [158°F]

Pressure cap for 99°C [210°F] system ..... 50 kPa [7 psi]

Pressure cap for 104°C [220°F] system ..... 103 kPa [15 psi]

Water Pressure (Upper manifold) at 2000 RPM engine speed ..... 103 to 276 kPa [15 to 40 psi]

Coolant flow (thermostats fully opened, engine speed 2000 RPM) ..... 258 lpm [68 gpm]

Coolant capacity (engine only)

- 6C8.3, 6CT8.3, C8.3* ..... 9.9 liters [10.5 U.S. Qts.]
- 6CTA8.3 ..... 10.9 liters [11.5 U.S. Qts.]

Intake Air and Exhaust System

Maximum allowable intake restriction at rated speed and load (with dirty air filter element)

- 6C8.3 ..... 50.8 cm H_20 [20 in H_20]
- 6CT8.3, 6CTA8.3, C8.3* ..... 63.5 cm H_20 [25 in H_20]

Maximum turbocharger outlet restriction at rated speed and load

- 6CT8.3, 6CTA8.3, C8.3* ..... 76.2 mm Hg [3 in Hg]
- *C8.3 with catalyst ..... 152.4 mm Hg [6.0 in Hg]
- 6CT8.3, 6CTA8.3, C8.3* ..... 101.6 cm H_20 [40 in H_20]

Fuel System

Fuel transfer pump maximum inlet restriction

- 6C8.3, 6CT8.3, C8.3* ..... 100 mm Hg [4 in Hg]

Fuel transfer pump minimum output pressure at rated speed

- 6C8.3, 6CT8.3, 6CTA8.3, C8.3* (all in-line)
  - P Pump (High Flow) ..... 172 kPa [25 psi]
  - Nippendenso EP-9, Bosch A, MW (Low Flow) ..... 83 kPa [12 psi]
- Minimum pressure to fuel pump inlet (all in-line) ..... 1.2 Barr [18 psi]

Fuel filter restriction (maximum pressure drop across filters) ..... 35 kPa [5 psi]

Fuel return restriction (maximum) ..... 518 mm Hg [20.4 in Hg]

*** All 1991 and newer automotive engines with charge air cooling are designated as C8.3**

Electrical System

Minimum Recommended Battery Capacity

12 Volt System

-18°C [0°F] Cold cranking amperes 1800

(Reserve capacity amperes)* ..... (640)

0°C [32°F] Cold cranking amperes 1280

(Reserve capacity amperes)* ..... (480)

24 Volt System**

-18°C [0°F] Cold cranking amperes 900

(Reserve capacity amperes)* ..... (320)

0°C [32°F] Cold cranking amperes 640

(Reserve capacity amperes)* ..... (240)

* The number of plates within a given battery size determining reserve capacity. Reserve capacity determines the length of time sustained cranking can occur.

** Per battery (two 12 volt batteries in series) CCA Ratings are based on -18°C [0°F].

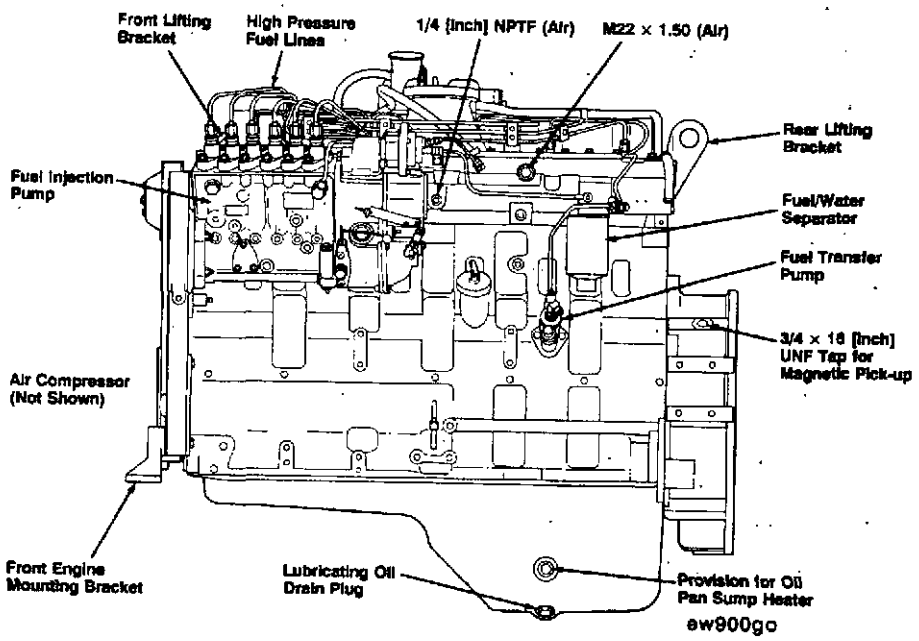
Batteries (Specific Gravity)

Specific Gravity at 27°C [80°F]	State of Charge
1.260 - 1.280	100%
1.230 - 1.250	75%
1.200 - 1.220	50%
1.170 - 1.190	25%
1.110 - 1.130	Discharged

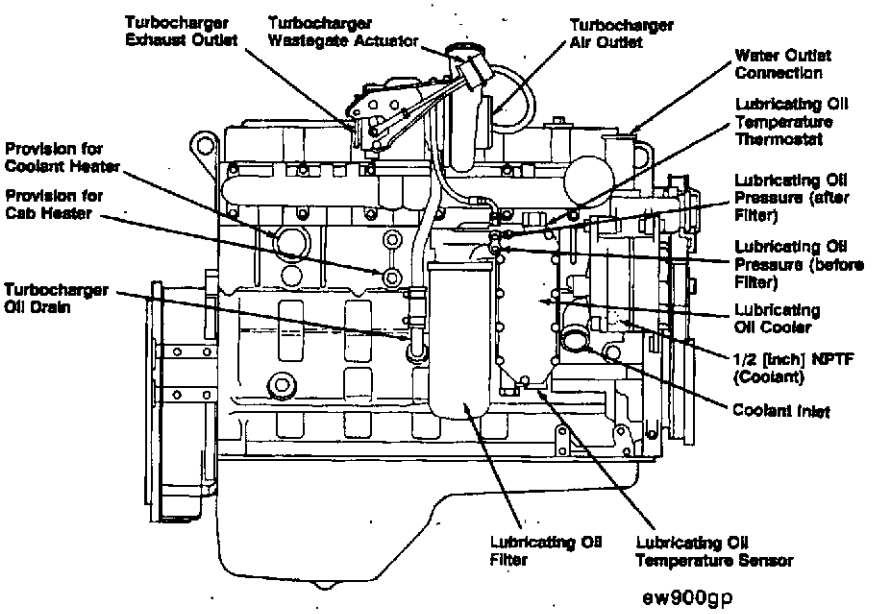
Engine Diagrams

The following illustrations contain information about engine components, filter locations, drain points and access locations for instrumentation and engine controls.

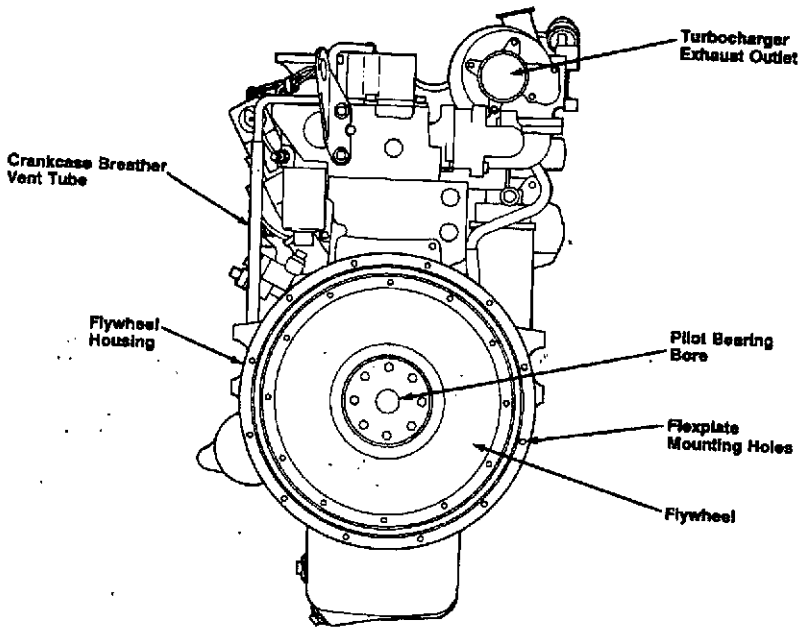
The information and configuration of components shown in these drawings are of a general nature. Some component locations will vary depending on applications and installations.



Fuel Pump Side View



Turbocharger Side View



Rear View

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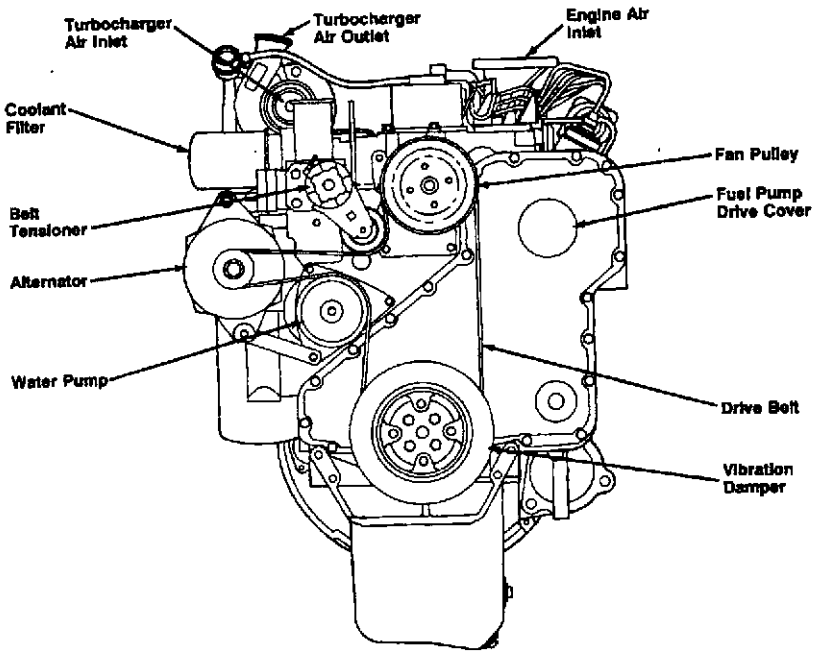

Front View

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NOTES

Section T - Troubleshooting Logic

Section Contents

Section T - Troubleshooting

Procedures and Techniques

A thorough analysis of the customer's complaint is the key to successful troubleshooting. The more information known about a complaint, the faster and easier the problem can be solved.

The "Troubleshooting Symptoms Charts" beginning on Page T-3 are organized so that a problem can be located and corrected by doing the easiest and most logical things first. Complete all steps in the sequence shown from top to bottom.

It is **not** possible to include all the solutions to problems that can occur; however, these charts should stimulate a thought process that will lead to the cause and correction of the problem.

Follow these basic troubleshooting steps:

- Get all the facts concerning the complaint.
- Analyze the problem thoroughly.
- Relate the symptoms to the basic engine systems and components.
- Consider any recent maintenance or repair action that may relate to the problem.
- Double-check before beginning any disassembly.
- Solve the problem by using the logic charts and doing the easiest things first.
- Determine the cause of the problem and make a thorough repair.
- After repairs have been made, operate the engine to make sure the cause of the problem has been corrected.

Troubleshooting Symptoms Charts

Use the charts on the following pages of this section to aid in diagnosing specific engine problems. Read each row of blocks from top to bottom. Follow the arrows through the chart to identify the corrective action.

Air Compressor Operates with Excessive Noise

Cause	Corrections
Excessive Carbon Buildup in the Air Compressor	Check the air compressor for carbon buildup. Refer to Procedure 4-01.
OK ↓	
Air compressor drive gear or engine gear train damaged	Inspect condition of gears and repair as needed. Refer to Procedure 4-05.
OK ↓	
Internal Air Compressor Damage	Replace the air compressor. Refer to Procedure 4-05.

Air Compressor Pumping Excessive Lubricating Oil into Air System

Cause	Corrections
Air Compressor Cylinder Bore or Piston Rings are Worn or Damaged	Check air compressor discharge line. Refer to Procedure 4-01.
OK ▼	
For E Type Air Compressors, E CON Valve Plumbed Wrong or Malfunctioning	Correct the plumbing or replace the valve.

Air Compressor Air Pressure Rises Slowly

Cause	Corrections
Air System Leaks	Check for air compressor gasket leaks. Refer to Procedure 4-02. Refer to the manufacturer's instructions for other air system leaks.
OK ⬇	
Carbon Buildup in the Air Discharge Line Excessive	Inspect the discharge line. Refer to Procedure 4-01.
OK ⬇	
Air System Component is Malfunctioning	Check operation of check valves, alcohol evaporators, air driers, etc. Refer to the manufacturer's instructions.
OK ⬇	
Air Compressor Unloader Valve Assembly Malfunctioning	Check unloader valve operation. Refer to Procedure 4-03.
OK ⬇	
Air Compressor Intake or Exhaust Valve Air Leaks	Inspect the intake and exhaust valve assemblies. Refer to Procedure 4-01.

Air Compressor Will Not Maintain Adequate Air Pressure (Not Pumping Continuously)

Cause	Corrections
Air System Leaks Excessive	Check air system plumbing. Refer to the manufacturer's instructions.
OK ↓	
Air Governor is Malfunctioning or Not Set Correctly	Check air governor. Refer to Procedure 4-04.

Air Compressor Will Not Pump Air Pressure

Cause	Corrections
Air System Leaks Excessive	Check air system plumbing. Refer to the manufacturer's instructions.
OK ▼	
Air Governor Malfunctioning or Not Set Correctly	Check air governor operation. Refer to Procedure 4-04.
OK ▼	
Air Compressor Unloader Valve Assembly Malfunctioning	Check the unloader valve operation. Refer to Procedure 4-03.

Air Compressor Will Not Stop Pumping Air

Cause	Corrections
Air System Leaks	Check air compressor for gasket leaks. Refer to Procedure 4-02. Refer to the manufacturer's instructions for other air system leaks.
OK ↓	
Air Compressor Unloader Valve is Not Receiving Correct signal From the Air Governor	Check the air governor operation. Refer to Procedure 4-03.
OK ↓	
Air Compressor Unloader Valve Assembly Leaks	Check the unloader valve operation. Refer to Procedure 4-03.
OK ↓	
Air Compressor Unloader Valve Spring Incorrect	Check the unloader valve spring specifications and application. Refer to Procedure 4-03.

Alternator Not Charging or Insufficient Charging

Cause	Corrections
Battery Connections Loose or Corroded	Clean/tighten battery connections. Refer to Procedure 6-01.
OK ↓	
Battery Condition	Load test the battery. If battery charge is low, charge the battery and load test again. If the battery fails the load test, replace the battery.
OK ↓	
Alternator Belt Slipping	Check/replace belt tensioner. Refer to Procedure 1-04.
OK ↓	
Alternator Pulley Loose on Shaft	Tighten pulley. Refer to Procedure 6-03.
OK ↓	
Gauge or Lamp Malfunction	Check/replace the gauge or lamp. Refer to Procedure 6-01.
OK ↓	
Alternator Wires Loose or Broken	Repair Wiring.
OK ↓	
Alternator Malfunction	Replace alternator. Refer to Procedure 6-03. Refer to the vehicle manufacturer's instructions for troubleshooting.

Compression Knock

Cause	Corrections
Ether Starting Aid Malfunctioning	Repair or replace ether starting aids.
OK ↓	
Air in Fuel System	Bleed fuel system and check for suction leaks. Refer to Procedure 5-01.
OK ↓	
Fuel Quality Poor	Verify by operating engine from a temporary tank that contains good fuel. Refer to "Fuel Specifications C Series" in the Operation and Maintenance Manual.
OK ↓	
Engine Overloaded	Use lower gear, verify that engine load rating is not being exceeded.
OK ↓	
Injection Pump Timing Incorrect	Check injection pump timing. Refer to Procedure 5-11.
OK ↓	
Injectors Malfunctioning	Replace injectors. Test and repair. Refer to Procedure 5-07.

Coolant Contaminated

Cause	Corrections
Coolant Rusty, Operation Without Correct Mixture of Antifreeze, DCA4 and Water	Drain and flush the cooling system. Fill with correct mixture of antifreeze and water. Refer to Procedure 1-01.
OK	
	Review the coolant change interval. Refer to the C Series Operation and Maintenance Manual.
Transmission Oil Cooler Leaking	Check/replace oil cooler. Refer to equipment manufacturer's instructions.
OK	
Oil Leaks From Oil Cooler, Cylinder Head Gasket, Cylinder Head and Cylinder Block	Refer to Troubleshooting Logic Chart for "Lubricating Oil Loss."

Coolant Loss

Cause	Corrections
Radiator or Cab Heater Leaking	Visually inspect the radiator, heater hoses and connections to locate the leak. Refer to Procedure 1-02.
OK	
	If oil is present in the coolant, check for a transmission or lube oil cooler leak. Refer to Procedure 2-03.
Engine External Leaks	Visually inspect the engine and components for seal, gasket, or drain cock leaks. Refer to Procedure 2-03.
OK	
Overheating or Leaking Compression Gases Resulting in Loss Through the Radiator Overflow	Refer to Troubleshooting Logic Chart for "Coolant Temperature Above Normal".
OK	
Transmission Cooler Leaking, if Equipped	Check for mixing of coolant and transmission fluid.
OK	
Air Compressor Head or Head Gasket Leaking	Check for coolant in the oil. Check/replace head or gasket. Refer to the equipment manufacturer's instructions.
OK	

(Continued)

Coolant Loss (Continued)

Cause	Corrections
Aftercooler Leaking	Check/replace the aftercooler. Check for coolant in the intake manifold and in the oil. Refer to Procedure 3-10.
OK ▼	
Lubricating Oil Cooler Leaking	Check/replace the oil cooler. Check for coolant in the oil. Refer to Procedure 2-03.
OK ▼	
Cylinder Head Gasket Leaking	Check/replace the head gasket. Refer to Procedure 7-09. Check liner protrusion. Refer to Procedure 7-15.
OK ▼	
Cylinder Head Cracked, Porous, or Expansion Plugs Leaking	Check/replace the head. Refer to Procedure 7-09.
OK ▼	
Liner O-Ring Leaking	Remove the oil pan and check liner o-rings for leakage. Refer to Procedure 2-13.
OK ▼	
Cylinder Block Coolant Passages Leaking	Check/replace the cylinder block. Refer to the C Series Shop Manual.

Coolant Temperature Above Normal - Gradual Overheat

Cause	Corrections
Coolant Level Low	Add coolant. Refer to Procedure 1-01. Locate and correct the source of the leak. Refer to Troubleshooting Logic Chart for "Coolant Loss".
OK ▼	
Radiator Charge Air Cooler Fins Plugged (Automotive Only)	Inspect charge air cooler fins, clean as necessary. Refer to Procedure 3-07.
OK ▼	
Air Flow to the Radiator Inadequate or Restricted	Check and repair fan shroud, fan sensor and fan clutch as required. Refer to the equipment manufacturer's instructions.
OK ▼	
Water Pump or Fan Drive Belt Loose	Check the belt tensioner. Refer to Procedure 1-04.
OK ▼	
Radiator Hose Collapsed, Restricted or Leaking	Inspect hoses, replace if necessary. Refer to Procedure 1-02.
OK ▼	
Lubricating Oil Level Incorrect	Add or drain engine oil. Refer to Procedure 2-06.
OK ▼	
Cooling Fan Shroud Damaged or Missing	Inspect shroud, repair/replace or install. Refer to Procedure 1-02.
OK ▼	
Radiator Cap Incorrect or Malfunctioning	Check the radiator cap, replace if necessary. Refer to Procedure 1-02.
OK ▼	

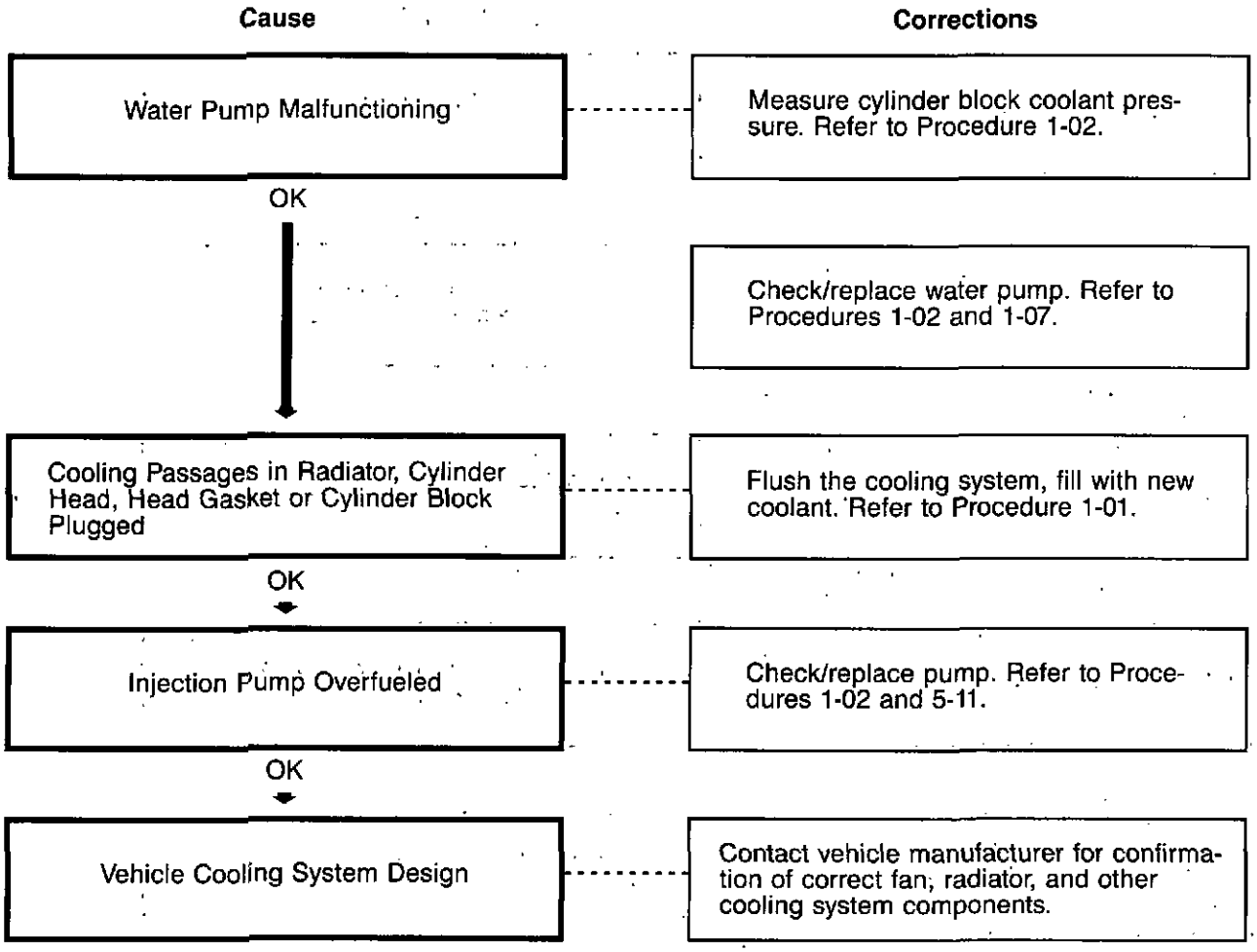
(Continued)

Coolant Temperature Above Normal - Gradual Overheat (Continued)

Cause	Corrections
Anti-freeze Over Concentrated	Check concentration, partially drain the cooling system, replace with water. Refer to Procedure 1-01.
OK ↓	
Temperature Sensor or Gauge Malfunctioning	Test the gauge and sensor, repair or replace if necessary. Refer to Procedure 1-02.
OK ↓	
Thermostat Incorrect, Missing or Malfunctioning	Check/replace thermostat. Refer to Procedure 1-08.
OK ↓	
Radiator Shutters Are Not Opening Completely or Cold Weather Radiator Cover Closed	Inspect the shutters, repair or replace if necessary. Open radiator cover. Refer to Procedure 1-02.
OK ↓	
Air or Combustion Gases in Cooling System	Check hose clamps for leaks on the suction side of the pump. Make sure the fill rate is not being exceeded.
OK ↓	
	If aeration continues, check for compression leak through cylinder head gasket. Refer to Procedure 1-02.

(Continued)

Coolant Temperature Above Normal - Gradual Overheat (Continued)



Coolant Temperature Above Normal - Sudden Overheat

Cause	Corrections
Coolant Level Low	Add coolant. Refer to Procedure 1-01.
OK ↓	
Temperature Sensor Malfunctioning	Check/clean sensor and coolant passage. Refer to Procedure 1-01.
OK ↓	
	Test/replace sensor. Refer to Procedure 1-02.
Temperature Gauge Malfunctioning	Test the gauge, repair or replace if necessary. Refer to Procedure 1-02.
OK ↓	
Fan Drive Belt Broken or Loose	Check belt and tensioner. Refer to Procedure 1-02.
OK ↓	
Radiator Hose Collapsed, Restricted, or Leaking	Inspect hoses. Refer to Procedure 1-02.
OK ↓	
Radiator Cap Incorrect or Malfunctioning. Cap Rated Pressure Too Low	Check the radiator pressure cap. Refer to Procedure 1-02.
OK ↓	
Thermostat Incorrect or Malfunctioning	Check thermostat. Refer to Procedure 1-02.
OK ↓	

(Continued)

Coolant Temperature Above Normal - Sudden Overheat (Continued)

Cause	Corrections
Radiator Shutters Are Not Opening Completely or Cold Weather Radiator Cover Closed. Shutterstat Setting Incorrect	Inspect the shutters. Repair or replace if necessary. Open radiator cover. Refer to Procedure 1-02. Check shutterstat setting. Refer to Procedure 1-02.
OK ▼	
Air or Combustion Gases in the Cooling System	Check for air or combustion gases in the cooling system. Refer to Procedure 1-02.
OK ▼	
Vent Line From Engine and/or Radiator Plugged or Incorrectly Routed	Check routing and operation of vent line. Refer to Procedure 1-12.
OK ▼	
Water Pump Malfunctioning	Check water pump operation. Replace the water pump. Refer to Procedure 1-02.

Coolant Temperature Below Normal

Cause	Corrections
Air Flow Across Radiator Excessive	Check/repair fan clutch, and viscous fan, as required. Refer to the manufacturer's instructions.
OK ▼	
Radiator Shutters Stuck in Open Position	Inspect the shutters, repair or replace if necessary. Refer to Procedure 1-02.
OK ▼	
Thermostat Broken, Damaged, Incorrect or Malfunctioning	Check thermostats and replace if necessary. Refer to Procedures 1-02 and 1-07.
OK ▼	
Fan Malfunctioning	Check fan for continuous operation. Refer to Procedure 1-02.

Engine Crankcase Gases (Blowby) - Excessive

Cause	Corrections
Crankcase Breather Vent Tube Restricted	Check breather tube restriction. Refer to Procedures 7-03 and 8-01.
OK ⬇	
Turbocharger Seals Leaking	Check turbocharger seals. Refer to Procedure 3-01.
OK ⬇	
Air Compressor Malfunctioning	Check air compressor. Refer to Procedure 4-02.
OK ⬇	
Cylinder Head Valve Guides Excessively Worn	Replace cylinder head. Refer to Procedure 7-09.
OK ⬇	
Piston Rings Broken or Worn	Check piston rings and cylinder liners. Refer to Procedure 7-13.

Engine Cranks, But Will Not Start - No Smoke from Exhaust

Cause	Corrections
No Fuel in Tank	Add fuel.
OK	
Electrical or Manual Fuel Shutdown Not Open	Check for loose wires and verify that the solenoid is functioning. Check to be sure manual shut off lever is in the run position. Refer to Procedure 5-01.
OK	
Improper Starting Procedure	Verify proper starting procedure. Refer to Starting Instructions in the Operation and Maintenance Manual.
OK	
Injection Pump Not Receiving Fuel	Loosen the bleed plug at the filter head end. Operate the hand primer on the fuel transfer pump to check for fuel. Check/replace fuel transfer pump if necessary. Refer to Procedure 5-01, 5-04.
OK	
Air in the Fuel System. If the Condition Occurs During Initial Start, Following an Extended Period of Non Use or After Replacing a Fuel System Component	Bleed the fuel system. Refer to Procedure 5-01.
OK	
Fuel Drain Back	Verify that the fuel return line is plumbed to the bottom of the fuel tank.
OK	
Malfunctioning Fuel Return Overflow Valve	Check fuel pump return overflow valve. Refer to Procedure 5-09.
OK	
Fuel Filter Plugged With Water or Other Contamination	Drain fuel/water separator or replace fuel filter. Refer to Procedure 5-01.
OK	

(Continued)

Engine Cranks, But Will Not Start - No Smoke From Exhaust (Continued)

Cause	Corrections
Injection Pump Timing Incorrect	Check injection pump timing. Refer to Procedure 5-11.
OK ▼	
Injection Pump Worn or Malfunctioning	Remove the fuel injection pump, have calibration checked. Refer to Procedure 5-11.
OK ▼	
Camshaft Timing Incorrect	Check/correct gear train timing alignment. Refer to Procedure 7-22.

Engine Difficult to Start or Will Not Start - Exhaust Smoke Present

Cause	Corrections
Starting Procedure Incorrect	Refer to the Operation and Maintenance Manual.
OK ▼	
Engine Cranking Speed Too Slow	Check engine cranking RPM. Refer to Troubleshooting Logic Chart for "Engine Will Not Crank or Cranks Slowly".
OK ▼	
Electrical or Manual Fuel Shut Down Binds	Check for loose wires and verify that the solenoid is functioning. Check to be sure manual shutoff lever is not binding at the injection pump. Refer to Procedure 5-01.
OK ▼	
Improper Starting Procedure	Verify proper starting procedure. Refer to Starting Instructions in the Operation and Maintenance Manual.
OK ▼	
Starting Aid Needed for Cold Weather or Not Working Properly	Check/repair or replace cold starting aid, if necessary.
OK ▼	
Air in the Fuel System	Bleed the fuel system and check for suction leaks. Refer to Procedure 5-01.
OK ▼	
Fuel Drain Back	Verify that the fuel return line is plumbed to the bottom of the fuel tank.
OK ▼	
Malfunctioning Fuel Return Overflow Valve	Check/replace return overflow valve. Refer to Procedure 5-09.
OK ▼	

(Continued)

Engine Difficult to Start or Will Not Start - Exhaust Smoke Present (Continued)

Cause	Corrections
Fuel Supply Restricted	Clean or replace pre-filters and screens and check fuel lines for restrictions. Refer to Procedure 5-01.
OK ↓	
Intake Air System Restricted	Check intake air system for restrictions. Refer to Procedure 3-06.
OK ↓	
Fuel Contaminated	Verify by operating engine from a temporary supply tank.
OK ↓	
Injection Pump Timing Incorrect	Check top dead center (TDC). Refer to Procedure 7-07. Check injection pump timing. Refer to Procedure 5-11. Check/time the fuel injection pump using the spill port timing if equipment is available. Refer to Procedure 5-13.
OK ↓	
Injectors Worn or Malfunctioning	Check/replace injectors. Refer to Procedure 5-07.
OK ↓	
Valves Incorrectly Adjusted	Adjust valves. Refer to Procedure 7-06.
OK ↓	
Engine Compression Low	Perform compression check to identify problem. Refer to Procedure 7-01.
OK ↓	
Injection Pump Worn or Malfunctioning	Remove the fuel injection pump. Have calibration checked. Refer to Procedure 5-11.

Engine Idle Rough, Warm Engine

Cause	Corrections
Idle Speed Set too Low (Below 700 RPM)	Check/adjust low idle screw setting. Refer to Procedure 5-12.
OK ↓	
Air in Fuel System	Bleed fuel system and check for suction leaks. Refer to Procedure 5-01.
OK ↓	
Fuel Return Overflow Valve Malfunctioning	Check/replace fuel return overflow valve.
OK ↓	
Fuel Transfer Pump Malfunctioning	Check/replace fuel transfer pump. Refer to Procedure 5-04.
OK ↓	
Fuel Supply Restricted	Clean pre-filters and screens and check fuel line for restriction. Replace fuel filter. Refer to Procedure 5-01.
OK ↓	
Injection Nozzles Plugged or Inoperative	Check/replace injectors. Refer to Procedure 5-07.
OK ↓	
Injection Pump Timing Incorrect	Check injection pump timing. Refer to Procedure 5-11.
OK ↓	
Engine Mounts Broken	Replace mounts.
OK ↓	

(Continued)

Engine Idle Rough, Warm Engine (Continued)

Cause	Corrections
Valves Incorrectly Adjusted	Adjust intake and exhaust valves. Refer to Procedure 7-06.
OK ▼	
Engine Compression Low	Perform compression check, repair as required. Refer to Procedure 7-01.
OK ▼	
Injection Pump Malfunctioning	Remove the fuel injection pump, check calibration, check for debris in delivery valve. Refer to Procedure 5-11.

Engine Misfiring

Cause	Corrections
Air in Fuel System	Bleed fuel system and check for suction leaks. Refer to Procedure 5-01.
OK ⬇	
Fuel Contaminated	Verify by operating from a temporary supply tank that contains good fuel.
OK ⬇	
Fuel Injection Lines Leaking	Check for loose connections. Inspect and replace broken lines. Refer to Procedure 5-05.
OK ⬇	
Malfunctioning Fuel Return Overflow Valve	Check/replace return overflow valve. Refer to Procedure 5-09.
OK ⬇	
Fuel Transfer Pump Malfunctioning	Check/replace fuel transfer pump. Refer to Procedure 5-04.
OK ⬇	
Fuel Supply Restricted	Clean pre-filters and screens and check fuel line for restriction. Replace fuel filter. Refer to Procedure 5-01.
OK ⬇	
Valves Incorrectly Adjusted	Inspect push rods and springs. Adjust valves. Refer to Procedure 7-06.
OK ⬇	
Injection Nozzles Plugged or Inoperative	Replace injectors. Refer to Procedure 5-07.
OK ⬇	

(Continued)

Engine Misfiring (Continued)

Cause	Corrections
Injection Pump Timing Incorrect	Check/time injection pump. Refer to Procedure 5-11.
OK ↓	
Compression Low on One or More Cylinders	Perform compression check to identify cause (piston rings, head gasket or valves). Refer to Procedure 7-01.
OK ↓	
Camshaft Timing Incorrect	Check/correct gear train timing alignment. Refer to Procedure 7-22.
OK ↓	
Camshaft, Tappets or Push Rods Damaged	Check/replace parts as required. Refer to Procedures 7-22, 7-24 and 7-08.

Engine Power Output Low

Cause	Corrections
Engine Overloaded	Check for added loading from malfunctioning accessories or driven units, brakes dragging and other changes in vehicle loading.
OK ▼	
Throttle Linkage Incorrectly Adjusted	Check and adjust throttle linkage for full travel of the fuel control lever. Refer to Procedure 5-01.
OK ▼	
Mechanical Shutoff Lever Partially Engaged	Check/adjust solenoid linkage. Refer to Procedure 5-01.
OK ▼	
Fuel Quality Poor or Diesel Fuel Grade No. 1 Used Above 0°C [32°F]	Verify by operating the engine from a temporary tank of No. 2 diesel fuel. Refer to the "Fuel Recommendations/Specifications" in the C Series Operation and Maintenance Manual, Bulletin No. 3810248-08.
OK ▼	
If the Condition is Slow Throttle Response, Air Fuel Control Tube Leaking, Wastegate Diaphram Ruptured, Wastegate Plumbing Damaged	Tighten fittings. Replace tube if necessary. Repair plumbing or wastegate diaphram. Refer to Procedure 3-03.
OK ▼	
AFC Plumbing Orifice Blocked	Check AFC Fittings between intake manifold and fuel pump.
OK ▼	
High Pressure Fuel Lines or Fittings Leaking	Tighten/replace fittings or lines. Refer to Procedure 5-05.
OK ▼	
Air in the Fuel System	Bleed the fuel system and check for suction leaks. Refer to Procedure 5-01.
OK ▼	
Fuel Supply Restricted	Clean pre-filters and screens and check fuel line for restriction. Replace fuel filter. Refer to Procedure 5-01.
OK ▼	

(Continued)

Engine Power Output Low (Continued)

Cause	Corrections
Fuel Return Overflow Valve Malfunctioning	Check/replace fuel return overflow valve. Refer to Procedure 5-09.
OK ↓	
Fuel Transfer Pump Malfunctioning	Check/replace fuel transfer pump. Refer to Procedure 5-04.
OK ↓	
Lubricating Oil Level Too High	Drain oil to proper level.
OK ↓	
Intake Air Temperature High - (Above 75°C [168°F])	Use outside air to turbocharger in warm weather.
OK ↓	
	Coolant passages plugged in the aftercooler.
	Check charge air cooler for internal restriction. Replace restricted cooler.
	Check/clean debris from front of charge air cooler.
Intake or Exhaust System Restricted	Check intake and exhaust systems for restrictions. Inspect air filter and replace as necessary. Refer to Procedure 3-01 and Page 3-19..
OK ↓	

(Continued)

Engine Power Output Low (Continued)

Cause	Corrections
Fuel Temperature High - (Above 71°C [160°F])	Fill tanks, turn off fuel heater in warm weather.
OK ↓	
Air Leak Between Turbocharger and Intake Manifold	Check and correct leaks in the air crossover tube, charge air cooler connections, hoses,or through holes in the manifold cover. Refer to Procedure 3-08.
OK ↓	
Exhaust Leak Between Turbocharger and Exhaust Manifold	Check and correct leaks. Check for a cracked exhaust manifold. Refer to Procedure 3-12.
OK ↓	
Injector Nozzles Worn or Malfunctioning	Check/replace injectors. Refer to Procedure 5-07.
OK ↓	
Turbocharger Worn or Malfunctioning	Check for correct boost pressure. Refer to specifications on Page 3-4. Replace turbo-charger if low. Refer to Procedure 3-11.
OK ↓	
Valves Incorrectly Adjusted	Adjust valves. Inspect push rods, springs, etc. Refer to Procedure 7-06.
OK ↓	
Injection Pump Timing Incorrect	Check injection pump timing. Refer to Procedure 5-11.
OK ↓	
Injection Pump Worn or Malfunctioning	Remove the fuel injection pump. Have calibration checked. Refer to Procedure 5-11.
OK ↓	
Engine Compression Low	Perform compression check to identify malfunction. Repair as required. Refer to Procedure 7-01.

Engine Noise Excessive

Cause	Corrections
Drive Belt Squeal, Insufficient Tension or Abnormally High Loading	*Check the tensioner and inspect the drive* belt. Make sure water pump, tensioner pulley, fan hub and alternator turn freely.
OK	Check the tension of accessory drive belts. Refer to the equipment manufacturer's instructions. Make sure the accessories turn freely.
Intake Air or Exhaust Leaks	Refer to Troubleshooting Logic Chart for "Exhaust Smoke Excessive Under Load".
OK	
Valve Lash Excessive	Adjust valves. Make sure the push rods are not bent or the rocker levers are not severely worn. Refer to Procedure 7-06.
OK	
Turbocharger Noise	Check turbocharger impeller and turbine wheel for housing contact. Refer to Procedure 3-01.
OK	
Gear Train Noise	Check/replace vibration damper. Refer to Procedure 7-16.
OK	Visually inspect and measure gear backlash. Replace gears as required. Refer to Procedure 7-20.
Internal Engine Noise	Check/replace connecting rod and main bearings. Refer to Procedures 7-11 and 7-12.

Engine Starts But Will Not Keep Running

Cause	Corrections
Engine Starting Under Load	Disengage driven units and check for loading from malfunctioning accessories.
OK ▼	
Engine Idle Speed Too Low (Below 700 RPM)	Adjust idle speed. Refer to Procedure 5-12.
OK ▼	
Intake or Exhaust System Restricted. Engine Shut Down Device Malfunctioning	Visually check the intake and exhaust system for restrictions. Make sure shut down is not occurring too soon. Refer to Procedure 3-01.
OK ▼	
Air in the Fuel System or the Fuel Supply is Inadequate	Check the flow through the filter. Bleed the fuel system and check for suction leaks. Refer to Procedure 5-01.
OK ▼	
Fuel Filter Plugged or Fuel Waxing Due to Cold Weather	Drain fuel-water separator or replace filter. Check for fuel waxing in cold weather. Refer to Procedure 5-01.
OK ▼	
Fuel Supply Restricted	Clean or replace pre-filters and screens and check for fuel line restrictions. Refer to Procedure 5-01.
OK ▼	
Fuel Contaminated	Verify by operating engine from a temporary supply tank that contains good fuel.
OK ▼	
Injection Pump Timing Incorrect	Check and adjust injection pump timing. Refer to Procedure 5-11.
OK ▼	
Camshaft Timing Incorrect	Check/correct gear train timing alignment. Refer to Procedure 7-22.

Engine Surges at Idle

Cause	Corrections
Fuel Level Low in the Tank	Fill supply tank.
OK ↓	
Engine Idle Speed Set Too Low (Below 700 RPM)	Check/adjust low idle speed screw. Refer to Procedure 5-12.
OK ↓	
Idle Incorrectly Adjusted (Industrial Engines - RSV Governor)	Check/adjust the bumper spring adjustment. Refer to Procedure 5-12.
OK ↓	
Air in the Fuel System	Bleed fuel system and check for suction leaks. Refer to Procedure 5-11.
OK ↓	
Fuel Supply Restricted	Clean or replace pre-filters and screens and check fuel lines for restriction. Refer to Procedure 5-01.
OK ↓	
Injectors Worn or Malfunctioning	Check/replace injectors. Refer to Procedure 5-07.
OK ↓	
Injection Pump Malfunctioning or Worn	Remove fuel injection pump, check calibration. Refer to Procedure 5-11.

Engine Vibration - Excessive

Cause	Corrections
Engine Not Running Smoothly. Low Idle Speed Set Too Low.	Refer to Troubleshooting Logic Chart for "Engine Misfiring". Adjust engine low idle speed.
OK ▼	
Engine Mounts Loose or Broken	Check/replace engine mounts (refer to the equipment manufacturer's instructions).
OK ▼	
Fan Damaged or Malfunctioning Accessories	Check/replace the vibrating component (refer to equipment manufacturer's instructions).
OK ▼	
Vibration Damper Malfunctioning	Inspect/replace the vibration damper. Refer to Procedure 7-16.
OK ▼	
Fan Hub Malfunctioning	Inspect/replace the fan hub. Refer to Procedure 1-06.
OK ▼	
Alternator Bearing Worn or Damaged	Check/replace the alternator. Refer to Procedures 6-01 and 6-03.
OK ▼	
Flywheel Misaligned	Check/correct flywheel alignment. Refer to Procedure 7-26.
OK ▼	
Loose or Broken Internal Components	Inspect crankshaft and rods for damage that causes and unbalance. Refer to Procedure 7-14.
OK ▼	
Drive Line Components Worn or Unbalanced	Check/repair according to the equipment manufacturer's instructions.

Engine Will Not Crank or Cranks Slowly

Cause	Corrections
Starting Circuit Connections Loose or Corroded	Clean and tighten connections. Refer to Procedure 6-01.
OK ↓	
Battery Charge Low	Check electrolyte level and specific gravity, charge as required. Refer to Procedure 6-01.
OK ↓	
No Voltage to Starter Solenoid	Check voltage to solenoid. Refer to Procedure 6-01.
OK ↓	
Solenoid or Starting Motor Malfunction	*Replace starting motor.* Refer to Procedure 6-02.
Crankshaft Rotation Restricted	*Rotate the crankshaft to check for rotational resistance.* Refer to Procedure 7-12.
OK ↓	
Engine Driven Units Engaged	Disengage driven units and check for loading from malfunctioning accessories. Refer to the appropriate section.
OK ↓	
Starting Motor Operating But Not Cranking the Engine	Remove the starting motor and check for broken teeth on the flywheel or broken starting motor spring. Refer to Procedures 7-26 and 6-02.

Engine Will Not Reach Rated Speed When Loaded

Cause	Corrections
Tachometer Malfunction	Check with hand or digital tachometer.
OK ▼	
Vehicle Overloaded	Verify high idle speed without load. Reduce load or use lower gear.
OK ▼	
Throttle Linkage Worn or Incorrectly Adjusted	Check throttle linkage adjustment for full travel to the high idle stop screw. Refer to Procedure 5-01.
OK ▼	
Mechanical Shutoff Lever Partially Engaged	Check/adjust shutoff lever. Refer to Procedure 5-01.
OK ▼	
Fuel Quality Poor or Diesel Fuel Grade No. 1 Used Above 0°C [32°F]	Veriby by operating the engine from a temporary tank of No. 2 diesel fuel. Refer to the "Fuel Recommendations/Specifications" in the C Series Operation and Maintenance Manual, Bulletin No. 3810248-08.
OK ▼	
Fuel Supply Inadequate or Restricted	Change the fuel filter and check fuel line, pre-filter and screens for restrictions. Refer to Procedure 5-01.
OK ▼	
Malfunctioning Fuel Transfer Pump	Check/repair or replace fuel transfer pump. Refer to Procedure 5-01.
OK ▼	
Malfunctioning Fuel Return Overflow Valve	Check/replace return overflow valve. Refer to Procedure 5-09.
OK ▼	

(Continued)

Engine Will Not Reach Rated Speed When Loaded (Continued)

Cause	Corrections
Air Fuel Control Tube Leaking and/or Restricted Orifice, Wastegate Diaphram Ruptured	Check orifice, tighten fittings. Replace tube if necessary. Refer to Procedure 5-10. Injection Pump Malfunction
OK ↓	
Fuel Injection Malfunctioning	Remove the fuel injection pump, check calibration. Refer to Procedure 5-07.

Engine Will Not Shut Off

Cause	Corrections
Electrical or Manual Fuel Shutoff Not Closing	Verify the solenoid is not being energized by a short in the wiring. Check the linkage to the shutoff lever for binding. Check for the ability of the spring in the pump to pull the lever to the shutoff position. Refer to Procedure 5-08.
OK ▼	
Engine Running On Fumes Drawn into Air Intake	Check the air intake ducts. Locate and isolate the source of fumes.
OK ▼	
Fuel Leaking to Intake Manifold	Check for porosity between the fuel filter mounting to the intake manifold.
OK ▼	
Fuel Injection Malfunctioning	Remove the fuel injection pump for repair, check calibration. Refer to Procedure 5-11.

Exhaust Black Smoke Excessive Under Load

Cause	Corrections
Engine Being Lugged Down	Use lower gear.
OK ⬇	
Air Cleaner Plugged	Inspect air cleaner. Clean and replace. Refer to Procedure 3-01.
OK ⬇	
Air Leak Between Turbocharger and Intake or Exhaust Manifold	Correct leaks in the air crossover tube, hoses or through holes in the manifold cover. Refer to Procedure 3-08.
OK ⬇	
Charge Air Cooler Malfunctioning	Check for plugged charge air cooler, internal charge air restriction, or leaking charge air cooler.
OK ⬇	
Exhaust Leak at the Manifold or Turbocharger	Check/correct leaks in the manifold or turbocharger gaskets. Look for a cracked exhaust manifold. Refer to Procedure 3-12.
OK ⬇	
Turbocharger Wastegate Malfunctioning	Repair or replace wastegate. Refer to Procedure 3-04.
OK ⬇	
Turbocharger Malfunctioning	Replace turbocharger. Refer to Procedure 3-11.
OK ⬇	
More Than One Seal Washer Under Injector Nozzle	Remove extra washers. Refer to Procedure 5-07.
OK ⬇	

(Continued)

Exhaust Black Smoke Excessive Under Load (Continued)

Cause	Corrections
Injector Nozzle Malfunctioning	Remove and have nozzles tested. Replace injectors if necessary. Refer to Procedure 5-07.
OK ↓	
Engine Running Too Cold (Below 60°C [140°F])	Check thermostat and cooling system. Refer to Procedures 1-02 and 1-08.
OK ↓	
Injection Pump Timing Incorrect	Check and adjust injection pump timing. Refer to Procedure 5-11.
OK ↓	
AFC Malfunction or Injection Pump Overfueled	Remove and test injection pump. Refer to Procedure 5-11.
OK ↓	
Piston Rings Not Sealing	Perform a compression check. Repair as required. Refer to Procedure 7-01.

Exhaust White Smoke Excessive (Warm Engine)

Cause	Corrections
Improper Starting Procedure	Verify proper starting procedure. Refer to Starting Instructions in the Operation and Maintenance Manual.
OK ↓	
Coolant Temperature Too Low	Refer to Troubleshooting Logic Chart for "Coolant Temperature Below Normal".
OK ↓	
Intake Air Temperature Too Low	Refer to vehicle operation manual for shutter operation. Check intake air heater operation (if required).
OK ↓	
Fuel Quality Poor	Verify by operating engine from a temporary tank with good quality fuel. Clean and flush the fuel supply tanks.
OK ↓	
Injection Pump Timing Incorrectly Adjusted	Check top dead center (TDC). Refer to Procedure 7-07. Check/adjust injection pump timing. Refer to Procedure 5-11. Check/time the fuel injection pump using the spill port timing if equipment is available. Refer to Procedure 5-13.
OK ↓	
Injectors Malfunctioning	Replace injectors. Refer to Procedure 5-07.
OK ↓	
Coolant Leaking Into Combustion Chamber	Refer to Troubleshooting Logic Chart for "Coolant Loss".
OK ↓	
Injection Pump Malfunctioning	Remove fuel injection pump. Have calibration checked. Check for debris in delivery valves. Refer to Procedure 5-11.

Fuel Consumption Excessive

Cause	Corrections
Additional Loading From Malfunctioning Accessories	Check/repair accessories and vehicle components. Refer to equipment manufacturer's instructions.
OK ⬇	
Operator Technique	Review operation for correct gear shifts, deceleration, and idling.
OK ⬇	
Fuel Leaks	Check for external leaks and engine oil diluted with fuel. Check for internal leaks at the fuel transfer pump and injection pump.
OK ⬇	
Fuel Quality Poor or No. 1 Fuel Used	Verify by operating engine from a temporary tank that contains good No. 2 fuel. Refer to "Fuel Specifications" in the C Series Operation and Maintenance Manual.
OK ⬇	
Intake Air or Exhaust Restriction	Refer to Troubleshooting Logic Chart for "Exhaust Smoke Excessive Under Load".
OK ⬇	
Injectors Worn or Malfunctioning	Check/replace injectors. Refer to Procedure 5-07.
OK ⬇	
Injection Pump Timing Incorrect	Check injection pump timing. Refer to Procedure 5-11.
OK ⬇	
Injection Pump Calibration Incorrect or Overfueled	Check for broken adjustment seals on the injection pump. If the seals are broken, remove and calibrate the injection pump. Refer to Procedure 5-11.
OK ⬇	
Valves Not Seating	Check/adjust valves. Refer to Procedure 7-06.

Fuel or Oil Leaking from Exhaust Manifold

Cause	Corrections
Operating For Extended Periods Under Light or No Load Conditions	Review vehicle operation.
OK ↓	
Intake Air Restriction	Check/replace filter element. Refer to *Procedure* 5-01.
OK ↓	
	Review operation for excessive idling.
Fuel Injection Pump Timing Incorrect	Check/adjust fuel injection pump timing. Refer to Procedure 5-11.
OK ↓	
Injector Needle Valve Stuck Open	Locate and replace malfunctioning injector. Refer to Procedure 5-07.
OK ↓	
Turbocharger Drain Line Obstructed	Check/clean line. Refer to Procedure 3-11.
OK ↓	
Turbocharger Seals Leaking Oil	Check/replace turbocharger. Refer to Procedure 3-11.
OK ↓	
Crankcase Gases (Blowby) Excessive	Check for excessive blowby. Refer to Procedure 8-01.

Lubricating Oil Contaminated

Cause	Corrections
Coolant in the Oil, Internal Engine Component Leaks	Refer to Troubleshooting Logic Chart for "Coolant Loss".
OK	
Oil Sludge Excessive	Review oil and filter change intervals. Refer to the C Series Operation and Maintenance Manual.
OK	
	Make sure the correct oil is being used. Refer to the C Series Operation and Maintenance Manual.
Fuel in the Oil, Engine Operating Too Cold	Review the operation for excessive idling resulting in the engine running below normal temperature.
OK	
Fuel Transfer Pump Seal Leaking	Replace fuel transfer pump. Refer to Procedure 5-04.
OK	
Injector Needle Valves Not Sealing	Locate and replace malfunctioning injector. Refer to Procedure 5-07.
OK	
Fuel Pump Internal Plunger Seal Leaking	Remove the fuel injection pump, have repaired and calibrated. Refer to Procedure 5-11.
OK	
Injection Pump Malfunction	Remove the fuel injection pump, have repaired and calibrated. Refer to Procedure 5-11.

Lubricating Oil Consumption Excessive

Cause	Corrections
External Leaks	Visually inspect for oil leaks.
OK	
Crankcase Being Overfilled (Dipstick Calibrated Incorrectly)	Verify that the dipstick is correctly marked. Refer to Procedure 2-08.
OK	
Incorrect Oil (Specification or Viscosity)	Make sure the correct oil is being used. Refer to the C Series Operation and Maintenance Mannual.
OK	
	Check for reduced viscosity from dilution with fuel. Refer to Procedure 2-02.
	Review/reduce the oil change intervals. Refer to the C Series Operation and Maintenance Manual.
High Blowby Forcing Oil Out the Breather Tube	Check the breather tube area for signs of oil loss. Measure the blowby and perform the required repairs. Refer to Procedure 8-01.
OK	
Oil Cooler Leak	Check for oil in the coolant. Refer to Procedures 2-03 and 2-11.
OK	
Air Compressor Pumping Oil	Refer to Troubleshooting Logic Chart for "Air Compressor Pumping Excessive Lubricating Oil Into The Air System".
OK	

(Continued)

Lubricating Oil Consumption Excessive (Continued)

Cause	Corrections
Turbocharger Leaking Oil to the Air Intake or Exhaust	Inspect the turbocharger inlet and outlet for evidence of oil transfer. Refer to Procedure 3-01.
OK ▼	
Valve Seals Worn	Inspect/replace the valve seals. Refer to the C Series Engine Shop Manual.
OK ▼	
Piston Rings Not Sealing (Oil Being Consumed by the Engine)	Perform a compression check. Repair as required. Refer to Procedure 7-01.

Lubricating Oil Pressure Low

Cause	Corrections
Oil Level Incorrect	Add or drain engine oil. Refer to Procedures 2-04 and 2-05.
OK ⬇	
Oil Diluted With Fuel but Engine Operation Normal	Remove and check fuel transfer pump plunger seal. Replace leaking pump. Change oil. Refer to Procedure 5-04.
OK ⬇	
Oil Diluted With Fuel Accompanied by Rough Engine Operation or Low Power	Check for a stuck injector nozzle. If injectors are OK, replace injection pump. Change oil. Refer to Procedure 5-10.
OK ⬇	
Oil Diluted With Water	Look for missing rain caps, oil fill caps, dipsticks, etc. Change oil. Refer to Procedures 2-04 and 2-05.
OK ⬇	
Oil Diluted With Coolant (Anti-Freeze)	Check oil cooler, aftercooler, core plugs, *cylinder liner, head gasket, and cracked* passages in the block and head for leaks. Replace leaking component and change oil. Refer to Procedure 2-05.
OK ⬇	
Oil Specifications Incorrect	Check oil specifications. Refer to the C Series Operation and Maintenance Manual.
OK ⬇	
Oil Pressure Switch or Gauge Malfunction	Check oil pressure gauge and switch. Refer to Procedure 2-03.
OK ⬇	
Oil Pressure Regulating Valve Stuck Open or Broken Spring	Check and clean. Replace spring if broken. Refer to Procedure 2-10.
OK ⬇	

(Continued)

Lubricating Oil Pressure Low (Continued)

Cause	Corrections
Pipe Plug Loose or Missing	Check for external leak at rear of cylinder head, along fuel pump side of block, oil cooler cover and gear housing. Refer to Procedure 7-31.
OK ↓	
Oil Filter Plugged	Change oil and replace filter. Refer to Procedures 2-04 and 2-05.
OK ↓	
Oil Cooler Plugged	Check and replace oil cooler. Refer to Procedure 2-11.
OK ↓	
Cup Plug Internal Leak	Check oil rifle cup plugs, cup plug in front and rear face of block. Refer to Procedure 7-31.
OK ↓	
Suction Tube Loose or Gasket Leaking	Replace gasket and tighten tube. Refer to Procedure 2-13.
OK ↓	
Lubricating Oil Pump Worn	Check/replace oil pump. Refer to Procedure 2-14.
OK ↓	
Main Bearing Cap Loose	Check/install new bearing(s). Tighten cap. Refer to Procedure 7-11.
OK ↓	
Connecting Rod or Main Bearings Worn	Check/replace bearings. Also, check/replace piston cooling nozzles. Refer to Procedures 7-11 and 7-14.

Lubricating Oil Pressure High

Cause	Corrections
Pressure Switch/Gauge Malfunctioning	Verify the pressure switch/gauge are functioning correctly. Refer to Procedure 2-03.
OK ↓	
Engine Running Too Cold	Refer to Troubleshooting Logic Chart for "Coolant Temperature Below Normal".
OK ↓	
Oil Viscosity Too Thick	Make sure the correct oil is being used. Refer to the C Series Operation and Maintenance Manual.
OK ↓	
Pressure Regulator Valve Stuck Closed	Check/replace valve. Refer to Procedure 2-10.

Flame Start System Malfunctions

Cause	Corrections
Key Through the Wait to Start (WTS) Light	Wait for the wait to start (WTS) light to go out.
OK ▼	
Waiting too Long to Start Vehicle After WTS Light Goes Out	Turn the start switch to start no longer than 10 seconds after the WTS light goes out.
OK ▼	
Battery Voltage Below 9 Volts for a 12 Volt and 20 Volts for a 24 Volt System	Charge/replace the battery.
OK ▼	
WTS Light Never Turns On	Check the bulb, bulb socket, and wiring. Refer to Procedure 3-13.
OK ▼	
Electrical Glow Plug Heater of the Flame Plug Not Heating Up	Repair the electrical circuit to the flame plug. Refer to Procedure 3-13.
OK ▼	
Electrical Heater of the Flame Plug Failed	Check the flame plug electric heater. Refer to Procedure 3-13.
OK ▼	
Flame Start Temperature Sensor Bad	Check the sensor. Refer to Procedure 3-13.
OK ▼	
Engine Wiring Harness Bad	Check the wiring harness for shorts to the ground, insulation chafing, connector corrosion, and connector integrity.
OK ▼	

(Continued)

Flame Start System Malfunctions (Continued)

Cause	Corrections
Fuel Not Flowing to the Flame Plug	Check for fuel line waxing. Heat up the fuel lines and remove the wax deposit. Warm up the glow plug and remove the wax deposit.
OK ↓	
Flame Plug Solenoid Not Opening	Check the flame plug solenoid. Refer to Procedure 3-13.
OK ↓	
Flame Plug Filter Clogged	Remove the fuel line(s) and clean the filter. Refer to Procedure 3-13.
OK ↓	
Flame Plug Coked/Clogged	Check the flame plug for plugging and coking. Refer to Procedure 3-13.
OK ↓	
Fuel Line Leaks	Repair the leaks. Refer to Procedure 3-13.
OK ↓	
Controller Ground Bad	Check the wiring harness ground for corrosion or loose connections. Check the controller pin "B" on the two-pin connector for ground.
OK ↓	
Power Supply to the Controller Bad	Check the connector at the shutdown solenoid for loose connections, corrosion or connector cracks. Pin A supplies the controller with system voltage on the 6-pin connector.
OK ↓	
Oil Pressure Switch Failed	Check the oil pressure switch per Procedure 3-13. Replace sensor.
OK ↓	
Controller Malfunction	Check the controller logic. Refer to Procedure 3-13.

Engine Noise Diagnostic Procedures - General Information

NOTE: When diagnosing engine noise problems, make sure that noises caused by accessories, such as the air compressor and power takeoff, are **not** mistaken for engine noises. Remove the accessory drive belts to eliminate noise caused by these units. Noise will also travel to other metal parts **not** related to the problem. The use of a stethoscope can help locate an engine noise.

Engine noises heard at the crankshaft speed, engine RPM, are noises related to the crankshaft, rods, pistons, and piston pins. Noises heard at the camshaft speed, one-half of the engine RPM, are related to the valve train. A hand-held digital tachometer can help to determine if the noise is related to components operating at the crankshaft or camshaft speed.

There is **not** a definite rule or test that will positively determine the source of a noise complaint.

Engine driven components and accessories, such as gear-driven fan clutches, hydraulic pumps, belt-driven alternators, air-conditioning compressors, and turbochargers can contribute to engine noise. Use the following information as a guide to diagnosing engine noise.

Main Bearing Noise (Refer to Engine Noise Excessive - Main Bearing Symptom Chart)

The noise caused by a loose main bearing is a loud dull knock heard when the engine is pulling a load. If all main bearings are loose, a loud clatter will be heard. The knock is heard regularly every other revolution. The noise is the loudest when the engine is lugging or under heavy load. The knock is duller than a connecting rod noise. Low oil pressure can also accompany this condition.

If the bearing is **not** loose enough to produce a knock by itself, the bearing can knock if the oil is too thin, or if there is no oil at the bearing.

An irregular noise can indicate worn crankshaft thrust bearings.

An intermittent sharp knock indicates excessive crankshaft end clearance. Repeated clutch disengagements can cause a change in the noise.

Connecting Rod Bearing Noise (Refer to Engine Noise Excessive - Connecting Rod Symptom Chart)

Connecting rods with excessive clearance knock at all engine speeds, and under both idle and load conditions. When the bearings begin to become loose, the noise can be confused with piston slap or loose piston pins. The noise increases in volume with engine speed. Low oil pressure can also accompany this condition.

Piston Noise (Refer to Engine Noise Excessive - Piston Symptom Chart)

It is difficult to tell the difference between piston pin, connecting rod, and piston noise. A loose piston pin causes a loud double knock which is usually heard when the engine is idling. When the injector to this cylinder is held down, a noticeable change will be heard in the sound of the knocking noise. However, on some engines the knock becomes more noticeable when the vehicle is operated on the road at a steady speed condition.

Driveability - General Information

Driveability is a term which in general describes vehicle performance on the road. Driveability problems for an engine can be caused by several different factors. Some of the factors are engine related and some are not.

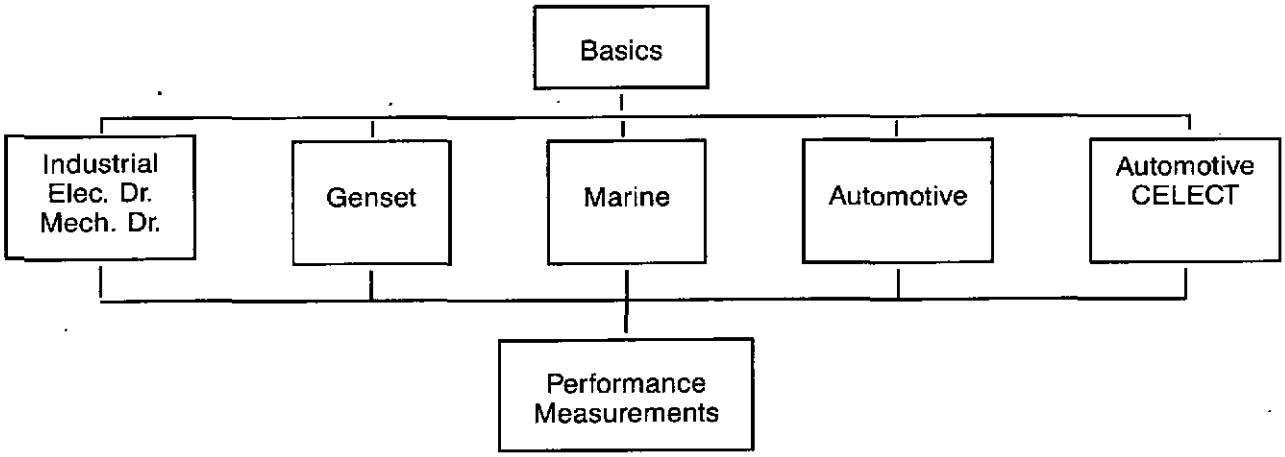
Before troubleshooting, it is important to determine the exact complaint and whether the engine has a real driveability problem, or if it simply does not meet driver expectations. The "Driveability-Low Power Customer Complaint Form" is a valuable list of questions that must be used to assist the service technician in determining what type of driveability problem the vehicle is experiencing. The checklist **must** be completed before troubleshooting the problem. If an engine is performing to factory specifications but does not meet customer expectations, it **must** be explained to the customer that nothing is wrong with the truck and why. The form can be found at the end of this section.

The troubleshooting symptom charts have been set up to divide driveability problems into two different symptoms: "Engine Power Output Low" and "Engine Acceleration/Response Poor".

Low Power is a term that is used in the field to describe many different performance problems. In this manual, however, Low Power is defined as follows: The inability of the engine to produce the power necessary to move the vehicle at a speed that can be reasonably expected under the given conditions of load, grade, wind, and so on. Low Power is usually caused by the lack of fuel flow which can be caused by any of the following factors:

- Incorrect Fuel Pump or Injector Calibration
- Lack of Full Travel of the Fuel Pump Throttle
- Plugged ASA
- Excessive Fuel Inlet, Intake, Exhaust or Drainline Restriction
- Loose Fuel Pump Suction Lines

Low Power is not the inability of the vehicle to accelerate satisfactorily from a stop or the bottom of a grade. Refer to the troubleshooting tree, "Engine Power Output Low" for the proper procedures to locate and correct a Low Power problem. The chart starts off with basic items 'Basics' which can cause low power. It then breaks off into application specific items 'Application Specific' that can cause low power. All of the 'Application Specific' charts end with a step called 'Fuel or Air Delivery Problem'. This step leads to an engine performance check which requires engine measurements. The last section of this chart is titled 'Performance Measurement' which leads the troubleshooter through the causes and corrections based on the outcome of the performance check.



Poor Acceleration/Response is described in this manual as the inability of the vehicle to accelerate satisfactorily from a stop or from the bottom of a grade. It can also be the lag in acceleration during an attempt to pass or overtake another vehicle at conditions less than rated speed and load. Poor Acceleration/Response is difficult to troubleshoot since it can be caused by factors such as:

- Engine/Pump Related Factors
- Driver Technique
- Improper Gearing
- Improper Engine Application
- Worn Clutch or Clutch Linkage

Engine related Poor Acceleration/Response can be caused by several different factors such as:

- Low No-Air Setting
- Plugged ASA
- AFC Delay
- Excessive Drainline Restriction
- Low Throttle Leakage
- Throttle Deadband

Refer to the troubleshooting symptom chart, Engine Acceleration/Response Poor, for the proper procedures to locate and correct a Poor Acceleration/Response complaint. For additional information, see Troubleshooting Driveability Complaints, Bulletin No. 3387245.

Driveability/Low Power - Customer Complaint Form

Customer Name/Company _____ Date _____

(1). How did the problem occur? ____ Suddenly ____ Gradually

(2). At what hour/mileage did the problem begin? _____ miles ____ Since New

After engine repair? ____ Yes ____ No
After equipment repair? ____ Yes ____ No
After change in equipment use? ____ Yes ____ No
After change in selectable programmable parameters? ____ Yes ____ No
If so, what was repaired and when? _____

(3). Does the vehicle also experience poor fuel economy? ____ Yes ____ No

Answer questions 5 through 9 using selections (A through F) listed below. Circle the letter or letters that best describes the complaint.

A - Compared to fleet
B - Compared to competition
C - Compared to previous engine
D - Personal expectation
E - Won't pull on hill
F - Won't pull on flat

A B C D E F (4). Can the vehicle obtain the expected road speed? ____ Yes ____ No
Speed desired _____ rpm/mph Speed achieved _____ rpm/mph
GVW _____

A B C D (5). *Is the vehicle able to pull the load?* ____ Yes ____ No *When?*
____ In the hills ____With highly loaded trailer
____ On the flat
____ Other _____

IF ANSWERED NO TO QUESTION 4 OR 5, FILL OUT THE DRIVEABILITY/LOW POWER/ EXCESSIVE FUEL CONSUMPTION CHECKLIST AND GO TO THE LOW POWER TROUBLESHOOTING TREE.

A B C D E F (6). Is the vehicle slow to accelerate/respond? ____ Yes ____ No
____ From a stop
____ After a shift What RPM _____
____ Before a shift What RPM _____
____ No shift What RPM _____

A B C D (7). Does the vehicle hesitate after periods of long deceleration or coasting? __ Yes __ No
What RPM _____

IF ANSWERED YES TO QUESTION 6 OR 7, FILL OUT THE DRIVEABILITY/LOW POWER/ EXCESSIVE FUEL CONSUMPTION CHECKLIST AND GO TO THE POOR ACCELERATION/RESPONSE TROUBLESHOOTING TREE.

A B C D E F (8). Additional Comments _____

_____

_____

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Driveability/Low Power/Excessive Fuel Consumption - Checklist

Vehicle/Equipment Specifications:

Year, Type and Model _____

Transmission (RT14609, etc) _____ Duty Cycle _____

Rear Axle Ratio, No. of Axles ____ Application: __ Industrial __ Marine __ Genset __ Automotive __

Typical GVW _____ Engine Rating: _____

Trailer Type and Size _____, Height _____, Width _____

Tire Size (11R x 24.5, Low Profile, etc.) _____

Tire Type: ____ Radial ____ Standard Tread ____ Extra Tread

Fan Type: ____ Direct Drive ____ Viscous ____ Clutch

Power Steering	____ Yes	____ No
Air Conditioner	____ Yes	____ No
Air Shield	____ Yes	____ No
Freon Compressor	____ Yes	____ No

General Information:

DO No. _____
SC No. _____

Fuel Pump Code _____ Fuel Pump Serial No. _____
Mileage _____ Engine Serial No. _____
Date in Service _____ Engine Model and Rating _____
Cruise Speed and RPM _____ Rated Speed and RPM _____

PT PACER Equipped	____ Yes	____ No	PCU Part No. _____
Road Speed Governor?	____ Yes	____ No	Type _____
STC Equipped?	____ Yes	____ No	STC Valve Part No. _____
Engine Brake?	____ Yes	____ No	Type/Brand _____

Chassis and Other Related Items:

Tank Vents ____ OK ____ Not OK Obvious Fuel Leaks ____ Yes ____ No
Brake Drag ____ OK ____ Not OK Axle Alignment ____ OK ____ Not OK

Altitude _____ Ambient Temperature _____

Fuel Heater _____

Fuel Type ____ No. 1 Diesel ____ No. 2 Diesel Other _____

Typical Terrain: Flat, Hilly, % Asphalt, % Concrete _____

Additional Comments:

_____

_____

_____

Recommended Literature:

Troubleshooting Driveability Complaints, Bulletin No. 3387137
Professional Driver Techniques, Bulletin No. 3604818
Troubleshooting Excessive Fuel Consumption, Bulletin No. 3387245
Guide to Troubleshooting, Bulletin No. 3379090
Guide to LCPM, Bulletin No. 3382021.

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Fuel Consumption - General Information

The cause of excessive fuel consumption is hard to diagnose and correct because of the potential number of factors involved. Actual fuel consumption problems can be caused by any of the following factors:

- — Engine Factors
- — Vehicle Factors and Specifications
- — Environmental Factors
- — Driver Technique and Operating Practices
- — Fuel System Factors
- — Low Power/Driveability Problems

Before troubleshooting, it is important to determine the exact complaint and whether the problem is real or perceived, does not meet drivers expectations. The "Fuel Consumption - Customer Complaint Form" is a valuable list of questions that can be used to assist the service technician in determining the cause of the problem. The form **must** be completed before troubleshooting the complaint. The form can be found at the end of the Troubleshooting Symptom section. The following are some of the factors that **must** be considered when troubleshooting fuel consumption complaints.

Result of a Low Power/Driveability Problem: An operator will change his driving style to compensate for a low power/driveability problem. Some things the driver is likely to do are, (a) shift to a higher engine RPM or (b) run on the droop curve in a lower gear instead of upshifting to drive at part throttle conditions. These changes in driving style will increase the amount of fuel used.

Driver Technique and Operating Practices: As a general rule, a 1 mph increase in road speed equals a 0.1 mpg increase in fuel consumption. This means that increasing road speed from 50 to 60 mph will result in a loss of fuel mileage of 1 mpg.

Environmental and Seasonal Weather Changes: As a general rule, there can be as much as a 1 to 1.5 mpg difference in fuel consumption depending on the season and the weather conditions.

Excessive Idling Time: Idling the engine can use from 0.5 to 1.5 gallons per hour depending on the engine idle speed.

Truck Route and Terrain: East/west routes experience almost continual crosswinds and headwinds. Less fuel can be used on north/south routes where parts of the trip are not only warmer, but see less wind resistance.

Vehicle Aerodynamics: The largest single power requirement for a truck is the power needed to overcome air resistance. As a general rule, each 10 percent reduction in air resistance results in a 5 percent increase in mpg.

Rolling Resistance: Rolling resistance is the second largest consumer of power on a truck. The type of tire and tread design have a sizeable effect on fuel economy and performance. Changing from a bias ply to a low profile radial tire can reduce rolling resistance by about 36 percent.

Additional vehicle factors, vehicle specs and axle alignment, can also affect fuel consumption. For additional information on troubleshooting fuel consumption complaints, see Troubleshooting Excessive Fuel Consumption, Bulletin No. 3387245.

Fuel Consumption - Automotive Customer Complaint Form

Customer Name/Company _____ Date _____

Answer the following questions. Some questions require making an X next to the appropriate answer.

(1). What fuel mileage is expected? Expected _____ mpg

(2). What are the expectations based on?
___ Original mileage ___ Other units in fleet ___ Competitive engines
___ Previous engine owned ___ Expectations only ___ VE/VMS report

(3). When did the problem occur?
___ Since New ___ Suddenly ___ Gradually

(4). Did the problem start after a repair? ___ Yes ___ No
If so, what was repaired and when? _____

(5). Is the vehicle also experiencing a Driveability problem (Low Power or Poor Acceleration/Response)? ___ Yes ___ No

IF ANSWERED YES, FILL OUT THE DRIVEABILITY/LOW POWER/EXCESSIVE FUEL CONSUMPTION CHECKLIST AND GO TO THE ENGINE POWER OUTPUT LOW TROUBLESHOOTING SYMPTOM CHART.

(6). Is the problem seasonal? ___ Yes ___ No

(7). Weather conditions during fuel consumption check?
___ Rain ___ Snow ___ Windy ___ Hot Temperatures ___ Cold Temperatures

(8). How is the fuel mileage measured? Tank ___ Trip ___ Month ___ Year ___
Hubometer ___ Odometer ___

(9). Are accurate records kept of fuel added on the road? ___ Yes ___ No

(10). Do routes vary between compared vehicles? ___ Yes ___ No

(11). Have routes changed for the engine being checked? ___ Yes ___ No

(12). What are the loads hauled compared to comparison unit? GVW _____
___ Heavier ___ Lighter

(13). What is the altitude that the truck is operating at?
___ Below 10,000 feet ___ Above 10,000 feet

(14). How much of the time is the truck spent idling? _____ Hours/day

(15). Is driver technique or operating practices affecting fuel economy?
___ High road speed: MPH _____
___ Operate at rated speed or above: RPM _____
___ Incorrect shift rpm: Shift RPM _____ Torque Peak _____
___ Operate at a cruise speed: RPM _____
___ Believe compensating for low power

IF AFTER FILLING OUT THIS FORM IT APPEARS THAT THE PROBLEM IS NOT CAUSED BY VEHICLE FACTORS, ENVIRONMENTAL FACTORS OR DRIVER TECHNIQUE, FILL OUT THE DRIVEABILITY/LOW POWER/EXCESSIVE FUEL CONSUMPTION CHECKLIST AND GO TO THE FUEL CONSUMPTION EXCESSIVE TROUBLESHOOTING SYMPTOM CHART.

This Page Can Be Copied For Your Convenience.

Fuel Consumption - Industrial Customer Complaint Form

Customer Name/Company _____ Date _____

Answer the following questions. Some questions require making an X next to the appropriate answer.

(1). What fuel consumption is expected? Expected _____ gph

(2). What are the expectations based on?
___ Original consumption ___ Other units in fleet ___ Competitive engines
___ Previous engine owned ___ Expectations only ___ Engine performance curve

(3). When did the problem occur?
___ Since New ___ Suddenly ___ Gradually

(4). Did the problem start after a repair? ___ Yes ___ No
If so, what was repaired and when? _____

(5). Is the vehicle also experiencing a Driveability problem (Low Power or Poor Acceleration/Response)? ___ Yes ___ No

IF ANSWERED YES, FILL OUT THE DRIVEABILITY/LOW POWER/EXCESSIVE FUEL CONSUMPTION CHECKLIST AND GO TO THE ENGINE POWER OUTPUT LOW TROUBLESHOOTING SYMPTOM CHART.

(6). Is the problem seasonal? ___ Yes ___ No

(7). Weather conditions during fuel consumption check?
___ Rain ___ Snow ___ Windy ___ Hot Temperatures ___ Cold Temperatures

(8). How is the fuel consumption measured? Tank ___ Trip ___ Month ___ Year ___ Hourmeter ___

(9). Do duty cycles vary between compared units? ___ Yes ___ No

(10). Have duty cycles changed for the engine being checked? ___ Yes ___ No

(11). What are the loads compared to a comparison unit?
___ Heavier ___ Lighter

(12). What is the altitude that the unit is operating at?
___ Below 10,000 feet ___ Above 10,000 feet

(13). How much of the time is the unit idling? _____ Hours/day

(14). Is operator technique or operating practices affecting fuel economy?
___ Operate at rated speed or above: RPM _____
___ Incorrect shift rpm: Shift RPM _____ Torque Peak _____
___ Believe compensating for low power

IF AFTER FILLING OUT THIS FORM IT APPEARS THAT THE PROBLEM IS NOT CAUSED BY VEHICLE FACTORS, ENVIRONMENTAL FACTORS OR OPERATOR TECHNIQUE, FILL OUT THE DRIVEABILITY/LOW POWER/EXCESSIVE FUEL CONSUMPTION CHECKLIST AND GO TO THE FUEL CONSUMPTION EXCESSIVE TROUBLESHOOTING SYMPTOM CHART.

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Oil Consumption

In addition to the information that follows, a service publication entitled Technical Overview of Oil Consumption is available, Bulletin 3379214-00.

Cummins defines "Acceptable Oil Usage" as outlined in the following table:

ACCEPTABLE OIL USAGE									
ANY TIME DURING COVERAGE PERIOD									
ENGINE FAMILY	HRS PER QT	HRS PER LITER	HOURS PER IMPERIAL QUART	MILES PER QUART	MILES PER LITER	MILES PER IMPERIAL QUART	KILOM PER QUART	KILOM PER LITER	KILOM PER IMPERIAL QUART
A	10.0	10.6	12.0	400	425	475	650	675	775
4B	10.0	10.6	12.0	400	425	475	650	675	775
6B	10.0	10.6	12.0	400	425	475	650	675	775
6C	10.0	10.6	12.0	400	425	475	650	675	775
V/VT-378	4.0	4.3	5.0	--	--	--	--	--	--
V/VT-504	4.0	4.3	5.0	250	265	310	400	425	485
V/VT-555	4.0	4.3	5.0	250	265	310	400	425	485
L Series	4.0	4.3	5.0	250	265	310	400	425	485
N Series	4.0	4.3	5.0	250	265	310	400	425	485
V/VT/ VTA-903	4.0	4.3	5.0	250	265	310	400	425	485
KT/ KTA19	3.0	32.	3.75	200	210	250	320	340	390
V/VT/ VTA28	2.0	2.1	2.5	--	--	--	--	--	--
KT/ KTA38	1.5	1.6	1.8	--	--	--	--	--	--
KTA50	1.1	1.2	1.3	--	--	--	--	--	--

Cummins
Engine Company, Inc.
Box 3005
Columbus, Indiana U.S.A.
47202-3005

Engine Lubricating Oil Consumption Report

Owner's Name	Date of Delivery Month Day Year	Engine Serial No.
Address	Equipment Manufacturer	Engine Model & HP
City State/Province	Equipment Serial No.	Fuel Pump Serial No.

Engine Application (Describe)	Oil & Filter Change Interval		Complaint Originally Registered	
	Oil	Filters	Date	Mile-Hours-Kilometers

Lubricating Oil Added

Date Added Oil	Engine Operation Miles-Hours-Kilometers	Quarts — Liters Oil Added	Brand & Viscosity of Oil Used
Start Test			

Last Mileage/Hours/Kilometers _____ Minus Start Mileage/Hours/Kilometers _____

Equals Test Mileage/Hours/Kilometers _____ Divided By Oil Added _____

Equals _____ Usage Rate _____

Customer Signature	Cummins Dealer	Cummins Distributor

Cummins Engine Company, Inc.
Form 4755

Cummins
Engine Company, Inc.
Box 3005
Columbus, Indiana U.S.A.
47202-3005

Oil Consumption Report

Customer Name _____ Dist./Dlr. _____
Engine Model _____ Mi/Km/Hr _____
Engine Serial No. _____ CPL No. _____
Vehicle Make/Model _____ Date _____

1. Review of maintenance history.
   List any previous failures that could have had a detrimental effect on cylinder component life. Failures could include fuel, coolant, and/or foreign abrasives in the oil, second ring groove beat-out, filter plugging, etc.

   _____
   _____

   Lube Oil Used.
   Brand _____
   Viscosity _____
   Change Interval _____ Mi/Km/Hr.

   By-pass Oil Filter.
   Model _____
   Element _____
   Change Interval _____ Mi/Km/Hr.

   Full Flow Oil Filter.
   Model _____
   Element _____
   Change Interval _____ Mi/Km/Hr.

   Air Cleaner _____
   Make and Model _____
   Change Interval _____

2. List any external engine leaks.

   _____
   _____
   _____

3. Visually check for any internal leaks and list. Check turbocharger seals, valve guides, air compressor, etc.

   _____
   _____
   _____

4. Had the fuel pump been tampered with? _____ What is maximum rail pressure readings? _____ If yes, the pump must be reset to factory specifications and the customer sent out to re-evaluate his oil consumption rate and the eligibility requirements must be met again.

5. Drain and refill oil pan to check dipstick markings and notes findings.

   _____

6. Only after above checks are completed, leaks corrected and proper documentation is completed, disassemble engine to determine cause for the failure and repair as required.

7. State reason for oil consumption.

   _____
   _____
   _____

Signed: _____

Form No. 5706

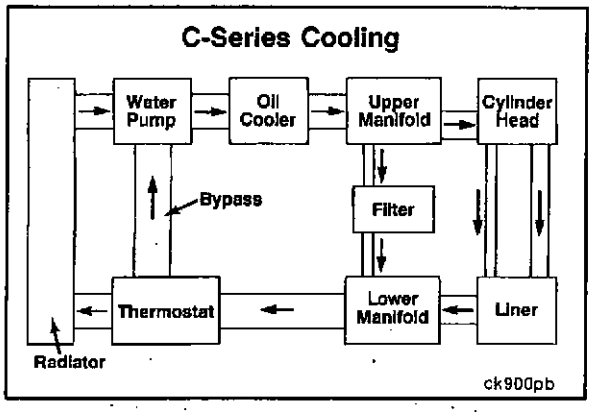
NOTES

Section 1 - Cooling System

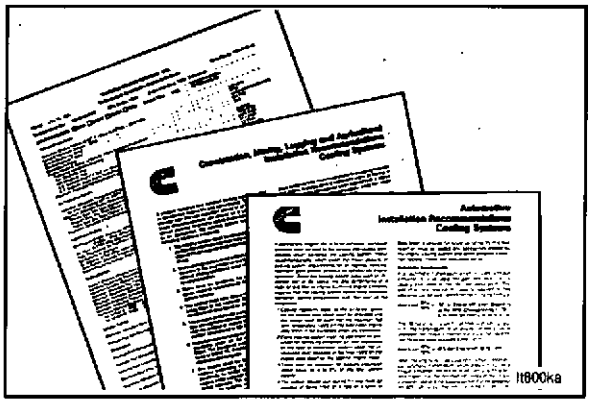
Section Contents

Cooling System - General Information

The primary function of the cooling system is to remove the heat created by the engine and its support components. The excess heat energy that is not removed by the cooling system is carried away by exhaust gases and radiation into the atmosphere.



The accompanying charts illustrate the coolant flow through the engine. For more detail refer to the cooling system flow diagrams on page 1-3.



The following publications are available through Cummins Distributors or Dealers to provide cooling system installation recommendations and specifications approved by Cummins Engine Co., Inc.:

- Installation Recommendations C Series Charge Air Cooling System, Bulletin No. 3884653
- B & C Series Engines Installation Recommendations, Bulletin No. 3382769

Cooling System - Flow Diagrams

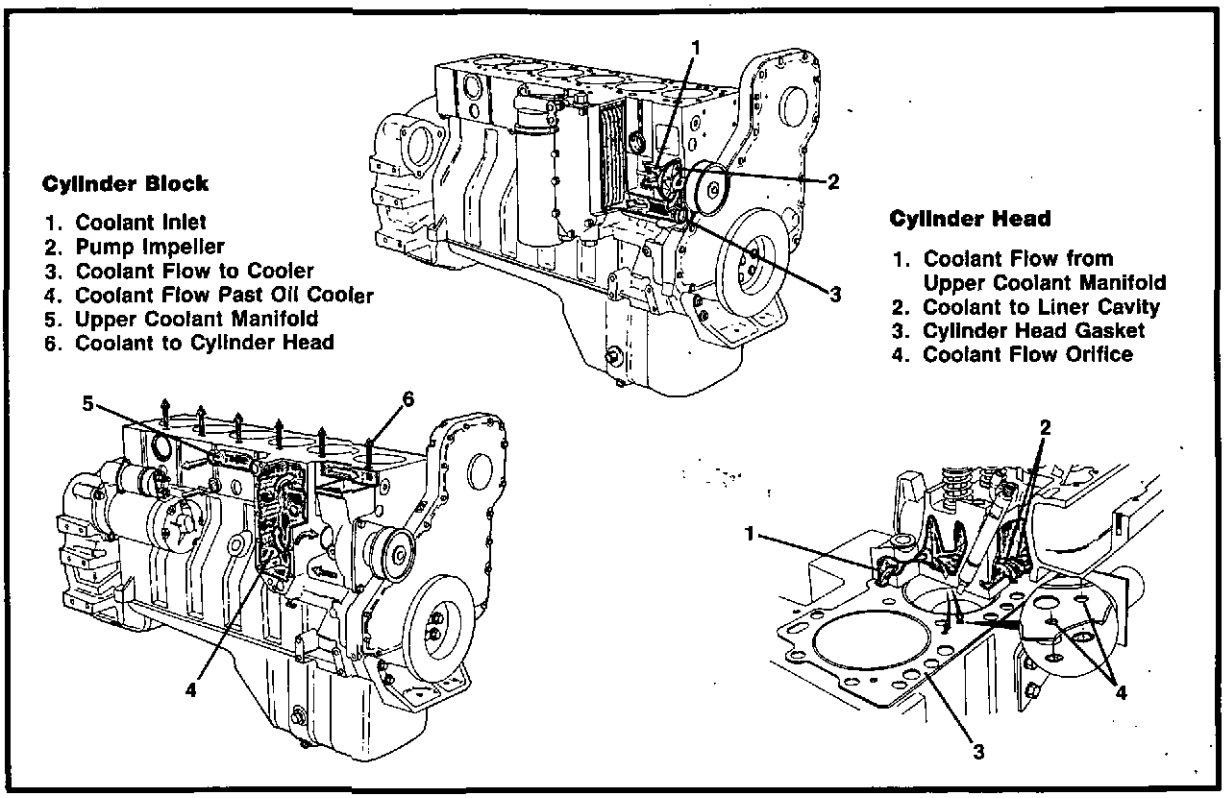
The following illustrations identify the significant features of the cooling system:

Coolant is drawn from the radiator by the integrally mounted water pump. The output from the water pump empties into the bottom of the oil cooler cavity in the cylinder block.

From the cooler cavity, the coolant flows into the upper water manifold. A portion of coolant flows through the coolant filter and returns to the lower manifold. The remainder flows through six cast openings up to the cylinder head.

A portion of the coolant flowing into the cylinder head is directed to the liner cavity and, by means of a diffuser plate cast into the cavity, is circulated around the top portion of the liners. The remainder of the coolant flows across the valve bridges around the injector bores and down into the liner cavities through two orificed holes per cylinder. The orificed holes control the coolant flow around the liners.

Coolant System

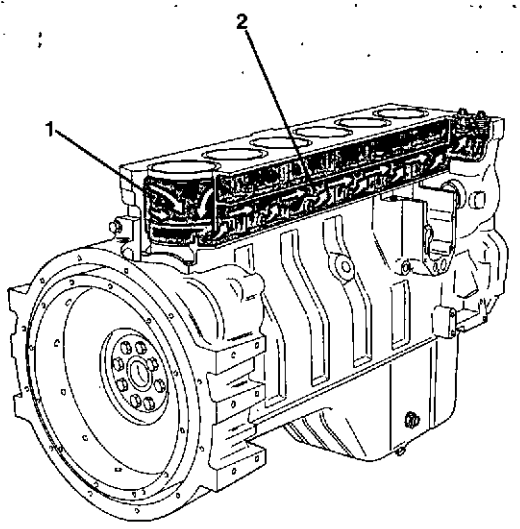


Cooling System - Flow Diagrams (Continued)

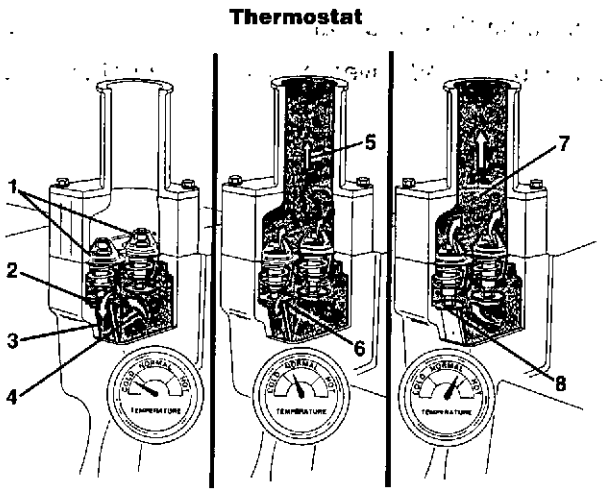
From the liner cavities the coolant flows through cast openings into the lower manifold and on to the thermostat cavity.

When engine is below operating temperature, the thermostats are closed. Coolant is bypassed to the water pump inlet. As the coolant temperature increases, both thermostats begin to open allowing some of the coolant to flow to the radiator. At normal operating temperature, both thermostats are fully open and the bypass circuit is closed.

Coolant System



1. Coolant Flow Past Cylinder Liners
2. Lower Coolant Manifold



Closed

1. Thermostats
2. Coolant to Pump Inlet
3. Bypass Passage
4. Coolant from Lower Coolant Manifold

Intermediate

5. Partial Coolant Flow to Radiator
6. Restricted Coolant Flow to Bypass

Open

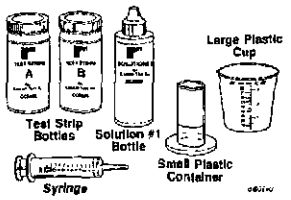
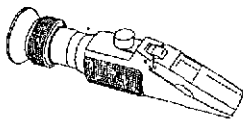
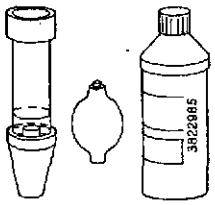
7. Coolant to Radiator
8. Bypass Closed

Cooling System - Specifications

	Metric [U.S.]
Coolant Capacity (engine only)	
C8.3, (air aftercooled)	9.9 liters [10.5 U.S. Qts.]
6CTA8.3 (water aftercooled)	10.9 liters [11.5 U.S. Qts.]
Thermostat	
Starts to Open	81 to 83°C [178 to 182°F]
Fully Open	95°C [203°F]
Maximum Allowable Top Tank Temperature	100°C [212°F]
Minimum Recommended Top Tank Temperature	70°C [158°F]
Minimum Allowable Pressure Cap	50 kPa [7.0 psi]
Supplemental Coolant Additives (SCA) Concentration	1.5 to 3.0 units per 3.7 liters [1 U.S. Gallon]

Cooling System - Service Tools

The following special tools are recommended to perform procedures in Section 1. The use of these tools is shown in the appropriate procedure. These tools can be purchased from your local Cummins Authorized Repair Location.

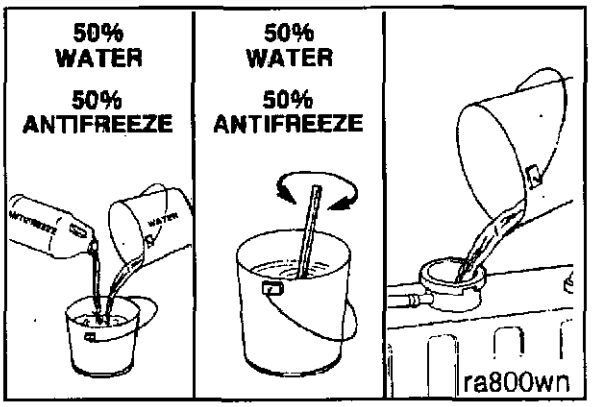
Tool No.	Tool Description	Tool Illustration
CC-2626	**Cooling System Test Kit** The Fleetguard® Coolant Test Kit is used to check the concentration of coolant additives in the cooling system.	
CC-2800	**Refractometer** The Fleetguard® Refractometer is used to measure the freeze point protection and antifreeze concentration.	
3822985	**Combustion Gas Leak Test Kit** Includes Part No. 3822986 Test Fluid, Part No. 3822987 Adapter, and Part No. 3877612 Instructions.	

Cooling System - Maintenance (1-01)

Antifreeze

Caution: Never use only water for engine coolant. In tropical climates where antifreeze availability can be limited, use a corrosion inhibitor (Cummins Liquid DCA) to protect the engine cooling system.

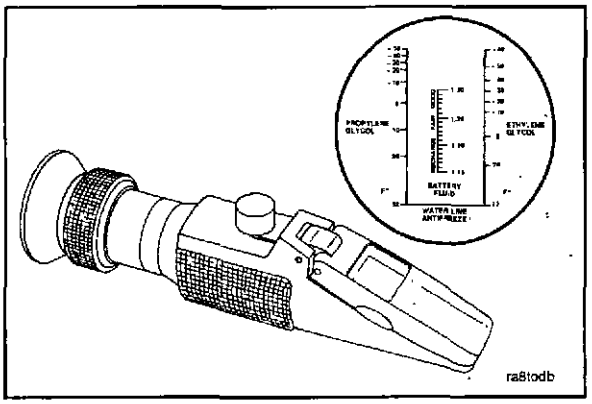
A premixture of 50 percent ethylene-glycol base antifreeze is required for operation of the engine in temperature environments above -37°C [-34°F]. A mixture of 32 percent water and 68 percent antifreeze is recommended for temperatures below -37°C [-34°F].



Antifreeze Concentration - Checking

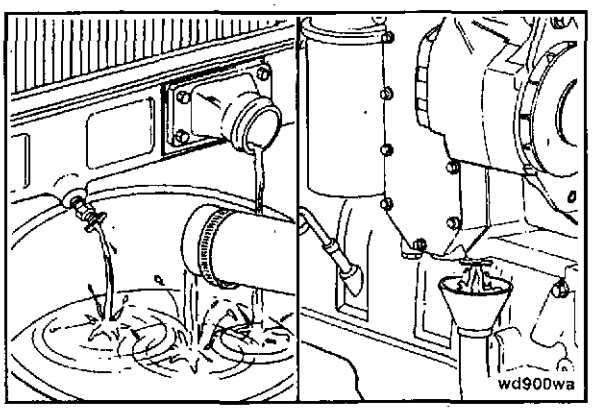
The Fleetguard® refractometer, Part No. CC-2800, provides a reliable and easy-to-read measurement of freeze point protection and glycol (antifreeze) concentration.

The freeze point protection **must** be checked if coolant is added to the cooling system or annually when operating in temperatures below 0°C [32°F]. Refer to the manufacturer's instruction manual chart for instructions.



Cooling System - Draining

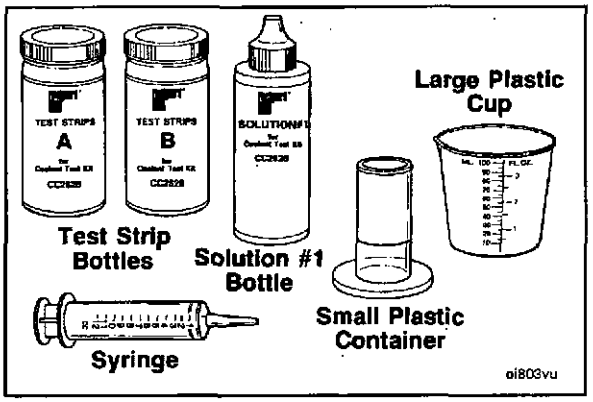
Open the petcocks at the bottom of the radiator and at the bottom of the oil cooler housing. Remove the lower radiator hose. A 20 liter [4 U.S. gallons] drain pan will contain the coolant in most applications.



Additive Concentration - Checking

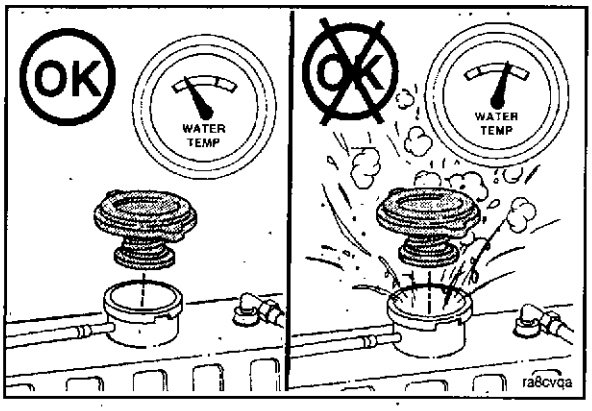
The cooling system **must** contain the proper coolant additive units to provide the best chemical protection. Refer to the C Series Operation and Maintenance Manual.

DCA4 Test Kit: Use only DCA4 Coolant Test Kit, Fleetguard® Part No. CC-2626, to check the coolant additive concentration in the cooling system.

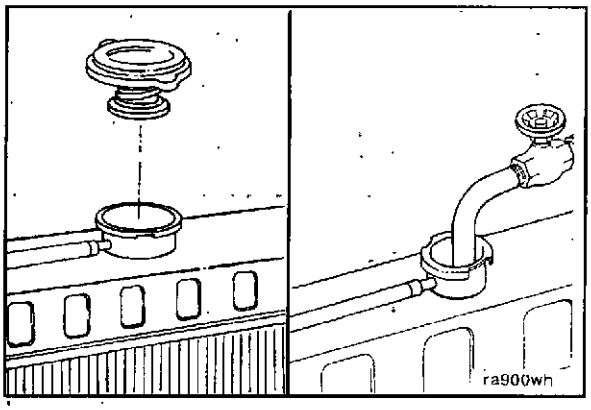


Cooling System - Cleaning

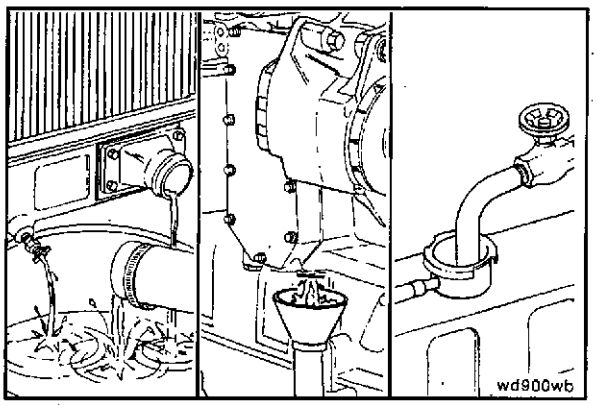
The following is the recommended procedure for flushing and cleaning the engine cooling system of oil or fuel contamination. It is assumed that the source of the contamination has been located and corrected:



Warning: Wait until the coolant temperature is below 50°C [122°F] before removing the coolant system pressure cap. Failure to do so can cause personal injury from heated coolant spray.

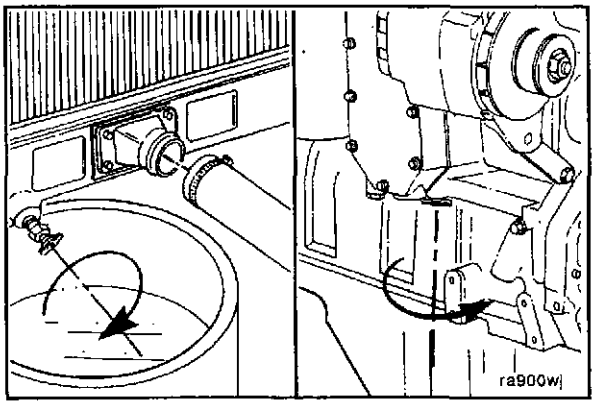


Remove the pressure cap. Slowly overfill the top tank to flush as much contaminated coolant as possible out the top of the tank.



Completely drain the cooling system (block, radiator, heaters). Do **not** remove the coolant filter. Use running water to quickly flush the majority of the contamination, leaving draincocks open. Plugged radiators can require extra treatment beyond these procedures. Consult local regulations concerning disposal of antifreeze and oil.

Connect all hoses, close all draincocks.



NOTE: The performance of RESTORE is dependent on time, temperature, and concentration levels. An extremely flow restricted system, for example, can require higher concentrations of cleaners, higher tempratures, or longer cleaning times. RESTORE can be safely used up to twice the recommended concentration levels. Extremely fouled systems can require more than one cleaning.

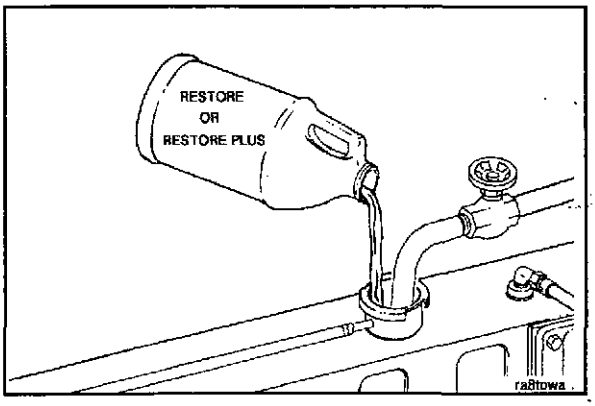
Cummins Engine Company, Inc., recommends using Fleetguard® RESTORE or an equivalent. Cooling systems can also be cleaned using non-sudsing washing soda or automatic dish washer soap.

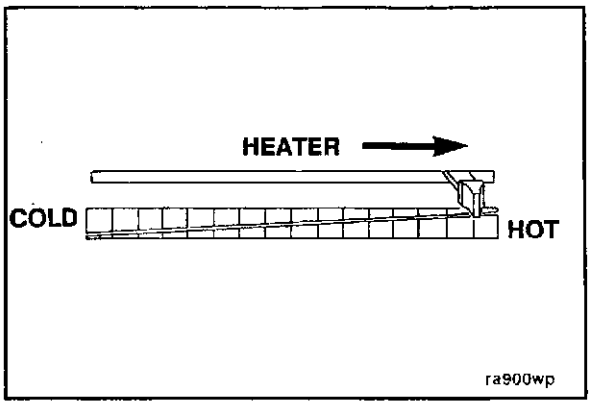
The product used **must** be alkaline (non-acidic). Use of a liquid cleaner will allow easier mixing and will **not** have the possibility to cake or plug the cooling system.

If using a cleaner other than RESTORE, consult the label to determine the amount of cleaner required for the cooling system capacity. When using a powdered cleaner, thoroughly mix the cleaner with water (an amount equal to the cooling system capacity) in a separate container. Fill the cooling system with the mixture.

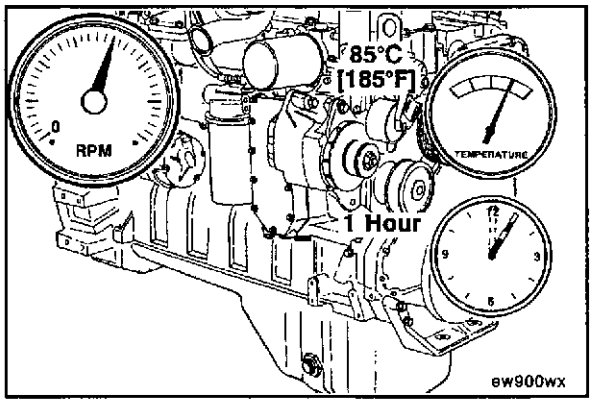
Caution: Fleetguard® RESTORE contains no antifreeze. Do not allow the cooling system to freeze during the cleaning operation.

Immediately add 3.8 liters [1 U.S. gallon] of Fleetguard® RESTORE (or equivalent) for each 38 to 57 liters [10 to 15 gallons] of cooling system capacity, and fill the system with plain water. Do **not** allow the cooling system to dry out. RESTORE will **not** be as effective if the cooling system is allowed to dry.

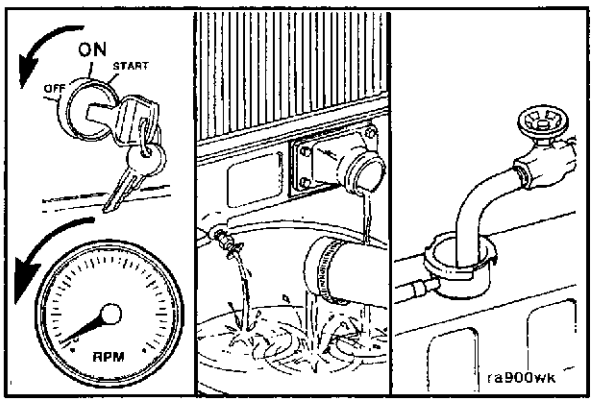




Turn the cab heater temperature switch to high to allow maximum coolant flow through the heater core. The blower fan does **not** have to be on.

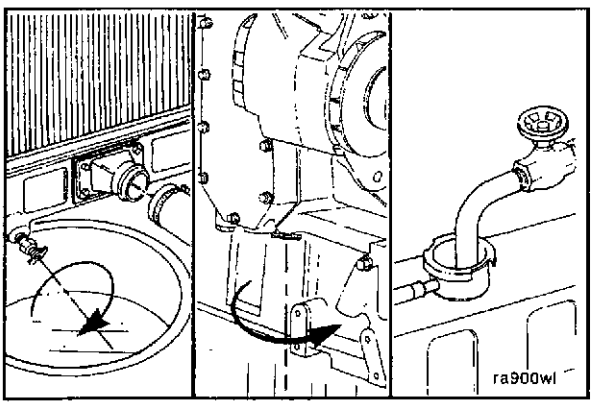


Operate the engine at 2100 RPM at normal operating temperatures (at least 85°C [185°F]) for 1 hour.



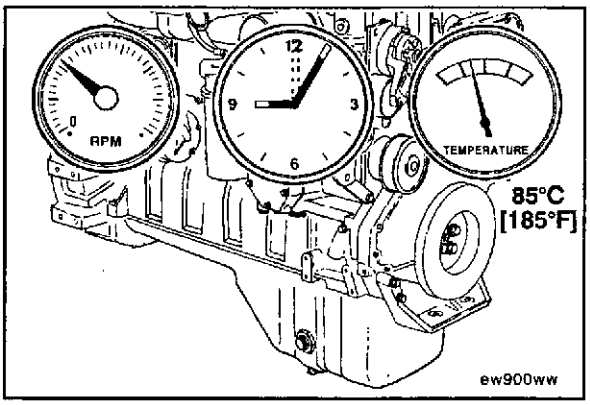
Shut off the engine, and drain the cooling system.

Use running water to flush the majority of the contaminated mixture, leaving all draincocks open.

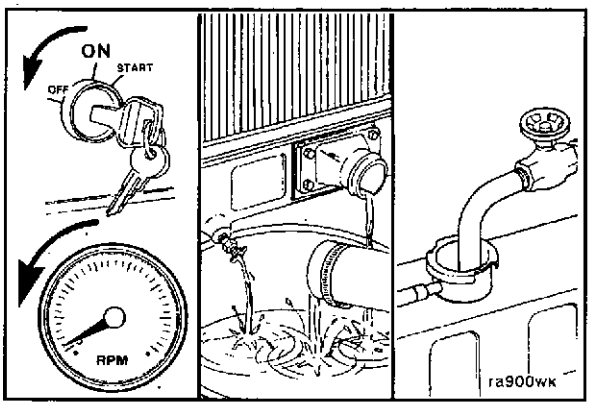


Connect all hoses, close all draincocks and fill the cooling system with clean water (and neutralizer if the cleaner used requires).

Operate the engine at high idle for 5 minutes with the coolant temperature above 85°C [185°F].

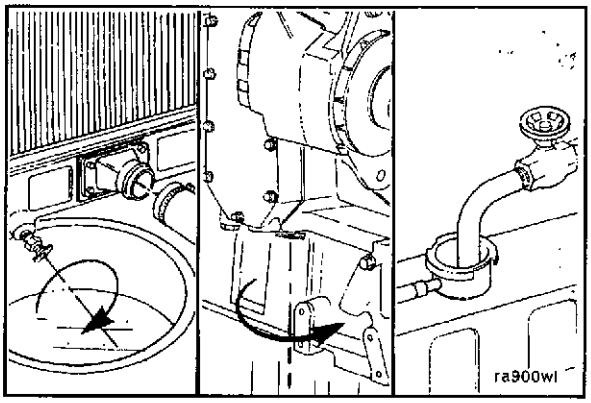


Shut off the engine and completely drain the cooling system again. Use running water to flush the remainder of the rinse water.



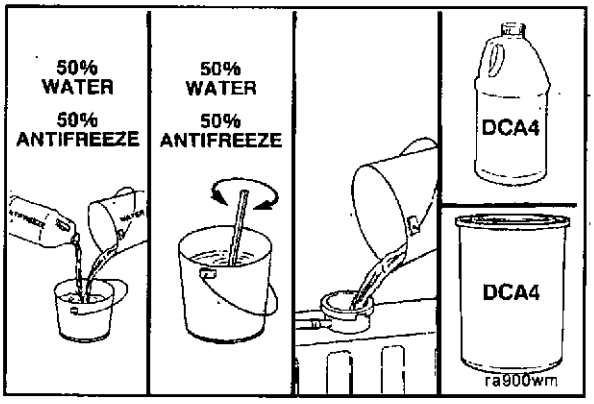
Connect all hoses, close all draincocks and leave all heater valves open.

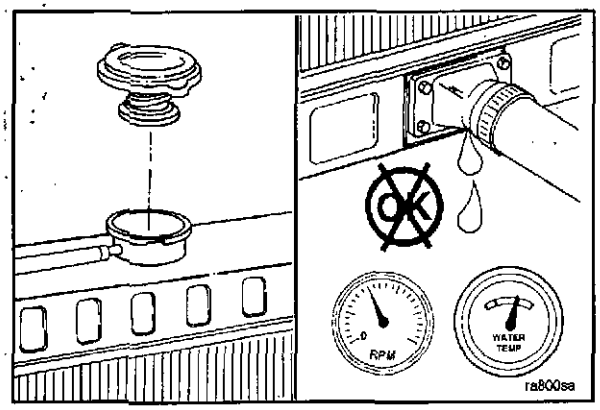
NOTE: If the drain water shows more than just a trace of contamination, the cooling system **must** be flushed again.



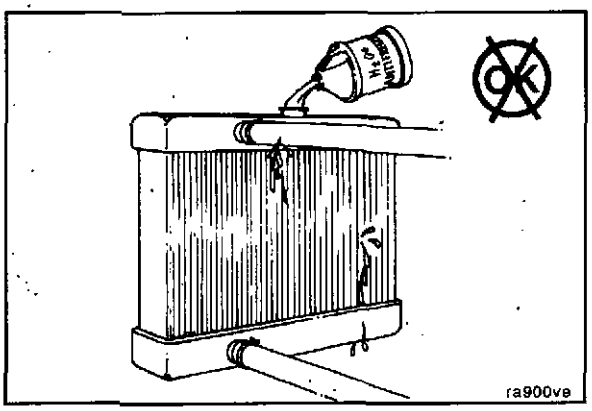
Install a new coolant filter, and fill the cooling system with a fresh premixture of 50 percent low silicate antifreeze and 50 percent water.

NOTE: Use an initial charge filter to bring the coolant to the correct DCA4 concentration level of 1.5 units per 3.8 liters [1 U.S. gallon] of coolant in the system. Refer to the C Series Operation and Maintenance Manual.





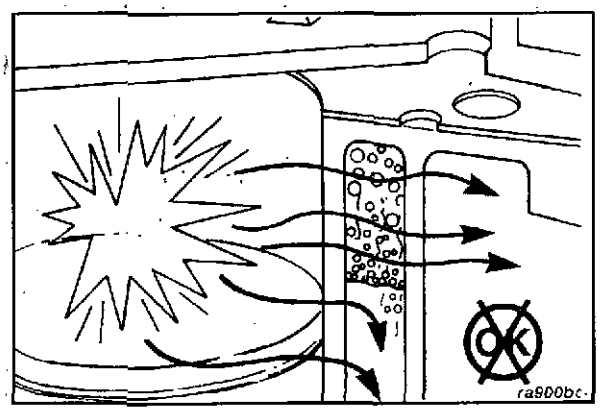
Install the pressure cap. Clean the engine compartment of any contamination residue accumulated during the top tank overfills. Operate the engine to check for leaks and normal operation.



Filling and Venting

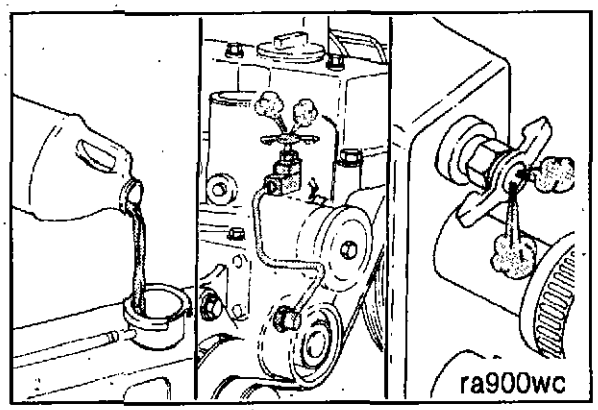
The system is designed to use a specific quantity of coolant. If the coolant level is low, the engine will run hot.

If frequent addition of coolant is necessary, the engine or system has a leak. Find and repair the leak.



The engine coolant passages must be completely filled with coolant.

During operation, entrapped air mixes with the coolant which results in cavitation corrosion and poor heat transfer. Highly aerated coolant can cause localized overheating of the cylinder head and block which can result in a cracked head, scored cylinder or blown head gasket.



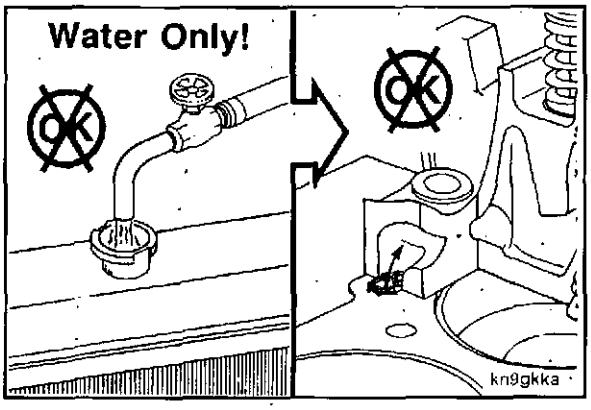
Caution: During filling, air must be vented from the engine coolant passages. Open the engine venting petcock and the petcock on the aftercooler for aftercooled engines. The system must be filled slowly to prevent air locks. Wait 2 to 3 minutes to allow air to be vented, then add mixture to bring the level to the top.

Refer to Cooling System - Maintenance for coolant recommendations.

Water will cause rust formation reducing the flow in the smaller coolant passages.

The small holes in the head gasket are especially susceptible to plugging.

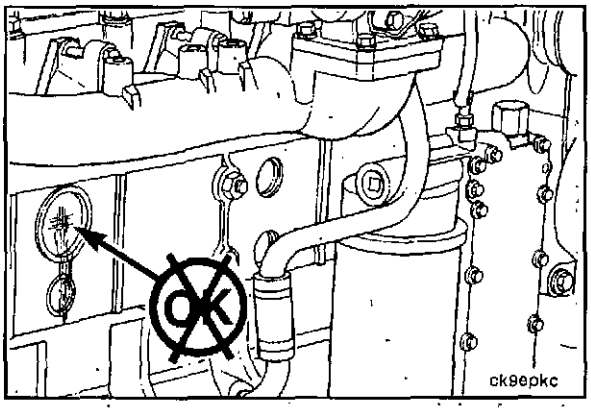
Caution: These holes are orifices and their size is critical. Do not enlarge the size of the orifices. To do so will disturb the coolant flow and will not solve an overheating problem.



Also, water used as a coolant for even a relatively short period can result in the cup plugs rusting through allowing the coolant to leak.

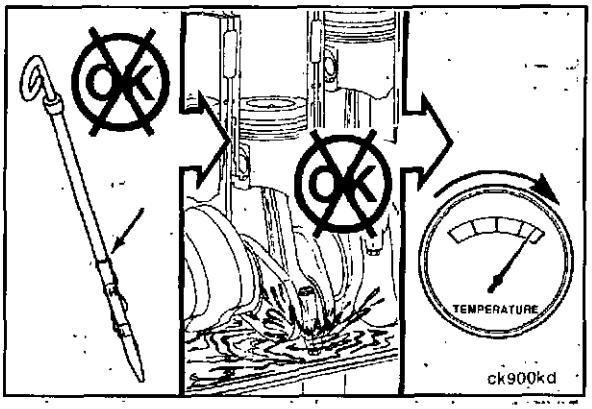
Caution: A sudden loss of coolant from a heavily loaded engine can result in severe damage to the pistons and cylinder bore.

NOTE: Use the correct amount of DCA4 corrosion inhibitor to protect the cooling system. Refer to the Coolant Recommendations in the Operation and Maintenance Manual, Bulletin No. 3810248.

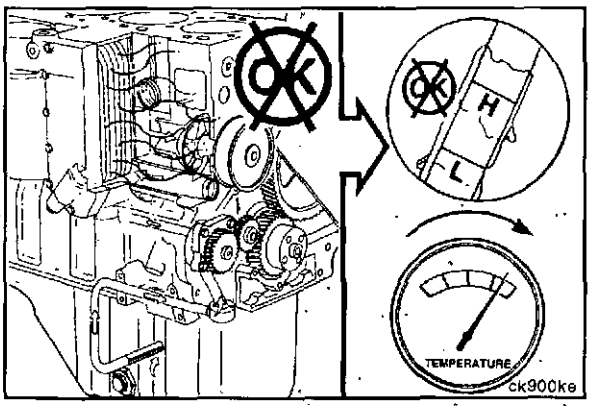


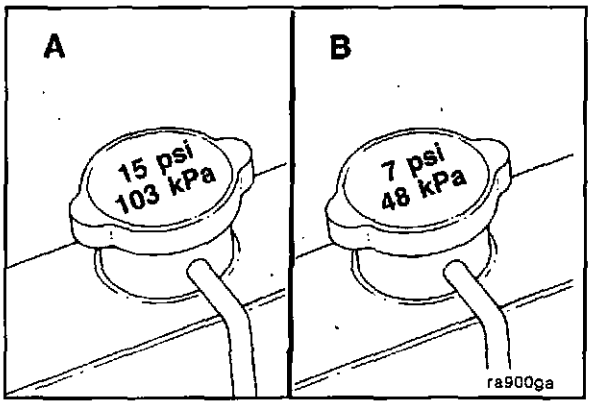
Cooling System - Diagnosing Malfunctions (1-02)

The function of the cooling system is to maintain a specified operating temperature for the engine. Some of the heat generated by the engine is absorbed by the coolant flowing through the passages in the cylinder block and head. Then, heat is removed from the coolant as it flows through the radiator. When troubleshooting overheating problems, remember that too much oil in the oil pan can cause additional heat from friction when the rod journals are submerged in oil.



Overfilling the oil pan raises the oil temperature which is transferred to the coolant system at the oil cooler.



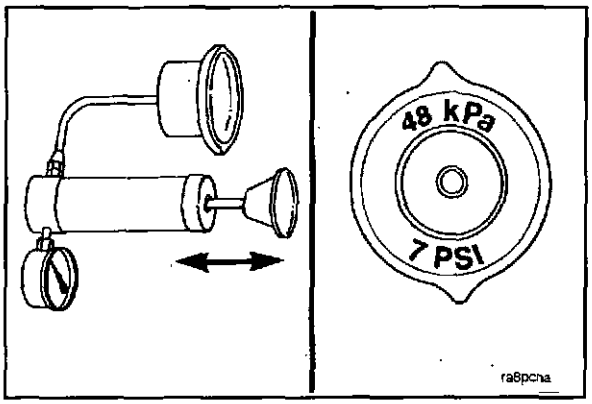


Radiator Cap - Pressure Test

The system is designed to use a pressure cap to prevent boiling of the coolant.

Different caps are specified for the two recommended systems:

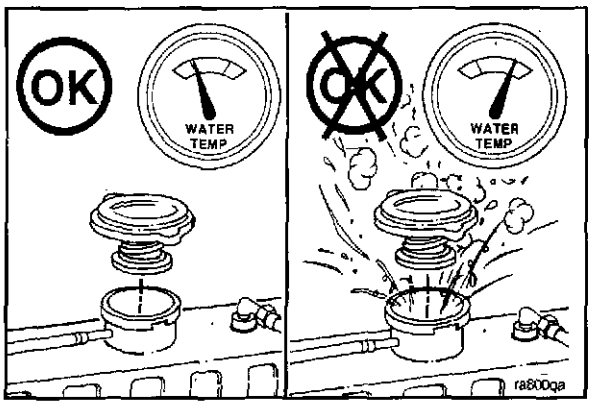
System	Cap
A - 104°C [220°F]	103 kPa [15 psi]
B - 99°C [210°F]	48 kPa [7 psi]



Pressure test the radiator cap.

The pressure cap **must** seal within 14 kPa [2 psi] of the value stated on the cap or it **must** be replaced.

An incorrect or malfunctioning cap can result in the loss of coolant and the engine running hot.

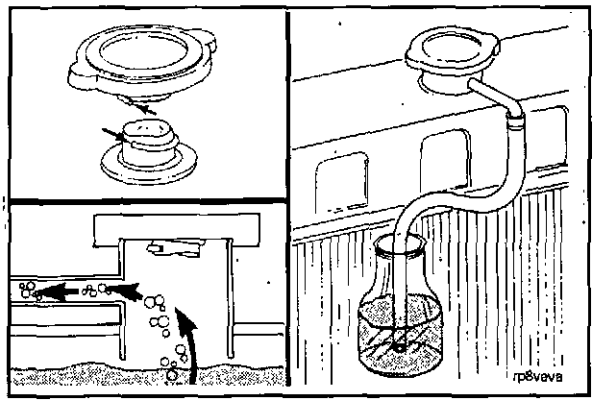


Cooling System - Test for Combustion Gases

Overflow Method

Warning: Wait until the temperature is below 50°C [122°F] before removing the coolant system pressure cap. Failure to do so can cause personal injury from heated coolant spray.

Allow the engine to cool, and remove the radiator cap.



Install a radiator pressure cap which has had the spring and the pressure relief valve removed to allow free flow from the overflow tube.

Attach a rubber hose to the radiator overflow connection.

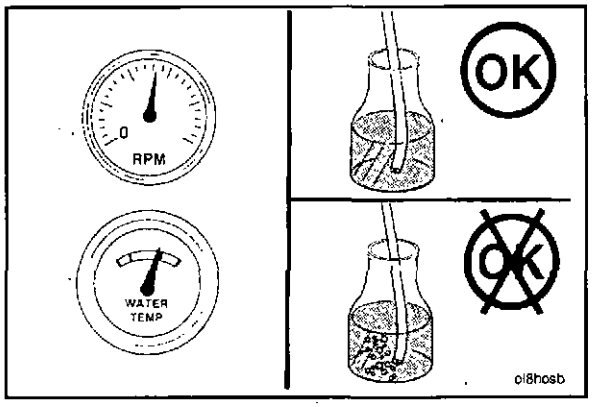
Put the free end of the hose below the water level in a container of water.

NOTE: *The pressure cap **must** be tightly sealed in the top of the radiator fill neck.*

Operate the engine at rated RPM until it reaches a temperature of 82°C [180°F].

Check for air bubbles in the water container. A combustion gas leak is present if a continuous flow of air bubbles is present.

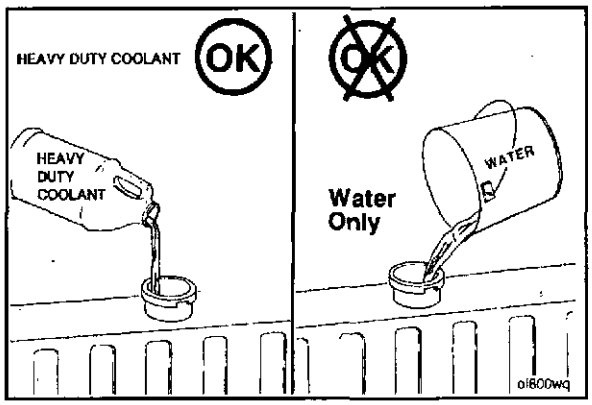
NOTE: The engine coolant temperature **must** be stable to perform this test. An increasing coolant temperature will give a false indication of air due to expansion of the coolant in the system.



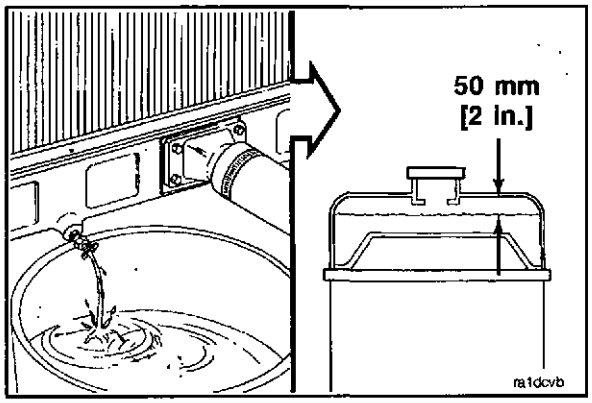
Combustion Gas Test

Use Part No. 3822985 Combustion Gas Tester or equivalent to test for combustion gasses in the cooling system.

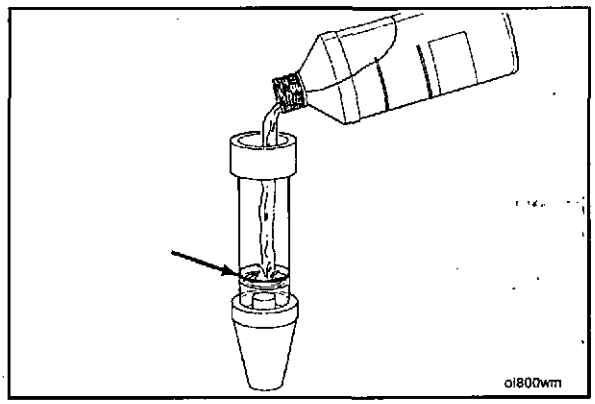
NOTE: It is recommended that the cooling system contain a premixture of 50 percent antifreeze and 50 percent water during the combustion gas leak test. The use of water only can result in a color change in the test fluid from blue to turquoise or light green during the test. This is **not** an indication of a combustion gas leak.

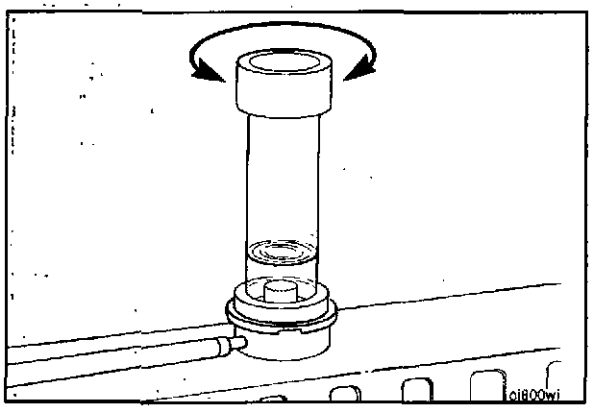


Drain the coolant level down approximately 50 mm [2 inch] below the radiator cap seal ledge in the radiator fill neck.

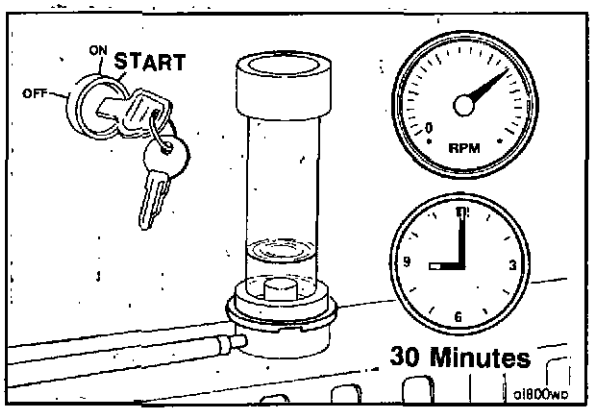


Pour the test fluid into the combustion gas test instrument until it is up to the yellow fill line on the instrument.

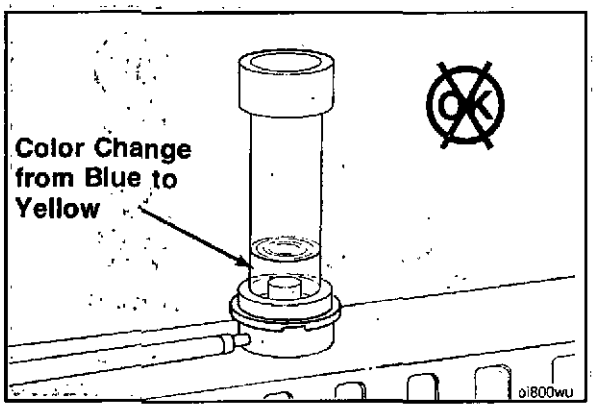




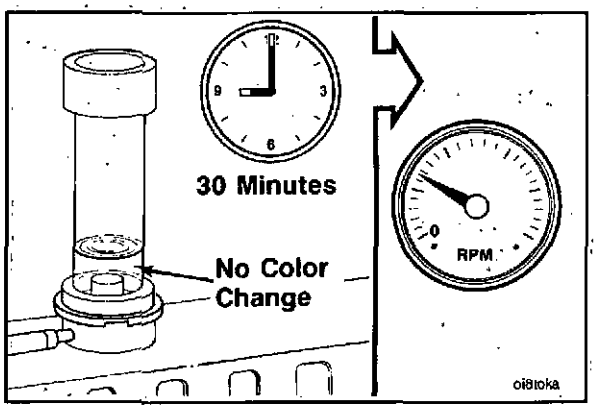
Insert the rubber tip of the combustion gas leak test instrument in the radiator fill neck. Hold the instrument down firmly and turn back and forth to make sure that an *air tight seal is formed between the tester and radiator fill* neck.



Start the engine and operate at high idle for approximately 30 minutes. Monitor the engine temperature and color of the test fluid during engine operation. Do **not** allow the engine temperature to exceed 100°C [212°F] during the test.

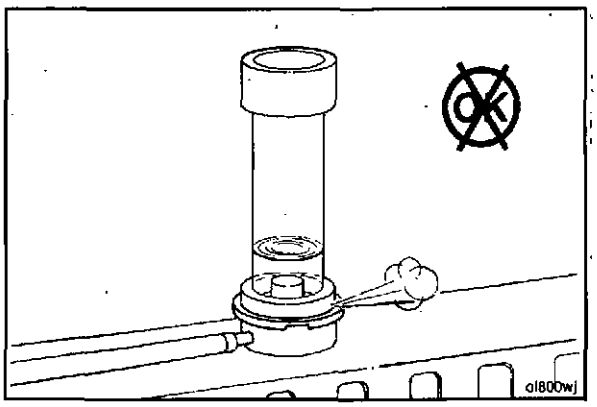


If the color of the test fluid changes from blue to yellow anytime during the test, combustion gasses are leaking into the cooling system. Discontinue the test if the color of test fluid changes from blue to yellow.



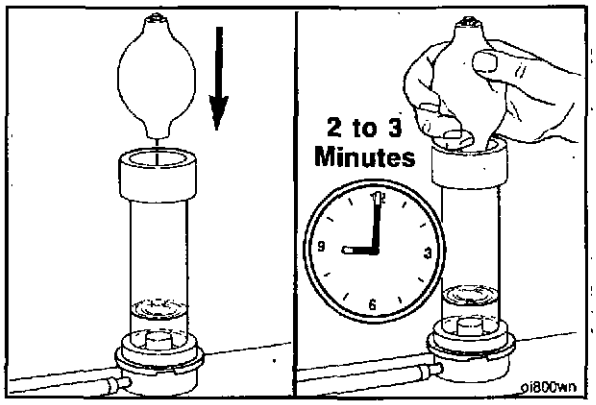
If a color of the test fluid does **not** change from blue to yellow during the 30 minutes test period, return the engine to low idle.

Check the test instrument to make sure that it is firmly sealed in the radiator fill neck.

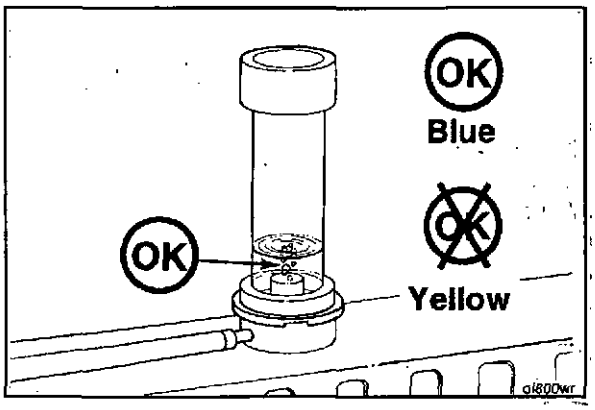


Insert the tip of the rubber ball into the hole in the top of the test instrument. Squeeze the rubber ball 2 to 3 minutes to draw air from the radiator through the test fluid.

If the color of the test fluid remains blue, combustion gasses are **not** entering the cooling system. If the color of the test fluid changes from blue to yellow, combustion gasses are entering the cooling system and further investigation is required to determine the source of the combustion leak.



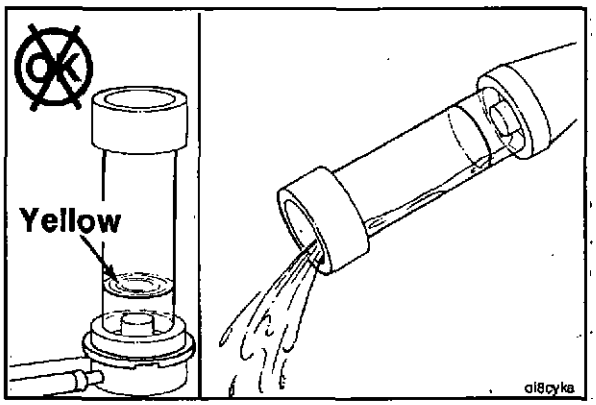
NOTE: As the cooling system warms up to operating temperature, air will be expelled through the combustion gas tester in the form of bubbles in the test fluid. This is due to normal expansion of the coolant. Do **not** mistake the presence of air bubbles in the tester as combustion gasses or air leaks into the cooling system. A change in the color of the test fluid from blue to yellow is the only indication of combustion gas in the cooling system.

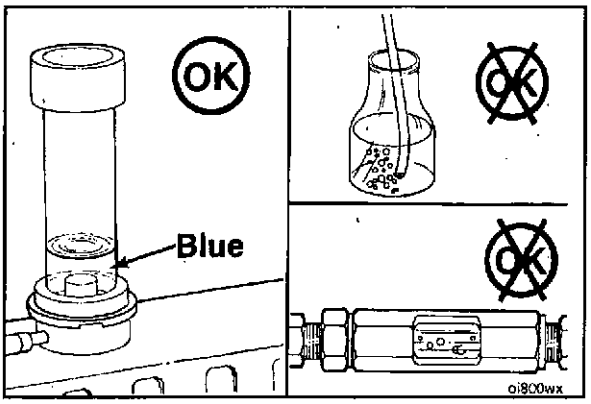


A positive result from the combustion leak tester indicates the following:

- Cracked cylinder head.
- Cylinder head or gasket leakage.
- Air compressor head or gasket leak.

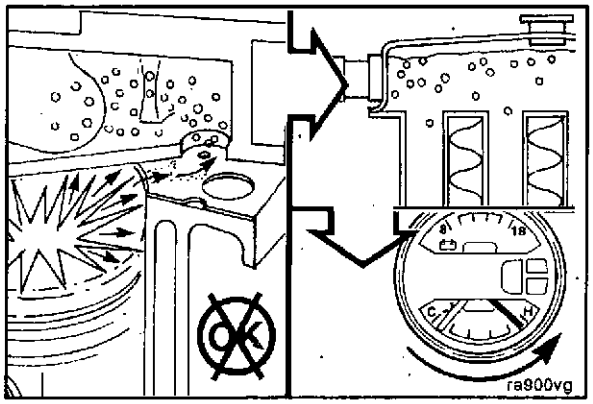
NOTE: Discard the tester fluid if it has indicated positive.



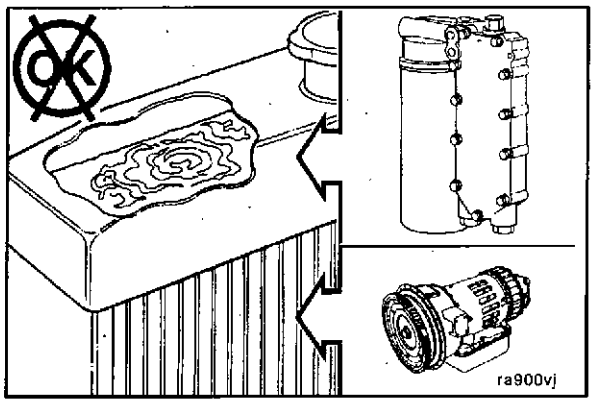


A negative result from the combustion leak tester coupled with a continuous flow of air bubbles from the previous test indicates the following:

- Air entrained due to faulty thermostat ball valve or incorrect fill.

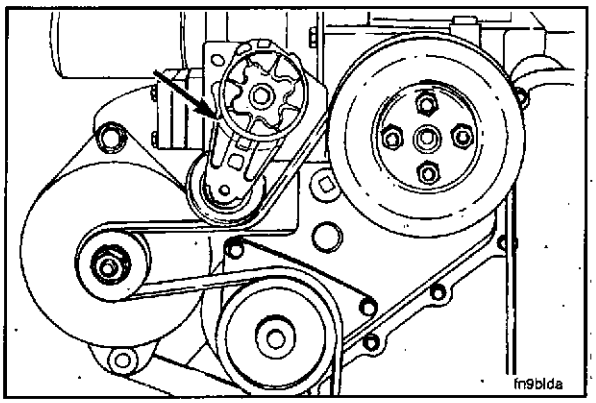


- Air in the coolant can result in loss from the overflow when the aerated coolant is hot. The heated air expands, increasing the pressure in the system causing the cap to open.
- Similarly, coolant can be displaced through the overflow if the head gasket leaks compression gasses to the coolant system.



- The operating pressure of the cooling system and the lubricating system can result in the mixing of the fluids if there is a leak between the systems: head gasket, oil cooler. Refer to the Lubricating Oil System.
- **Transmission fluid can also leak into the coolant through transmission oil coolers.**

NOTE: If the cooling system is contaminated with oil, it **must** be cleaned and flushed. Refer to Procedure 1-01.



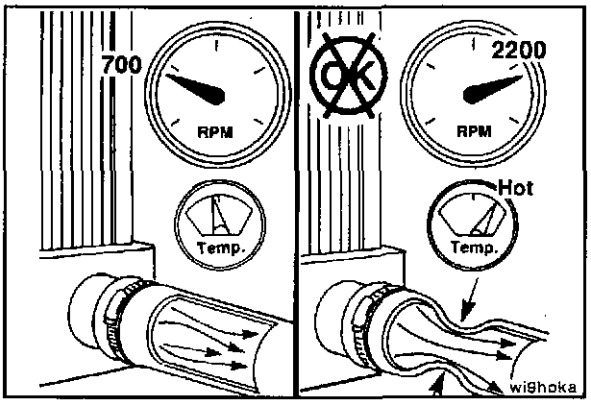
Belt Tension

The pump is belt driven from the crankshaft pulley. An automatic belt tensioner is used to prevent the belt from slipping on the pump pulley. A malfunction of the tensioner will cause the water pump impeller to rotate at a slower speed reducing the amount of coolant flow.

Coolant Hose - Inspection

The coolant flow can also be reduced if the inlet hose to the water pump collapses. A hose will usually not collapse while the engine is running at low speed. Check the hose while the engine is running at rated speed.

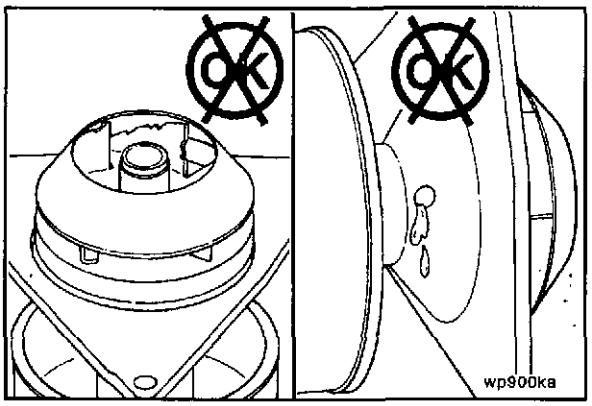
Be sure the engine is warm, a minimum of 88°C [190°F], so the thermostat is open.



Water Pump - Inspection

The water pump pulls coolant from the bottom of the radiator and pumps it through the engine back to the top of the radiator for cooling.

A worn or malfunctioning water pump will not produce the flow required to prevent the engine from running hot. However, be sure to check the other possibilities indicated in the Troubleshooting Logic Chart before checking the flow or replacing the pump.

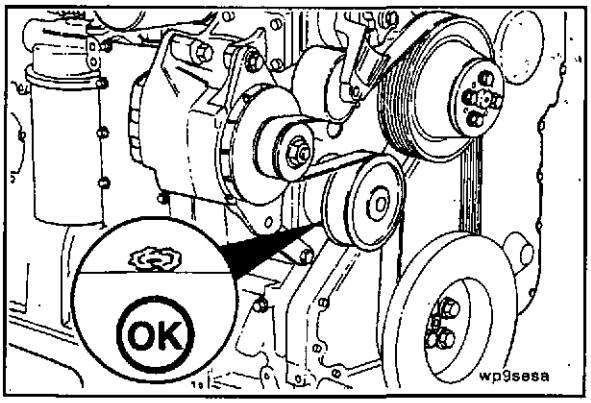


Water Pump Seal Weep Hole - Inspection

The water pump seal design requires a coolant film for lubrication and cooling. Therefore it is normal to observe a minor chemical build up or streaking at the weep hole.

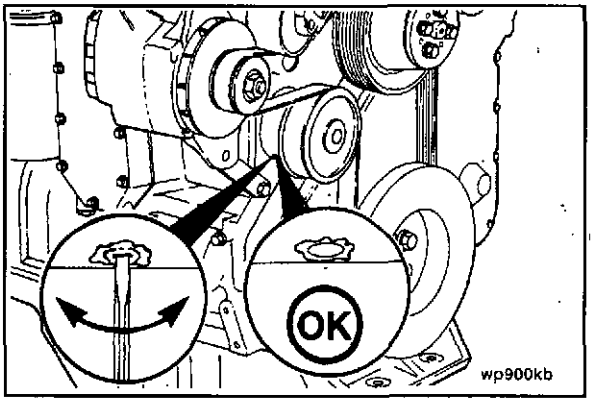
NOTE: A streak or chemical build up at the weep hole is **not** justification for water pump replacement.

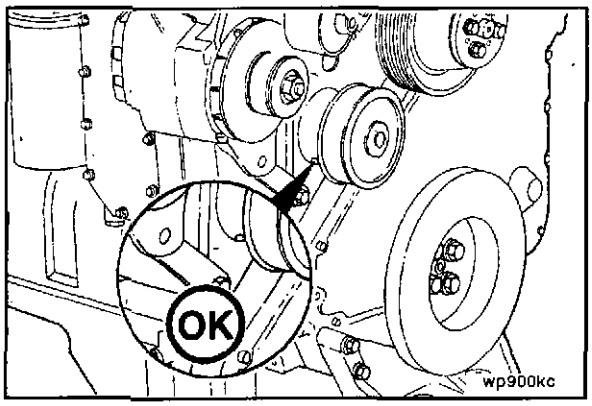
Use the following guidelines to determine if water pump replacement is necessary:



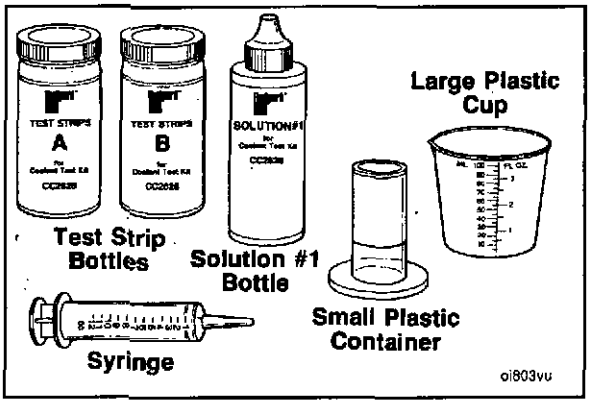
Make sure the weep hole is open.

A small screwdriver or a similar tool can be used to remove any debris.





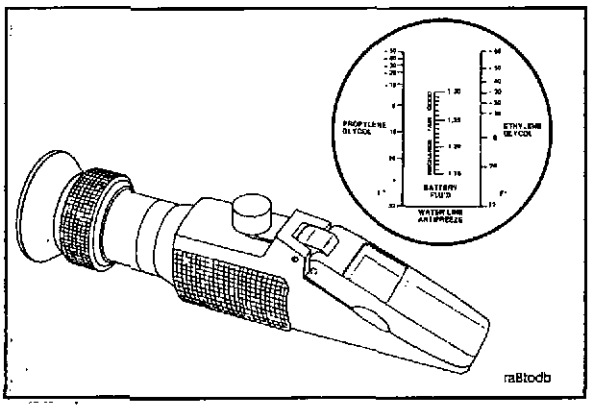
If no leakage is observed from the weep hole under operating conditions, do **not** replace the water pump.



If coolant is observed to be dripping from the weep hole:

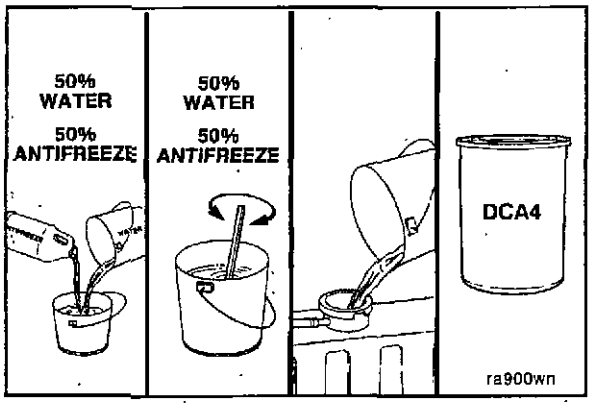
— Use Fleetguard® coolant test kit, Part No. CC-2626, to check the coolant inhibitor level, and adjust the inhibitor level per the test kit chart.

NOTE: Supplemental coolant additive concentrations exceeding 2.0 units per gallon will cause water pump seal leakage.



— Use Fleetguard® refractometer, Part No. CC-2800, to check the antifreeze level of the coolant.

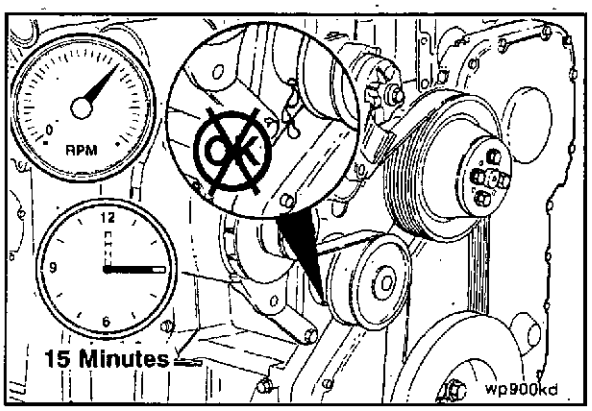
NOTE: Ethylene glycol type antifreeze concentration exceeding 70 percent will adversely affect freeze point protection and will contribute to water pump seal leakage.



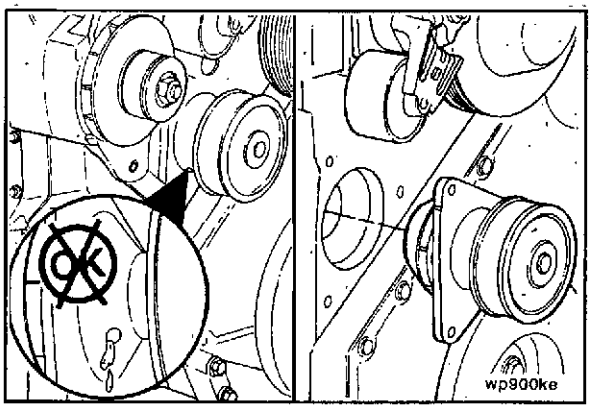
If the antifreeze concentration is above 60 percent, drain all the coolant and add make up water to bring the antifreeze concentration to a minimum of 40 percent to a maximum of 60 percent. Replace the coolant filter, add new coolant inhibitor to the recommended levels as outlined in the Operation and Maintenance Manual.

Caution: If the coolant leakage is observed as a steady stream upon start-up, stop the engine immediately and replace the water pump.

Operate the engine at high idle for 15 minutes with the proper inhibitor and antifreeze levels and check the water pump for leakage again.



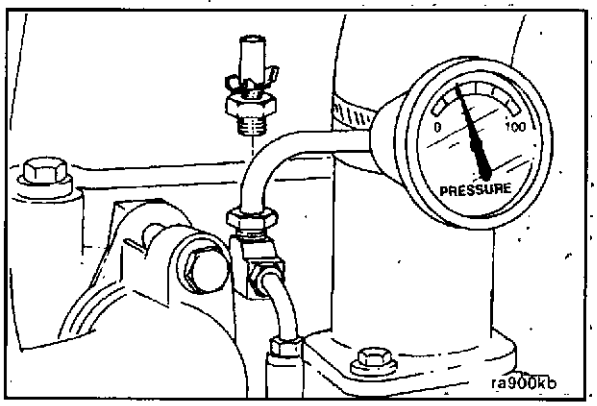
If the coolant is leaking after the above checks, replace the water pump. Refer to Procedure 1-07.



Coolant Pressure - Measurement

The coolant pressure can be measured from the vent petcock to help determine the condition of the pump. At normal operating temperature (thermostats open) and engine operating at 2,000 RPM, the pressure should be:

Pressure Cap	Minimum Pressure
103 kPa [15 psi]	124 kPa [18 psi]
48 kPa [7 psi]	69 kPa [10 psi]



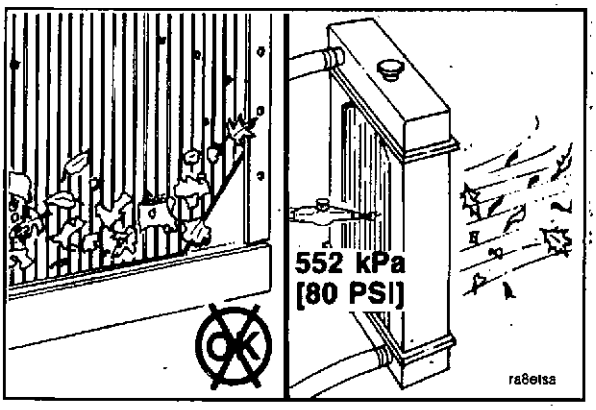
Radiator, Fan and Shutters

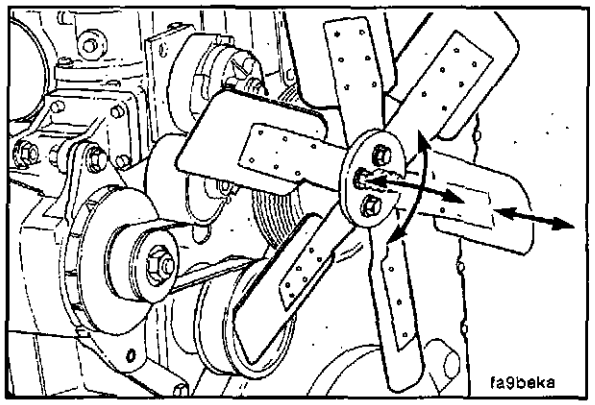
Air forced through the fins of the radiator by a fan cools the coolant pumped through the radiator. Environmental debris (paper, straw, lint, dust, and bugs) can obstruct the fins and stop the flow of air which will reduce the cooling affect of the radiator.

Caution: Wear appropriate eye and face protection when using compressed air. Improper use can cause bodily injury from flying debris and dirt.

Use compressed air to blow out the dirt and debris.

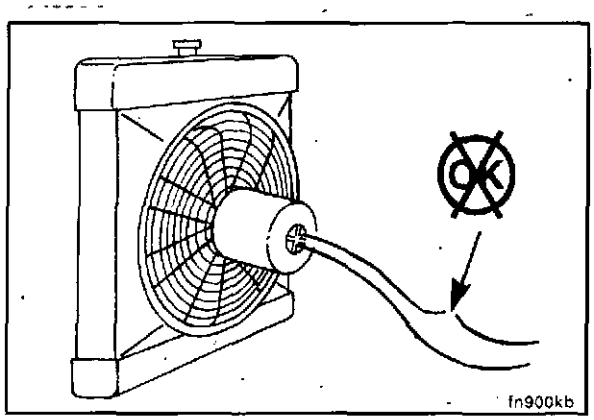
Air Pressure: 550 kPa [80 psi]





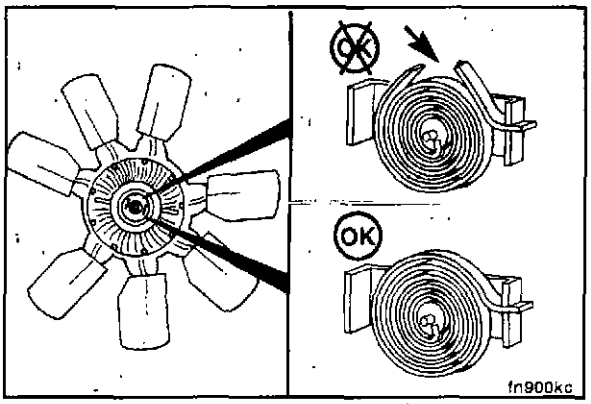
If the fan is belt driven, a slipping belt will result in a slower fan speed and reduced cooling. A malfunctioning automatic belt tensioner can be the problem.

Check the bearings in the fan hub and other pulleys to make sure they are not causing excessive belt vibration and slippage.



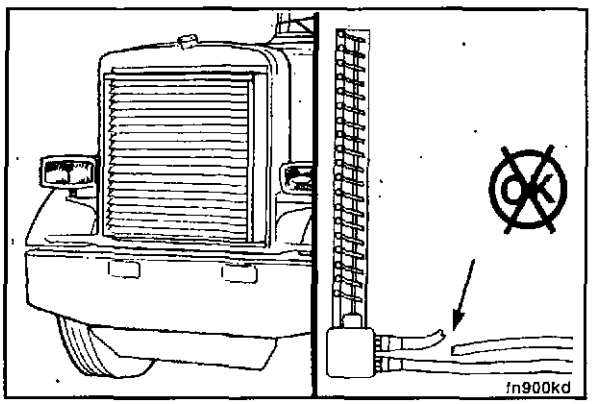
Interruption of the circuit to an electrically driven fan can result in insufficient air flow and cause the engine to run hot.

Make sure that the temperature sensor is functioning correctly.



Some applications use thermatic fans. These fans operate only as needed to keep the coolant at the correct temperature. If the fan does **not** operate when the temperature of the air flow through the radiator increases, the engine will run hot.

Make sure that the temperature sensor is functioning correctly.

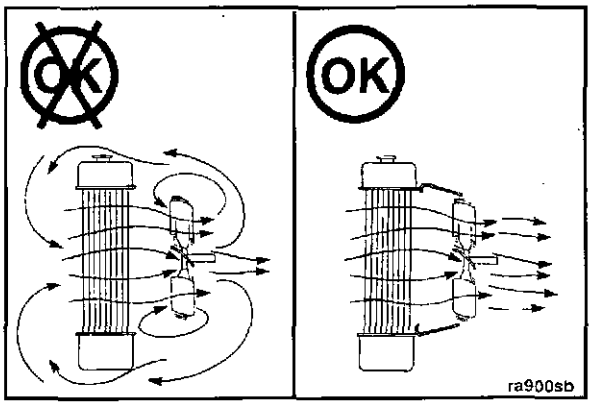


Shutters are designed to control air flow across the radiator. If the shutters fail to open when needed, the engine can run hot. Failure of the shutters to close can result in too much air flow and the engine running cold.

Make sure that the coolant temperature sensor is functioning correctly. Check the air operated shutter controls. Check for air leaks.

A missing or incorrect fan shroud or obstructions can reduce air flow and cause the engine to run hot.

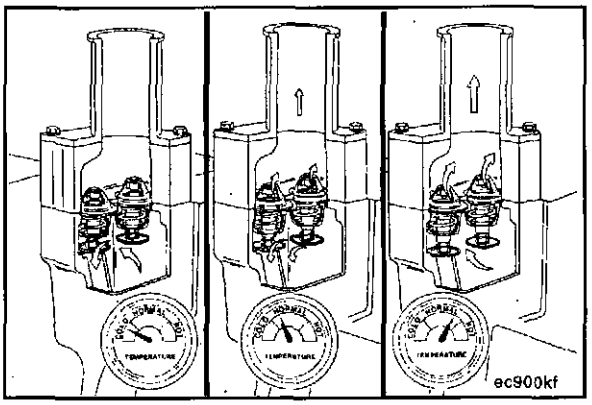
Check to be sure air is not recirculating. Check for missing baffles.



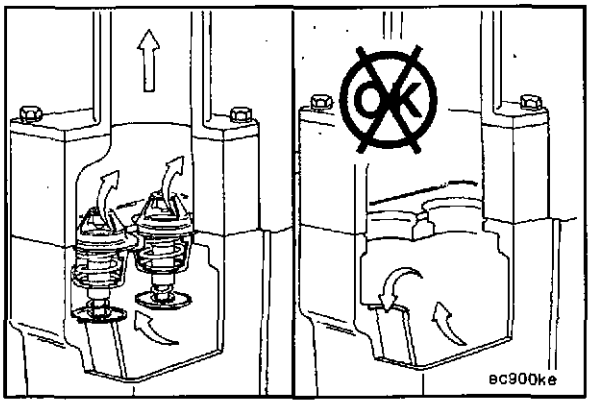
Thermostat Operation and Testing

The engine thermostats **must** operate properly in order for the engine to operate in the most efficient heat range. Overheating or overcooling will shorten engine life.

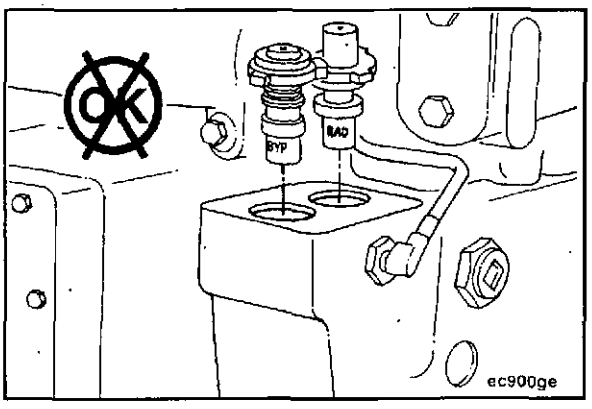
The thermostats controls the coolant temperature. When the coolant temperature is below operating temperature, the thermostats are closed, and coolant is bypassed to the water pump inlet. As the coolant temperature increases to the intermediate range, both thermostats will start to open, and coolant flow to the bypass will start to be restricted. At engine operating temperature the thermostat will be open and the bypass will be closed.

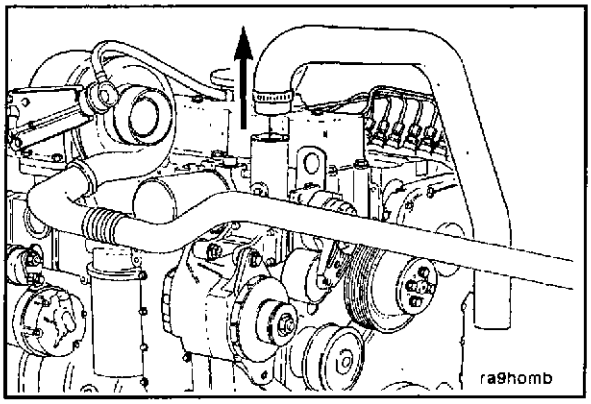


Caution: Never operate the engine without a thermostat. If operated without a thermostat, the path of least resistance for the coolant is through the bypass to the pump inlet. This will cause the engine to overheat.



Two identical thermostats are used. An incorrect, damaged, or malfunctioning thermostat can cause the engine to run too hot or too cold.

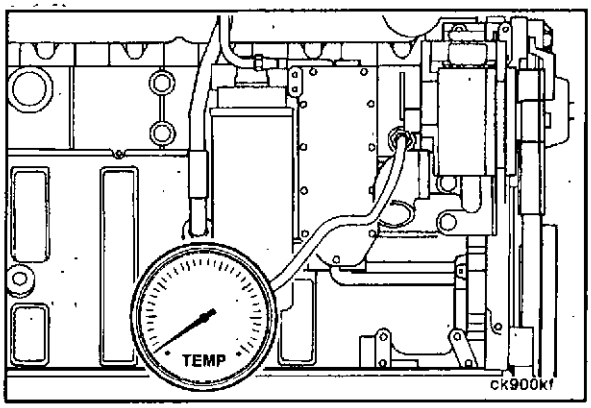




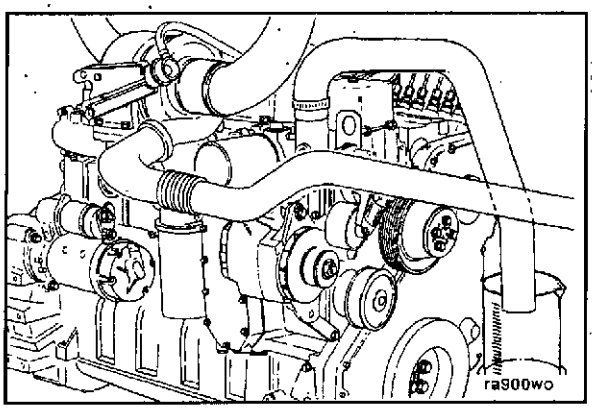
Thermostat Leakage and Opening Temperature - Testing "In-Chassis"

Warning: Complete this test with the engine coolant temperature below 49°C [120°F], hot steam can cause serious personal injury.

Remove the radiator hose from the thermostat housing.



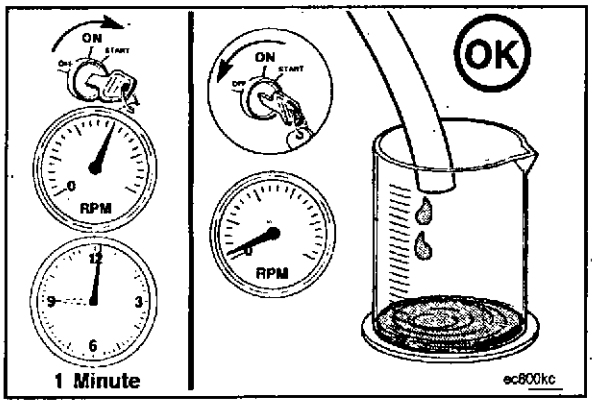
Install a thermocouple or temperature gauge which is known to be accurate in the 3/4-inch pipe plug located at the front of the cylinder block.



Install a hose of the same size on the thermostat housing outlet long enough to reach a remote dry container used to collect coolant.

Install and tighten a hose clamp on the housing outlet.

Insert the end of the hose in a dry container.

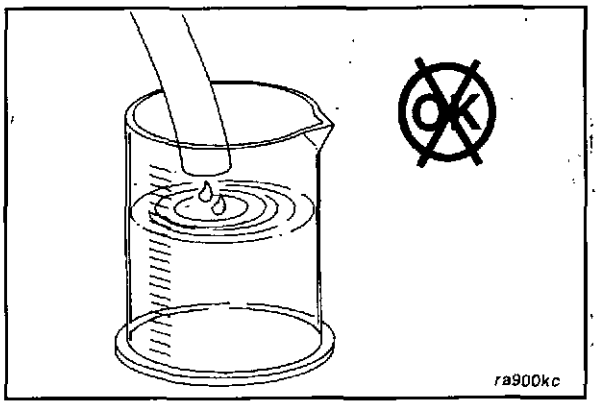


Operate the engine at rated speed for 1 minute.

Shut off the engine and measure the amount of coolant collected in the container.

The amount of coolant collected **must not** be more than 0.15 liter [5.1 fl. ounces].

If more than 0.15 liter [5.1 fl. ounces] of coolant is collected, the thermostats are leaking and **must** be replaced. Refer to Procedure 1-08.



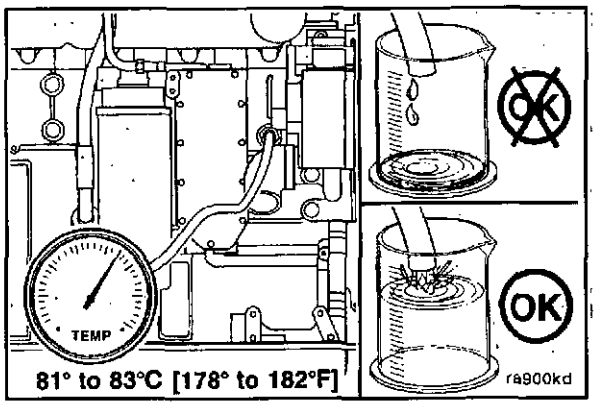
Complete the following test in-chassis to test the thermostat opening temperature.

Start the engine and monitor the water temperature gauge and the container. The thermostat initial opening temperature is:

81° to 83°C [178° to 182°F]

Shut off the engine when the coolant starts to flow.

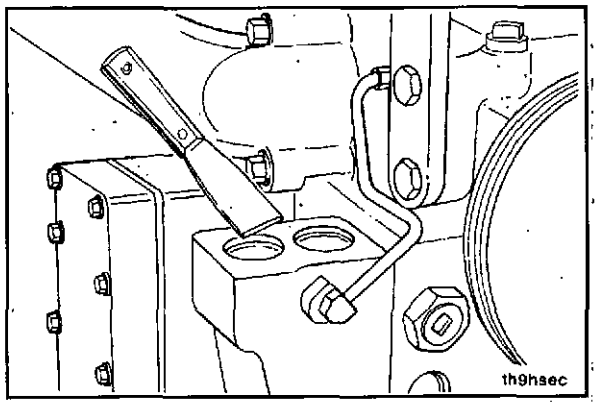
NOTE: If coolant does **not** start flowing into the container during the initial opening temperature range, the thermostat **must** be replaced. Refer to Procedure 1-08.



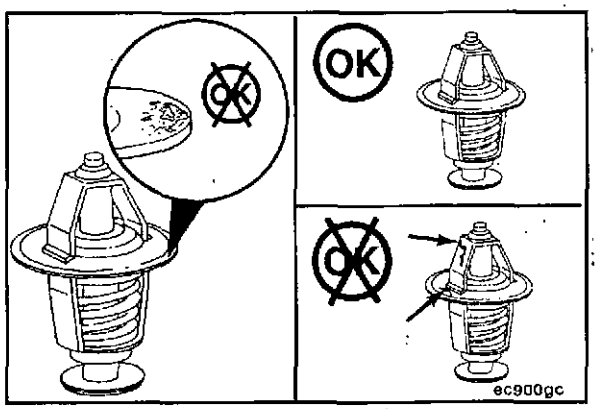
Thermostat Opening Temperature - Testing "Thermostat Removed"

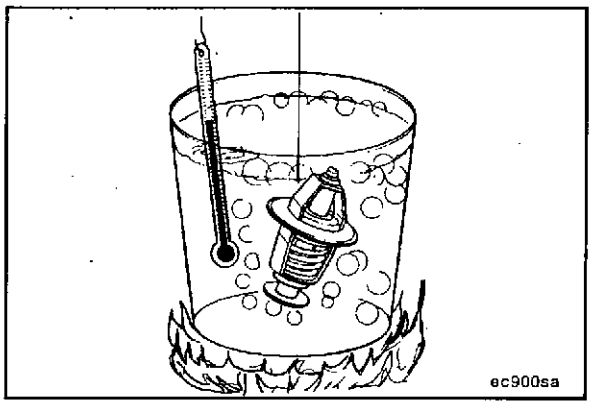
Remove the thermostats and clean the gasket surfaces. Refer to Procedure 1-08.

NOTE: Do **not** let any debris fall into the thermostat cavity when cleaning gasket surfaces.



Visually inspect the thermostats for damage.

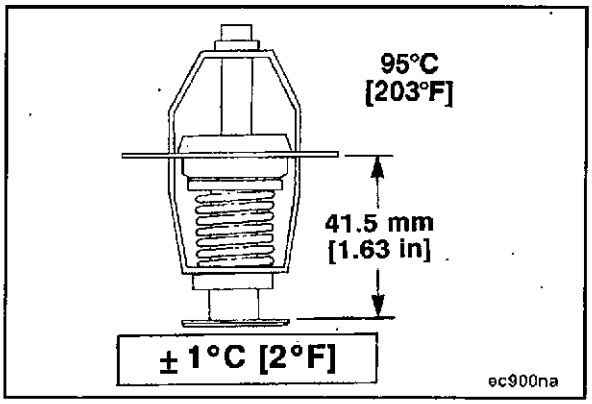




Suspend the thermostats and a 100°C [212°F] thermometer in a container of well stirred water.

NOTE: Do **not** allow the thermostats or thermometer to touch the container.

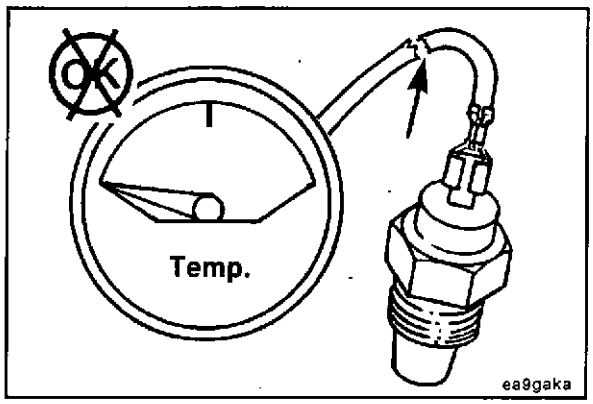
Heat the water and check the thermostats as follows:



NOTE: The nominal operating temperature is stamped on the thermostat.

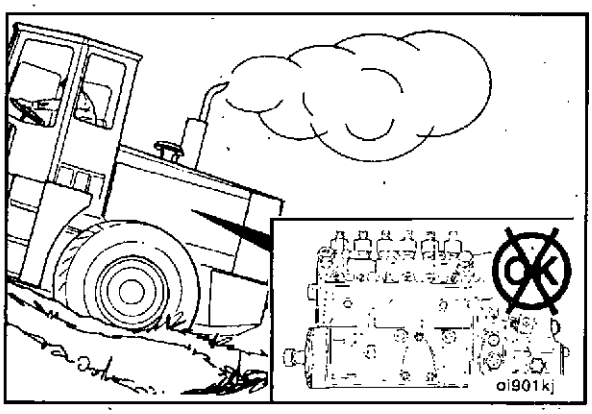
- Thermostat **must** begin to open within 1°C [2°F] of 82°C [180°F].
- Thermostat **must** be fully open within 1°C [2°F] of 95°C [203°F].

NOTE: The fully open clearance between the thermostat flow valve and flange must be 41.5 mm [1.63 inches] minimum.



Temperature Gauge Operation

Gauges and sensors are used in the system to measure the coolant temperature. These can malfunction and provide an incorrect temperature indication.

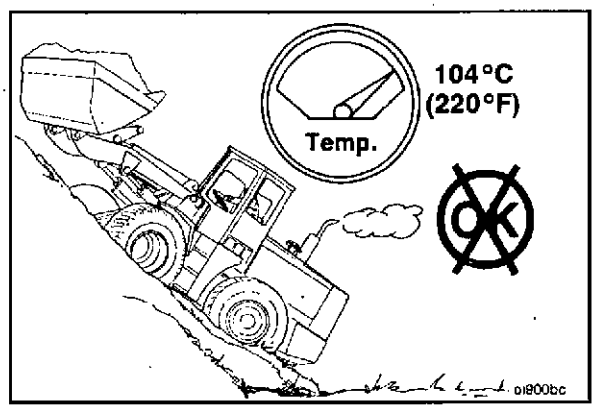


Fuel Pump Overfueled

Overfueling can cause the engine to overheat. Make sure that the fuel pump is calibrated correctly. Refer to Procedure 5-01.

Vehicle Overloaded

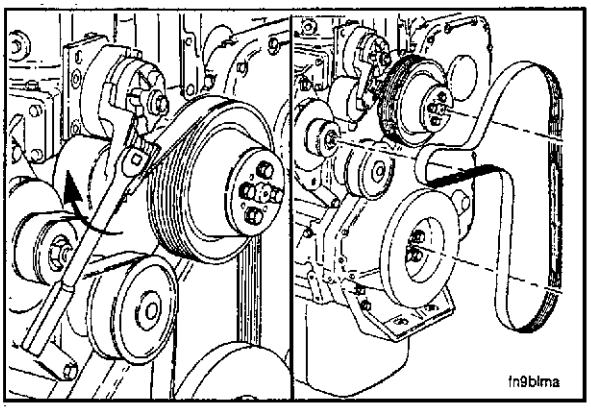
Constant overloading (lugging) can cause the engine to run hot.



Drive Belt - Replacement (1-03)

3/8 or 1/2 Inch Square Drive Ratchet

Lift the tensioner arm and pulley to remove and install the belt.



Belt Tensioner - Replacement (1-04)

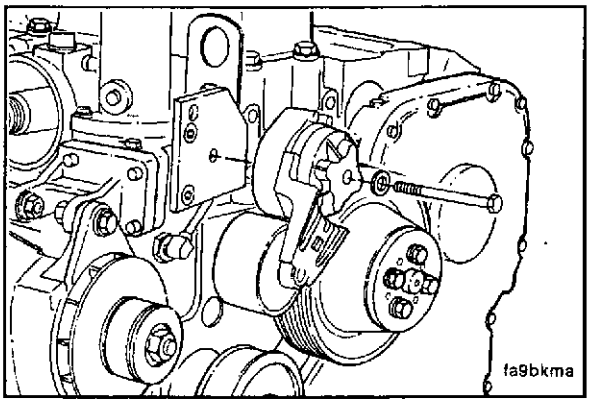
Preparatory Step:

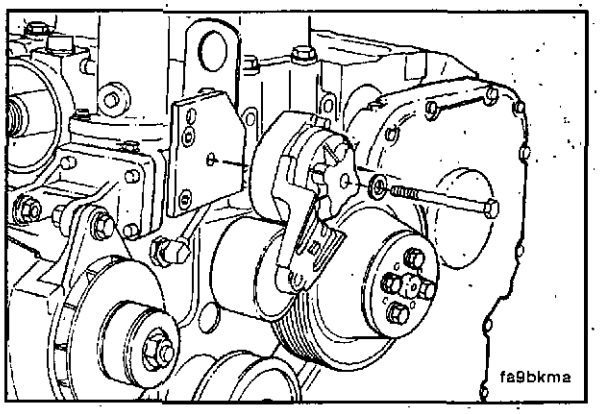
Remove the drive belt.

Removal

15 mm

Remove the belt tensioner from the bracket.





Installation

15 mm

Install the belt tensioner.

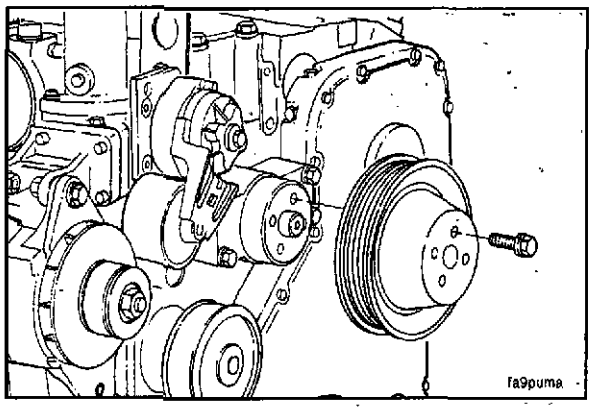
Torque Value: 43 N•m [32 ft-lb]

Fan Pulley - Replacement (1-05)

Preparatory Step:

Remove the drive belt. Refer to Procedure 1-03.

SERVICE TIP: Loosen the capscrews before removing the belt and torque the capscrews after the belt is installed.



Removal and Installation

10 mm

Remove the four capscrews, fan and spacer.

Install the fan pulley in the reverse order of removal.

Torque Value: 24 N•m [18 ft-lb]

Fan Hub - Replacement (1-06)

Preparatory Steps:

Remove the drive belt. Refer to Procedure 1-03.

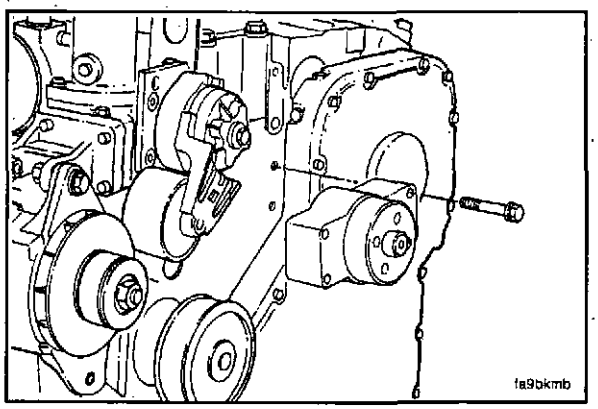
Remove the fan pulley. Refer to Procedure 1-05.

Removal and Installation

10 mm

Remove the four capscrews and replace the fan hub.

Torque Value: 24 N•m [18 ft-lb]



Water Pump - Replacement (1-07)

Preparatory Steps:

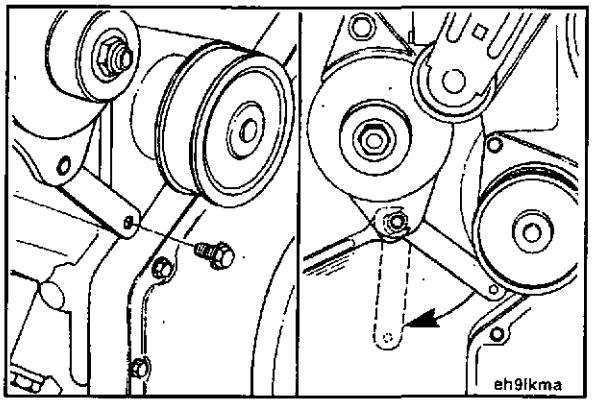
Drain the coolant. Refer to Procedure 1-01.

Remove the drive belt. Refer to Procedure 1-03.

Removal

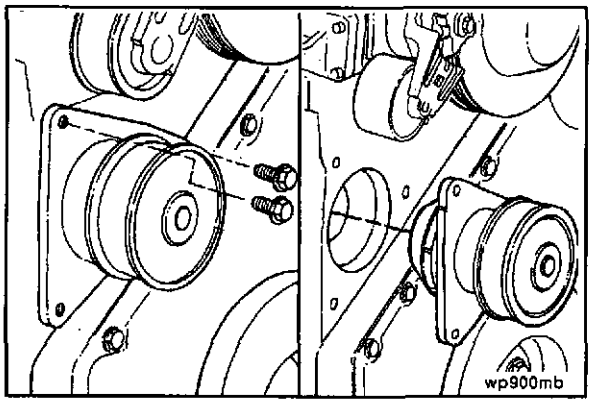
10 mm, 19 mm

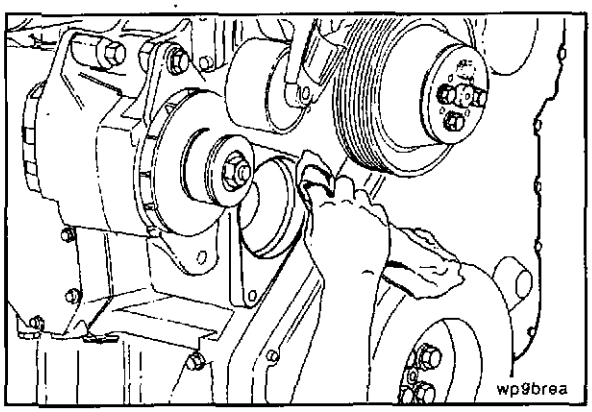
Remove the alternator link.



10 mm

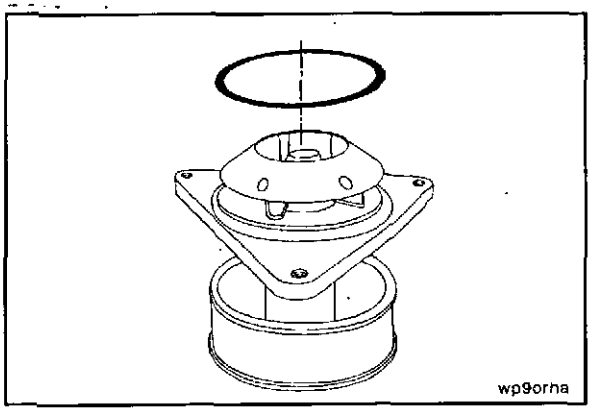
Remove the water pump.





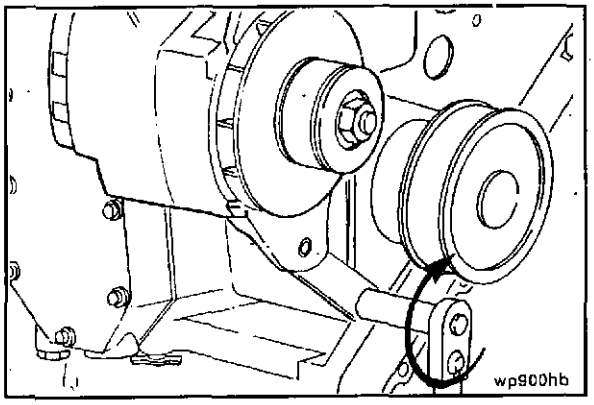
Cleaning

Clean the sealing surface on the cylinder block.



Installation

Install a new o-ring into the groove in the water pump.

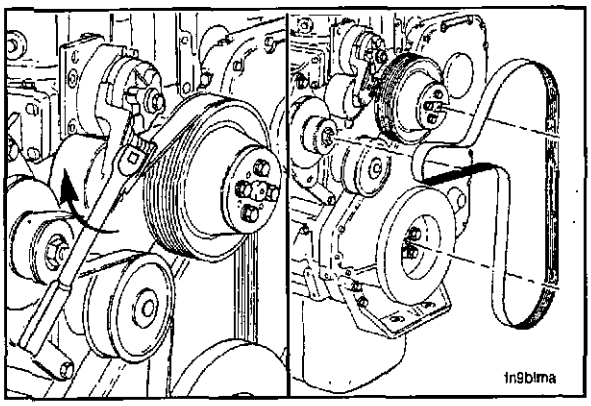


10 mm, 19 mm

Install the water pump and alternator link.

Torque Value:

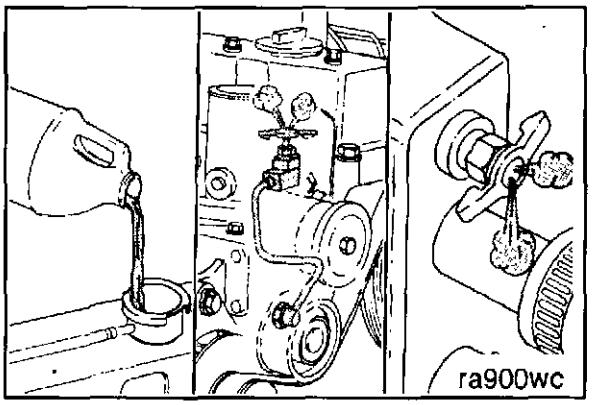
(Water Pump)	24 N•m	[18 ft-lb]
(Alternator Link)	43 N•m	[32 ft-lb]



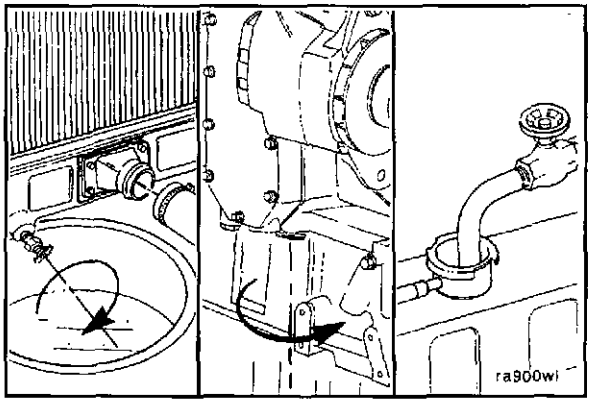
Lift the tensioner arm and pulley to install the drive belt.

During filling, air must be vented from the engine coolant passages. Open the engine vent petcock if equipped. Also, be sure to open the petcock on the aftercooler for aftercooled engines.

The venting will permit a fill rate of 19 liters/minute [5 U.S. gallons/minute].

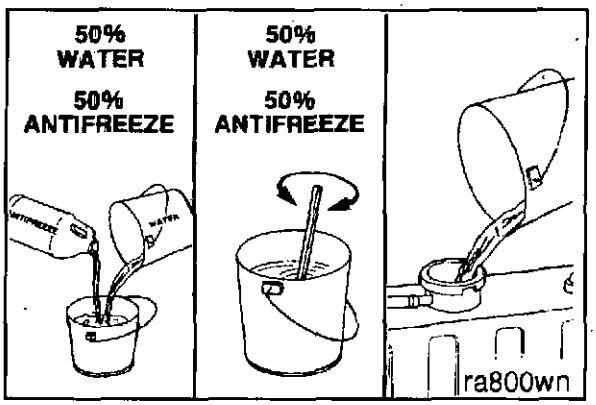


Close the drain valves. Install all hoses previously removed.

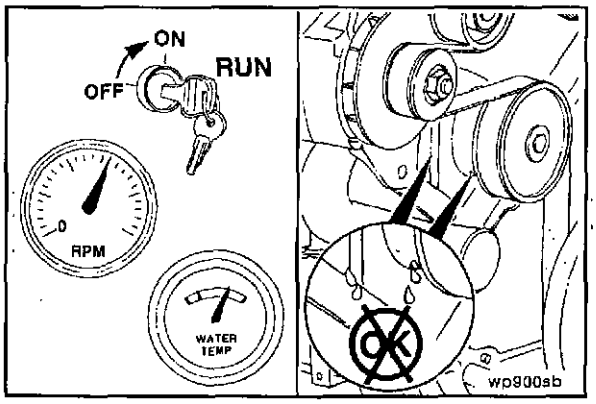


Fill the cooling system with a premixture of 50 percent water and 50 percent ethylene-glycol type antifreeze. Since the ability of antifreeze to remove heat from the engine is not as good as water, pouring antifreeze into the engine first could contribute to an over heated condition before the liquids are completely mixed. Refer to Procedure 1-01 for the correct amount of DCA corrosion inhibitor.

Refer to the Cooling System Specifications on page 1-5 for capacities.



Install the pressure cap. Operate the engine until it reaches a temperature of 80°C [180°F], and check for coolant leaks.



Thermostat - Replacement (1-08)

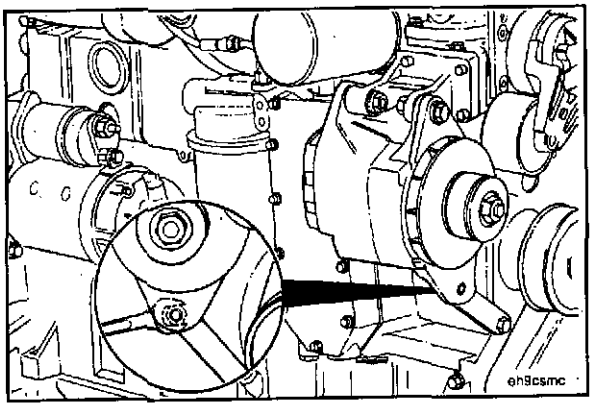
Preparatory Steps:

Disconnect the negative battery cable. Refer to Procedure 6-01.

Drain 2 liters (2.1 U.S. quarts) of coolant. Refer to Procedure 1-01.

Remove the radiator hose from the outlet connection.

Remove the drive belt. Refer to Procedure 1-03.

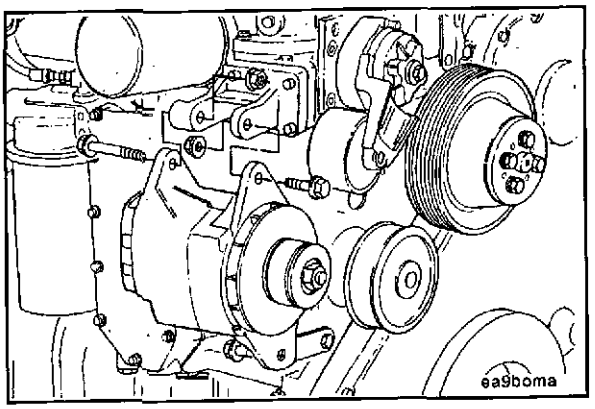


Removal

19 mm

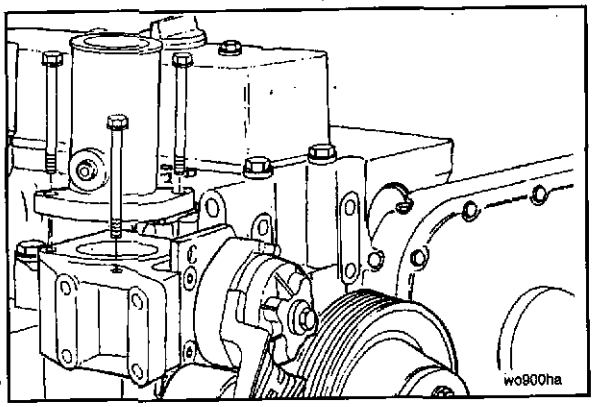
Loosen the alternator link capscrew.

Loosen the tail support capscrew if the alternator is so equipped.



18 mm, 19 mm

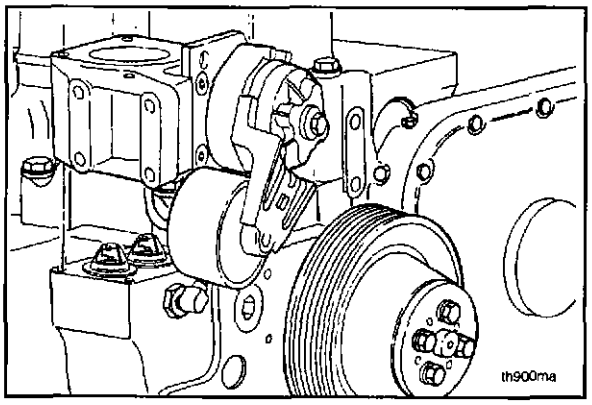
Remove the alternator mounting bolts and nuts. Lower the alternator.



10 mm

Remove the capscrews from the thermostat housing and water outlet connection. Remove the water outlet connection.

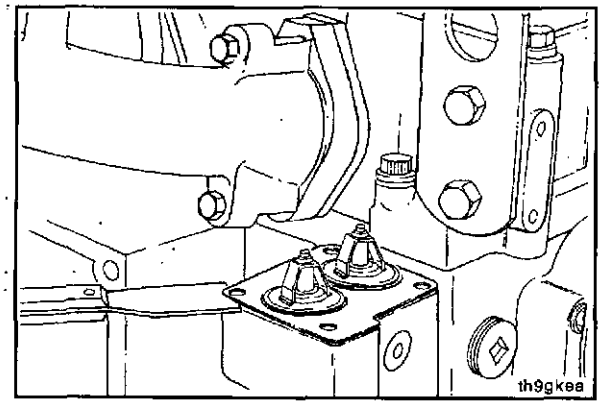
Remove the thermostat housing and belt tensioner assembly.



Cleaning

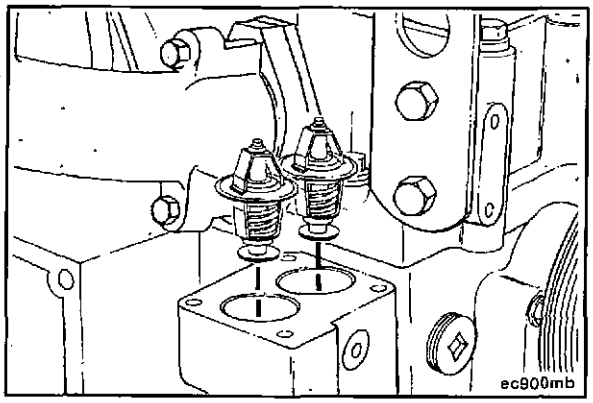
Caution: Do not let any debris fall into the thermostat cavity when cleaning gasket surfaces.

Remove the thermostats and clean the gasket surfaces.

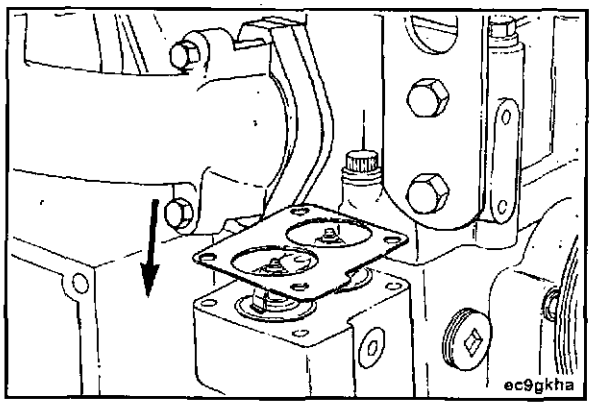


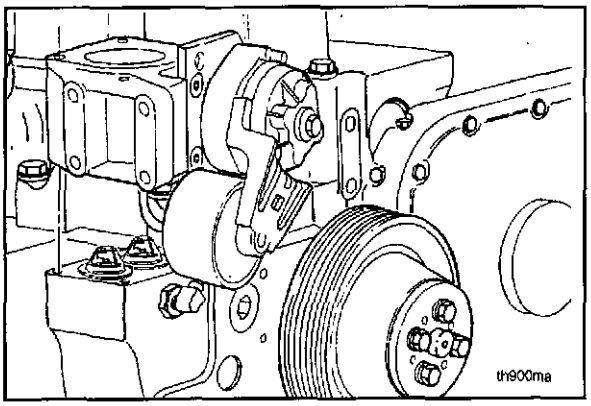
Installation

Install the new thermostats.

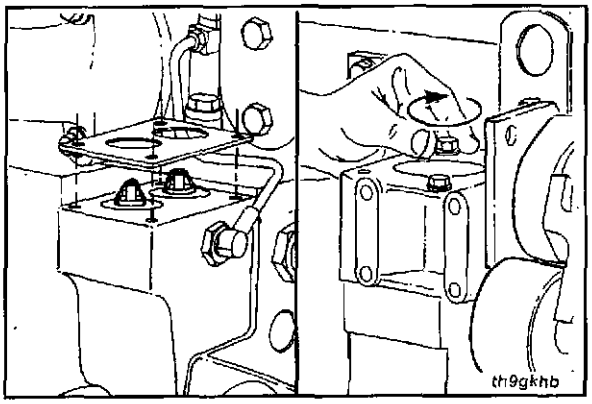


Position a new gasket over the thermostats.

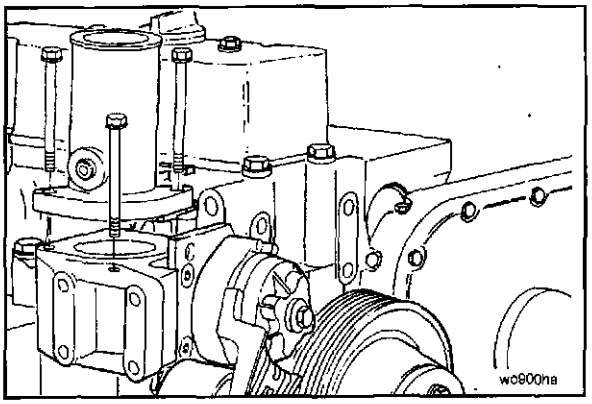




Position the thermostat housing and belt tensioner over the thermostats and gasket.



Make sure the gasket is aligned with the capscrew holes. Install the capscrews and use your fingers to tighten.

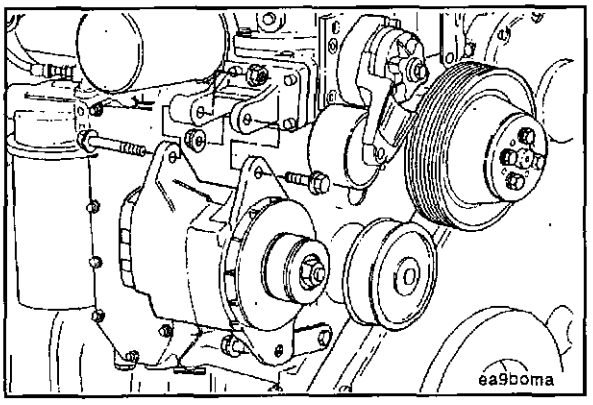


10 mm

Install the water outlet connection.

Tighten all capscrews.

Torque Value: 24 N•m [18 ft-lb]



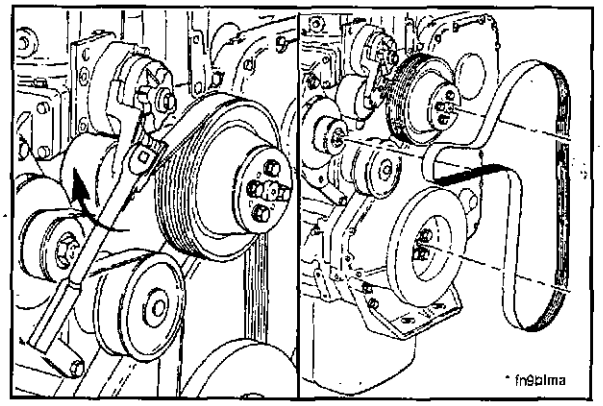
18 mm, 19 mm

Position the alternator and install the mounting bolts and *nuts*.

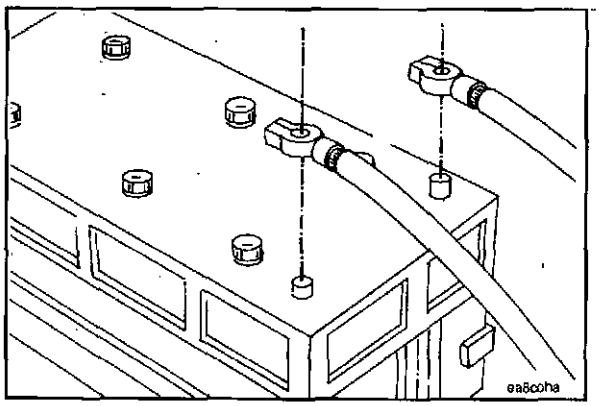
Torque Value:

(Alternator Mounting)	77 N•m	[57 ft-lb]
(Alternator Link)	43 N•m	[32 ft-lb]

Install the drive belt.

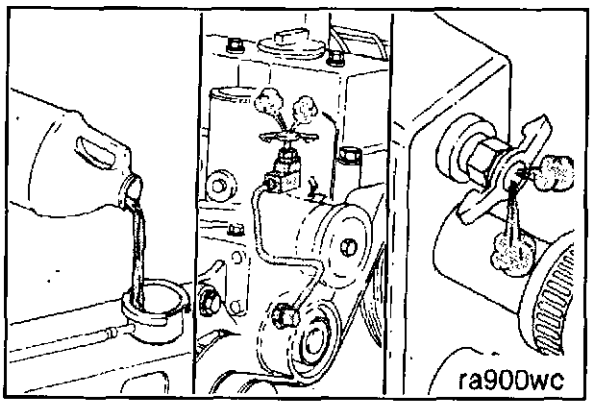


Install and tighten the battery electrical connections.

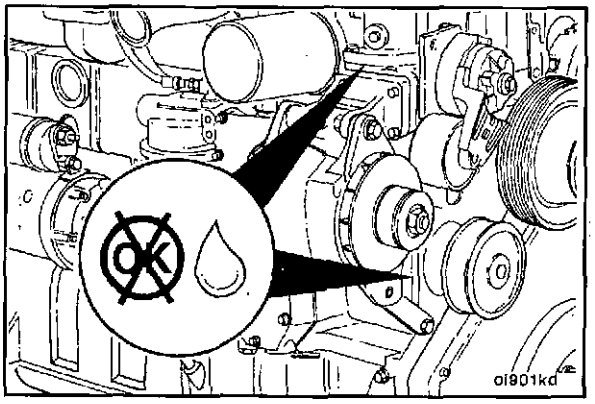


Caution: During filling, air must be vented from the engine coolant passages. Open the engine vent petcock if equipped. Also, be sure to open the petcock on the aftercooler for aftercooled engines. The system must be filled slowly to prevent air locks. Wait 2 to 3 minutes to allow air to be vented, then add coolant to bring the level to the bottom of the radiator filler neck.

Fill the cooling system. Refer to Procedure 1-01.



Operate the engine to normal operating temperature and check for leaks.



NOTES

Section 2 - Lubricating Oil System

Section Contents

Lubricating Oil System - Specifications

Oil Pressure - Low Idle (Minimum Allowable).....69 kPa [10 psi]
At Rated Speed (Minimum Allowable).....207 kPa [30 psi]

Differential Pressure to Open Oil Filter Bypass Valve.....138 kPa [20 psi]

Oil Flow at Rated Speed (Less Flow Through Pressure Regulator).....57 lpm [16 gpm]

Oil Temperature at Rated Speed.....99° to 126.6°C [210° to 260°F]

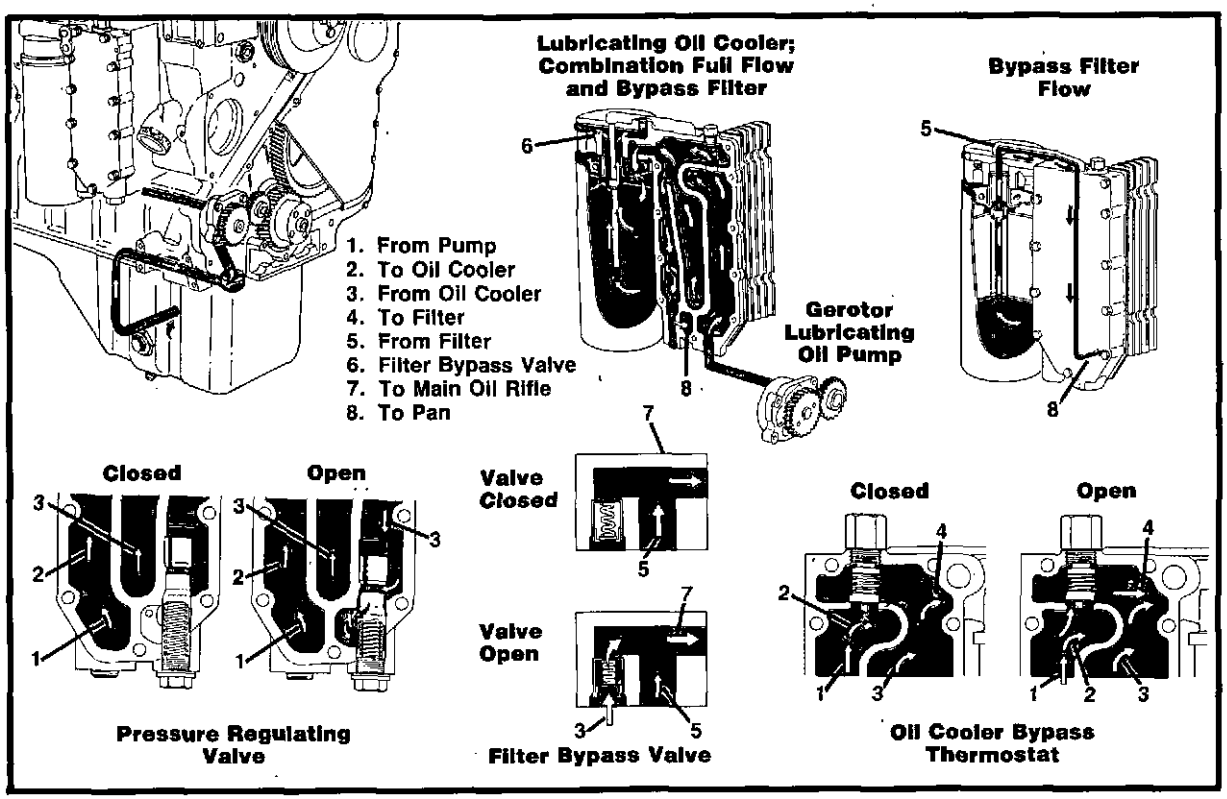
Oil Capacity of Pan (All Engines):
- Low Level.....15.1 liters [16.0 U.S. Qts.]
- High Level.....18.9 liters [20.0 U.S. Qts.]

Total System Capacity
6C8.3.....23.6 liters [25.0 U.S. Qts.]
6CT8.3.....23.8 liters [25.2 U.S. Qts.]

Lubricating Oil System - Flow Diagram

The lubricating oil flow begins as the gerotor pump draws oil from the pan through the rigid, internal suction tube. The pump then delivers the oil through an internal drilling in the cylinder block to the top of the oil cooler via the inner channels of the cover. When the oil reaches the top of the oil cooler, it flows by the thermostat before entering the oil cooler. If the oil is cold, the thermostat will open allowing some oil to bypass the cooler and flow to the filter. As the temperature of the oil increases, the thermostat will close and force the oil to flow through the cooler element, thereby regulating the oil temperature to the block. Coolant passing around the plates of the element cools the oil. From the cooler, the oil is directed to the combination full flow/bypass oil filter and also to the pressure regulator. The regulator valve remains closed until the oil pressure is approximately 518 kPa [75 psi]. At high pressure, the plunger moves toward the plug and relieves the system by allowing some oil to return to the oil pan. The tapered shoulder on the plunger creates a variable opening to regulate pressure. A combination full flow/bypass oil filter is used. The upper section of the filter contains the full flow filter element while the lower section contains the bypass element. Oil which flows through the full flow portion of the oil filter returns to the block. Oil that flows through the bypass returns to the oil pan. During normal engine operation, oil circulates through the full flow section of the combination filter and into the main oil rifle. If the full flow section of the combination filter becomes plugged to the point that a 137 kPa [20 psi] pressure difference exists across the filter, the bypass valve opens in the oil filter head and routes unfiltered oil to the main oil rifle. This is done to prevent oil starvation to the engine with a plugged filter.

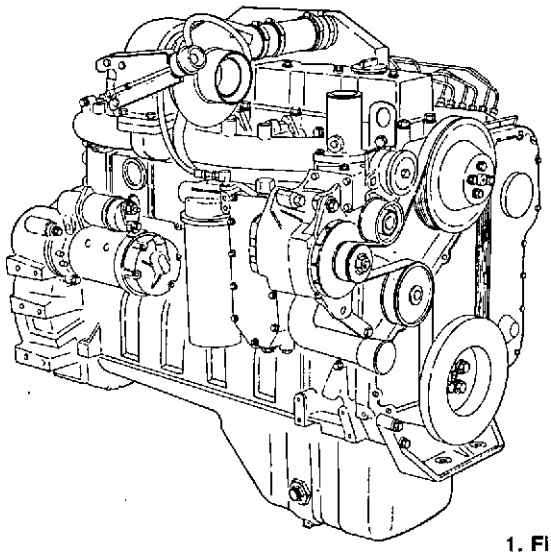
Lubricating Oil System

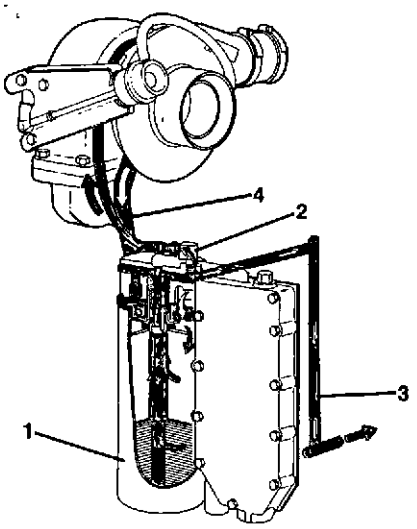


Lubricating Oil System Flow Diagram (Continued)

At the filter head, the oil flow is divided: A portion flows to the turbocharger; the rest flows down a passage in the cylinder block that connects to a cross drilling over the No. 3 main bearing.

Lubrication for the Turbocharger





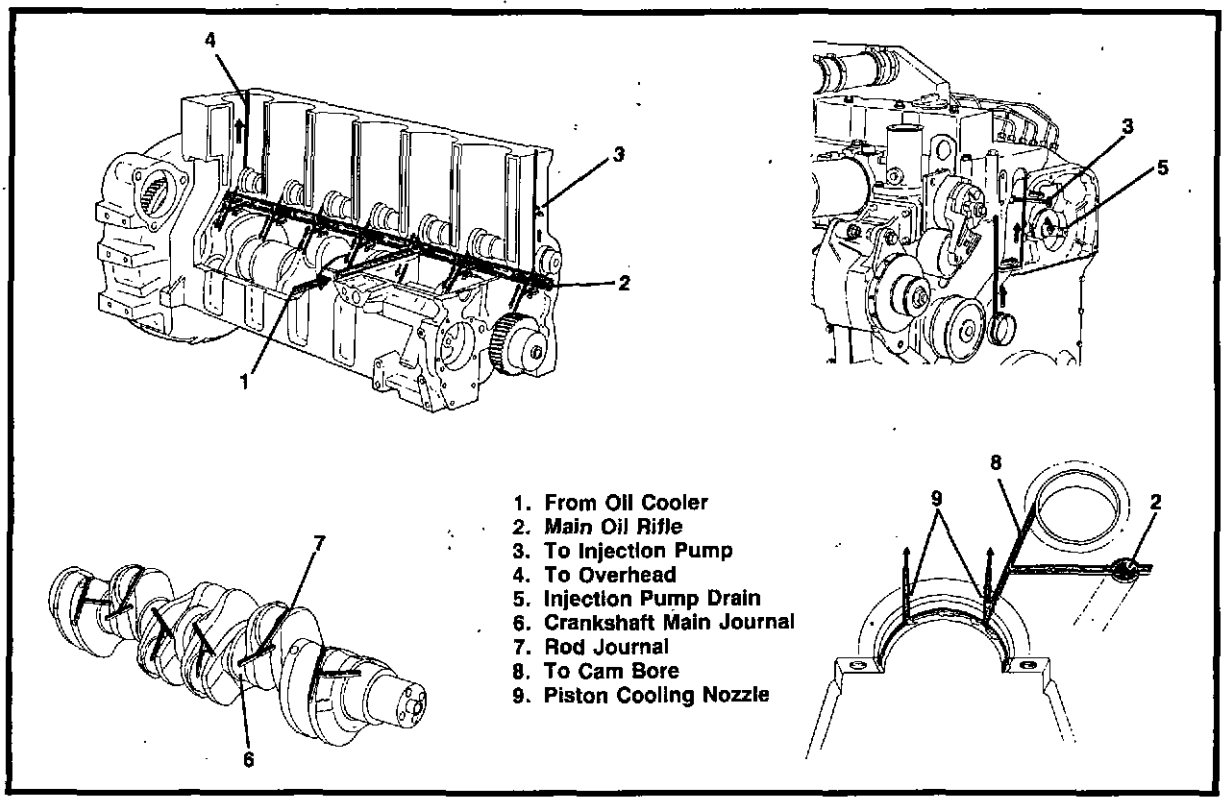
1. Filter
2. Turbocharger Supply
3. To Main Oil Rifle
4. Turbocharger Oil Drain

Lubricating Oil System - Flow Diagram (Continued)

The oil has been cooled and filtered, it flows through the cross drilling over the No. 3 main bearing to the main oil rifle. The main oil rifle is drilled through the length of the cylinder block and carries oil through individual drillings to the overhead and lower end of the block. A transfer drilling from the main oil rifle intersects with a drilling between the main bearing bore and the camshaft bushing bore. These drillings supply oil to the cam bushing and main bearing. The groove in the upper main bearing shell supplies oil to the piston cooling nozzles located in the main bearing saddle. The spray from the nozzle splash lubricates the piston pin. From the main bearings, the oil enters the crankshaft and lubricates the connecting rod bearings through internal cross drillings.

Drillings in the cylinder block and gear housing connect to the external groove on the No. 1 camshaft bushing to supply oil to the injection pump. An overflow hole located above the injection pump shaft allows oil to return to the oil pan.

Lubrication for the Power Components



1. From Oil Cooler
2. Main Oil Rifle
3. To Injection Pump
4. To Overhead
5. Injection Pump Drain
6. Crankshaft Main Journal
7. Rod Journal
8. To Cam Bore
9. Piston Cooling Nozzle

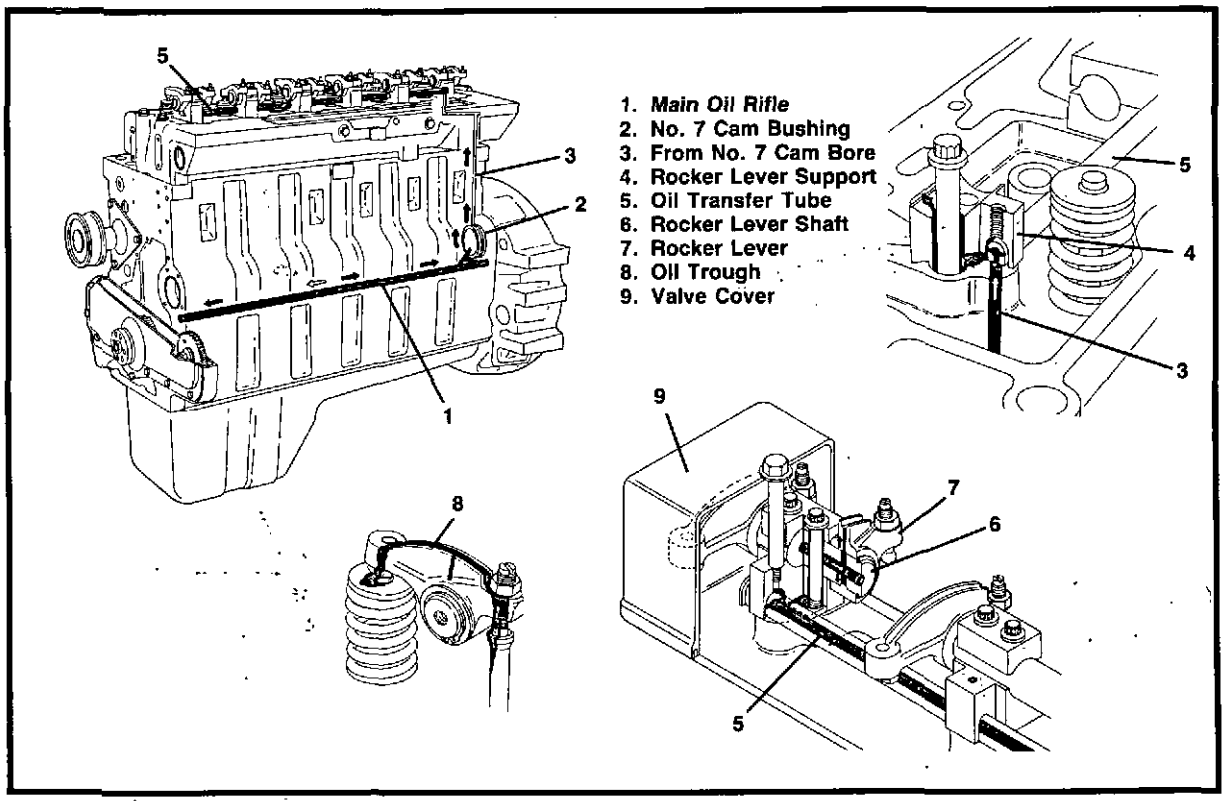
Lubricating Oil System - Flow Diagram (Continued)

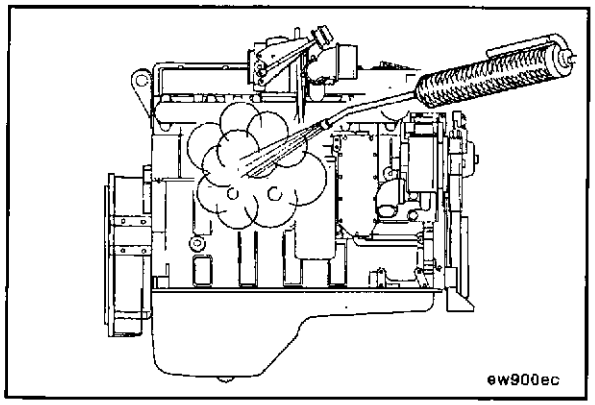
Oil for the overhead components is supplied by a vertical drilling through the cylinder head and block that intersects the external groove on the No. 7 camshaft bushing. The main oil rifle supplies oil to the camshaft bushing. Oil flows from the vertical drilling to an angle drilling in the cylinder head. From the angle drilling the oil flows through the transfer tube. The rocker lever supports are installed over the transfer tube. From a hole in the transfer tube the oil is transferred to the rocker lever support capscrews by the relieved area in the base of the support.

Oil flows around the capscrews up to the rocker lever shaft. Oil flows into the inside diameter of the shaft and along its length. The ends of the shaft are sealed by cup plugs. Drillings in the shaft allow the oil to flow from the inside diameter to the bores of the rocker levers. The rocker lever has a drilling that transfers oil from the bore to a trough on the top of the lever. Oil flows along the trough to lubricate the push rod socket and the valve stem.

The front gear train assembly is lubricated from oil splash and carry-over. The oil pump idler gear is force lubricated. From the gear train assembly the oil drains back to the oil pan for recirculation.

Lubrication for the Overhead



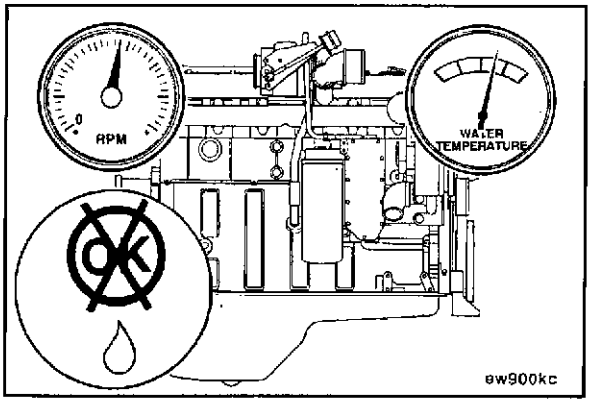


Lubricating Oil Leaks (External) - Checking (2-01)

The first step in diagnosing excessive lube oil consumption is to verify that there are no external oil leaks.

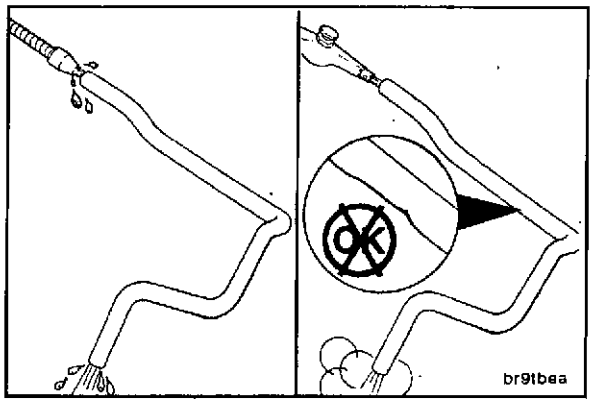
Warning: When using a steam cleaner, wear protective clothing and safety glasses or a face shield. Hot steam can cause serious personal injury.

Use a steam cleaner or high pressure washer to clean the engine. Dry with compressed air.



Operate the engine until the coolant temperature reaches 82°C [180°F]. Inspect the exterior of the engine for leaking gaskets, seals, o-rings, pipe plugs, or fittings.

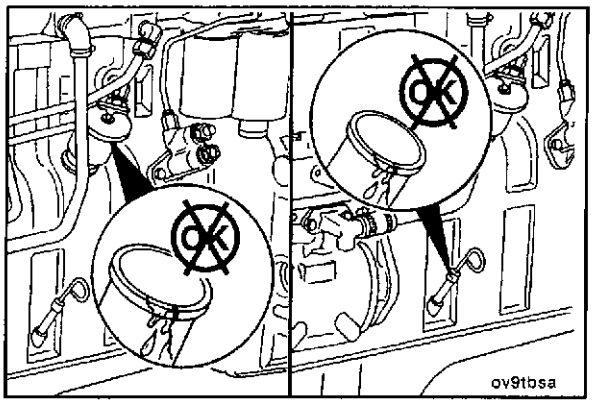
NOTE: Before replacing any gaskets, check the capscrews to make sure they are tightened to the correct torque values. Refer to Section V for capscrew torque specifications.



Check the engine crankcase breather tube and hose for restriction.

Refer to Procedure 7-03 for removal.

Use a solvent to clean the hose and tube. Dry with compressed air.



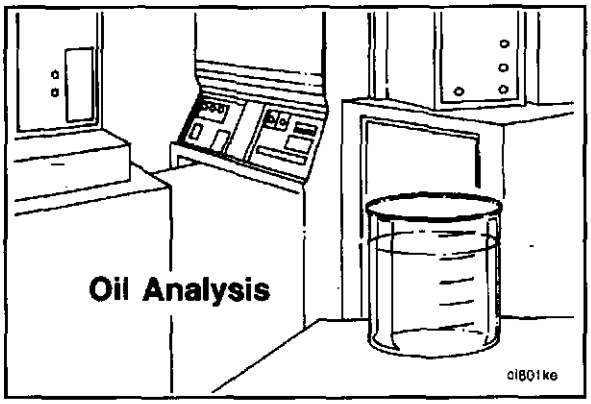
Check for a loose or missing oil dipstick tube, dipstick, or oil fill cap.

Internal Engine Damage - Checking (2-02)

Lubricating Oil Analysis

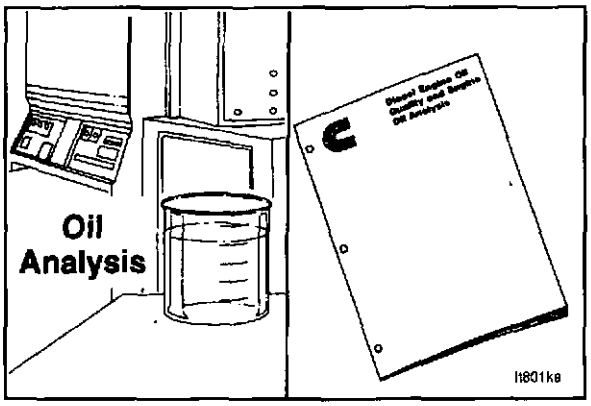
An analysis of used oil can help diagnose internal engine damage and determine if it was caused by one of the following:

- Intake air filter malfunction.
- Coolant leaks.
- Oil diluted with fuel.
- Metal particles causing wear.



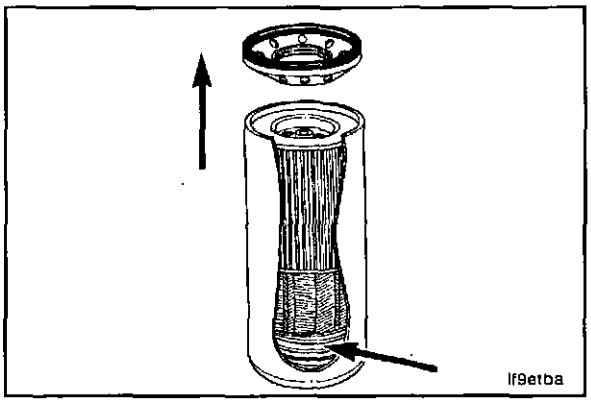
For additional oil analysis information, refer to Cummins Engine Oil Recommendations, Bulletin No. 3810340.

NOTE: Do **not** disassemble an engine for repair based only on the results of an oil analysis. Inspect the oil filters also. If the oil filter shows evidence of internal damage, find the source of the problem and repair the damage. Refer to the appropriate procedure(s) based on the following oil filter inspection:



Lubricating Oil Filter Inspection

Caution: Carefully cut the full flow oil filter (upper section of combo filter) open. The filter element spring is *under compression and can cause personal injury.*

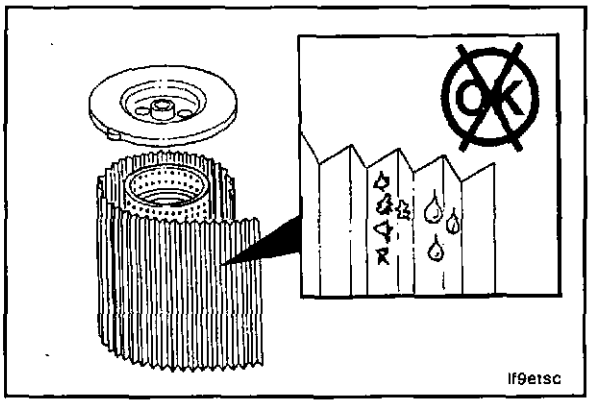


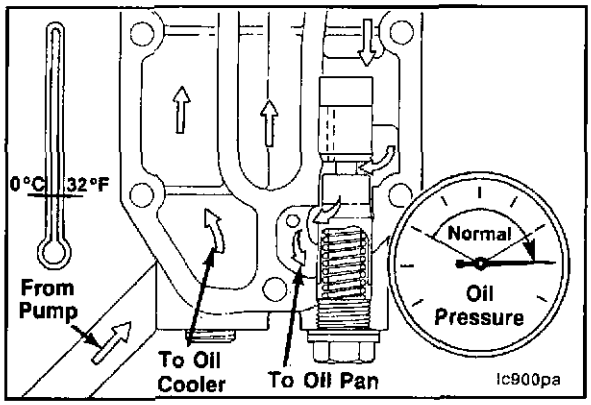
Part No. 3376579 Tube Cutter

Use the tube cutter, Part No. 3376579, to open the full flow oil filter (upper section of the bypass filter).

Inspect the filter element for evidence of moisture or metal particles.

Metal	Probable Source
Copper	Bearings and Bushings
Chromium	Piston Rings
Iron	Cylinder Liners
Lead	Bearing Overlay Material
Aluminum	Piston Wear or Scuffing



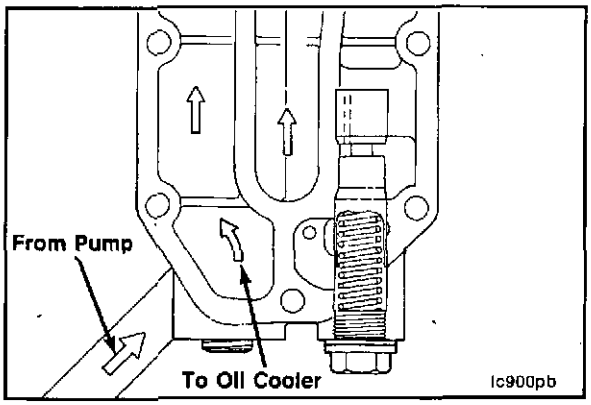


Lubricating Oil System - Diagnosing Malfunctions (2-03)

Be sure to check items related to oil pressure, such as: gauges, high and low oil level, excessive oil contamination and oil viscosity.

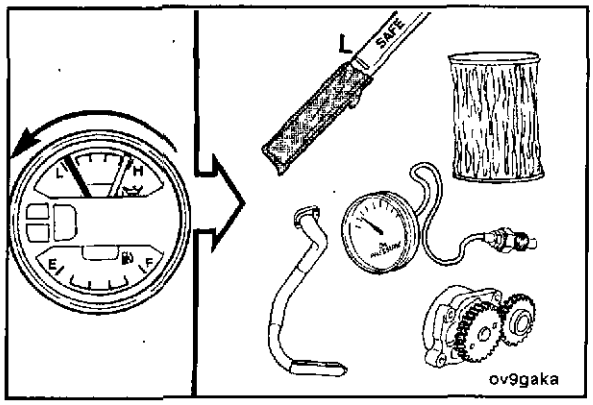
High Oil Pressure

High oil pressure usually occurs after the engine is first started in cold weather. The lubrication system does **not** have a cold start relief valve. The pressure regulating valve components are machined to a size that will relieve the excessive pressure created by cold engine oil.



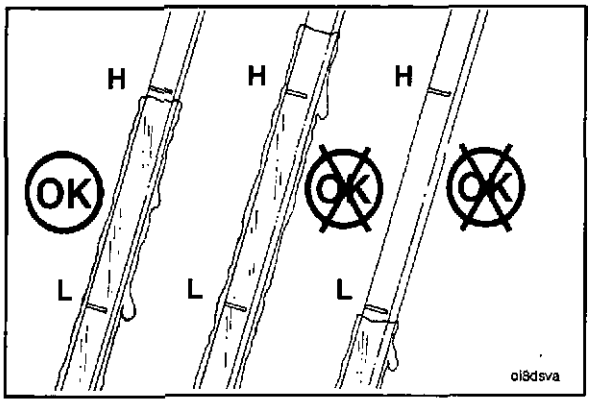
Oil Pressure Regulating Valve

The engine will have high oil pressure if the regulator sticks in the closed position. Check the regulator for freedom of movement.



Low Oil Pressure

Low oil pressure can be caused by several lubrication system related malfunctions. To begin the investigation, determine the engine operating conditions when the low pressure was first observed.



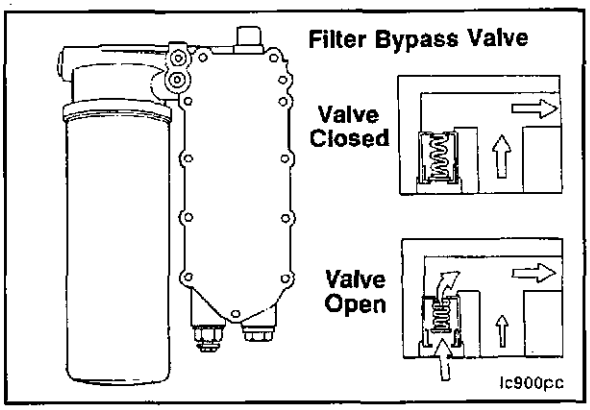
Oil Level

Improper lubricating oil level can cause low lubricating oil pressure.

Never operate the engine with the oil level below the low (L) mark or above the high (H) mark.

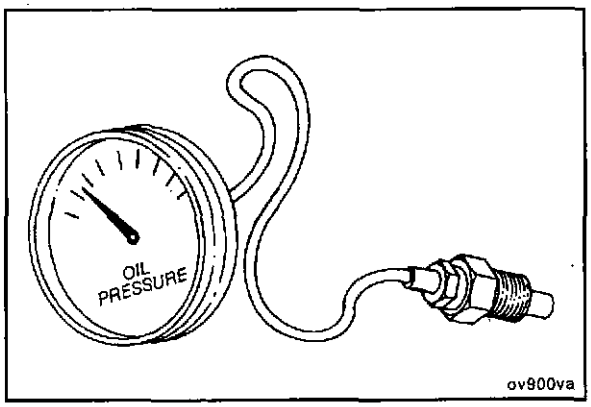
Oil Filter

A plugged filter will cause a gradual loss of oil pressure by approximately 69 kPa [10 PSI]. This will cause the bypass valve to open, allowing unfiltered oil to flow to internal engine components. The oil pressure will remain low until a new filter is installed.



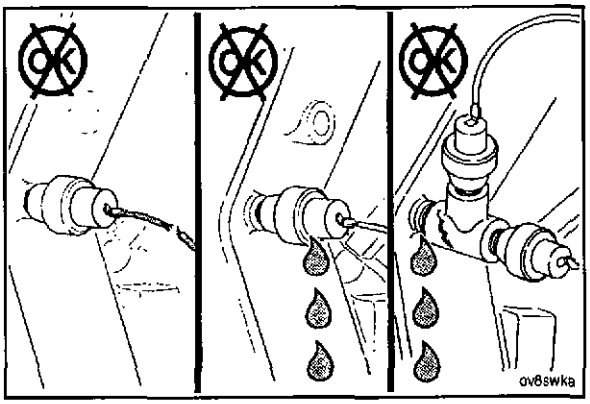
Oil Pressure Gauge - Checking

Check the oil gauge and sending unit to make sure they are operating correctly by verifying the pressure with a manual gage.



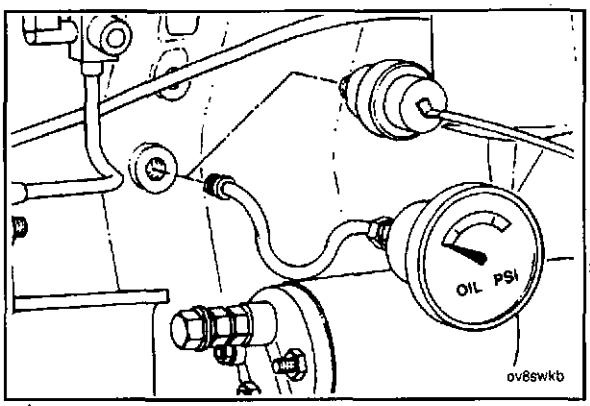
Check the following for defects:

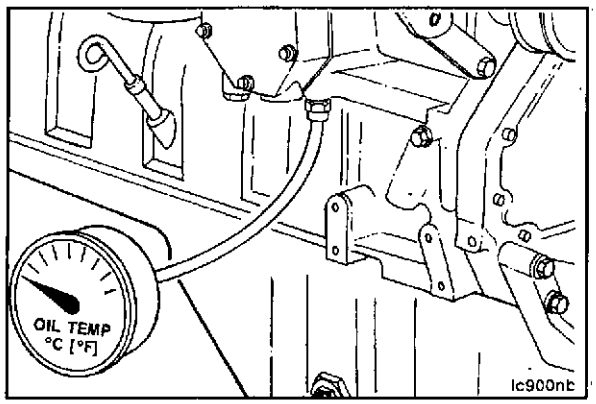
- Electrical wiring broken
- Sending unit malfunction
- Plumbing loose or broken



If a sending unit malfunction is found:

- Use a master gauge of known accuracy to verify the *reading of the suspect gauge.*
- Connect the line from the master gauge to the main oil rifle on the fuel pump side of the engine.
- Replace the sending unit if it is defective.

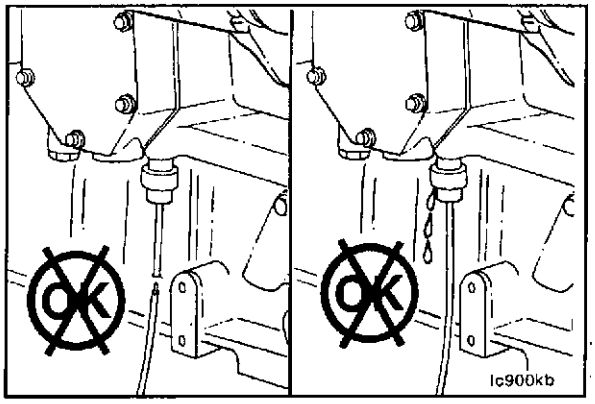




Oil Temperature Gauge - Checking

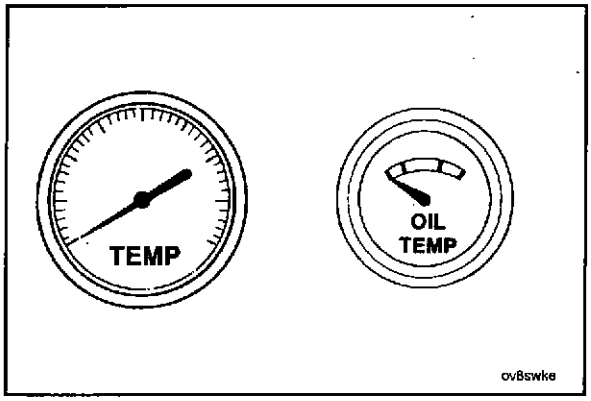
Remove the pipe plug from the bottom of the oil cooler and install the oil temperature gauge sending unit.

The maximum oil temperature at rated engine speed is 126.6°C [260°F].



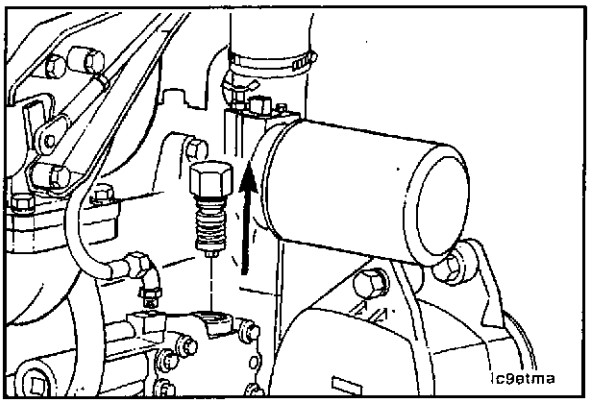
Check the following for defects:

- Electrical wiring broken
- Sending unit malfuntion



If a sending unit malfunction is found:

- Use a master gauge of known accuracy to verify the reading of the suspect gauge.
- Replace the sending unit if it is defective.

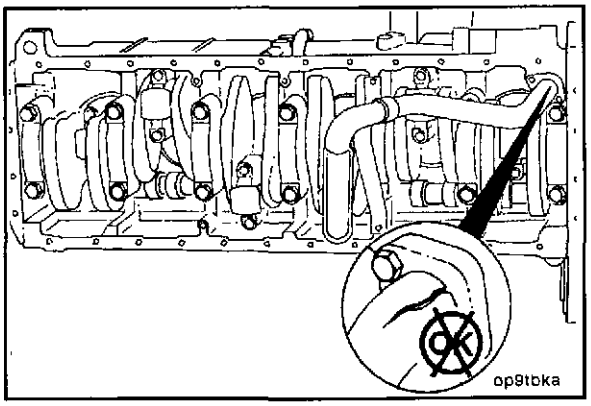


Oil Temperature Thermostat

NOTE: The oil temperature thermostat cannot be checked in-chassis, it **must** be removed for testing. Refer to Procedure 2-12.

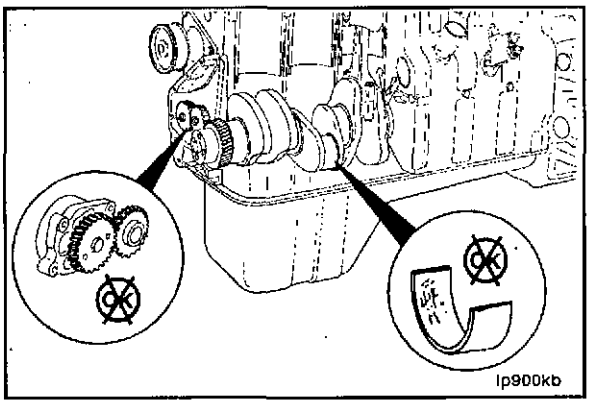
Oil Suction Tube

A loose suction tube, damaged gasket or crack in the suction tube can cause a temporary loss of prime for the oil pump. The engine will have low pressure or no oil pressure at starting, followed by normal or low oil pressure.



Bearings and Oil Pump

A steady decrease in oil pressure over a long period of time can be an indication of worn bearings or excessive oil pump wear. Refer to Procedure 2-02 to check for internal engine damage.

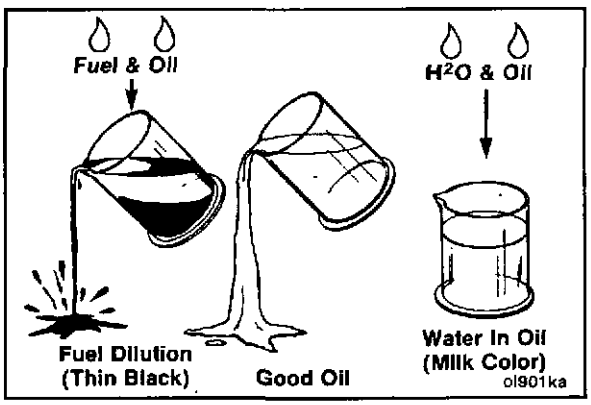


Oil Dilution

Diluted oil can cause severe engine damage

Check the condition of the oil.

- Thin, black oil is an indication of fuel in the oil.
- Milky discoloration is an indication of coolant in the oil.

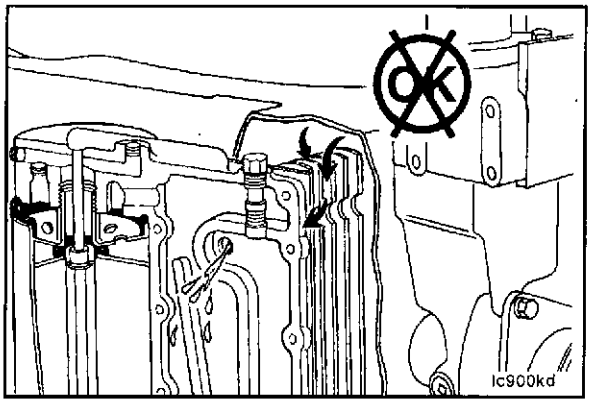


Coolant Diluted Oil

Coolant in the oil results from a crack or leak between the coolant and oil circuits.

The possibility for intermixing can occur in these components:

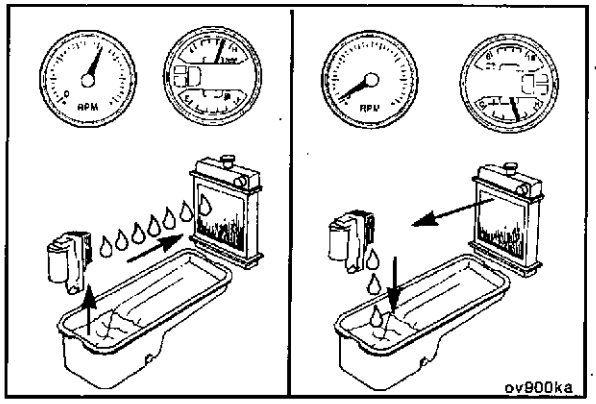
- Oil cooler
- Aftercooler
- Core plugs in cylinder head
- Cylinder liner seals
- Head gasket
- Cylinder liner (crack)
- Cylinder head (cracked passage)
- Cylinder block (cracked passage)
- Air compressor (coolant cooled)



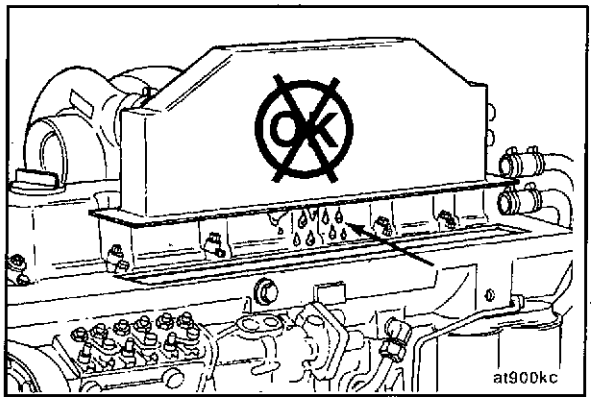
Oil Cooler

The oil cooler design does **not** require gaskets or seals to maintain the separation of oil and coolant.

If either the coolant or oil is contaminated, check for a leaking element. Refer to the checking procedure in this section.



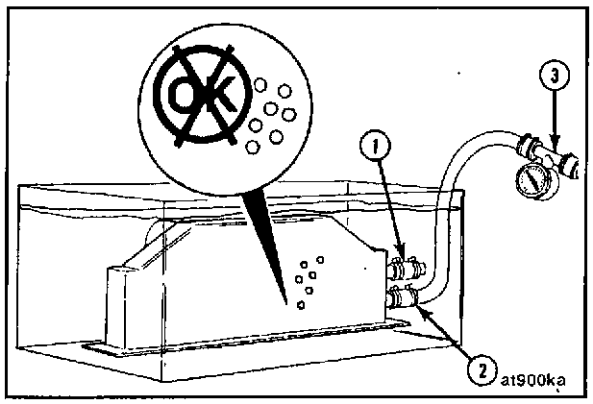
During operation the oil pressure will be higher than coolant pressure. A leak in the oil cooler will show as oil in the coolant. However, following an engine shutdown, the residual pressure in the coolant system can cause coolant to seep through the leak path into the oil.



Aftercooler

An aftercooler is also a source for coolant to get in the lubricating oil.

Remove the aftercooler and look for evidence of leaking into the intake manifold.



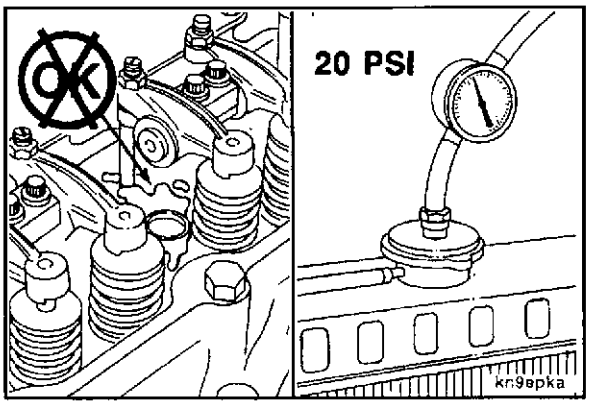
Plug the bottom inlet tube and pressurize the aftercooler with 348 kPa [50 psi] to check for leaks by submerging in water.

Cylinder Head Expansion Plugs

The expansion plugs in the cylinder head under the valve cover is another potential for oil dilution.

If possible, check for the leaks while the engine is warm, remove the valve cover to look for signs of leaks.

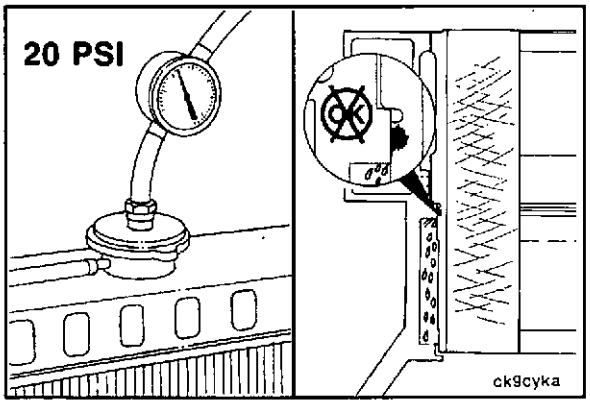
It may be necessary to pressurize the coolant system to 140 kPa [20 psi].



Cylinder Liner Seals

Coolant can enter the lubricating oil through a deteriorated or damaged liner seal.

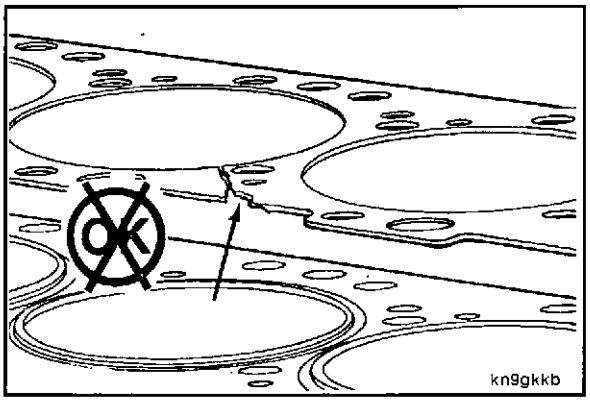
Remove the oil pan and visually inspect the bottom side of liners with the cooling system pressurized.



Cylinder Head Gasket

Coolant in the oil can also be caused by a damaged cylinder head gasket.

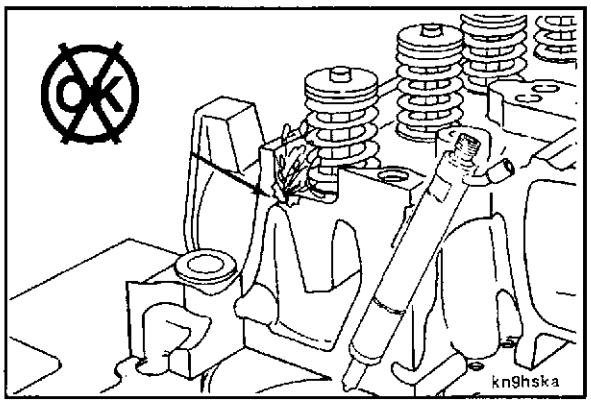
Pressurize the cooling system to check for leaks. It may be necessary to remove the oil pan to locate internal leaks. Refer to Procedure 2-13.

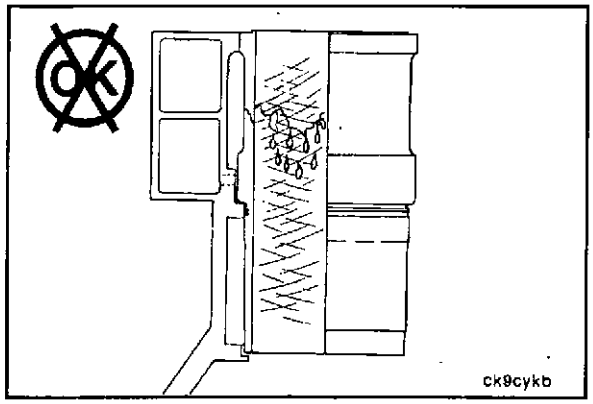


Cracked Cylinder Head

A crack in the head from the water jacket to an oil passage or to the top rocker lever area will cause oil dilution.

Pressurize the cooling system to 140 kPa [20 psi] and check for leaks.

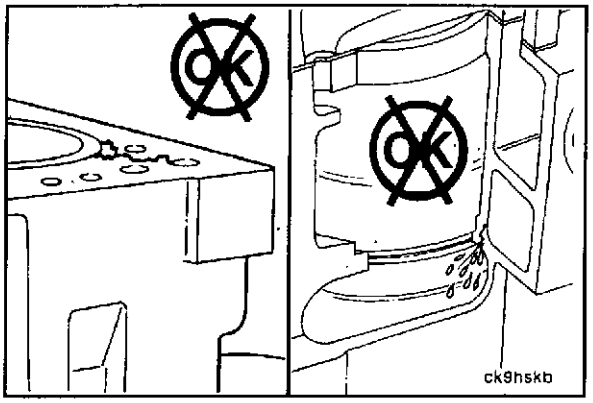




Cracked Cylinder Liner

A cracked cylinder liner can leak coolant into the lubricating oil. Remove oil pan and look for coolant leaking from inside of liner bore.

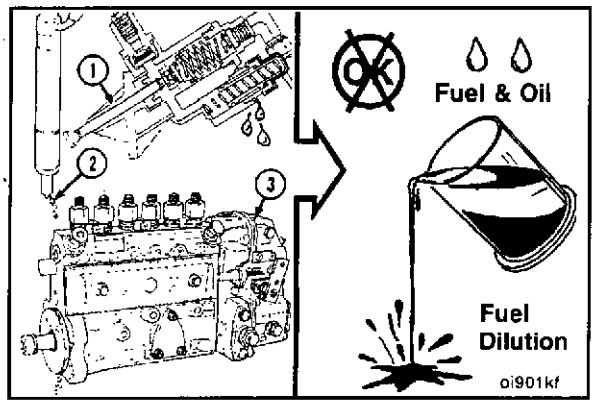
NOTE: Air compressor leaks will produce the same symptoms, be sure to perform Procedure 4-02 before concluding the leak is from the cylinder liner.



Cracked Cylinder Block

A crack in the cylinder block from an oil drilling or passage to the water jacket can cause oil dilution, and can normally be found either as an external leak from a gasket, i.e. head gasket, or from the oil pickup tube with the oil pan off.

The cooling system should be pressurized to 140 kPa [20 psi] to detect leaks.



Fuel Diluted Oil

Fuel dilution is limited to three sources:

1. Fuel transfer pump
2. Fuel leaking by the rings
3. Injection pump internal wear

Use the following logic to determine the source of the oil dilution with fuel:

Power Low - Increased White Smoke During Start Up -

↓

Check/Replace the Injectors

Power Low - Increased Black Smoke

↓

Verify the Rings are Sealing by Performing a Compression Check

Power Normal

↓

Check Fuel Transfer Pump For Seal Leakage

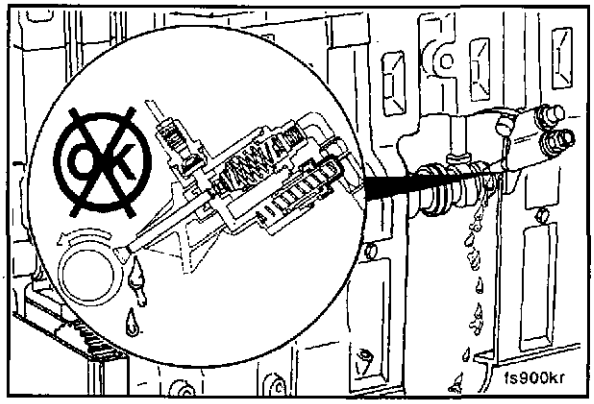
↓

Replace the Fuel Transfer Pump

Fuel Transfer Pump

NOTE: On non-automotive engines, a worn or damaged seal around the plunger can allow fuel to leak to the oil pan.

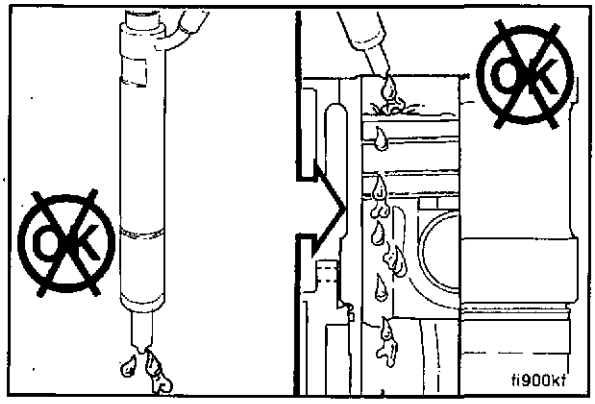
Automotive engines have a weep hole to allow the fuel to leak externally.

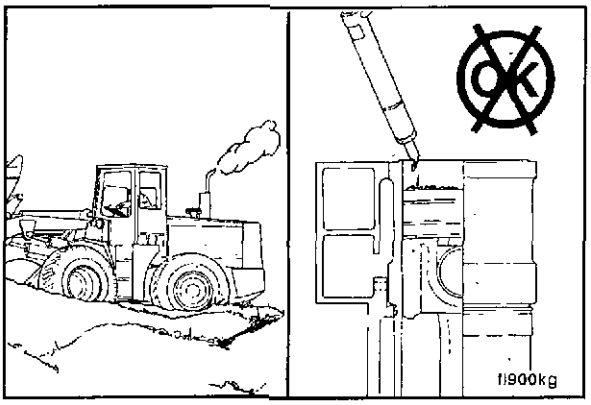


Fuel Leaking by Piston Rings

Incomplete combustion in the cylinders can result in unburned fuel draining into the oil pan.

This condition can be caused by a leaking injector or reduced compression caused by inadequate piston ring sealing.

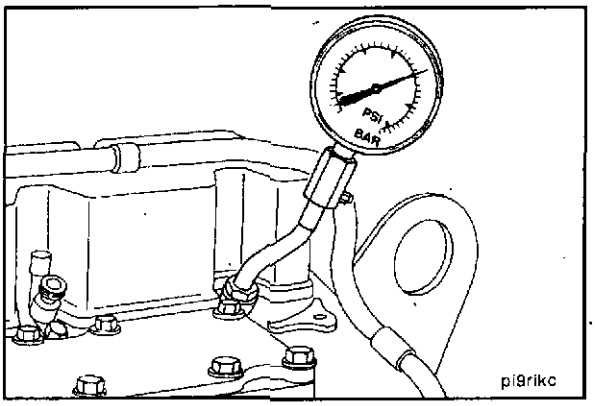




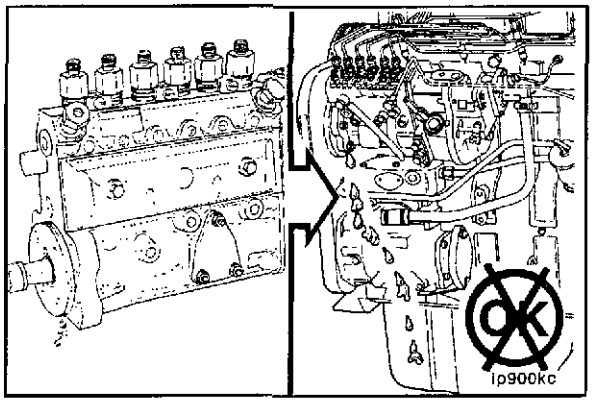
An increase in white exhaust smoke during the first start of the day is a symptom of an injector leaking.

An injector leak will also cause the engine to run rough and have low power.

Remove and replace leaking injectors. Refer to Procedure 5-07. Refer to the Shop Manual, for test and repair instructions.

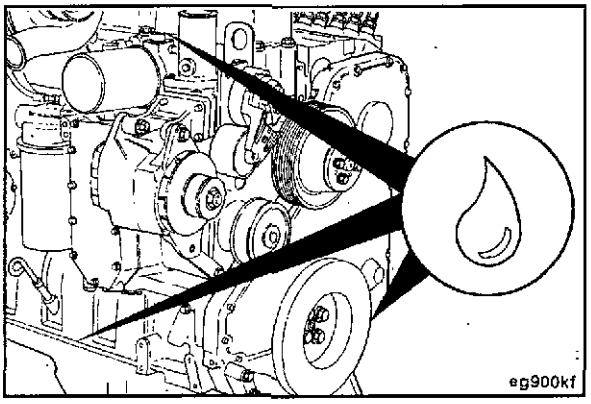


Perform a compression check to verify piston rings are properly sealing. Refer to Procedure 7-01.



Injection Pump

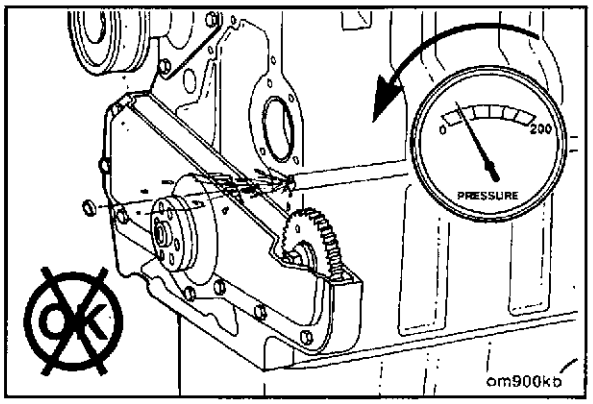
A worn or damaged injection pump can allow fuel to leak into the lubricating oil as it passes through the pump.



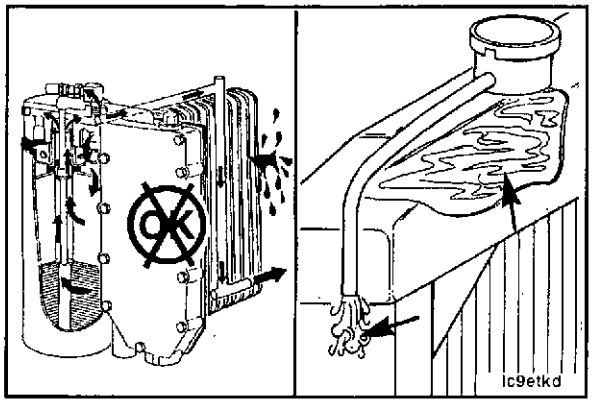
Oil Leaks

Various gaskets, seals and plugs are used to contain the oil. Most leaks can be identified during routine inspection of the engine and vehicle.

A damaged rocker assembly oil manifold or blown expansion plug can allow a large quantity of oil to escape resulting in a sudden drop in the oil pressure.

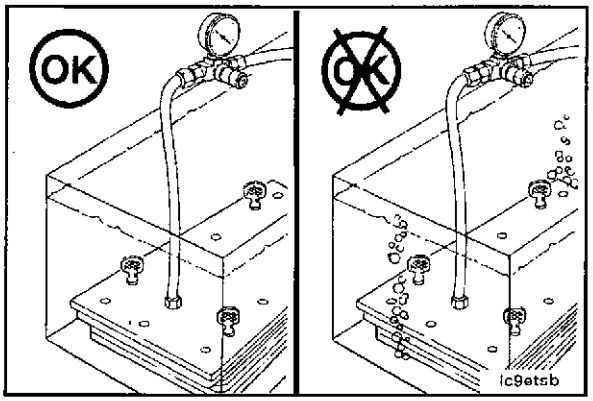


If the oil cooler element ruptures, the oil pressure will force oil into the cooling system. Oil in the coolant should be visible when the radiator cap is removed. As the oil is forced into the cooling system, coolant will be displaced through the radiator overflow.

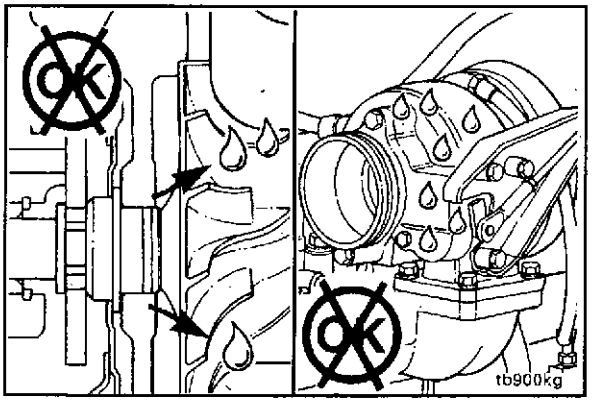


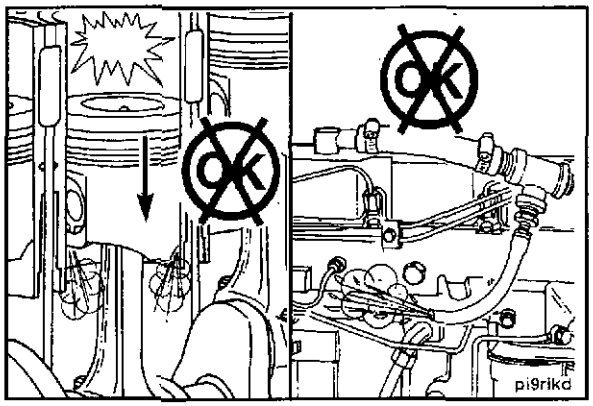
Part No. 3823876 Lubricating Oil Cooler Pressure Test Kit

Leaks can be verified by pressure testing the oil cooler element. Apply 483 kPa [70 psi] air pressure to the element to check for leaks.

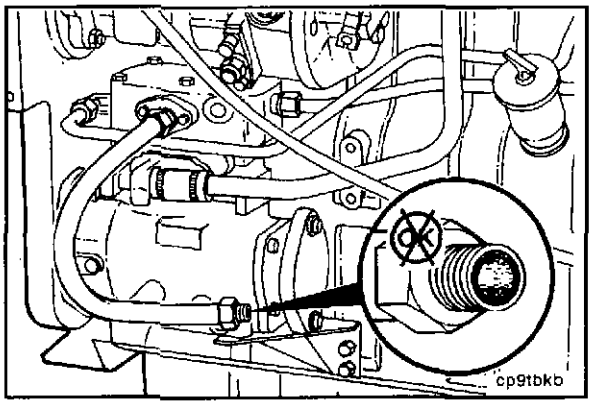


High intake air restriction and worn or damaged seals in the turbocharger can also allow oil to leak into the air crossover pipe and be burned in the engine. This condition can be verified by removing the air crossover tube and looking for oil.

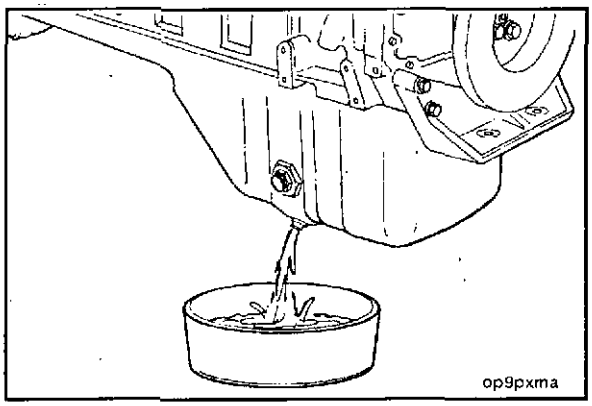




Inadequate sealing of the piston rings will result in combustion gas and oil droplets being blown out the crankcase breather tube and/or consumed by the engine. Refer to Procedure 8-01 for measuring crankcase gases (blowby).



Oil can also be lost through a worn or malfunctioning air compressor. Look for carbon build up in the air line from the compressor to the air tank and look for oil when draining the tank. Refer to Compressed Air Section for additional diagnostic procedures.



Lubricating Oil Pan - Draining (2-04)

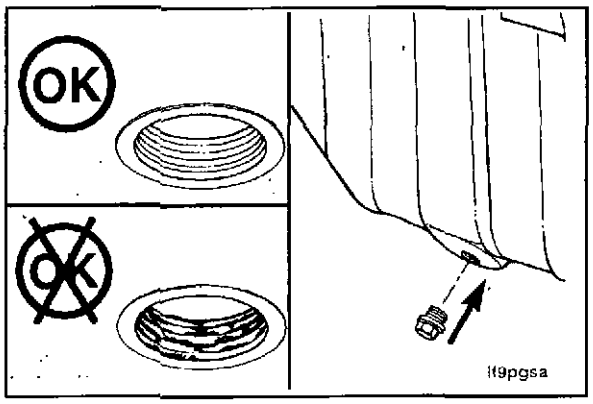
17 mm

Warning: Hot oil can cause serious personal injury.

Warning: Avoid prolonged and repeated skin contact with used engine oils. Such prolonged and repeated contact can cause serious skin disorders or other bodily injury.

Operate the engine until the coolant temperature reaches 60°C [140°F]. Shut off the engine. Remove the oil drain plug. Drain the oil immediately to make sure all the oil and suspended contaminates are removed from the engine.

NOTE: Use a container that will hold at least 22 liters [23 U.S. Qts.] of oil.



Lubricating Oil Pan - Filling (2-05)

17 mm

Clean and check the oil drain plug threads and sealing surface.

Install the oil pan drain plug.

Torque Value: 80 N•m [59 ft-lb]

NOTE: Use a high quality 15W-40 multi-viscosity oil, such as Cummins Premium Blue, or its equivalent in Cummins engines. Choose the correct oil for your operating climate as outlined in the C Series Operation and Maintenance Manual.

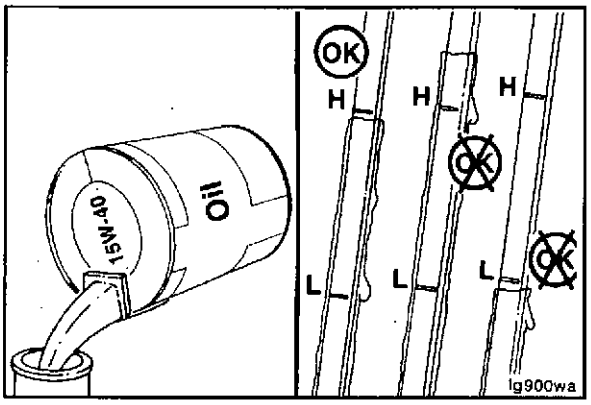
- **Turbocharged engines** **CE/SG**
- **Naturally aspirated engines** **CC/CD/SG**

Lubricating Oil Level - Checking (2-06)

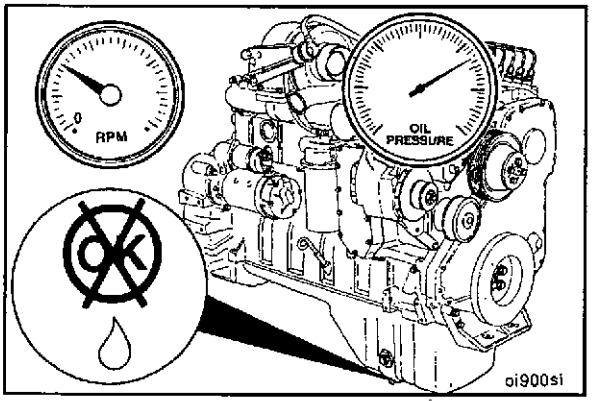
Fill the engine with clean oil to the proper level.

NOTE: When filling the oil pan, use the fill tube on the side of the engine rather than on top of the valve cover.

Refer to Lubricating Oil System Specifications, page 2-5 for capacities.

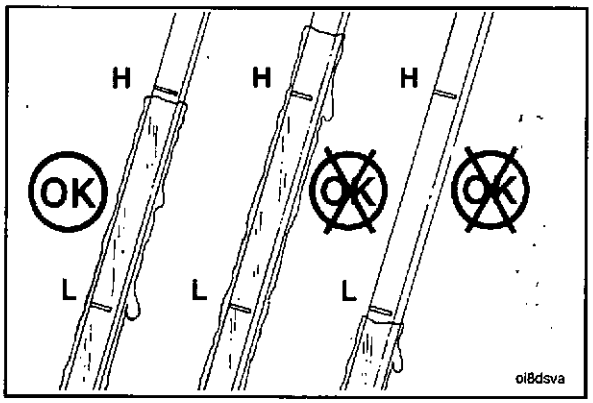


Idle the engine to inspect for leaks at the drain plug.

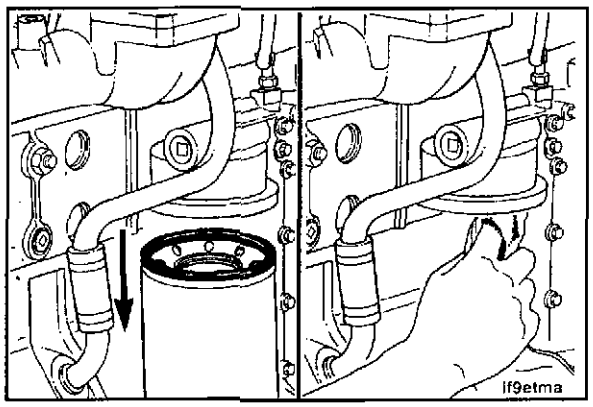


Shut off the engine. Wait approximately 5 minutes to let the oil drain from the upper parts of the engine. Check the level again.

Add oil as necessary to bring the oil level to the "H" (High) mark on the dipstick.



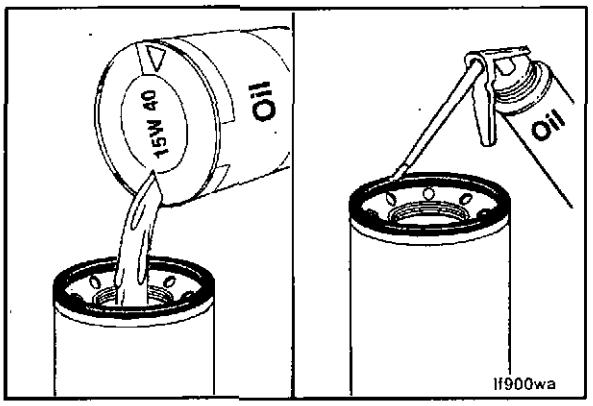
Lubricating Oil Filter - Changing (2-07)



Part No. 3375049 Filter Wrench

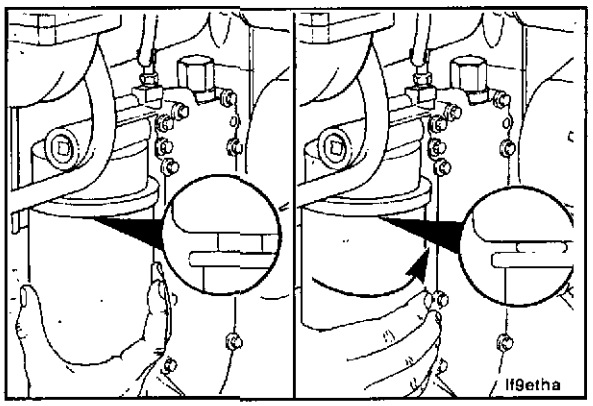
Use oil filter wrench, Part No. 3375049, to remove the filter.

Clean the area around the lubricating oil filter head. Remove the filter. Clean the gasket surface of the filter head.



Use clean 15W-40 oil to coat the gasket surface of the filter.

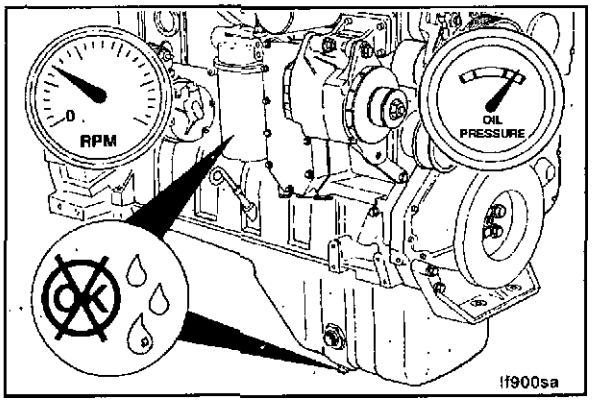
Fill the filter with clean 15W-40 oil.



Part No. 3375049 Oil Filter Wrench

Install the filter on the oil filter head. Tighten the filter until the gasket contacts the filter head surface.

Use oil filter wrench, Part No. 3375049, to tighten the filter an additional three-fourths to one turn, or follow the instructions supplied with the filter.

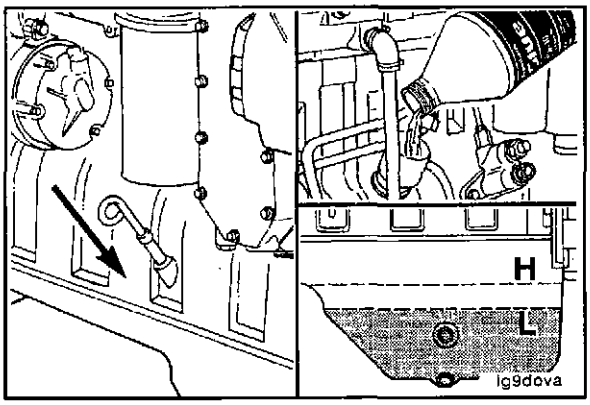


Operate the engine and check for leaks.

Lubricating Oil Dipstick - Calibration (2-08)

Install the dipstick in the dipstick tube housing.

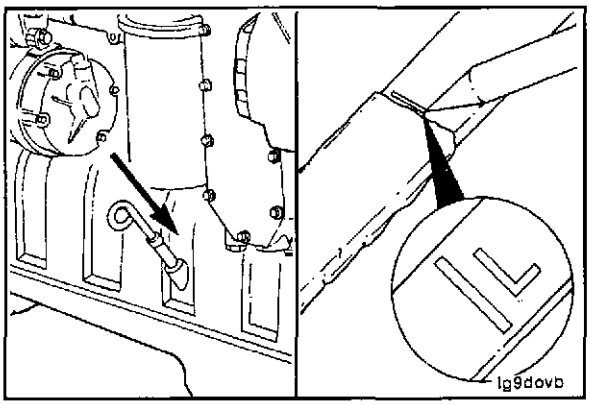
Use clean 15W-40 oil to fill the oil pan to the specified "low" oil level. Refer to Lubricating Oil System Specifications, page 2-5, for engine oil capacity.



Caution: The dipstick will break if the scribe mark is too deep.

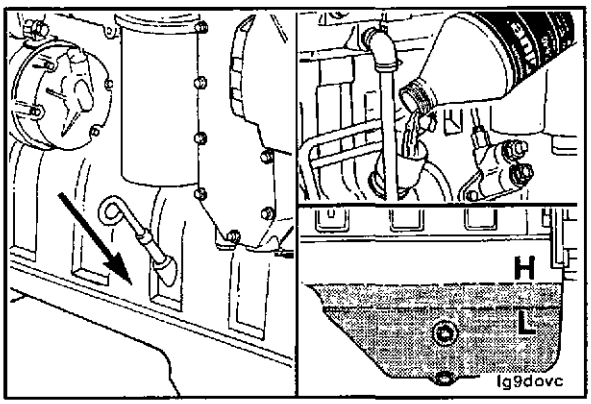
Remove the dipstick and scribe a mark across the dipstick and mark the "low" oil level with an "L".

NOTE: If a new blank dipstick is being used, cut the dipstick off approximately 38 mm [1.5 inch] below the "low" oil level mark.

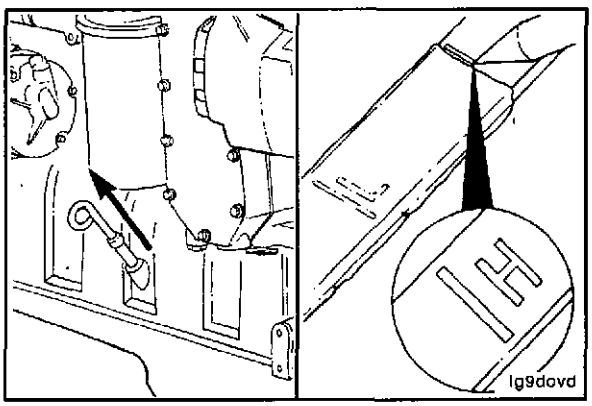


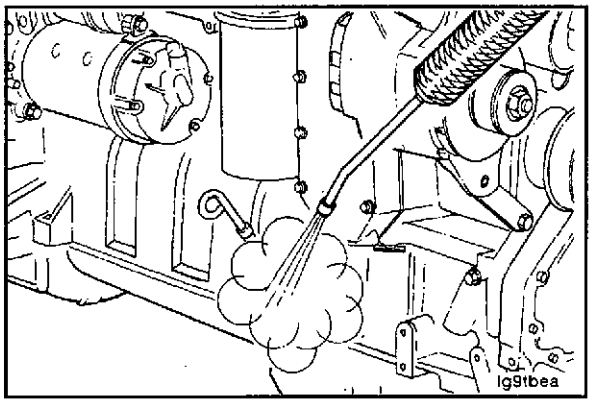
Install the dipstick into the dipstick tube housing.

Fill the oil pan to the specified "high" oil level. Refer to Lubricating Oil System Specifications, page 2-5, for engine oil capacity.



Remove the dipstick and scribe a mark across the dipstick and mark the "high" oil level with an "H".

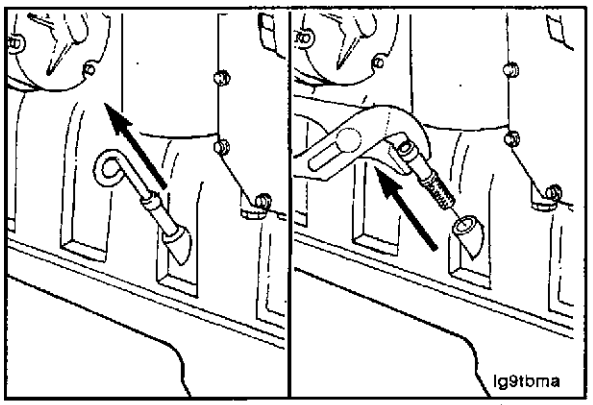




Lubricating Oil Dipstick Tube - Replacement (2-09)

Removal

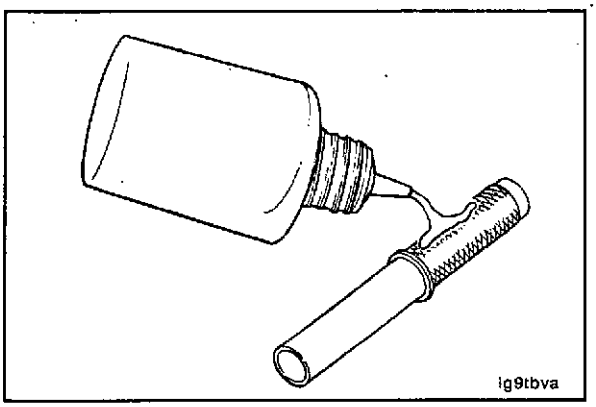
Clean the area around the dipstick tube before removing to prevent debris from entering the oil system.



Remove dipstick from the dipstick tube.

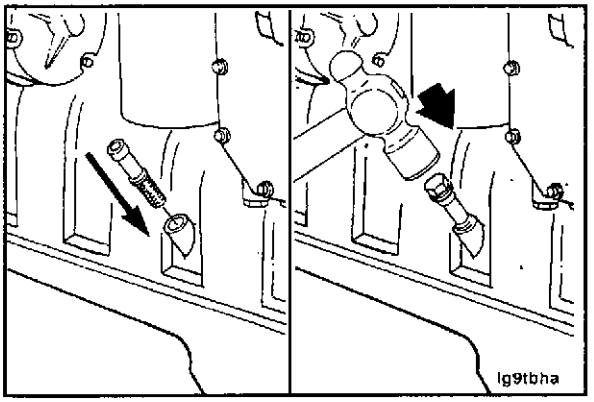
Remove dipstick tube from the cylinder block.

Service Tip: Use a dent puller and a M8 X 1.25 X 21mm self-tapping capscrew. Thread the capscrew into the dipstick tube and remove the tube.



Installation

Apply a thin bead of Loctite™ No. 277 around the bottom of the knurled end of the tube.

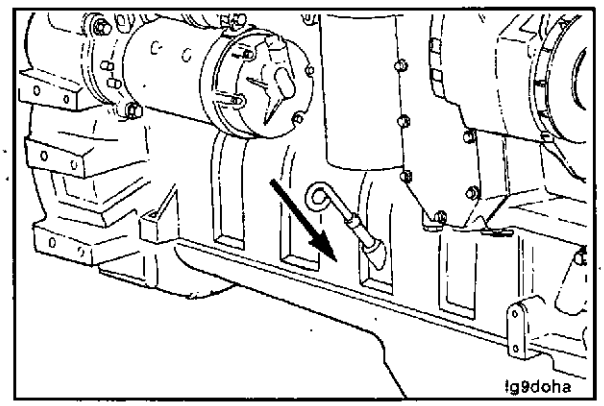


Place knurled end of tube into the dipstick tube bore in the cylinder block.

Use a flat washer and hex head capscrew to drive the tube into the cylinder block.

Lightly drive the dipstick tube until it seats against the block casting.

Install dipstick into the dipstick tube.



Lubricating Oil Pressure Regulator, Valve and Spring - Replacement (2-10)

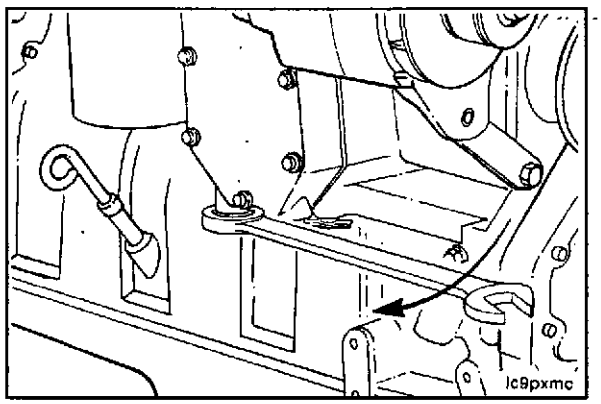
Preparatory Steps:

Clean debris.

Removal

22 mm

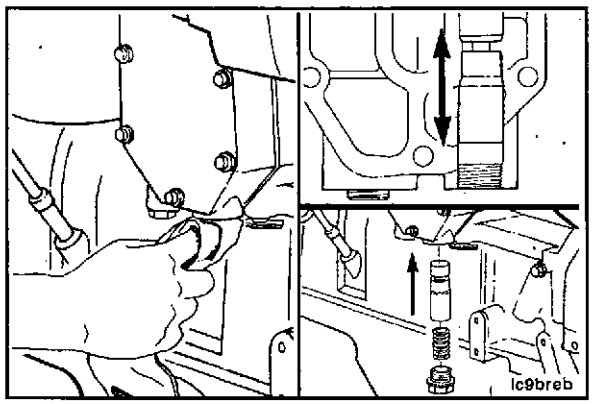
Remove the plug and regulator valve.

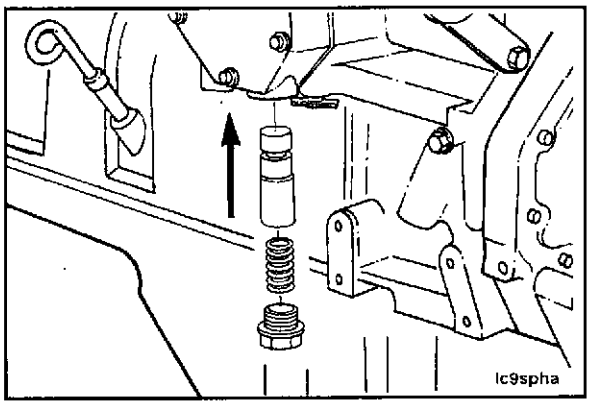


Cleaning and Inspection

Clean and inspect the bore and regulator valve before assembly.

The valve must move freely in the bore.





Installation

22 mm

Install the regulator and spring.

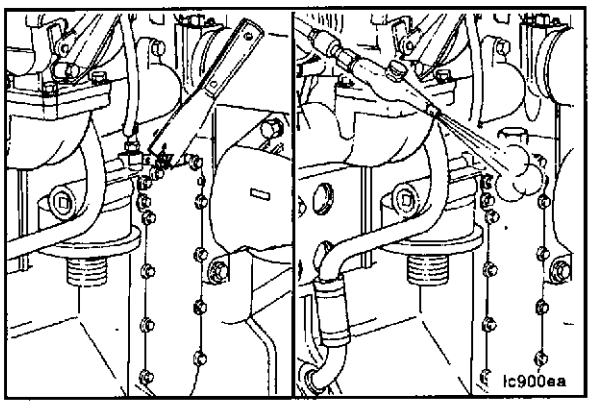
Torque Value: 80 N•m [59 ft-lb]

Lubricating Oil Cooler Element and Gasket - Replacement (2-11)

Preparatory Steps:

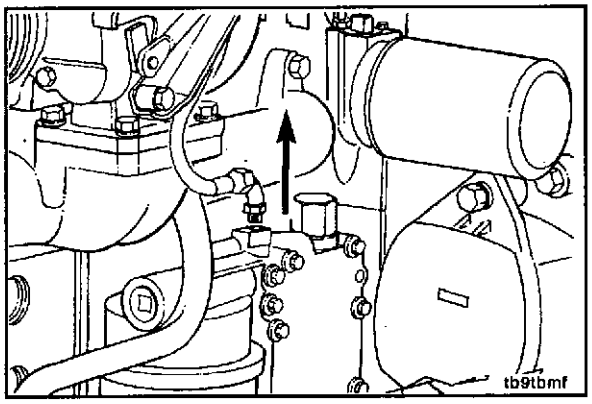
Drain the coolant. Refer to Procedure 1-01.

Remove the oil filter. Refer to Procedure 2-07.



Removal

Clean all debris from around the oil cooler.



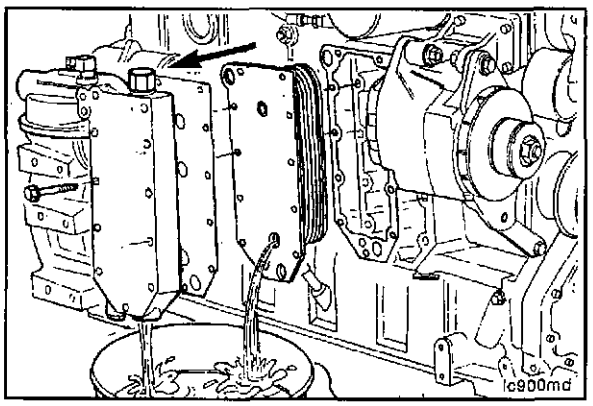
16 mm

Disconnect the turbocharger oil supply line from the oil filter head.

10 mm

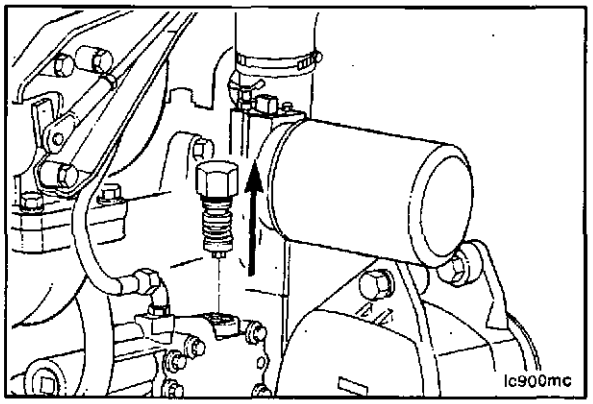
NOTE: Due to the design of the present production lubricating oil cooler cover, there is approximately 0.7 liter [0.75 U.S. Qts.] oil that does **not** drain when the system is drained. Place a container under the cooler to catch the oil when the cover is removed.

Remove the oil cooler cover, element and gaskets.



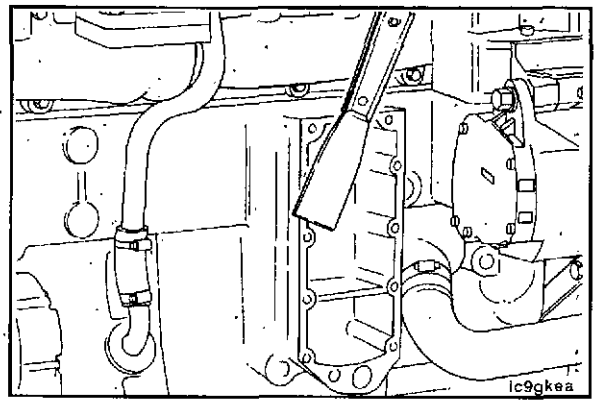
32 mm

Remove the oil temperature thermostat. Refer to Procedure 2-12.



Cleaning and Inspection

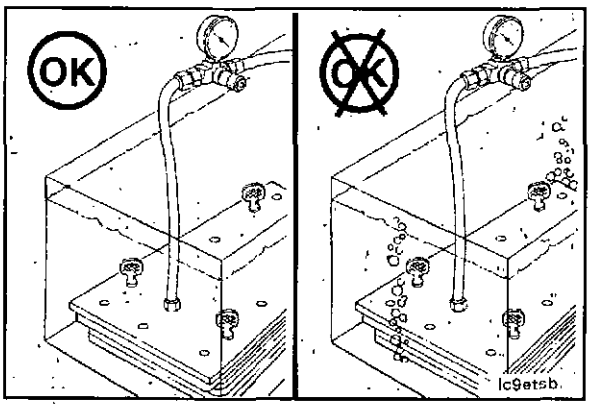
Clean the sealing surfaces.

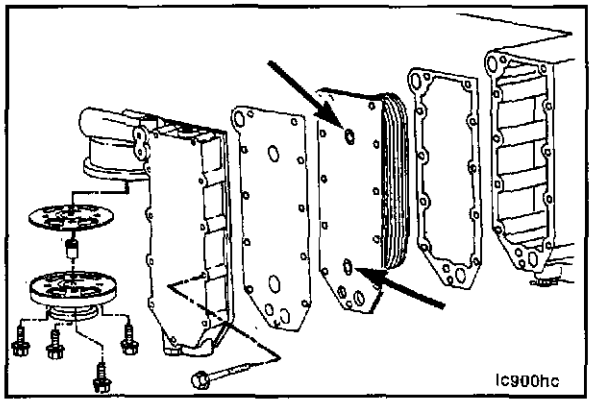


Pressure Test

Part No. 3823876 Lubricating Oil Cooler Pressure Test Kit

Apply 483 kPa [70 PSI] air pressure to the element to check for leaks.





Installation

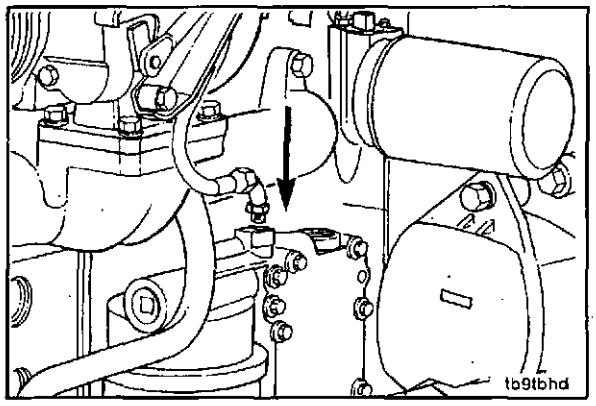
10 mm

Assemble the oil cooler gasket, element, cooler cover gasket, oil temperature thermostat and cooler cover to the cylinder block.

Install the filter head and gasket if removed.

NOTE: Be sure to remove the shipping plugs from the new cooler element.

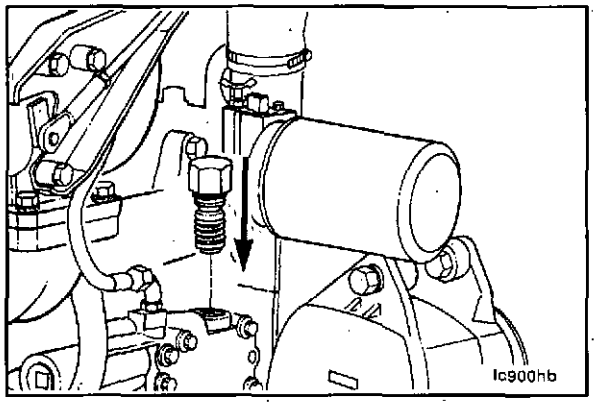
Torque Value:
Oil Cooler Cover Capscrews 24 N•m [18 ft-lb]
Oil Filter Head Capscrews 24 N•m [18 ft-lb]



16 mm

Connect the turbocharger oil supply line.

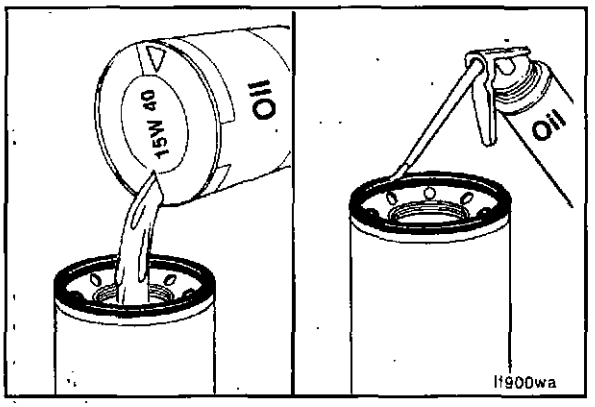
Torque Value: 17 N•m [13 ft-lb]



32 mm

Install the lubricating oil temperature thermostat.

Torque Value: 50 N•m [37 ft-lb]



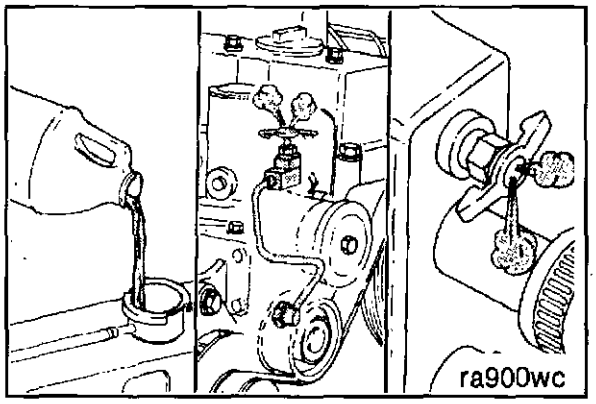
NOTE: Fill the filters with clean lubricating oil before installation.

Install a new oil filter.

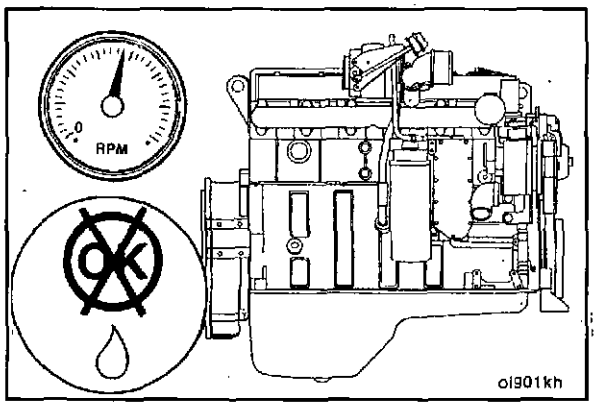
Follow the manufacturer's instructions for tightening.

NOTE: Be sure to open the engine and aftercooler vents to allow air to escape as the system is filled. Refer to Procedure 1-01.

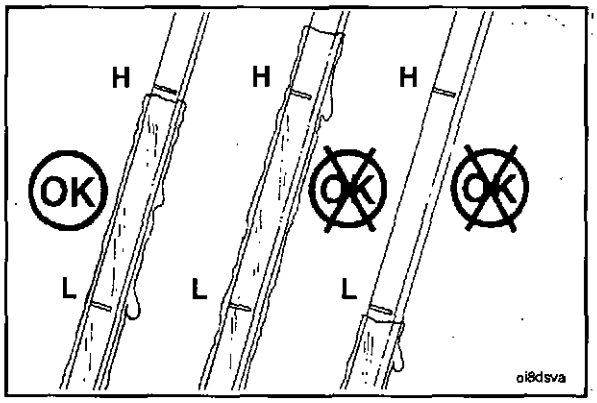
Fill the cooling system.



Operate the engine to check for leaks.



Shut off the engine and check the oil and coolant level.

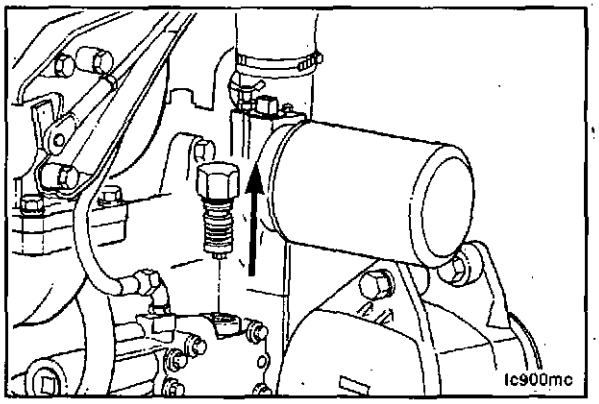


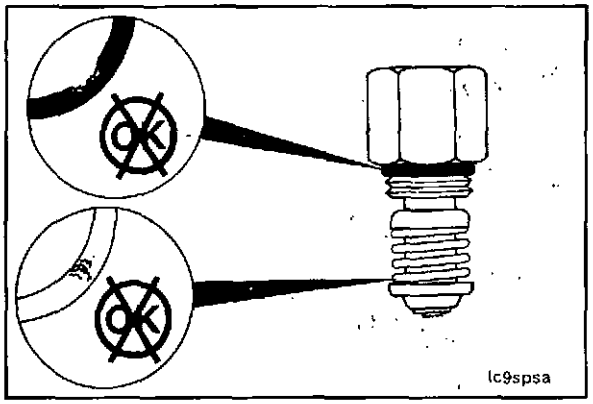
Lubricating Oil Temperature Thermostat - Replacement (2-12)

Removal

32 mm

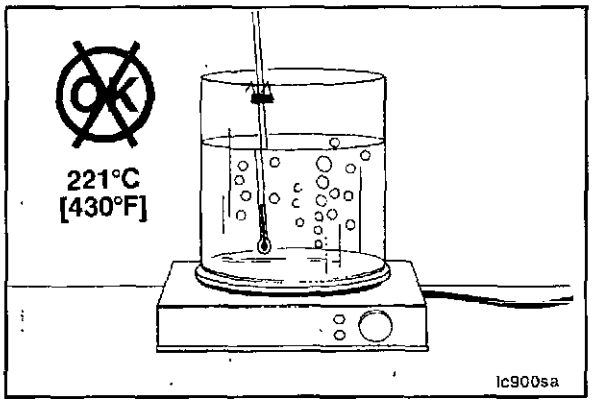
Remove the oil temperature thermostat.



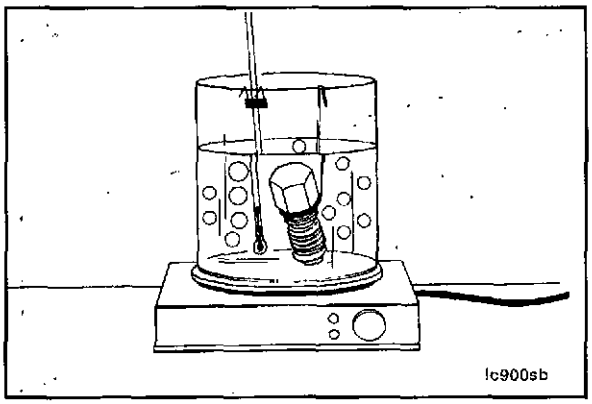


Inspection

Visually inspect for a damaged o ring, broken spring or other damage.

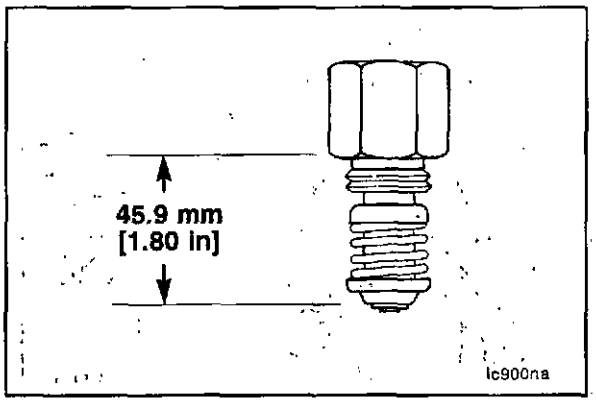


Caution: The flash point of new lubricating oil is approximately 221°C [430°F]. Do not allow oil temperature in the container to exceed 150°C [300°F]. Do not allow water droplets to enter the container of hot oil. Water droplets will cause a violent reaction which can cause personal injury.



Suspend the thermostat and a 116°C [240°F] thermometer in a container of new lubricating oil. Do **not** allow the thermostat or the thermometer to touch the sides of the container.

Heat the lubricating oil.



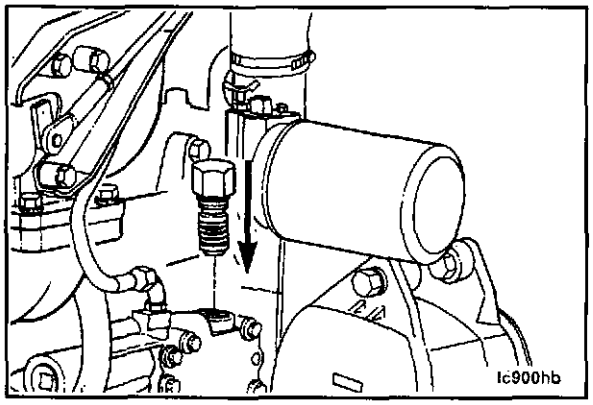
NOTE: Write down the temperature at which the thermostat is fully extended. The thermostat **must** be fully extended to at least 45.9 mm [1.80 inch] when the temperature reaches 104°C [220°F] or 116°C [240°F] depending on what temperature the thermostat is rated.

Replace the thermostat if it does **not** operate as described.

Installation

Install the oil temperature thermostat.

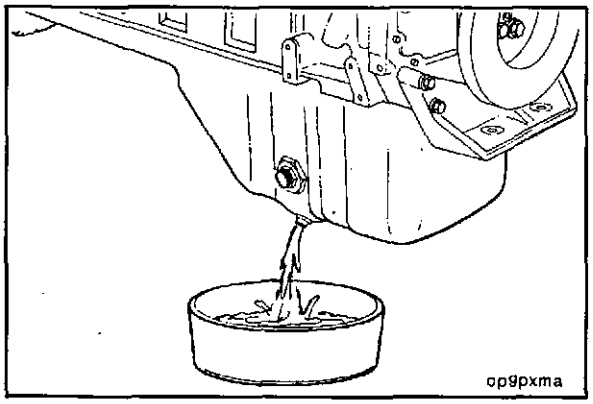
Torque Value: 50 N•m [37 ft-lb]



Lubricating Oil Pan, Suction Tube and Gasket - Replacement (2-13)

17 mm

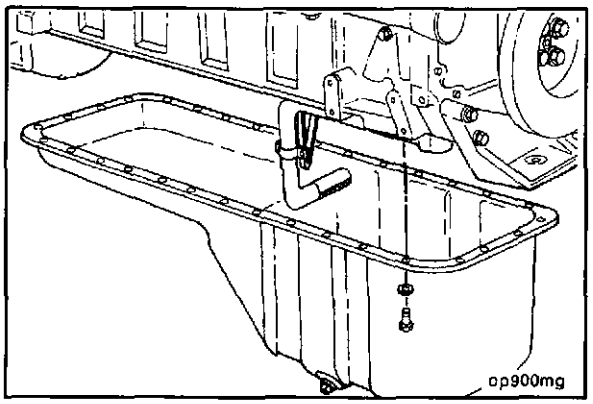
Remove the oil pan drain plug to drain the oil.



Oil Pan - Removal

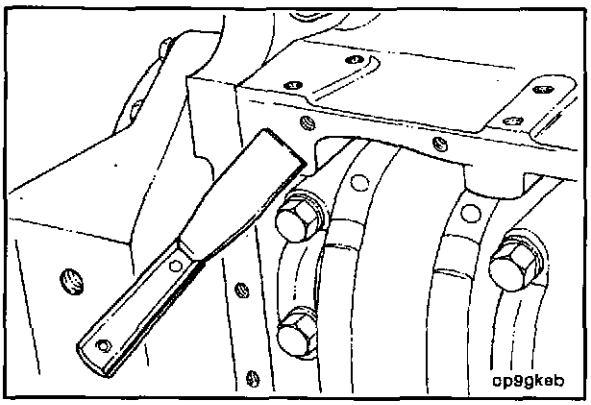
10 mm

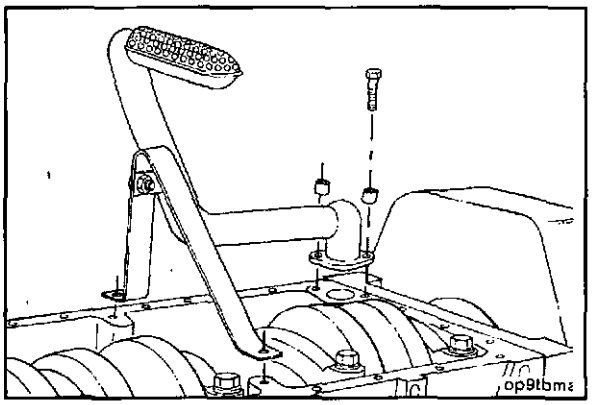
Remove the oil pan.



Cleaning

Clean the sealing surface.



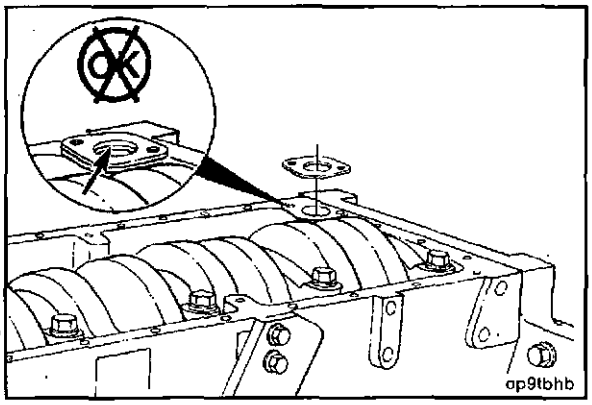


Suction Tube - Replacement

8 mm

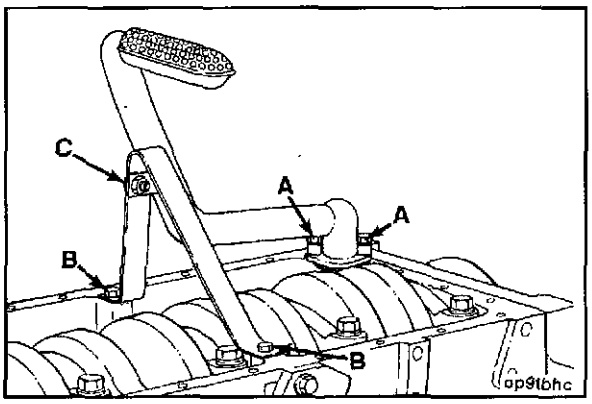
Remove the suction tube and gasket.

Clean the sealing surface.



Position the new lubricating oil suction tube gasket onto the cylinder block.

Make sure the gasket is correctly installed and does **not** block the hole for oil passage.



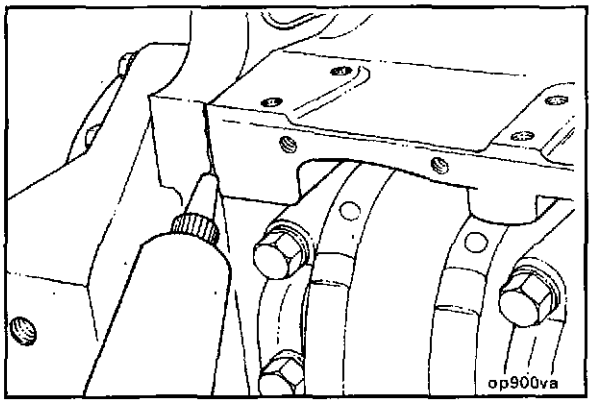
8 mm

Install the lubricating oil suction tube over the gasket and align the mounting holes.

Use the following sequence to tighten the capscrews:

Torque Value:

Step A Suction Tube to Block	9 N•m [80 in-lb]
Step B Brace to Block	9 N•m [80 in-lb]
Step C Brace to Suction Tube	9 N•m [80 in-lb]



Oil Pan - Installation

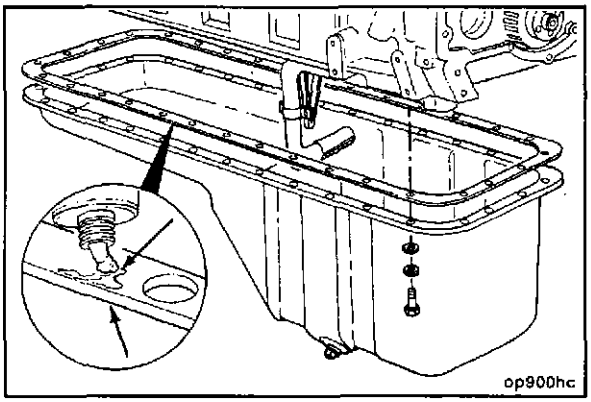
Be sure to fill the joints between the pan rail, gear housing and rear cover with Three Bond RTV sealant, Cummins *Part No. 3823494.*

NOTE: The lubricating oil pan should be assembled and the capscrews torqued within 15 minutes after applying the sealant.

Apply a 2 mm [1/16 inch] bead of Three Bond Sealant, Part No. 3823494, to both sides of the new lubricating pan gasket.

Install the gasket.

Install the lubricating oil pan.

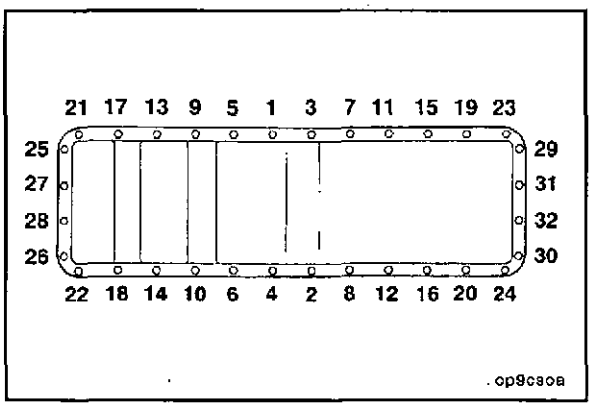


10 mm

Assemble the washers and capscrews to secure the lubricating oil pan as illustrated.

Tighten all capscrews in the sequence shown in the accompanying chart.

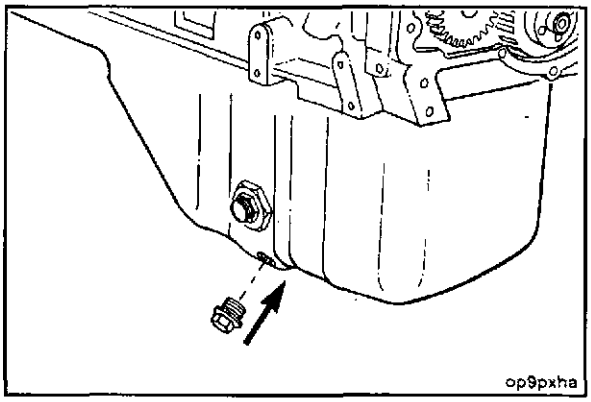
Torque Value: 24 N•m [18 ft-lb]



17 mm

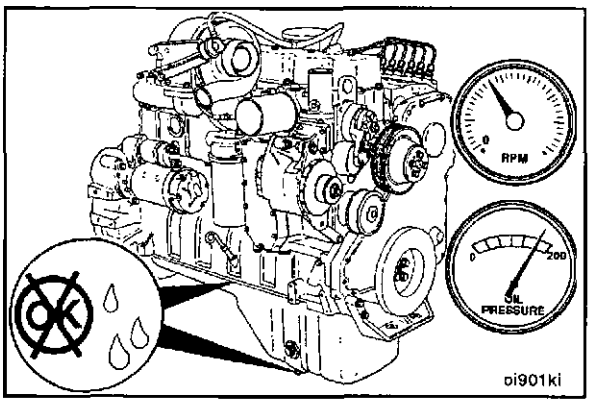
Install the oil pan drain plug.

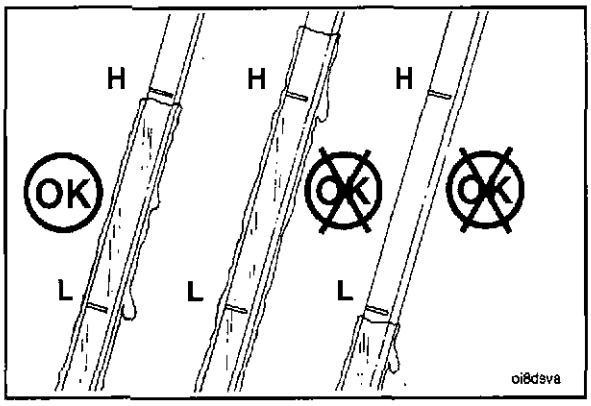
Torque Value: 80 N•m [59 ft-lb]



Fill the oil pan with clean 15W-40 engine oil.

Operate the engine and check for leaks.



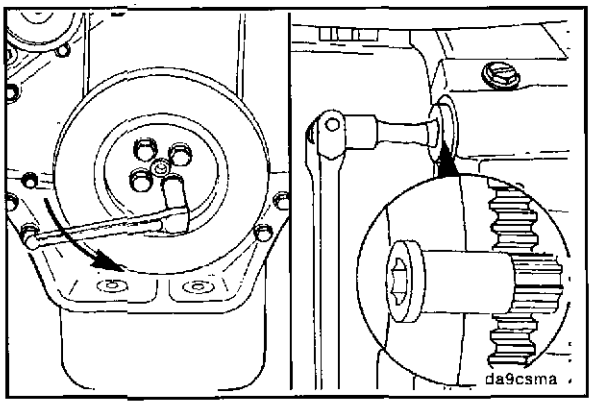


Shut off the engine and check the oil level with the dipstick.

Lubricating Oil Pump - Replacement (2-14)

Preparatory Step:

Remove the drive belt. Refer to Procedure 1-03.

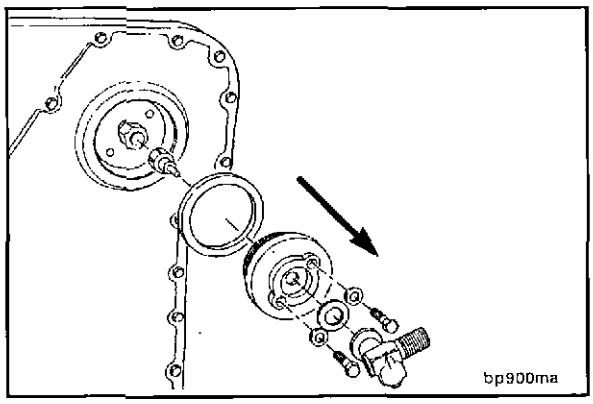


Removal

18 mm, Part No. 3377371, Engine Barring Tool

Remove the vibration damper. Use the barring tool, Part No. 3377371, to keep the crankshaft from rotating.

Refer to Procedure 7-16.



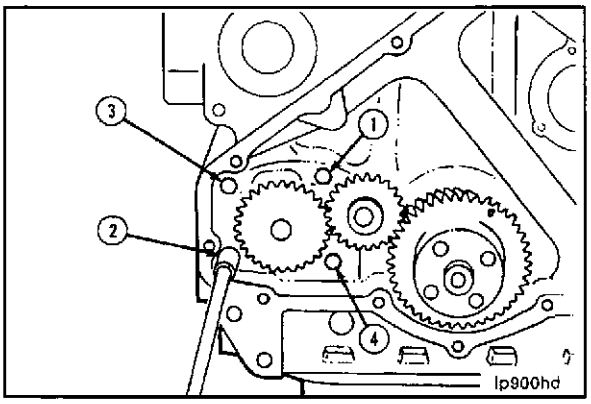
10mm

Remove gear cover cap/tachometer drive adapter assembly.

Remove the gear cover. Refer to Procedure 7-17.

10mm

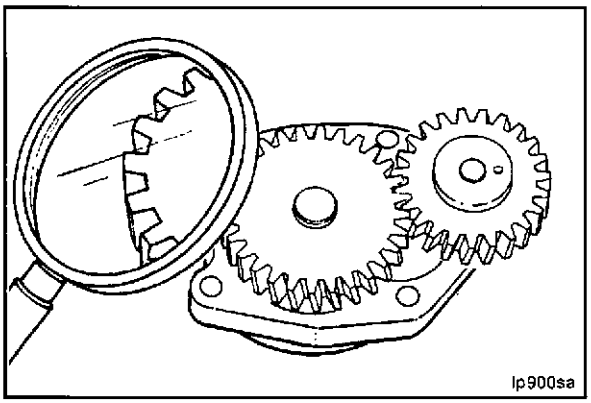
Remove the four lubricating oil pump mounting capscrews.



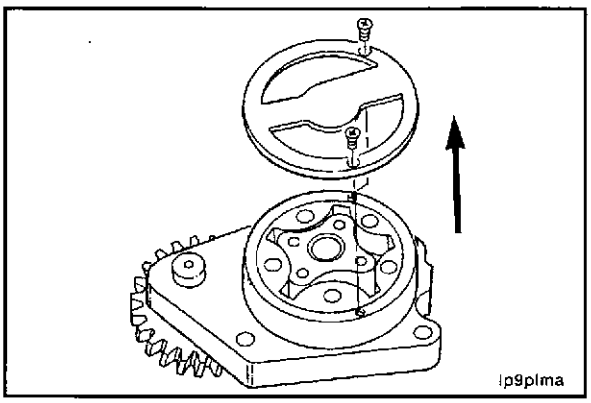
Cleaning and Inspection

Visually inspect the lubricating oil pump gears for chips, cracks, or excessive wear.

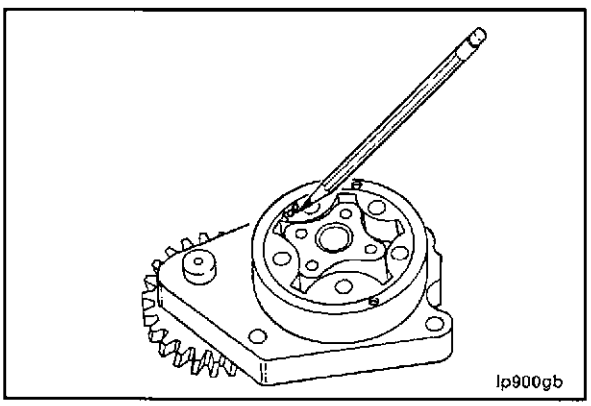
NOTE: Parts replacement is **not** practical if any of the internal parts are worn beyond the specifications, the pump should be replaced.

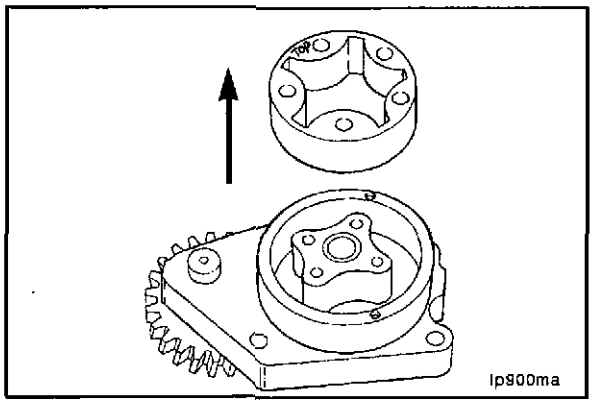


Remove the back plate.



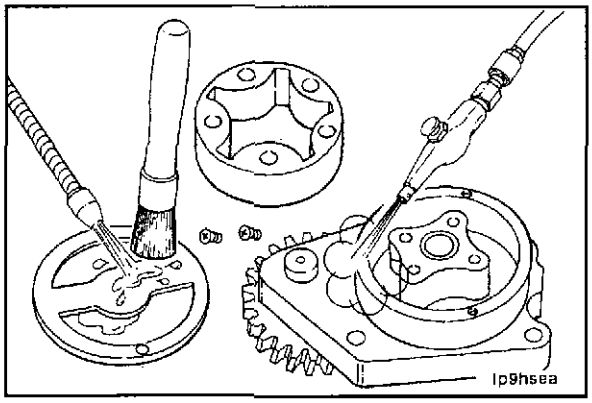
Mark "TOP" on the gerotor planetary.



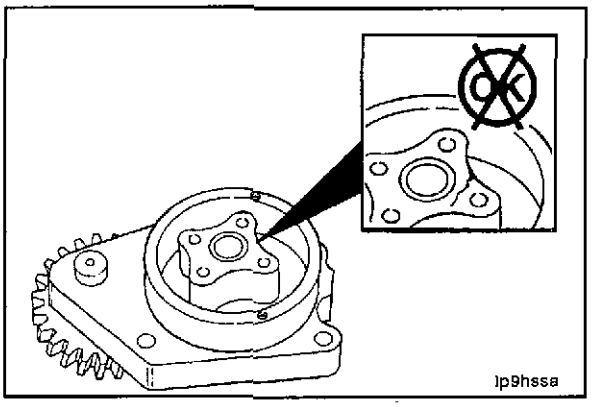


Remove the gerotor planetary.

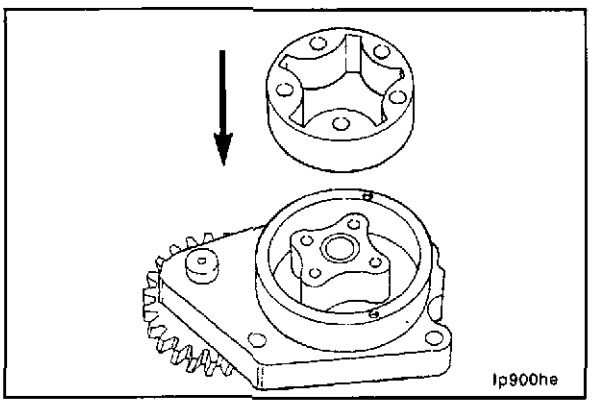
Inspect for excessive wear or damage.



Clean all parts in solvent and dry with compressed air.



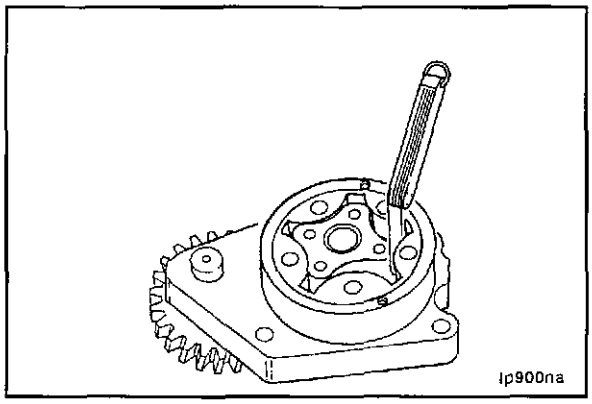
Inspect the pump housing and gerotor drive for damage wear.



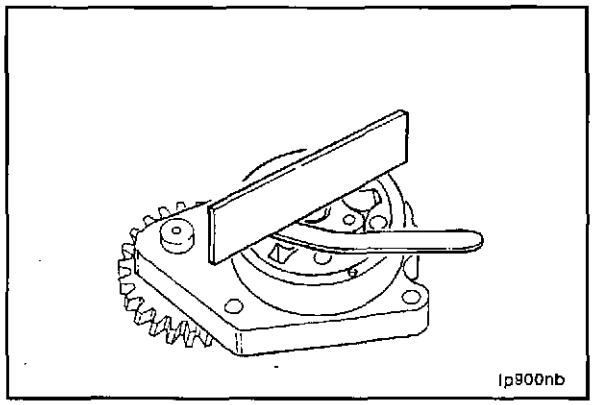
Install the gerotor planetary.

NOTE: Be sure the gerotor planetary is installed in the original position.

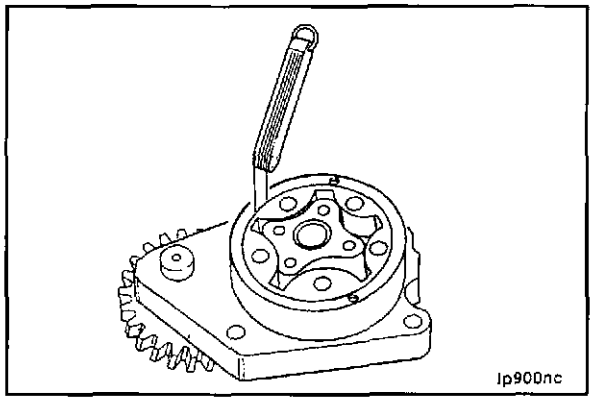
Oil Pump Gerotor Tip Clearance		
mm		in
0.025	MIN	0.001
0.1778	MAX	0.007



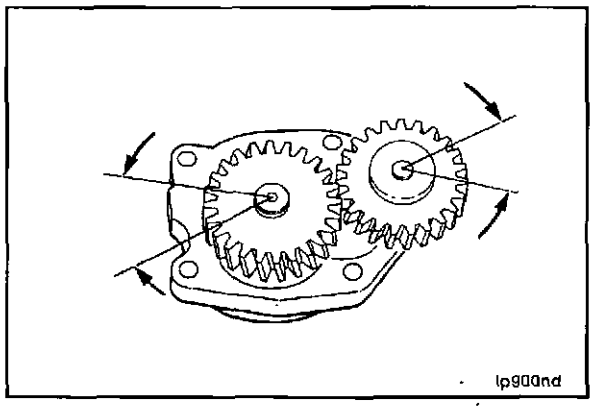
Oil Pump Gerotor Drive/Gerotor Planetary to Port Plate Clearance		
mm		in
0.025	MIN	0.001
0.127	MAX	0.005

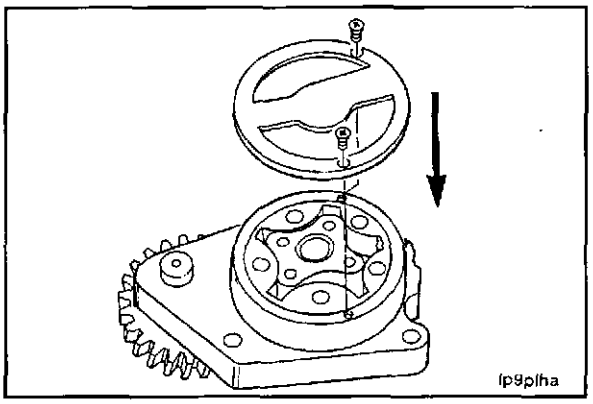


Oil Pump Gerotor Planetary to Body Bore		
mm		in
0.127	MIN	0.005
0.381	MAX	0.015

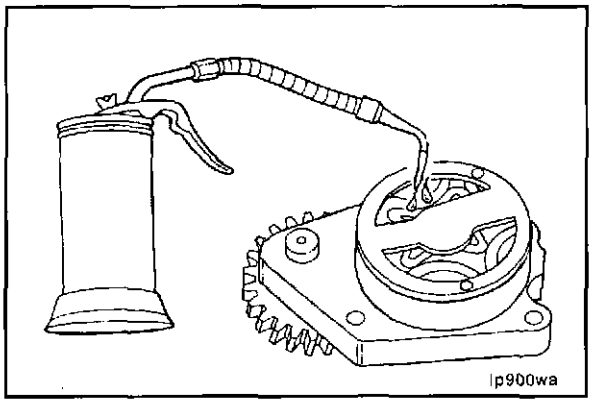


Oil Pump Drive Gear Backlash (Used Pump)		
mm		in
0.08	MIN	0.003
0.33	MAX	0.013





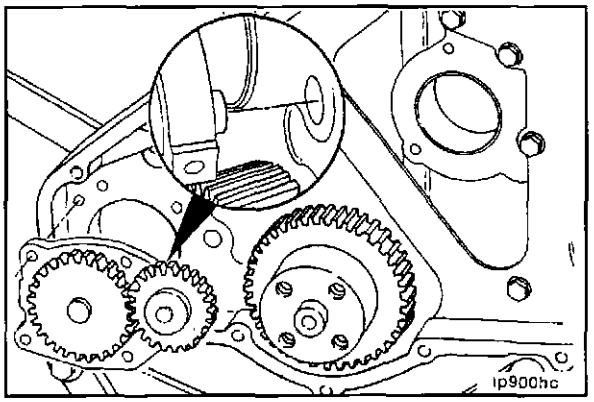
Install the back plate.



Installation

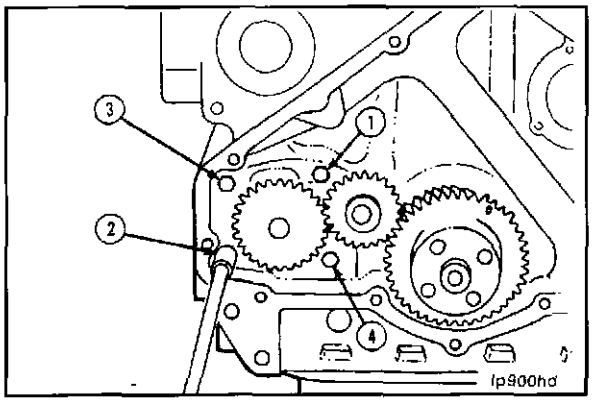
Lubricate the pump with clean 15W-40 engine oil.

NOTE: Fill the pump with oil during installation to aid in quicker oil suction when the engine is started.



Install the pump.

Make sure the idler gear pin is installed in the locating bore in the cylinder block.

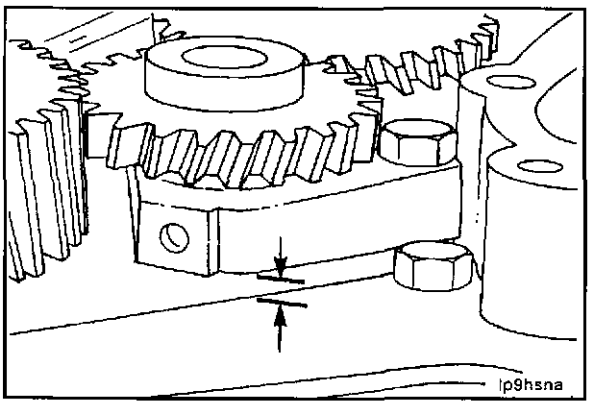


10mm

Tighten in the sequence shown.

Torque Value: Step 1 5 N•m [44 in-lb]
Step 2 24 N•m [18 ft-lb]

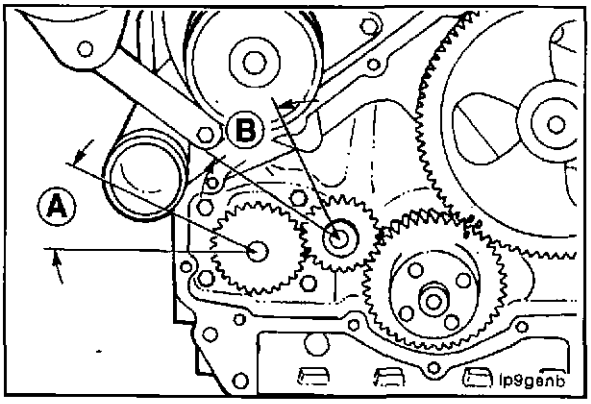
The back plate on the pump seats against the bottom of the bore in the cylinder block. When the pump is correctly installed, the flange on the pump will **not** touch the cylinder block.



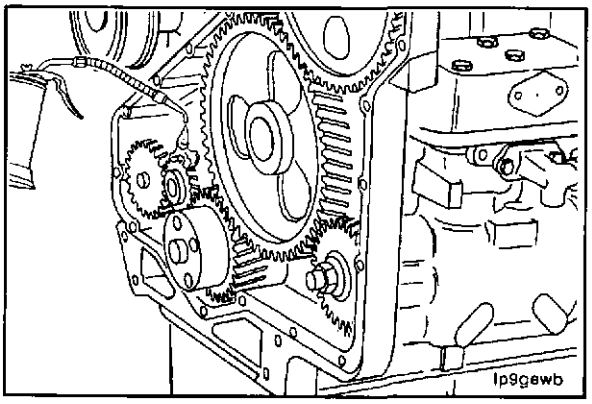
Use a dial indicator with a magnetic base to measure the idler gear backlash.

NOTE: Do **not** allow the mating gears to rotate while measuring the backlash.

Oil Pump Idler Gear Backlash (A & B)		
mm		**in**
0.08	MIN	0.003
0.33	MAX	0.013



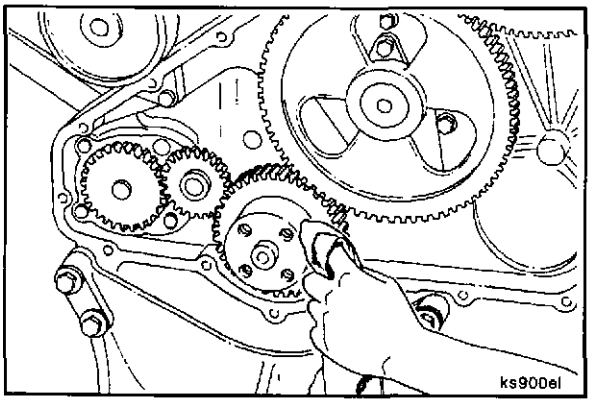
Lubricate the front gear train with clean 15W-40 engine oil.

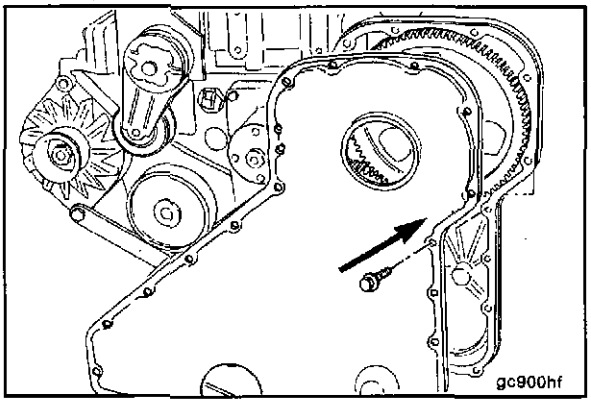


Thoroughly clean the front seal area of the crankshaft.

If the contact area has a groove worn deep enough to feel with a fingernail or sharp object, it will be necessary to install a wear sleeve over the sealing surface.

NOTE: The seal lip and the sealing surface on the crankshaft **must** be free from all oil residue to prevent seal leaks.





Use sealant, Part No. 3823494, on both sides of the front cover gasket.

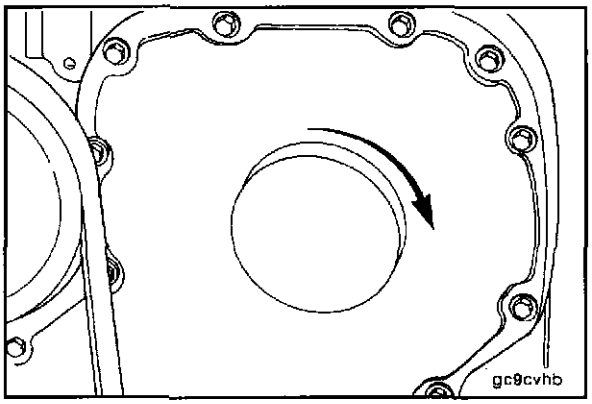
Install the front cover and gasket.

Refer to Procedure 7-17.

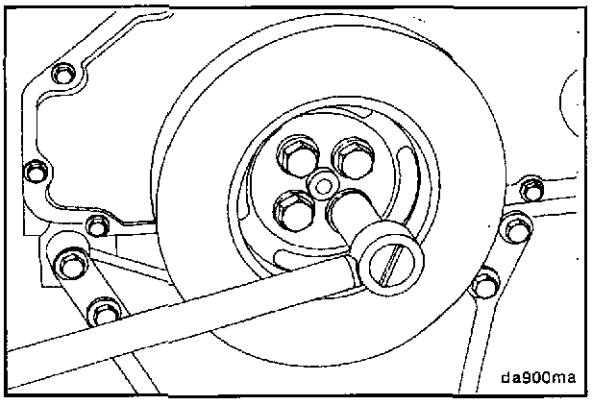
Install the capscrews.

Torque Value: 24 N•m [18 ft-lb]

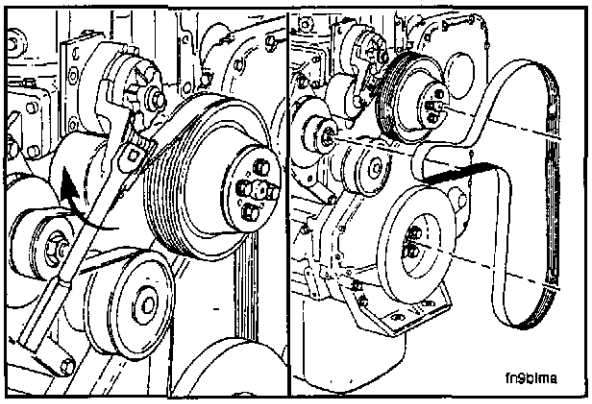
NOTE: Torque the capscrews within 15 minutes after applying the sealant.



Install the gear cover cap/tachometer drive adapter assembly.



Install the vibration damper. Do **not** tighten the capscrews to the correct torque value at this time. Refer to Procedure 7-16.



1/2 inch or 3/8 inch Square Drive

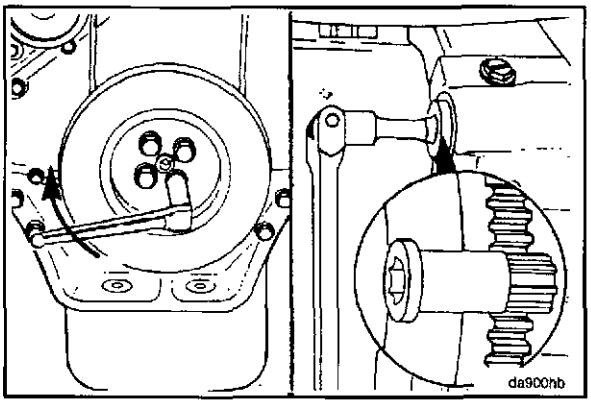
Raise the belt tensioner to install the belt.

18 mm, Part No. 3377371 Engine Barring Tool

Use engine barring tool, Part No. 3377371, to hold the crankshaft when tightening the capscrews.

Use a star pattern torque sequence.

Torque Value: 200 N•m [148 ft-lb]



NOTES

Section 3 - Combustion Air System

Section Contents

Page

Combustion Air System Flow - General Information

The engine was designed as a turbocharged engine, but a naturally aspirated engine is available for industrial applications.

Air is pulled into the engine from an air filter. Clean air is very important to the life of the engine. Ingested dust and dirt can very quickly damage the cylinders.

Make sure that an excellent quality air cleaner is used and that it is periodically replaced according to the manufacturer's recommendations.

Intake air for the naturally aspirated engine flows from the air cleaner to the intake manifold. From the intake manifold, the air is pulled into the cylinders and used for combustion. After combustion it is forced out of the cylinders and through the exhaust manifold.

On the turbocharged engines the intake air is drawn through the air cleaner into the compressor side of the turbocharger and then through the crossover tube and into the intake manifold. From the intake manifold the air is forced into the cylinders and used for combustion. Energy from the exhaust gases is utilized by flowing the exhaust through the exhaust side of the turbocharger to drive the turbine wheel. The turbine wheel and shaft drives the compressor wheel which forces more air into the cylinders for combustion. The additional air provided by the turbocharger allows more fuel to be injected to increase the power output from the engine.

On turbocharged-aftercooled engines, intake air from the turbocharger flows through the cooling fins of the aftercooler before entering the intake manifold. The cooled air becomes more dense and contains more oxygen which allows more fuel to be injected further increasing the power output from the engine.

The 1991 to 1994 automotive engines use a chassis-mounted charge air cooler instead of an engine mounted aftercooler to provide cooler charge air to the engine to improve engine performance and reduce emissions. This system also uses large diameter piping to transfer the air from the engine turbocharger to the charge air cooler, then returns the air from the charge air cooler to the engine intake manifold.

NOTE: The long term integrity of the charge air cooling system is the responsibility of the vehicle and component manufacturers.

Some turbocharged engines use a wastegated turbocharger to limit the maximum boost pressure that the turbo can develop. Wastegate operation is controlled by an actuator that senses compressor pressure and balances it against a preset spring load. The wastegate valve is located in the turbine inlet passage. When open, it diverts a portion of the exhaust gas around the turbine wheel, thereby controlling the shaft speed and boost.

Caution: The turbocharger is a performance part and must not be tampered with. The wastegate bracket is an integral part of the turbocharger. Tampering with the Wastegate Components can reduce durability by increasing cylinder pressure and thermal loading due to incorrect inlet and exhaust manifold pressure. Poor fuel economy and failure to meet regulatory emissions laws may result. Increasing the turbocharger boost will not increase engine power.

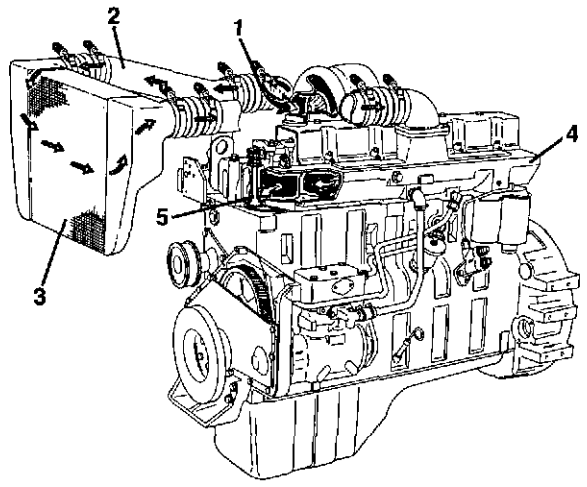
The turbine and compressor wheels and shaft are supported by two rotating bearings in the bearing housing. Passages within the bearing housing direct filtered, pressurized engine oil to the shaft bearings and thrust bearing. The oil is used to lubricate and cool the rotating components to provide for smooth operation. The oil then drains from the bearing housing to the engine sump through the oil drain line. A restricted or damaged oil drain line can cause the turbocharger bearing housing to be pressurized causing oil to leak past the seals.

NOTE: An adequate supply of good, filtered oil is very important to the life of the turbocharger. Make sure that an excellent quality oil is used and that it and the oil filter are changed according to the maintenance recommendations.

Caution: A catalyst is installed on all EPA and CARB approved automotive applications. Lubricating oil blending is not permitted. It will plug up and eventually damage the catalyst. High sulfur fuels must not be used with the catalyst. No welding or modifications of the catalyst are permitted without permission of catalyst manufacturer.

Air System Flow - Diagrams

Air System

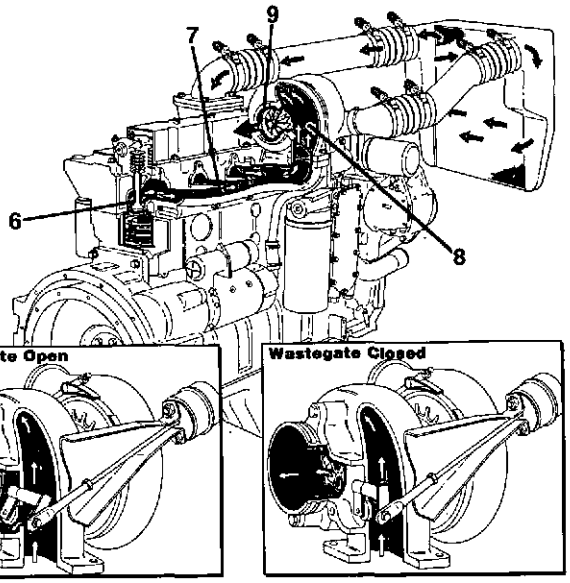


Intake System

1. Intake Air Inlet to Turbocharger
2. Turbocharger Air to Charge Air Cooler
3. Charge Air Cooler
4. Intake Manifold
   (Integral Part of Cylinder Head)
5. Intake Valve

Exhaust System

6. Exhaust Valve
7. Exhaust Manifold (Pulse Type)
8. Dual Entry to Turbocharger
9. Turbocharger Exhaust Outlet



Intake Air and Exhaust System Specifications

Maximum allowable intake restriction (compressor inlet)
(with dirty air filter element)
- 6C8.3 ..... 50.8 cm H_20 [20 in H_20]
- 6CT8.3, 6CTA8.3, and C8.3 ..... 63.5 cm H_20 [25 in H_20]

Maximum turbocharger exhaust restriction (turbine outlet)
at rated speed and load
- 6CT8.3 ..... 75 mm Hg [3 in Hg]
- 6CT8.3, 6CTA8.3, and C8.3 ..... 100 cm H_20 [40 in H_20]
- C8.3 (with catalyst) ..... 152 mm Hg [6 in Hg]

Wastegate calibration air pressure 6CTA8.3, C8.3 ..... 165 to 179 kPa [24.0 to 26.0 psi]

Charge Air Cooler ..... 21 kPa [3 psi]

Turbocharger Boost Pressure Specifications

Refer to the following table for the critical parts list (CPL), engine model, engine rating and corresponding rated turbocharger boost pressure.

NOTE: Measurement of boost pressure is not a short cut to logical troubleshooting. Low power can be caused by the fuel used, filter maintenance and several engine components. Follow the logic charts for "Engine Power Output Low" and measure boost pressure as indicated. Refer to page 3-10 for measurement instructions.

These pressures are valid only at rated conditions (rated speed and power). Any attempt to use the values at engine speeds and loads other than those specified will result in an incorrect diagnosis.

CPL	ENGINE MODEL	ENGINE RATING (HP @ RPM)	RATED BOOST PRESSURE kPa	[in. Hg]
0602	6CT8.3	129 @ 2100	34 to 54	10 to 16
		149 @ 2200	47 to 68	14 to 20
		153 @ 2500	51 to 71	15 to 21
		157 @ 2200	51 to 71	15 to 21
		165 @ 2100	54 to 74	16 to 22
		170 @ 2000	54 to 74	16 to 22
		170 @ 2200	57 to 78	17 to 23
		173 @ 2200	57 to 78	17 to 23
		173 @ 2350	61 to 81	18 to 24
		177 @ 2100	61 to 81	18 to 24
		177 @ 2500	64 to 84	19 to 25
		179 @ 2200	61 to 81	18 to 24
		180 @ 2200	64 to 84	19 to 25
		185 @ 2200	64 to 84	19 to 25
		186 @ 2500	68 to 88	20 to 26
		190 @ 2100	68 to 88	20 to 26
		190 @ 2500	71 to 91	21 to 27
		200 @ 2500	74 to 95	22 to 28
		202 @ 2200	74 to 95	22 to 28
		215 @ 2500	81 to 105	24 to 31
0603	6CT8.3	210 @ 2200	159 to 179	47 to 53
0604	6CTA8.3	220 @ 2100	98 to 118	29 to 35
		220 @ 2500	118 to 138	35 to 41
		234 @ 2200	108 to 128	32 to 38
		240 @ 2100	122 to 142	36 to 42
		250 @ 2200	122 to 142	36 to 42
		250 @ 2500	118 to 138	35 to 41
0605	6CTA8.3	240 @ 2100	111 to 132	33 to 39
		250 @ 2100	118 to 138	35 to 41

CPL	ENGINE MODEL	ENGINE RATING (HP @ RPM)	RATED BOOST PRESSURE kPa	[in. Hg]
0753	6CT8.3	180 @ 2400	71 to 91	21 to 27
		211 @ 2400	91 to 111	27 to 33
0754	6CTA8.3	240 @ 2400	135 to 155	40 to 46
0755	6CTA8.3	190 @ 2100	74 to 95	22 to 28
		210 @ 2200	105 to 132	31 to 39
		220 @ 2200	95 to 122	28 to 36
		220 @ 2500	91 to 111	27 to 33
		222 @ 2000	84 to 105	25 to 31
		230 @ 2000	98 to 125	29 to 37
		233 @ 2100	108 to 128	32 to 38
		234 @ 2200		32 to 38
0818	6CT8.3	210 @ 2200	169 to 189	50 to 56
0819	6CT8.3	210 @ 2200	169 to 189	50 to 56
0828	6CT8.3	121 @ 2100	30 to 51	9 to 15
0829	6CT8.3	181 @ 1500	68 to 88	20 to 26
		207 @ 1800	84 to 105	25 to 31
0830	6CTA8.3	230 @ 2500	91 to 111	27 to 33
		250 @ 2500	118 to 138	35 to 41
0831	6CTA8.3	241 @ 1500	118 to 138	35 to 41
		277 @ 1800	142 to 162	42 to 48
0848	6CTA8.3	240 @ 2100	118 to 138	35 to 41
0890	6CTA8.3	250 @ 2100	165 to 186	49 to 55
0892	6CTA8.3	250 @ 2200	162 to 182	48 to 54
0893	6CTA8.3	235 @ 2100	155 to 176	46 to 52
		237 @ 2100	155 to 176	46 to 52
		240 @ 2200	155 to 176	46 to 52
		250 @ 2200	165 to 186	49 to 55
0954	6CTA8.3	240 @ 2400	125 to 145	37 to 43
		265 @ 2400	125 to 145	37 to 43
0955	6CT8.3	210 @ 2500	155 to 176	46 to 52
0959	6CTA8.3	230 @ 2200	98 to 118	29 to 35
0982	6CTA8.3	240 @ 2200	132 to 159	39 to 47
		250 @ 2200	149 to 169	44 to 50
0984	6CTA8.3	220 @ 2500	91 to 111	27 to 33

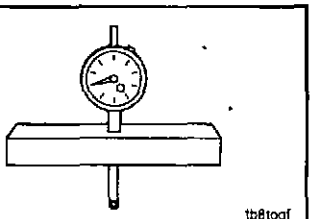
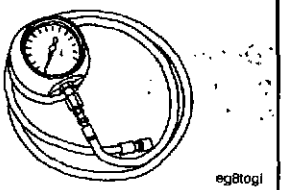
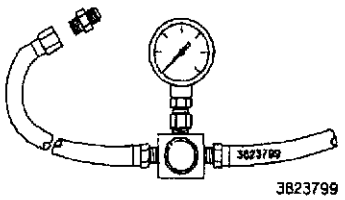
CPL	ENGINE MODEL	ENGINE RATING (HP @ RPM)	RATED BOOST PRESSURE kPa	[in. Hg]
0985	6CT8.3	138 @ 1900	30 to 51	9 to 15
		181 @ 1500	68 to 88	20 to 26
		200 @ 2100	88 to 108	26 to 32
		202 @ 2000	78 to 98	23 to 29
		207 @ 1800	84 to 105	25 to 31
		207 @ 2100	84 to 105	25 to 31
		210 @ 2200	95 to 115	28 to 34
	6CT8.3-G	181 @ 1500	64 to 91	19 to 27
		207 @ 1800	81 to 108	24 to 32
1196	6CTA8.3	240 @ 2400	125 to 145	37 to 43
1212	6CTA8.3	222 @ 2000	145 to 165	43 to 49
1221	6CTA8.3	280 @ 2200	98 to 118	29 to 35
		300 @ 2500	115 to 135	34 to 40
	6CTA8.3-M1	250 @ 2100	81 to 108	24 to 32
		300 @ 2500	112 to 139	33 to 41
1222	6CTA8.3	250 @ 2400	152 to 172	45 to 51
1248	6CT8.3	210 @ 2200	95 to 115	28 to 34
*1262	C8.3	250 @ 2400	118 to 138	35 to 41
		260 @ 2000	132 to 152	39 to 45
		250 @ 2200	125 to 145	37 to 43
		270 @ 2200	132 to 152	39 to 45
		275 @ 1800	132 to 152	39 to 45
		275 @ 2000	132 to 152	39 to 45
*1263	C8.3	210 @ 2400	125 to 145	37 to 43
		225 @ 2400	132 to 152	39 to 45
1269	6CTA8.3	240 @ 2400	132 to 152	39 to 45
1270	6CTA8.3	275 @ 2500	145 to 165	43 to 49
1273	6CTA8.3	230 @ 2200	95 to 115	28 to 34
1274	6CT8.3	180 @ 2200	64 to 84	19 to 25
		202 @ 2200	81 to 101	24 to 30
1275	6CT8.3	202 @ 2200	98 to 118	29 to 35
1281	6CT8.3	211 @ 2400	84 to 105	25 to 31
1282	6CTA8.3-M2	400 @ 2600	186 to 213	55 to 63
1356	6CT8.3	210 @ 2200	125 to 145	37 to 43
1368	6CTA8.2-M2	350 @ 2600	139 to 166	41 to 49
*1371	C8.3	290 @ 2200	145 to 165	43 to 49
*1372	C8.3	275 @ 2200	152 to 172	45 to 51
*1377	C8.3	240 @ 2200	125 to 145	37 to 43

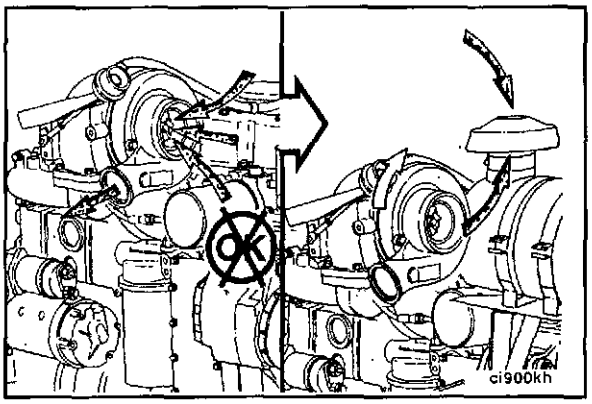
CPL	ENGINE MODEL	ENGINE RATING (HP @ RPM)	RATED BOOST PRESSURE kPa	[in. Hg]
*1406	C8.3	285 @ 2400 300 @ 2200	142 to 162 149 to 169	42 to 48 44 to 50
1419	6CTA8.3	250 @ 2200	129 to 156	38 to 46
1439	6CTA8.3	210 @ 2200 225 @ 2200	135 to 163 152 to 169	40 to 48 42 to 50
1539	6CTA8.3	240 @ 2200	112 to 139	33 to 41
1547	6CTA8.3	260 @ 2200	135 to 163	40 to 48
1603	6CT8.3	211 @ 2200	88 to 115	26 to 34
1616	6CT8.3	211 @ 2200	88 to 115	26 to 34
1633	6CTA8.3	230 @ 2200	135 to 163	40 to 48
1639	6CTA8.3-G	241 @ 1500	108 to 135	32 to 40
1639	6CTA8.3-G	277 @ 1800	139 to 166	41 to 49

*Designates 1991 charge air cooled ratings. Boost readings measured at the intake manifold may be 4 to 6 in. Hg less than the values shown in the above table due to a normal pressure drop through the charge air cooler. Be sure the charge air cooler, and related components are **not** the cause of a low pressure reading.

Combustion Air System - Service Tools

The following special tools are recommended to perform procedures in Section 3. The use of these tools is shown in the appropriate procedure. These tools can be purchased from your local Cummins Authorized Repair Location.

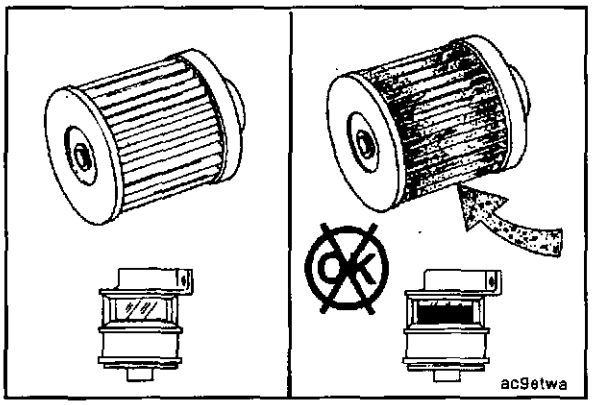
Tool No.	Tool Description	Tool Illustration
ST-537	**Dial Depth Gauge** Measure turbocharger axial motion.	
ST-1273	**Pressure Gauge (0-75 in. Hg.)** Used to measure the intake manifold pressure and exhaust back pressure.	
3823799	**Turbocharger Wastegate Pressure Setting Kit** Use to set wastegate pressure.	



Combustion Air System - Diagnosing Malfunctions (3-01)

Clean Air

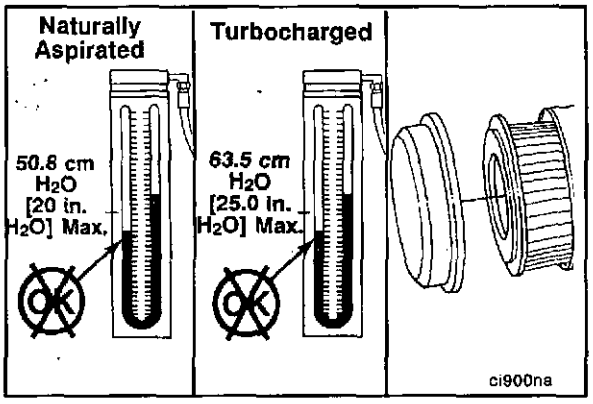
The correct amount of clean air to the cylinders is required for good performance. As discussed earlier in Air Flow System, ingested dust and dirt will damage the engine cylinders. Dust and dirt can also damage the valve stems and guides as well as wear down the turbocharger compressor vanes affecting efficiency. Larger debris can damage the blades of the turbocharger.



Air flow restriction results in excessive smoke and low power.

Restriction increases as the filter removes contaminants from the intake air. Restricted air flow changes the air-to-fuel ratio, reducing power and increasing smoke from the engine. Verify that the air cleaner is being maintained correctly.

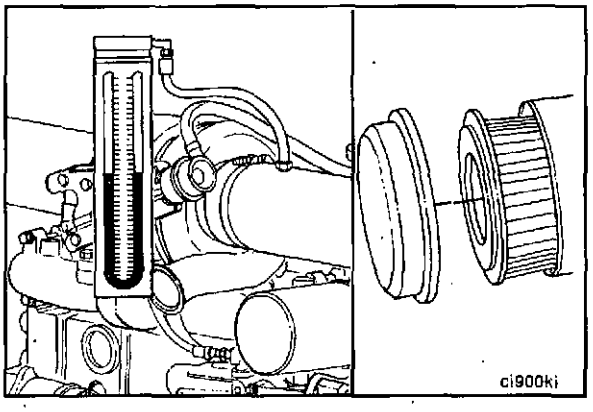
Measurement of air intake restriction is described in this Section.



Intake Air Restriction - Checking

Replace the air cleaner element when the restriction reaches the maximum limit at rated engine power and speed.

Naturally Aspirated	Turbocharged
50.8 cm H_2O	63.5 cm H_2O
[20 in. H_2O]	[25 in. H_2O]

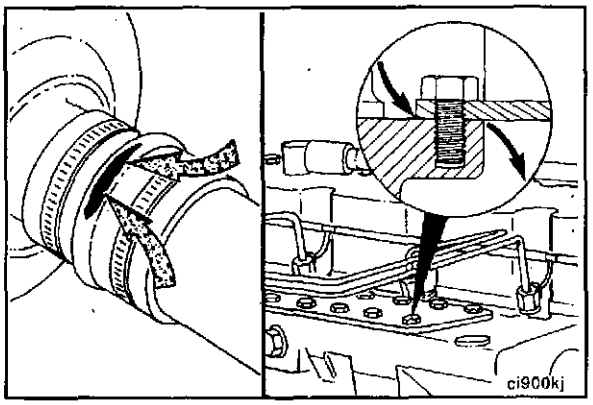


For turbocharged engines, measure the restriction just before the turbocharger. Measure just before the intake manifold for naturally aspirated engines.

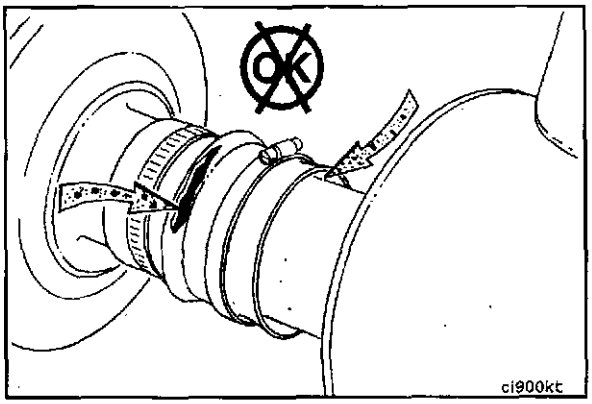
Damage From Non-filtered Air

Loose connections or cracks in the suction side of the intake pipe can allow debris to be ingested by the engine causing rapid wear in the cylinders.

Leaks at the intake manifold, unsealed bolt holes or manifold cover gasket can also allow dust and dirt to be ingested into naturally aspirated engines.

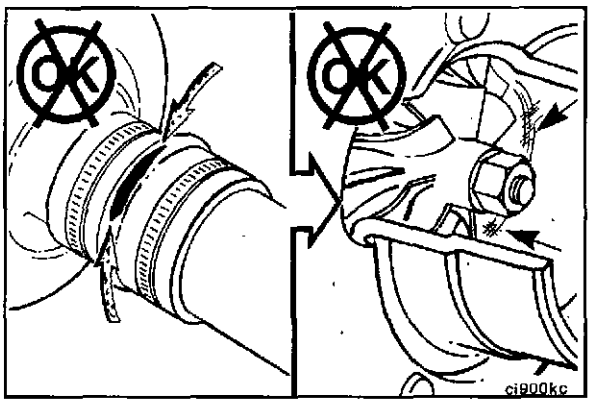


Loose connections or cracks in the suction side of the intake pipe on turbocharged engines can allow debris to be ingested into the turbocharger compressor and forced into the engine.



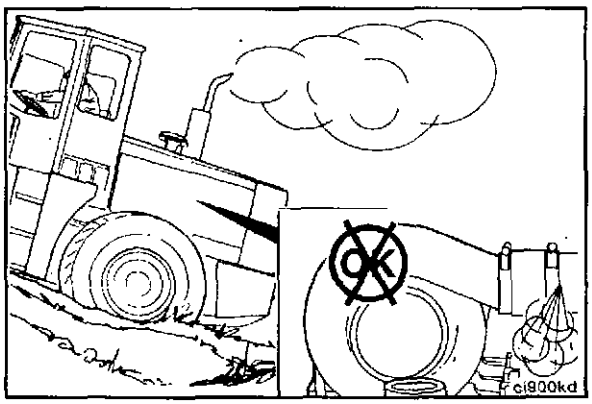
Debris drawn into the air suction side can damage the compressor blades causing an imbalance resulting in bearing failure.

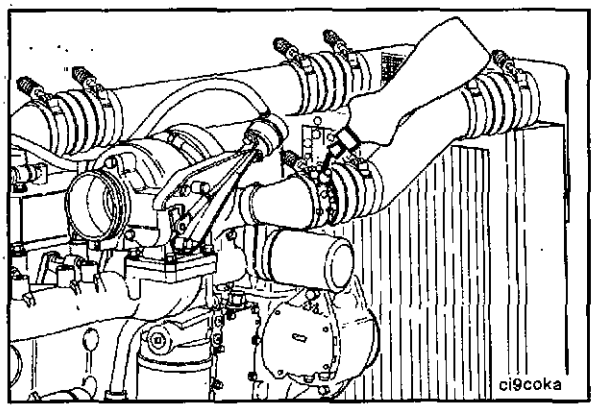
To verify a bearing failure or damaged compressor, remove the intake and exhaust piping and check for contact. The rotor assembly **must** rotate freely and should not be damaged. Measurement of axial and radial clearance is described in this Section.



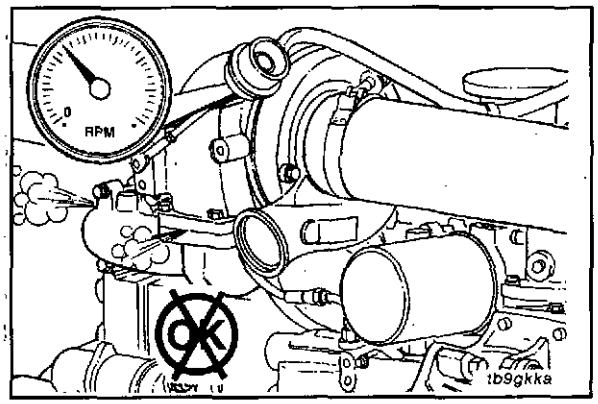
Turbocharged Engines - Air Leaks, Pressure Side

Excess smoke and low power from a turbocharged engine can be caused by pressurized air leaking from loose connections or cracks in the crossover tube or intake manifold. This can also cause a noise problem.



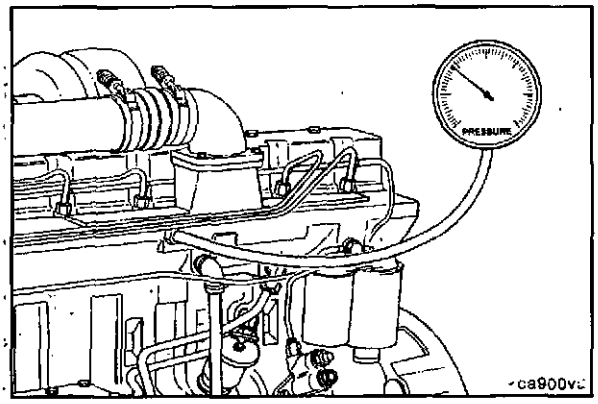


In addition to the visual inspection for cracks and loose fittings, liquid soap can be applied to the charge air cooler, connections and the manifold cover sealing surfaces to find the leaks. The leaks will create bubbles that are easier to detect. Measurement of manifold pressure is described in this Section.



Turbocharged Engines - Exhaust Leaks

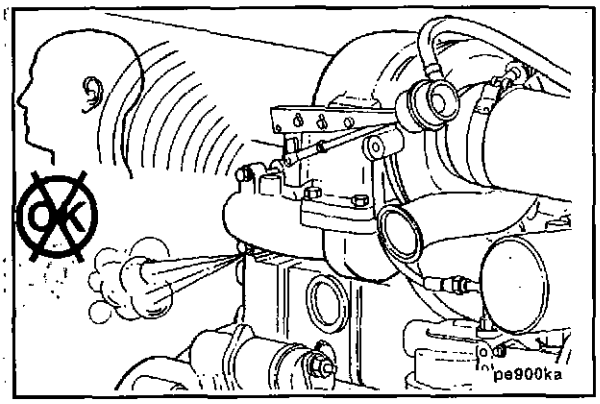
Inspect for exhaust leaks at the exhaust manifold and turbocharger, gasket leaks, exhaust pipe, muffler or catalyst restrictions. Leaks or restrictions will cause the turbine and impeller to operate at a lower speed and reduce the amount of air being forced into the cylinders. Again, the symptom will be excess smoke, low manifold pressure and low power.



Turbocharger Boost Pressure - Measurement

Measure the boost pressure at the intake manifold by using one of the tapped or plugged intake access holes shown in the illustration. Refer to the specifications in this section.

NOTE: If the engine has charge air cooling, testing **must** be done to be sure that the charge air cooler system is **not** leaking or restricting the turbocharger boost pressure. Refer to Procedure 3-06 for detailed charge air cooler testing.



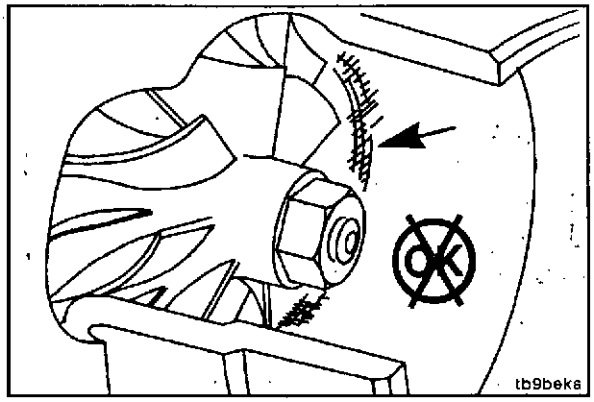
Exhaust leaks can usually be detected audibly or visually by a discoloration caused by the escaping hot gases.

Don't overlook exhaust restriction as a cause of low power. If the exhaust gasses can **not** flow freely, the turbocharger will **not** operate efficiently.

Malfunctioning Turbocharger

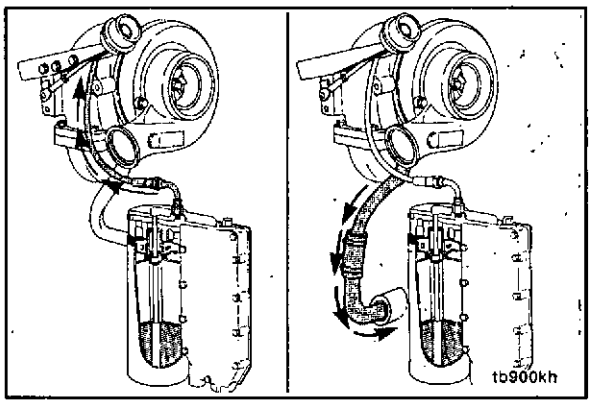
Failure of the internal components of the turbocharger can reduce its effectiveness and also cause excessive smoke and low power. A bearing failure can produce friction which will slow the speed of the rotor assembly. Failed bearings can also allow the blades of the rotor assembly to rub the housings, thus reducing the rotor assembly speed.

Malfunctioning turbocharger wastegate failure or miscalibration of the turbocharger wastegate can result in excessively high or low boost pressures. Low boost pressures can cause excessive smoke and low power. High boost pressures can cause major engine damage.



Oil Consumption and Leaks

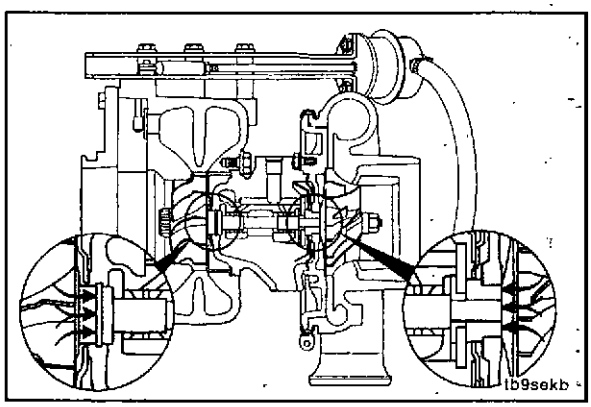
Engine lubricating oil is used to lubricate the bearings and provide some cooling for the turbocharger. The oil supplied to the turbocharger through the supply line is at engine operating pressure. A return line connected to the bottom of the turbocharger routes the oil back to the engine oil pan.



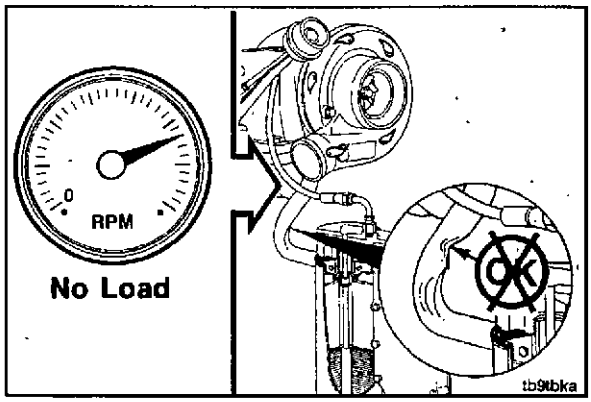
Seal rings are used on each end of the rotor assembly. The primary function of the seals is to prevent exhaust gases and compressed air from entering the turbocharger housing. Oil leakage from the seals is rare, but it can occur.

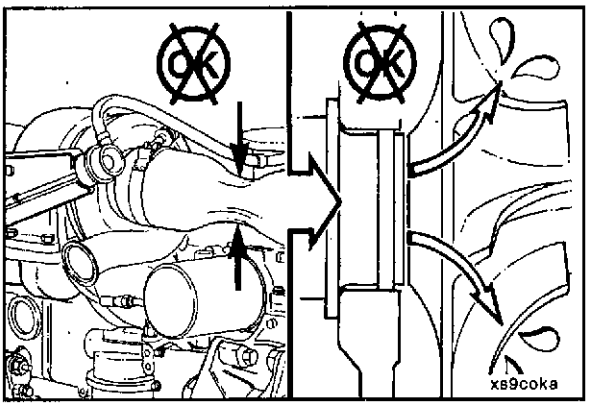
NOTE: Excessive crankcase pressure will **not** allow the oil to drain from the turbocharger. This will load the bearing housing and allow oil to leak past the compressor seals and into the engine.

NOTE: If turbine seal leakage into the exhaust system occurs on engines with catalysts, check the catalyst back pressure during repair.

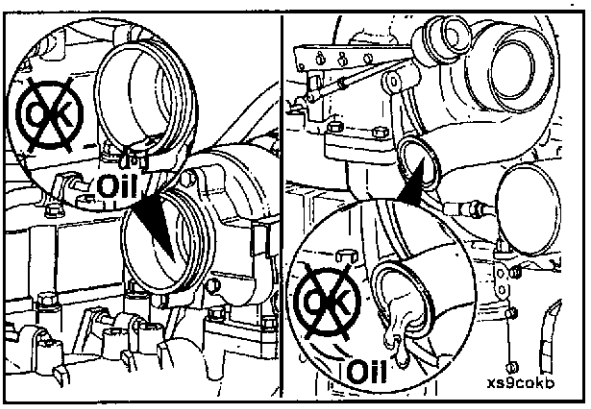


A restricted or damaged oil return line will cause the turbocharger housing to be pressurized causing oil to migrate past the seals.

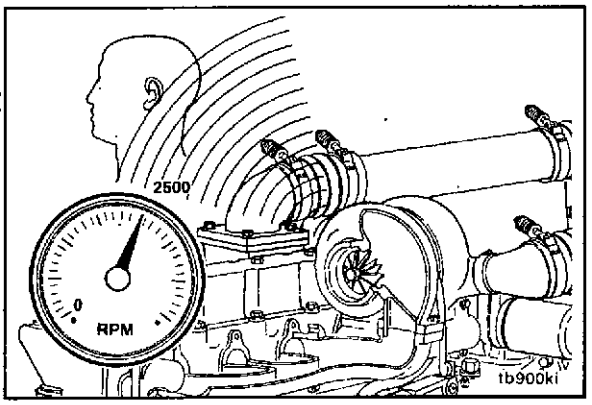




Additionally, high intake or exhaust restrictions can cause a vacuum between the compressor and the turbocharger housing resulting in oil leaking past the seals.



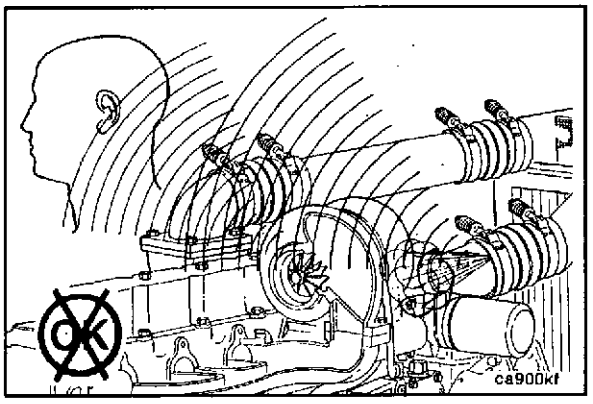
To verify oil leakage past the seals, remove the exhaust pipe and crossover tube and look for oil in the turbine casing and the crossover tube. Locate and correct the restriction as previously discussed.



Turbocharger Noise

It is normal for the turbocharger to emit a "whine" sound that varies in intensity depending on engine speed and load. The sound is caused by the very high rotational speed of the rotor assembly. Consequently, the sound will be more audible at full speed.

If possible, operate the engine at full speed to verify the noise level.

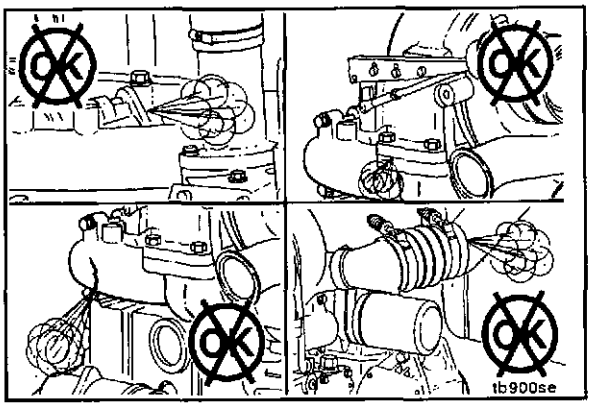


Leaks in the air system intake and/or exhaust components can produce additional noises.

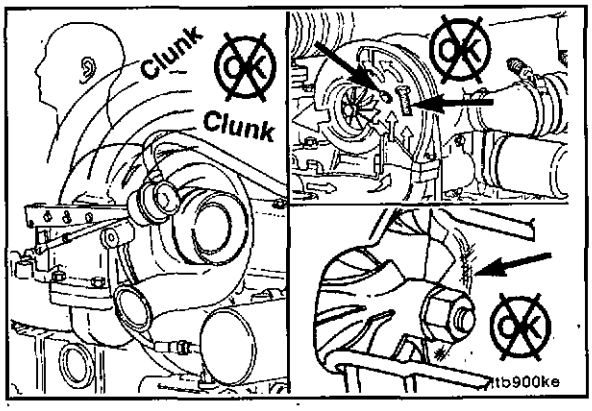
Pressurize the intake system by operating the engine at high idle and check for air intake and crossover tube leaks.

Before removing the turbocharger, make sure that the noise complaint is not caused by leaks in the air system components.

Look for loose turbocharger mounting, exhaust manifold gasket leaks, and cracks in the exhaust manifold.



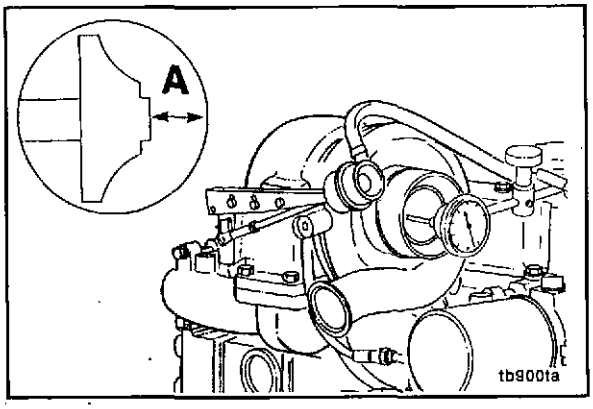
Lower pitch sounds or rattles at slower engine speeds can indicate debris in the system or the rotor assembly is touching the housings.



Rotor Assembly Clearance - Measurement

Part No. ST-537, Dial Depth Gauge

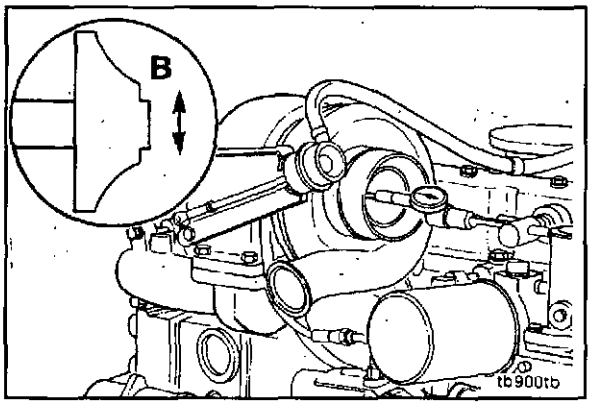
Measure the shaft end play.



End Play (A)		
mm		in
* 0.10	MIN	[0.004]
0.16	MAX	[0.006]
** 0.03	MIN	[0.001]
0.08	MAX	[0.003]

* For turbochargers with a serial number **before** 840638.

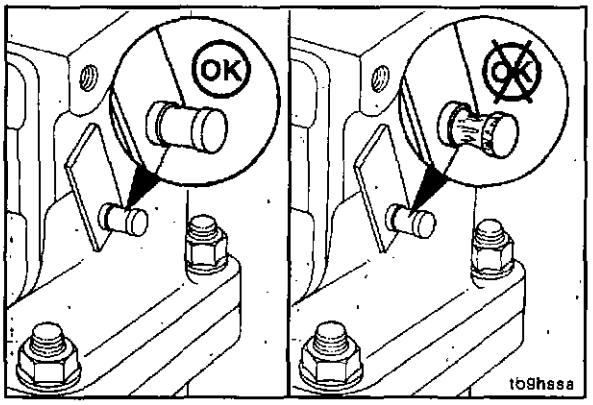
** For turbochargers with a serial number 840638 and **after**.



Measure radial clearance of the shaft.

Radial Clearance (B)		
mm		in
0.21	MIN	[0.008]
0.46	MAX	[0.018]

The turbocharger **must** be removed for replacement or rebuild if the clearances are beyond these limits. Refer to the Turbocharger Shop Manual, Bulletin No. 3810321, for rebuild procedures.

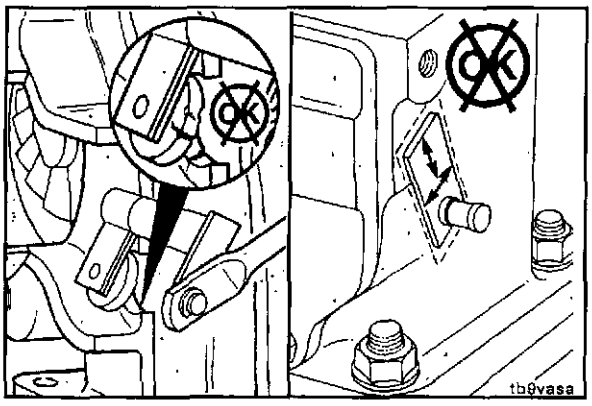


Turbocharger Wastegate Actuator - Visual Inspection (3-02)

Visually inspect the lever pin.

Replace the turbine housing assembly if worn excessively.

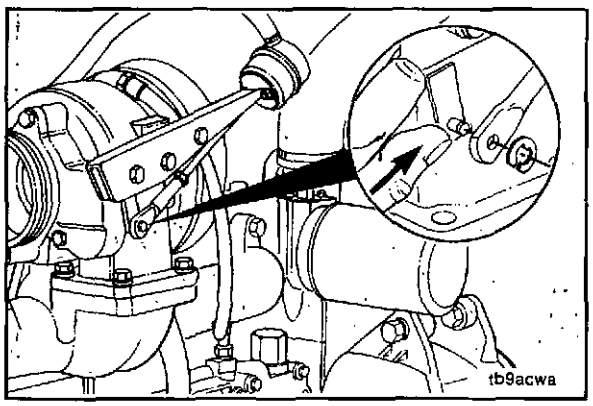
Refer to the Turbocharger Shop Manual, Bulletin No. 3810321.



Visually inspect the valve and valve seat for cracks or erosion.

Replace the turbine housing assembly if worn excessively.

Refer to the Turbocharger Shop Manual, Bulletin No. 3810321.



Actuate the lever by hand to be sure that the shaft moves freely and is **not** seized.

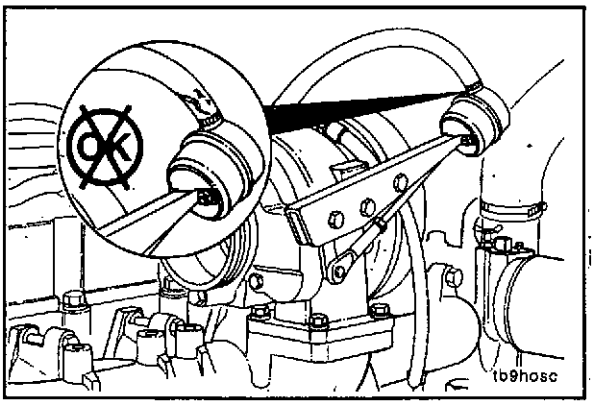
Check for excessive movement between the shaft and bushing.

Replace the turbine housing if the shaft and bushing are damaged or seized.

Refer to the Turbocharger Shop Manual, Bulletin No. 3810321.

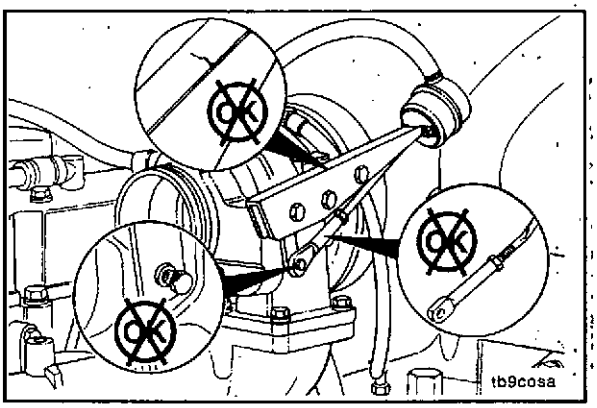
Visually inspect the wastegate actuator hose for cracks or holes. Replace the hose if damaged.

Caution: Before making any adjustments to the wastegate assembly, refer to the information on page 3-2.



Visually inspect the wastegate mounting bracket, actuator rod, and lever for damage. A bent wastegate mounting bracket, actuator rod, or lever can cause improper operation.

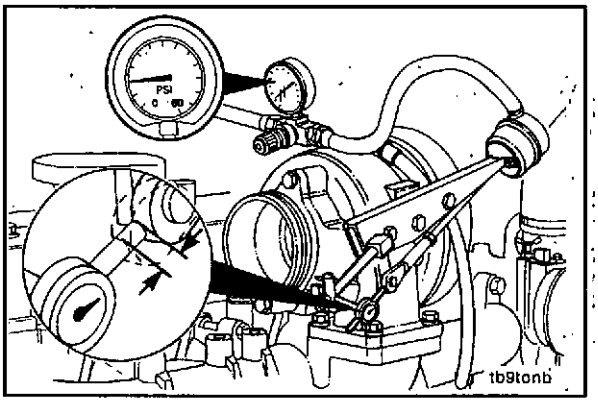
If the wastegate mounting bracket, actuator rod, or lever is bent, it **must** be replaced. Refer to Procedure 3-04.



Turbocharger Wastegate Actuator - Functional Checking (3-03)

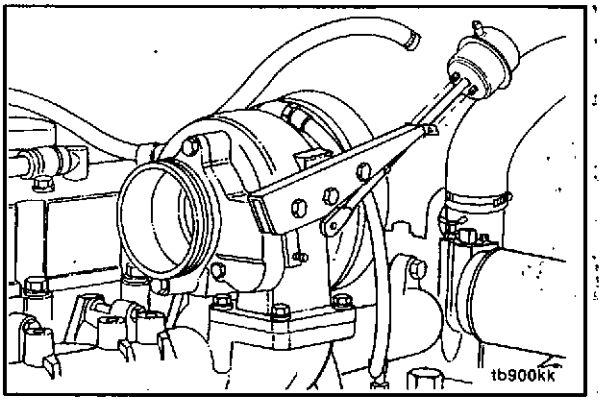
Connect regulated air pressure and an accurate pressure gauge to the capsule. Apply 180 kPa [26 psi] to make sure the wastegate is functioning properly. The actuating rod should move approximately 5 mm [0.200 in] without sticking or air leakage.

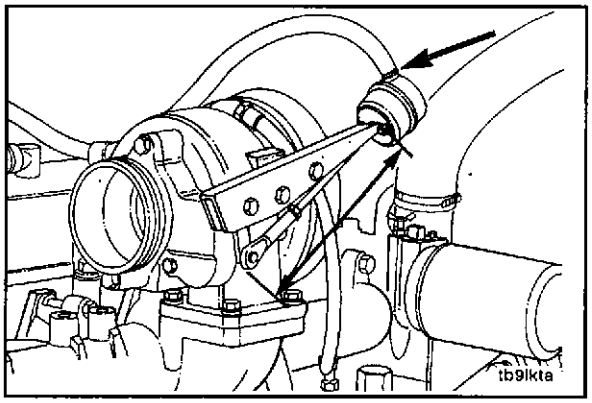
NOTE: A small amount of travel when air pressure is first applied is normal, the tolerance is being removed from the system.



Replace the actuator if no movement of the actuator rod and lever is detected. Refer to Procedure 3-04.

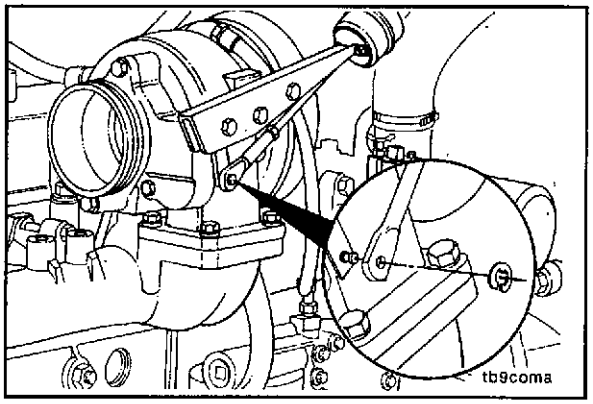
If repair is not correct, refer to Procedure 3-05 for Turbocharger Wastegate Actuator - Calibration.





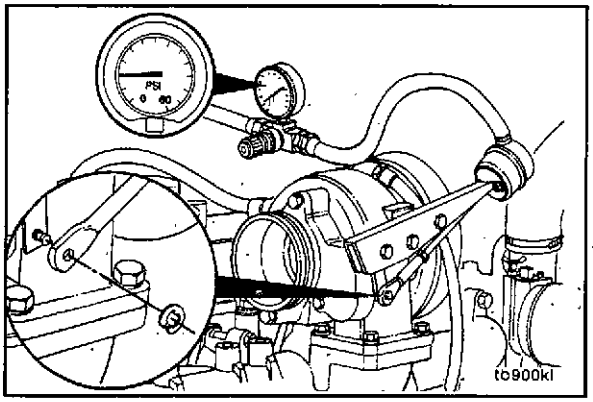
Turbocharger Wastegate Actuator - Replacement (3-04)

NOTE: Prior to removal, note position length of the control rod from the actuator housing and orientation of the actuator hose connector in relation to the mounting bracket.



Air regulator with pressure gauge

Remove the retaining clip from the control lever.

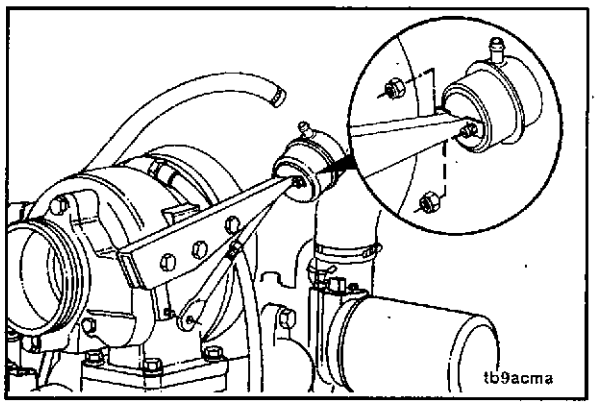


Disconnect the actuator rod end from the turbocharger wastegate lever. This can be accomplished by applying regulated air pressure to the actuator in a sufficient amount to activate control rod movement.

Disconnect the control rod from the turbocharger wastegate lever pin.

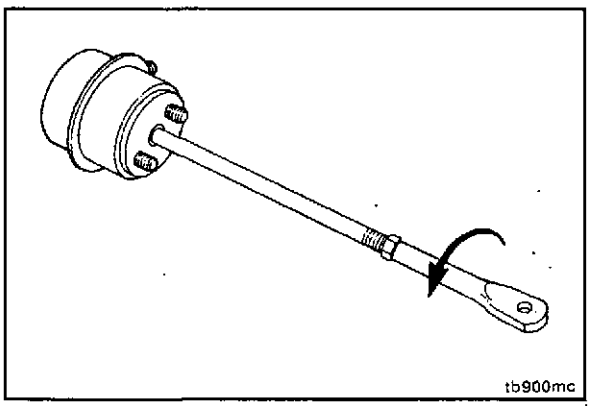
Caution: Be careful not to bend the control lever.

NOTE: If the actuator diaphragm material is ruptured and will **not** hold air pressure other than by hand, manually pull the control rod outward in order to overcome actuator spring tension for removal of the control rod from the turbocharger wastegate lever pin.

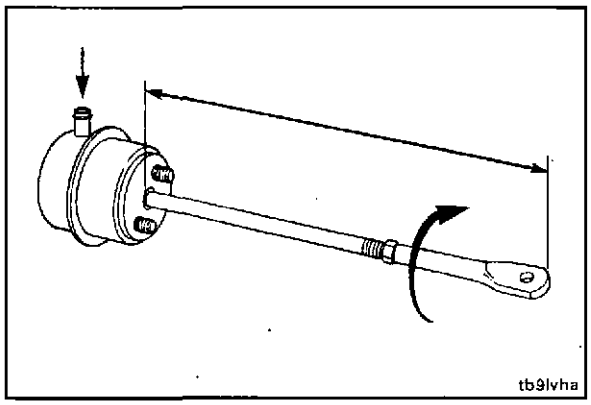


Loosen the actuator mounting capscrews and disconnect the air supply hose and remove assembly from the mounting bracket.

Remove the adjusting link end from the actuator.

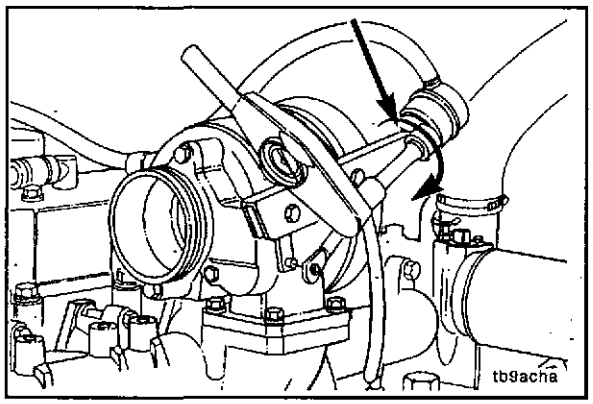


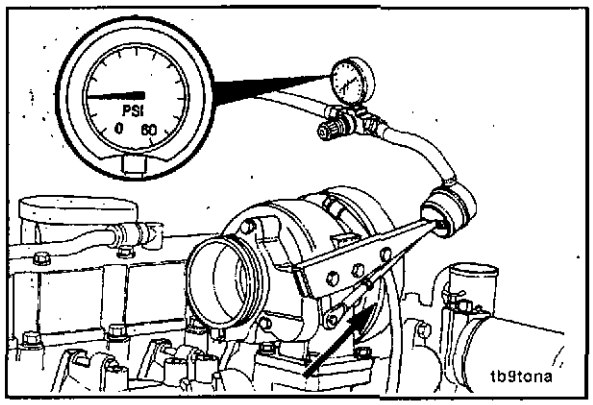
Install the adjusting link end onto the new replacement actuator assembly into approximately the same position as originally removed.



Fit the new actuator assembly to the actuator mounting bracket and install the mounting capscrews.

Torque Value: 4.5 N•m [40 in-lb]





Turbocharger Wastegate Actuator - Calibration (3-05)

NOTE: The wastegate is set accurately from the factory. Adjustment is not necessary unless the capsule is removed.

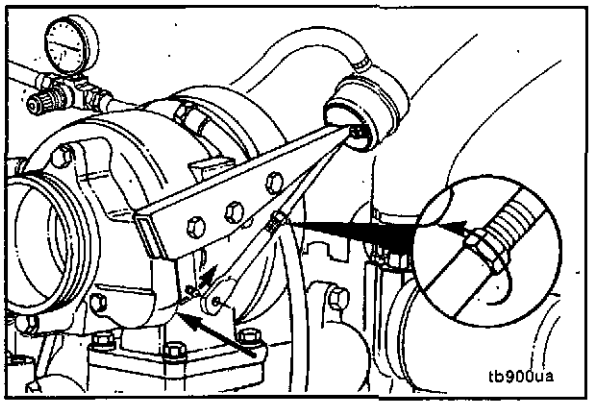
Attach a dial indicator as shown, so that its shaft is in line with the wastegate actuator rod. Set the indicator to zero, with no air pressure applied to the wastegate capsule.

Connect clean, regulated air pressure supply and an accurate pressure gauge to the capsule.

For industrial ratings apply 153 kPa [22.2 psi]. For all other C Series ratings, apply 172 kPa [25.0 psi]. Measure the rod travel and compare to the table below.

Wastegate Actuator Rod Movement		
mm		in
0.33	MIN	0.013
1.3	MAX	0.050

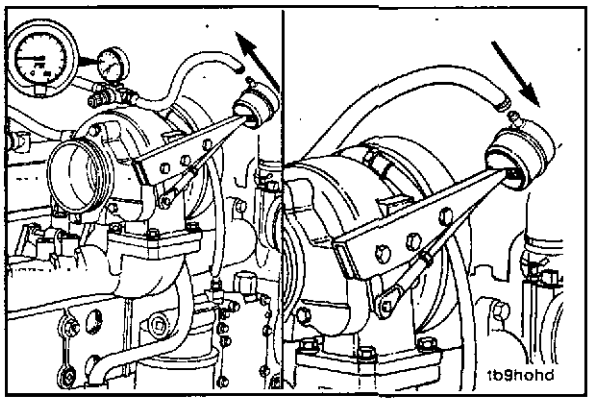
Replace the actuator if no movement of the actuator rod and lever is detected. Refer to Procedure 3-04.



Caution: Do not pull, push or force alignment of the clevis pin.

While pressure is being applied, adjust linkage as follows:

- Pull the wastegate lever to the foremost closed position (lever toward actuator).
- Adjust the length of the clevis end of the control rod to where the clevis pin hole aligns to the wastegate lever.
- Install the adjusting link and retaining clip.
- After adjustment is completed, tighten actuator rod locknut.



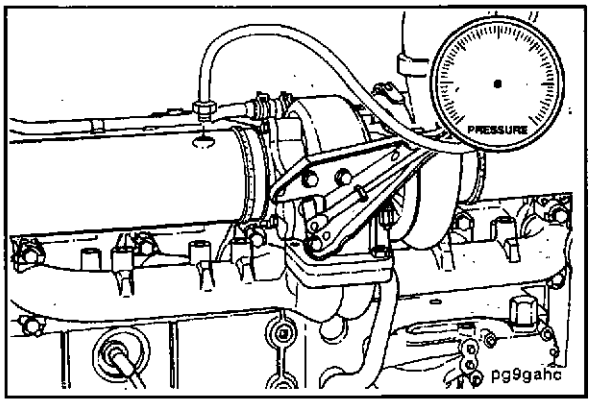
Disconnect regulated air pressure line from the actuator.

Connect the turbo boost line to the actuator and secure hose clamp.

Exhaust Restriction - Measurement

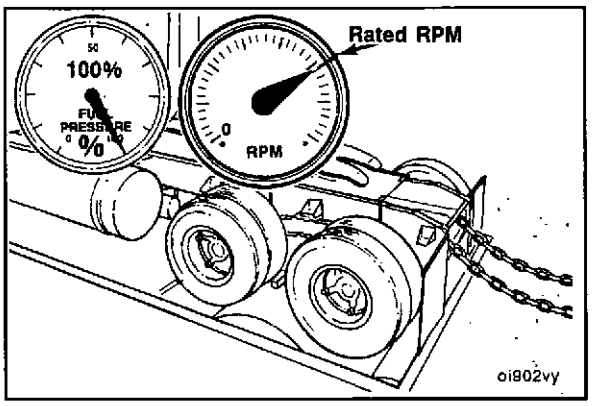
Install pressure gauge, Part No. ST-1273, to the pressure tap in the exhaust head pipe or at the inlet to the catalyst/ muffler assembly.

Operate the engine at rated speed and load. Record the exhaust restrictions.



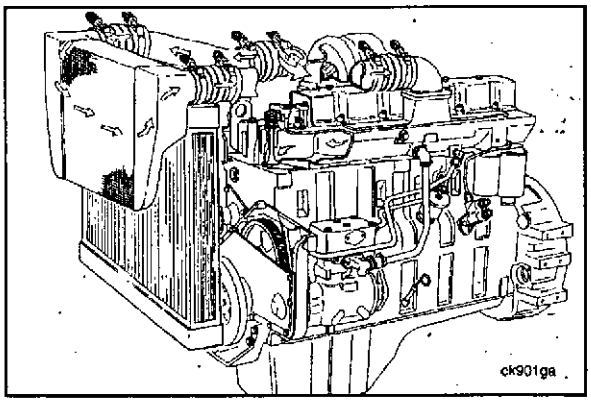
If restriction exceeds specification, inspect catalyst and/or muffler and replace per vehicle manufacturer's instructions.

Industrial.....76 mm Hg [3 in Hg]
91 EPA certification.....114 mm Hg [4.5 in Hg]
94 EPA certification with catalyst..152 mm Hg [6 in Hg]



Charge Air Cooler (CAC) - Troubleshooting (3-06)

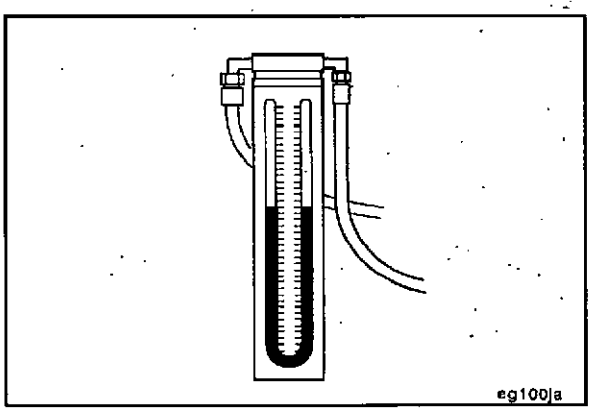
NOTE: The long term integrity of the charge air cooling system is the responsibility of the vehicle and component manufacturers; however, the following symptoms can be checked by any Cummins Authorized Repair Location:

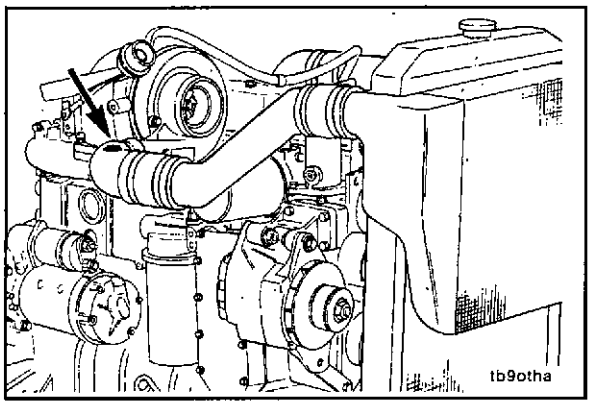


Pressure Drop - Checking

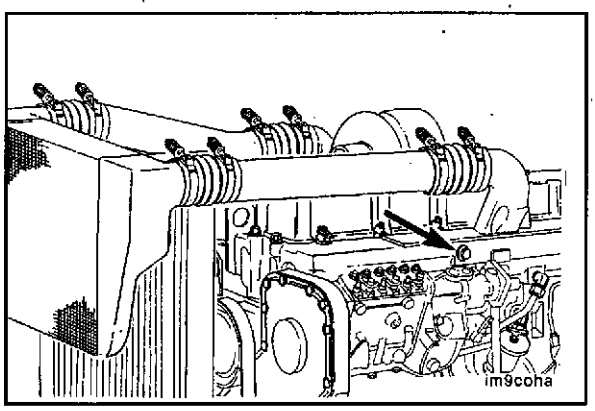
Preferred Method

Measure the CAC system pressure drop with a mercury manometer.

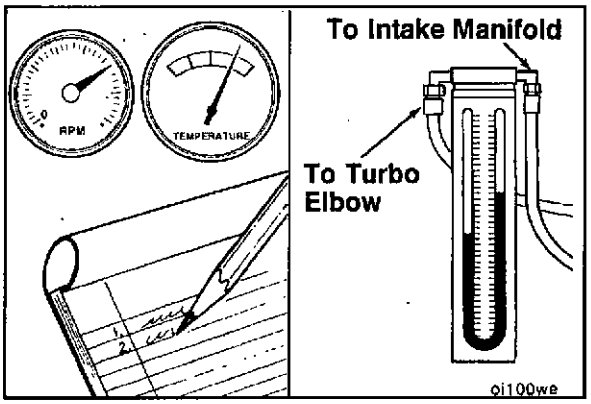




Install one end of the manometer into the 1/8 inch pipe tap in the turbocharger compressor outlet elbow.

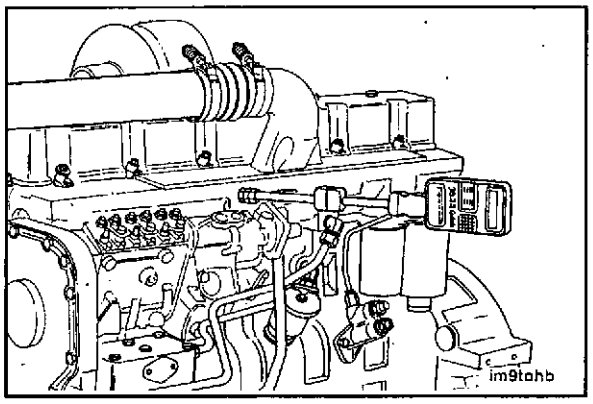


Install the other end of the manometer into the 1/8 inch pipe tap in the intake manifold.



Operate the engine at the maximum advertised horsepower and correlating RPM. Record the readings on the manometer.

If the differential pressure is greater than 156 mm Hg [6.0 in Hg] or 21 kPa [3 psi], check the CAC and associated piping for plugging. Clean or replace if necessary.



Install Fluke digital thermometer, Part No. 3822666, and thermocouple wire kit, Part No. 3822988, into the intake manifold at the 1/8 inch NPT tap near the air horn connection with the intake manifold.

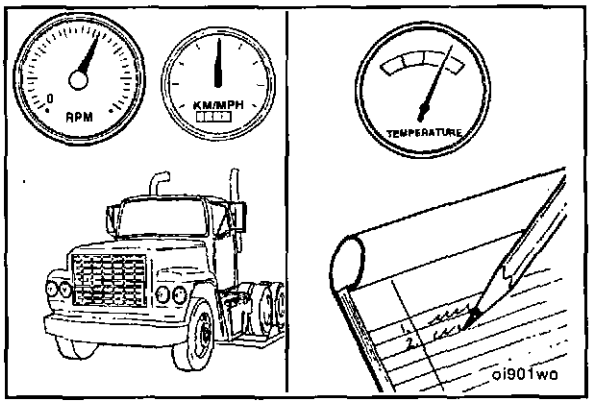
Install another thermocouple at the air cleaner inlet to measure the ambient temperature.

Perform a road test with the engine at peak power and a vehicle speed of 30 mph or greater.

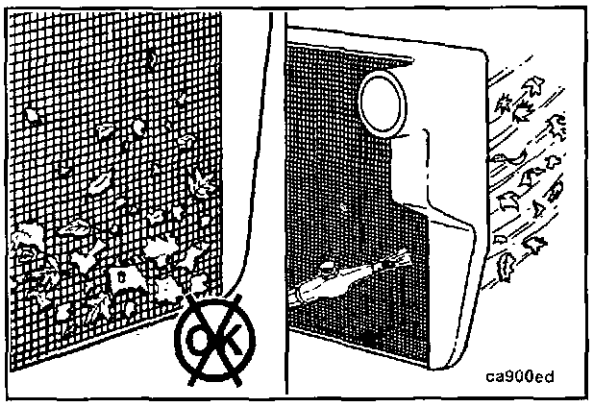
Record the intake manifold temperature and the ambient air temperature.

Calculate the differential temperature:

Intake Manifold Temperature	-	Ambient Air Temperature	-	Differential Temperature

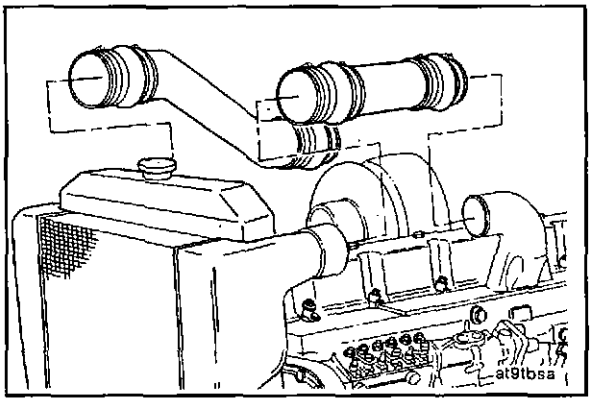


If the temperature differential is greater than 28°C [50°F], check the CAC for dirt and debris on the fins and clean as necessary. If the problem still exists, check the CAC for debris in fins or between the CAC and radiator. Confirm full fan engagement.



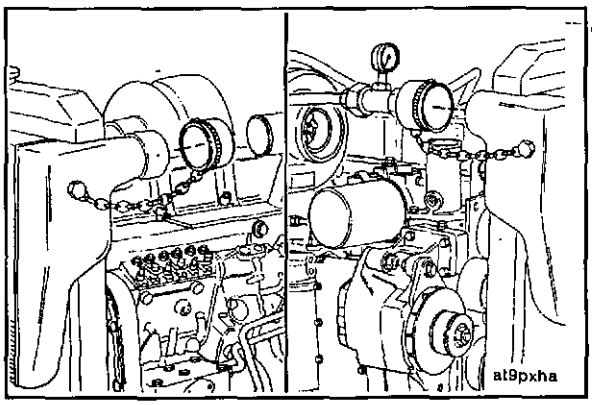
Checking - Air Leak

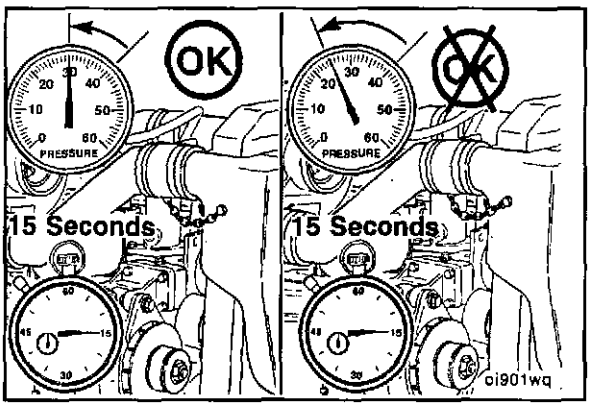
To check the CAC for cracked tubes or header, remove the inlet and outlet hoses from the cooler. The CAC does **not** have to be removed from the chassis.



Install a plug or cap on the outlet side of the cooler. Install a pressure gauge, air supply line, and air pressure regulator to the inlet side of the cooler.

Warning: To prevent possible injury if either plug blows off during the test, secure safety chains on the test plugs to any convenient capscrew on the radiator assembly. This test must be performed with securely fastened safety chains.



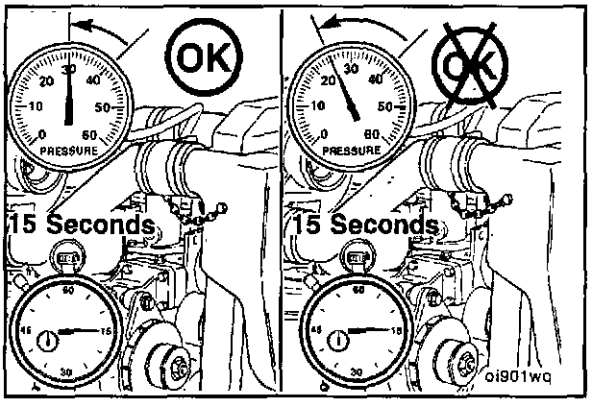


Apply 207 kPa [30 psi] of air pressure to the cooler. Close the air pressure regulator.

Monitor the pressure gauge and determine the rate of pressure decay with a stop watch.

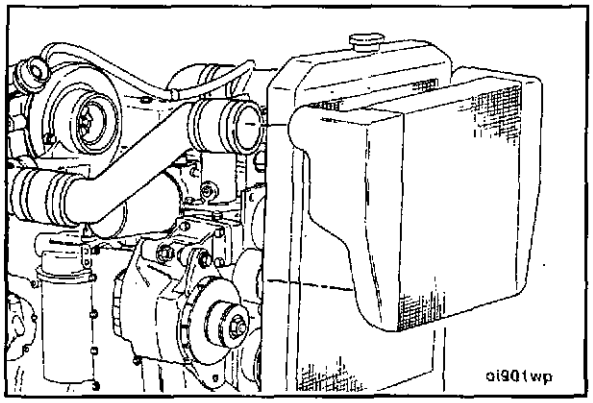
If the pressure decay is 49 kPa [7 psi] or less in 15 seconds, the cooler is okay. If the pressure drop is greater than 49 kPa [7 psi] in 15 seconds, check all connections again.

Determine if pressure decay is caused by a leak in the CAC or from a leaky connection. Use a spray bottle filled with soapy water applied to all hose connections, and watch for bubbles to appear at the location of the leak.



If the pressure decay is caused by a leaky connection, repair the connection and repeat the test. If the leak is within the CAC, repeat the test to verify the accuracy of the pressure delay measurement. Similar pressure decay readings **must** be obtained at least three consecutive tests before the reading can be considered accurate.

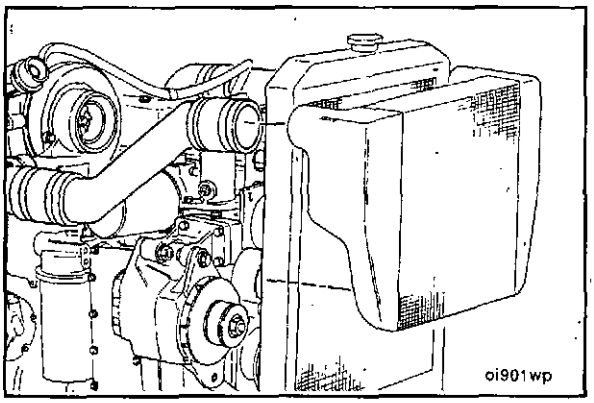
NOTE: If a CAC leaks more than 49 kPa [7 psi] in 15 seconds, it will appear as a major leak in a leak tank.



If the pressure drop is greater than 49 kPa [7 psi] in 15 seconds, the CAC **must** be replaced.

Refer to the manufacturer's repair manual for replacement instructions.

NOTE: Charge air coolers are not designed to be 100% leak free. If the pressure decay is less than 49 kPa [7 psi] in 15 seconds, then the CAC does not need to be replaced.



Charge Air Cooler (3-07)

Cleaning and Inspection

If the engine experiences a turbocharger failure or any other occasion where oil or debris is put into the CAC, the CAC **must** be cleaned.

Remove the CAC from the vehicle. Refer to the vehicle manufacturer's instructions.

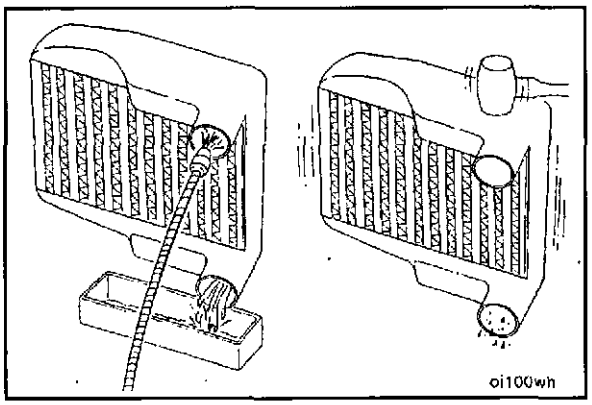
Caution: Do not use caustic cleaners to clean the CAC. Damage to the CAC will result.

NOTE: Make sure that the tubes are in the vertical direction when flushing.

Flush the CAC internally with solvent in the opposite direction of normal air flow. Shake the CAC and lightly tap on the end tanks with a rubber mallet to dislodge trapped debris. Continue flushing until all debris or oil is removed.

NOTE: If internal debris cannot be removed, scrap the CAC.

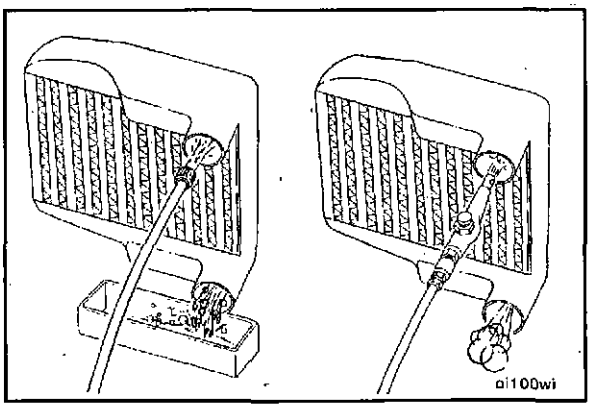
Use a flashlight and mirror to visually inspect the CAC for internal debris.



After the CAC has been thoroughly cleaned of all oil and debris with solvent, wash the CAC internally with hot soapy water to remove the remaining solvent. Rinse thoroughly with clean water.

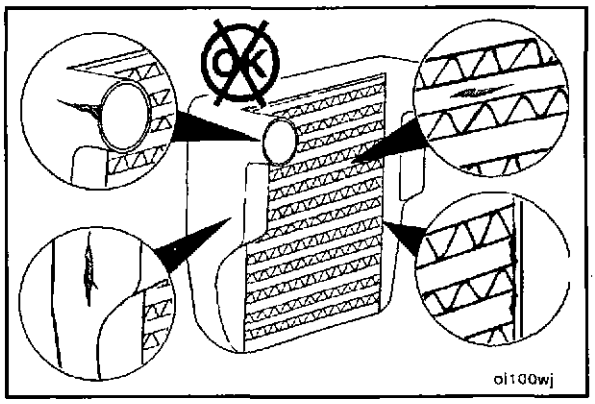
Blow compressed air into the CAC in the opposite direction of normal air flow until the CAC is dry internally.

Caution: The CAC must be rinsed, dried, and free of solvent, oil, and debris or engine damage will result.



Visually inspect the CAC for cracks, holes or damage.

Inspect the tubes, fins and welds for tears, breaks or other damage. If any damage causes the CAC to fail the air leak check mentioned earlier in this Procedure, the CAC **must** be replaced. Install the CAC on the vehicle. Refer to the vehicle manufacturer for instructions.



Air Crossover Tube - Replacement (3-08)

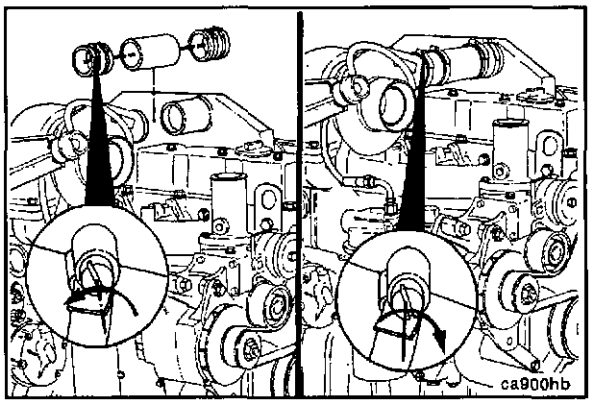
Removal and Installation

8 mm or Screwdriver

Loosen the hose clamps and position the hose so the crossover tube can be removed.

Use new hose and clamps as required to install the crossover tube.

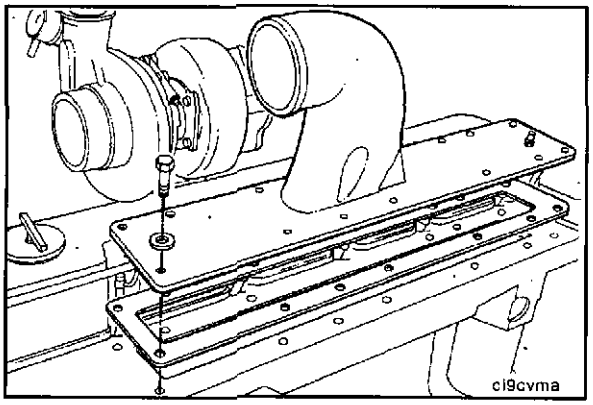
Torque Value: 5 N•m [44 in-lb]



Intake Manifold Cover and Gasket - Replacement (3-09)

Preparatory Steps:

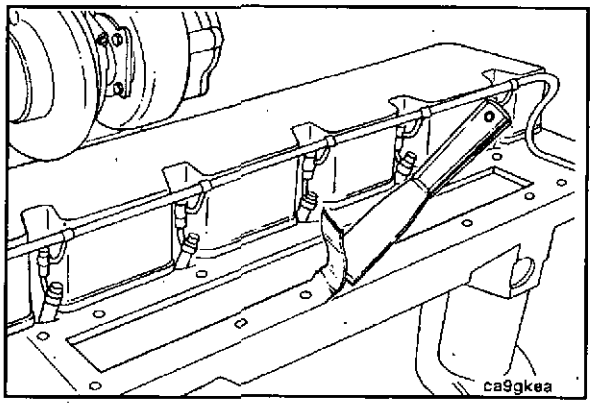
- Disconnect the cold starting aid, if used.
- Remove the air crossover tube, if used.
- Disconnect the charged air cooler hose, if used.



Removal

10 mm

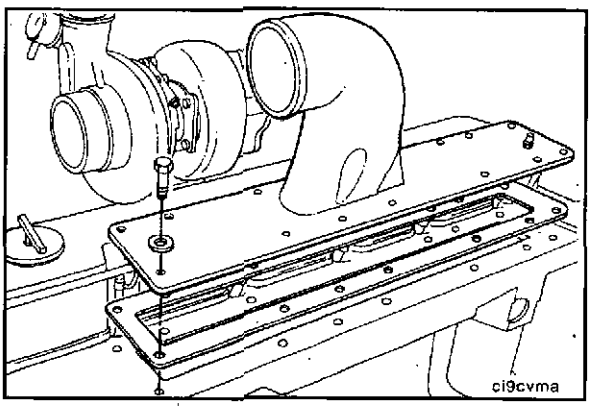
Remove the manifold cover and gasket.



Cleaning

Clean the sealing surface.

NOTE: Keep the gasket material and any other material out of the air intake.



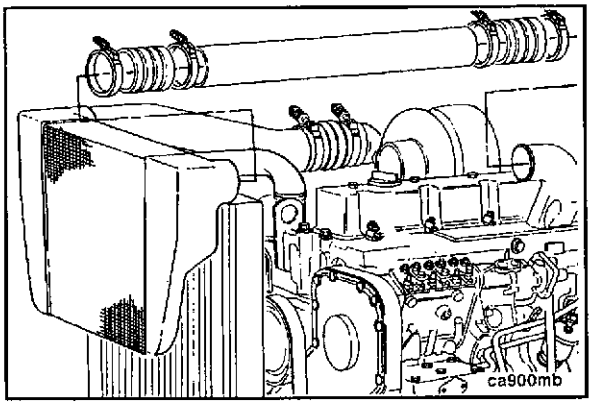
Installation

10 mm

Install the cover and a new gasket.

Torque Value: 24 N•m [18 ft-lb]

Assemble the intake piping and connect the cold starting aid if used.



Aftercooler and Gasket - Replacement (3-10)

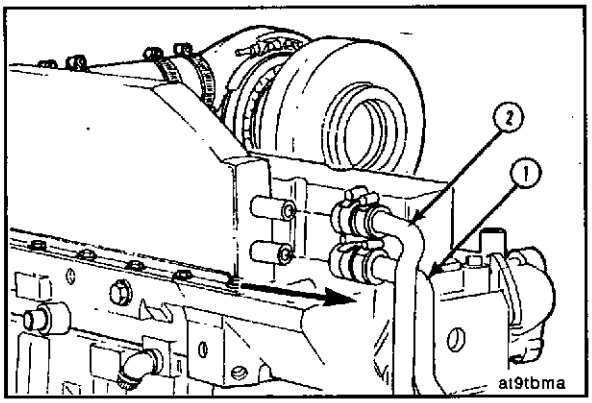
Preparatory Steps:

- Disconnect the cold starting aid, if used.
- Remove the air crossover tube.
- Drain 2 litres [2.1 U.S. quarts] of coolant.

Removal

8 mm

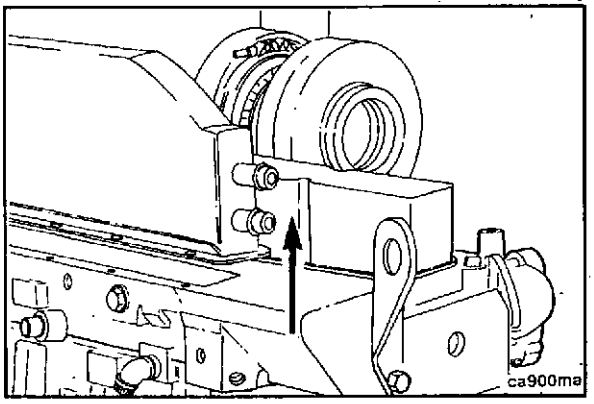
Remove the coolant supply tube (1) and the coolant return tube (2).

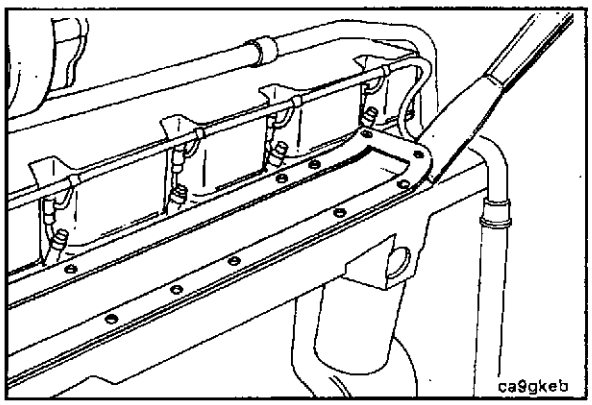


10 mm

Remove the aftercooler housing and gasket.

For a form-in-place gasket, cut the aftercooler gasket to remove.

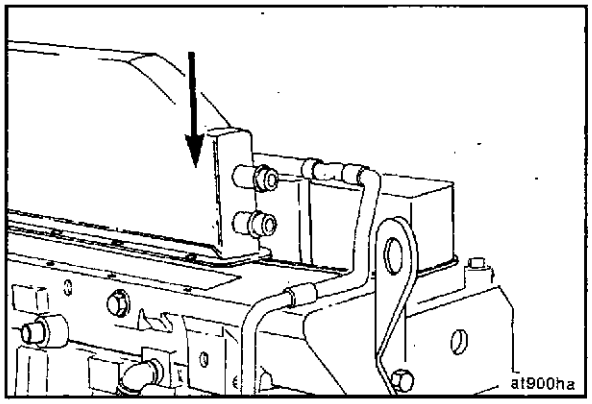




Cleaning

Clean the sealing surface.

NOTE: Keep the gasket material and any other material out of the air intake.



Installation

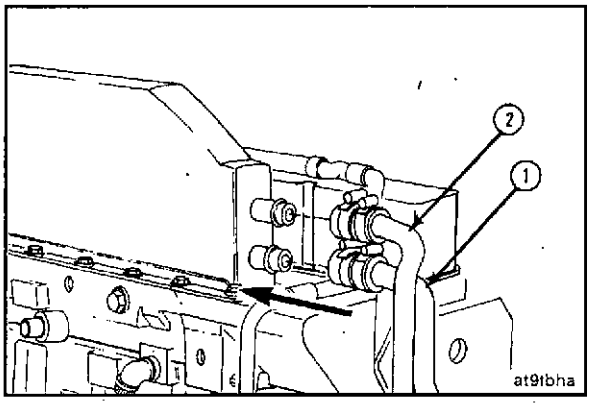
10 mm

Use sealant, Part No. 3823494, on both sides of the aftercooler housing gasket.

Install the aftercooler housing and a new gasket.

For aftercoolers with a form-in-place gasket, apply a 4 mm bead of sealant to the cylinder head.

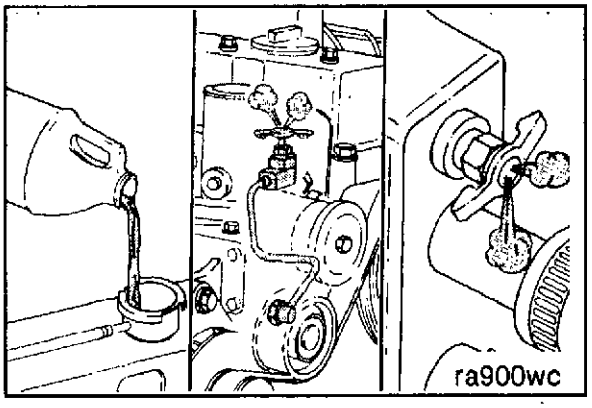
Torque Value: 24 N•m [18 ft-lb]



8 mm

Install the coolant supply tube (1) and coolant return tube (2). Install the air crossover tube.

Torque Value: 5 N•m [44 in-lb]



Caution: During filling, air must be vented from the engine coolant passages. Open the engine vent petcock. Also, be sure to open the petcock on the aftercooler for aftercooled engines. The system must be filled slowly to prevent air locks. Wait 2 to 3 minutes to allow air to be vented, then add coolant to bring the level to the bottom of the radiator filler neck.

Fill the coolant system with a pre-mixture of 50 percent water and 50 percent ethylene-glycol type antifreeze. Use the correct concentration of supplemental coolant additive (DCA4). Follow the recommendations given in Section 1.

Turbocharger - Replacement (3-11)

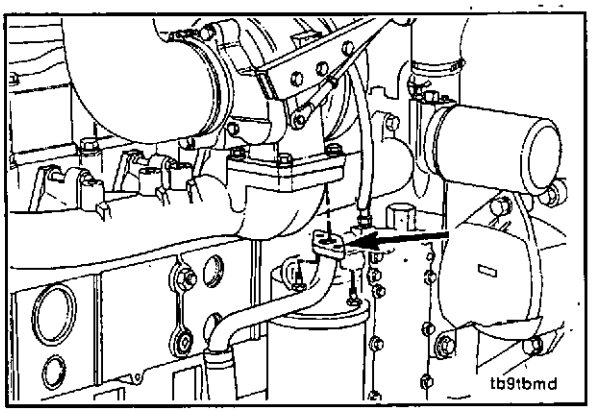
Preparatory Steps:

- Remove the air crossover tube, if used.
- Disconnect the charge air cooler hose.
- Disconnect the wastegate actuator hose.
- Disconnect the intake and exhaust piping.

Removal

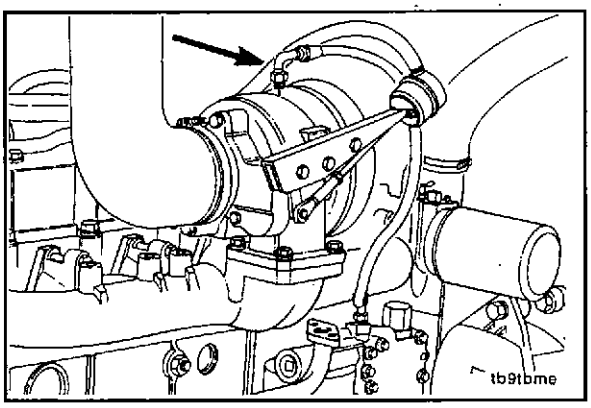
10 mm

Remove the capscrews from the oil drain tube.



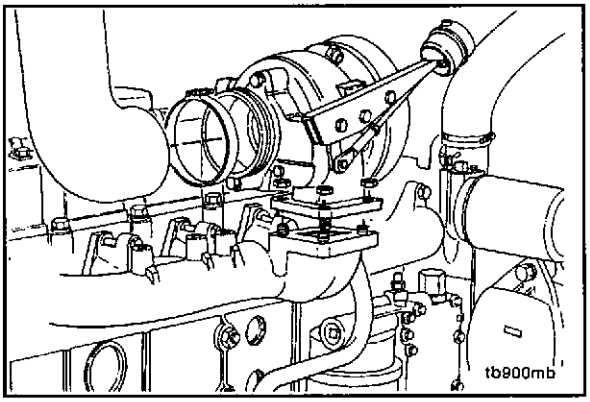
16 mm

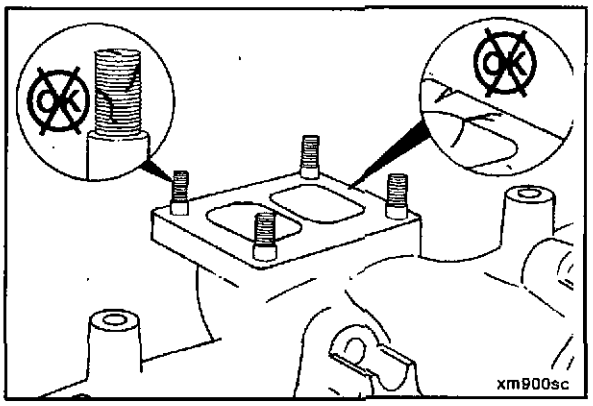
Disconnect the oil supply line.



15 mm and 7/16-inch

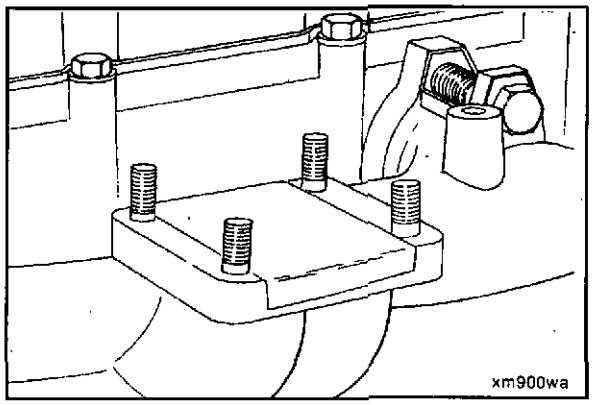
Remove the exhaust clamp, turbocharger, and gasket.





Cleaning and Inspection

Clean the sealing surfaces. Inspect the sealing surface and mounting studs for damage.

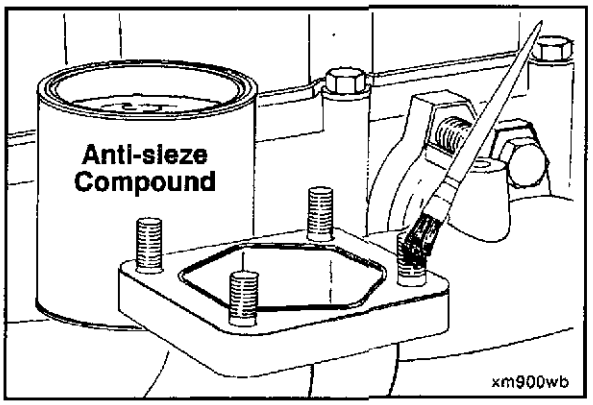


NOTE: If the turbocharger is **not** to be immediately replaced, cover the opening to prevent any material from falling into the manifold.

Inspect the turbocharger wastegate linkage, valve shaft, module, and pressure signal line.

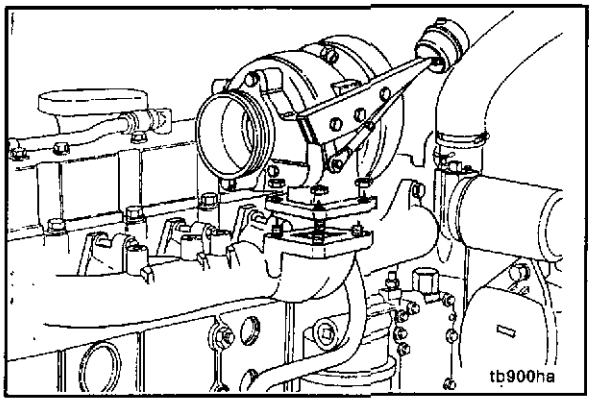
Check or calibrate wastegate.

Refer to the Turbocharger Shop Manual, Bulletin No. 3810321, for calibration procedures.



Installation

Install a new gasket and apply a high temperature anti-seize compound to the mounting studs.



15 mm

Install the turbocharger.

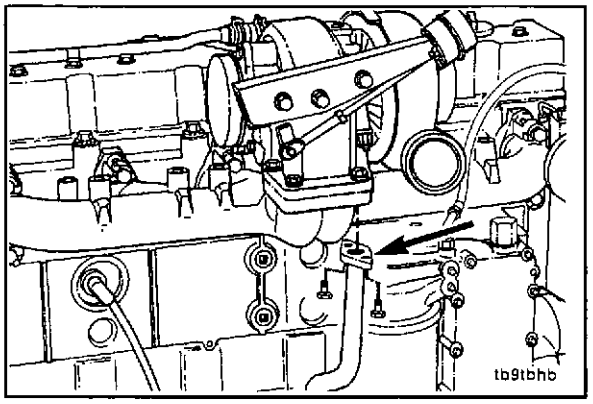
Torque Value: 45 N•m [33 ft-lb]

10 mm and 7/16-inch

Use a new gasket and connect the oil drain tube.

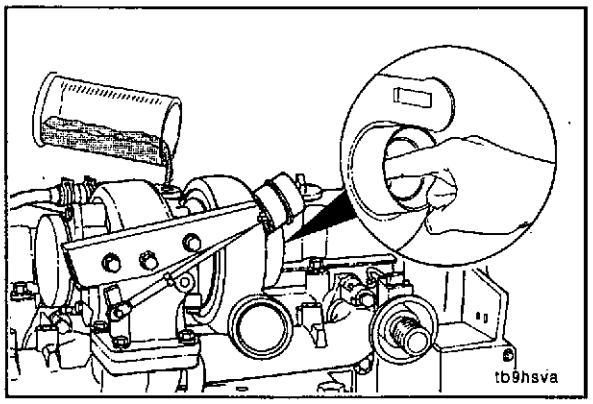
Torque Value:

(Exhaust Clamp)	8 N•m	[71 in-lb]
(Drain Tube)	24 N•m	[18 ft-lb]



NOTE: New turbochargers **must** be pre-lubricated before start-up.

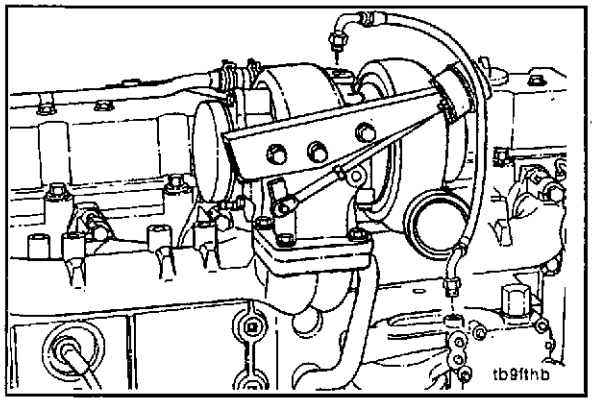
Pour 50 to 60 cc [2 to 3 ounces] of clean engine oil into the oil supply fitting. Rotate the turbine wheel to allow the oil to enter the bearing housing.



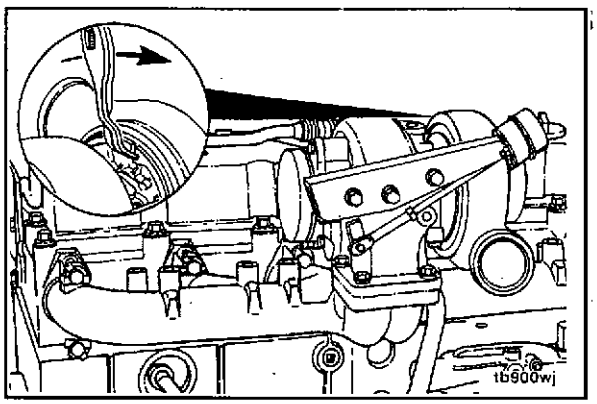
16 mm

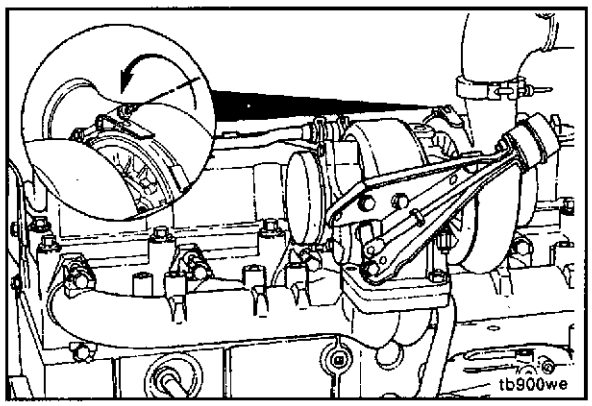
Connect the oil supply line.

Torque Value: 15 N•m [11 ft-lb]



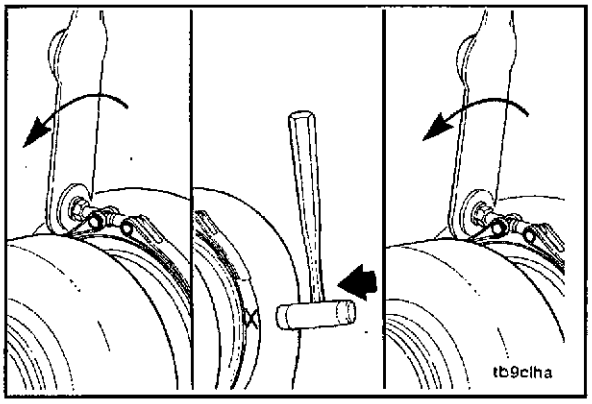
Loosen the snap ring and align the compressor housing with the turbocharger air outlet connection.





7/16 inch

NOTE: If required, loosen the compressor housing V-band clamp and position the housing to align with the turbocharger air outlet pipe.

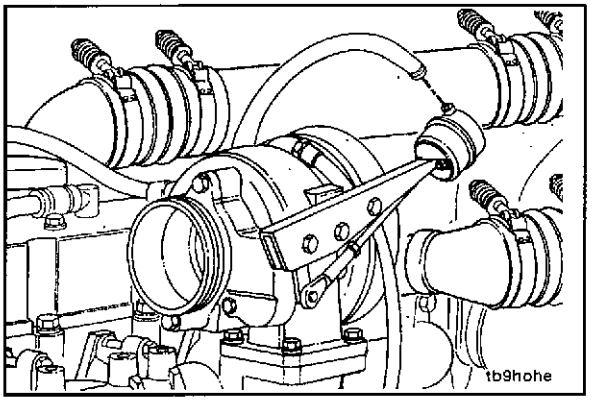


7/16 inch, Plastic Hammer

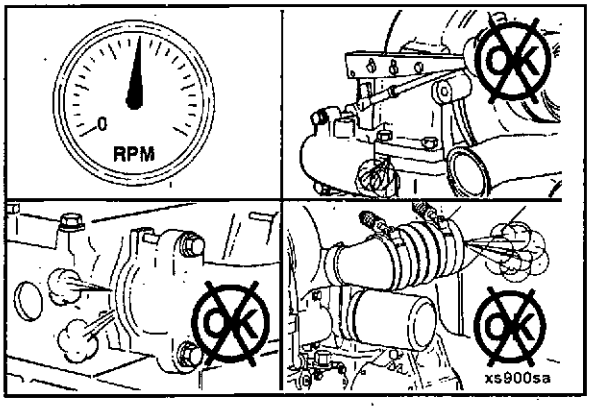
Tighten the band clamp. Tap around the clamp with a plastic hammer and tighten again.

Torque Value: 8 N•m [71 in-lb]

NOTE: Effective Oct. 1, 1990 all Holset Turbochargers use silver plated nuts with the v-band clamp. The silver plated nuts require a **lower** torque than the stainless steel nut to provide the same v-band clamp load.



Connect the wastegate actuator hose.



Install the air inlet and exhaust piping.

Operate the engine and check for leaks.

Exhaust Manifold and Gaskets - Replacement (3-12)

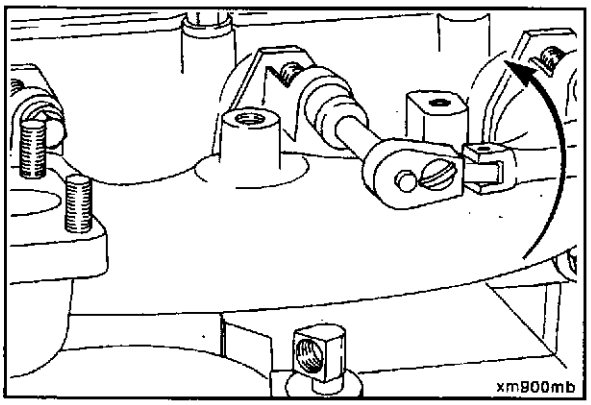
Preparatory Steps:

- Remove the air crossover tube, if used.
- Disconnect the charge air cooler hose.
- Disconnect the air intake and exhaust piping.
- Remove the turbocharger, if used.

Removal

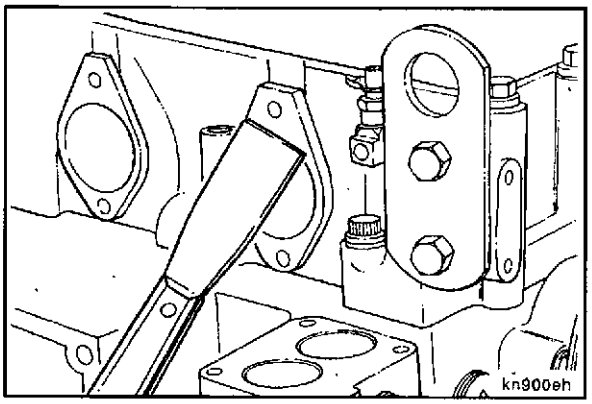
15 mm

Remove the exhaust manifold and gaskets.

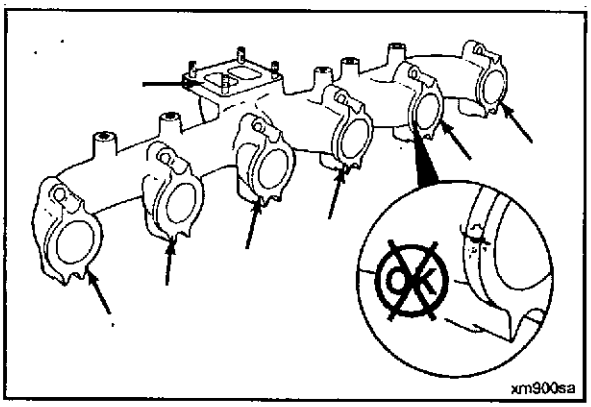


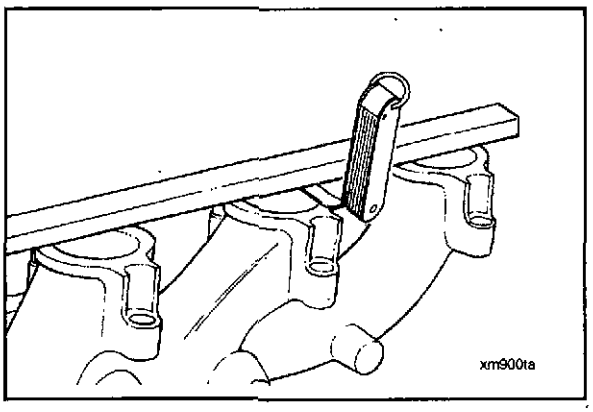
Cleaning and Inspection

Clean the sealing surfaces.



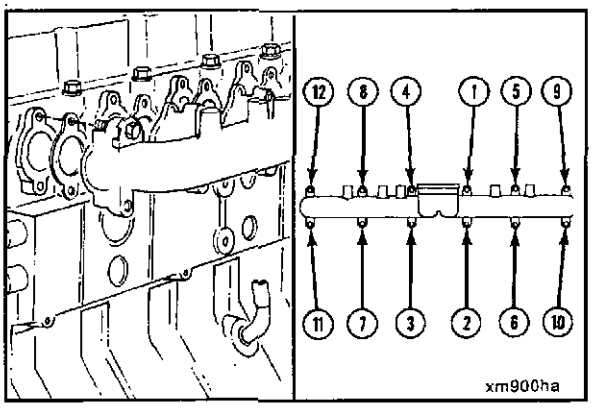
Inspect the gasket surfaces for gouges, scratches, or burn-out.





Place a straight edge across the exhaust ports to check for flatness.

Exhaust Manifold Flatness		
mm		in
0.20	MAX	0.008



Installation

15 mm

Install the exhaust manifold and new gaskets.

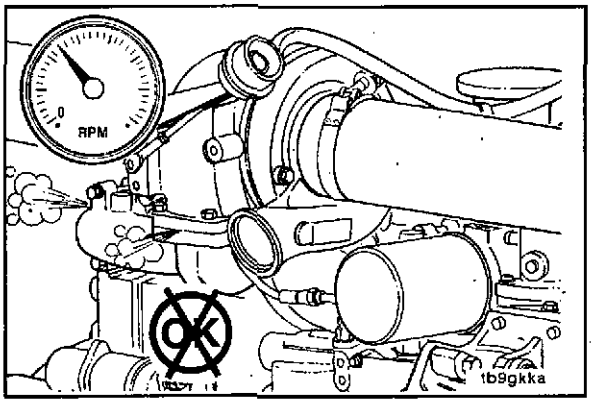
Use new lockplates on the capscrews.

Torque Value: 43 N•m [32 ft-lb]

Follow the tightening sequence shown in the illustration.

Repeat the tightening sequence a second time.

After the capscrews are tightened to the correct torque value, bend over the lockplates to prevent the capscrews from loosening.



Install the parts previously removed. Operate the engine and check for leaks.

Air Intake Heater Description and Operation

Warning: Ether must not be used in conjunction with this system.

The intake cold start system burns a small amount of diesel fuel in the intake manifold to aid engine starting under cold ambient conditions. The system also operates in a post-start mode to eliminate white smoke while the engine warms up to operating temperatures.

Typical Flame Plug Operation

- Key switch "ON".
  Controller sensors block temperature and battery voltage.
  If below 45°F, wait to start (WTS) light on.

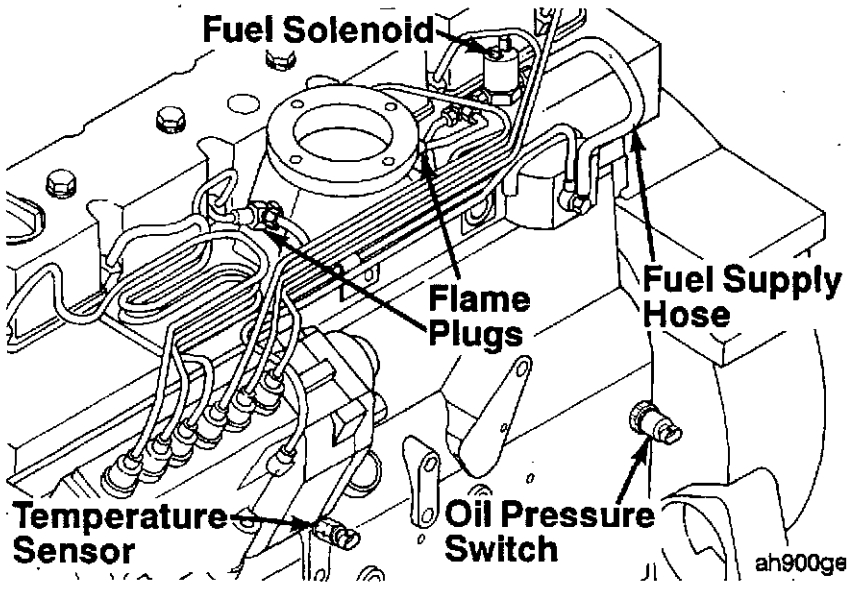
  If above 45°F, wait to start (WTS) light on for 5 seconds for bulb check.
- Preheat cycle starts.
  Relay closes and starts heating flame plug.
  Cycle time battery voltage dependent (see table 1)
  Peak current 45A/plug, decreases with time.
- Preheat cycle complete.
  WTS light goes out.
- Operator starts engine.
  5 second starts typical.
  Heater current on
  Fuel solenoid powered open
- Post heat cycle for white smoke begins.
  Duration is block temperature dependent (see table 2).

Table 1
Preheat Cycle

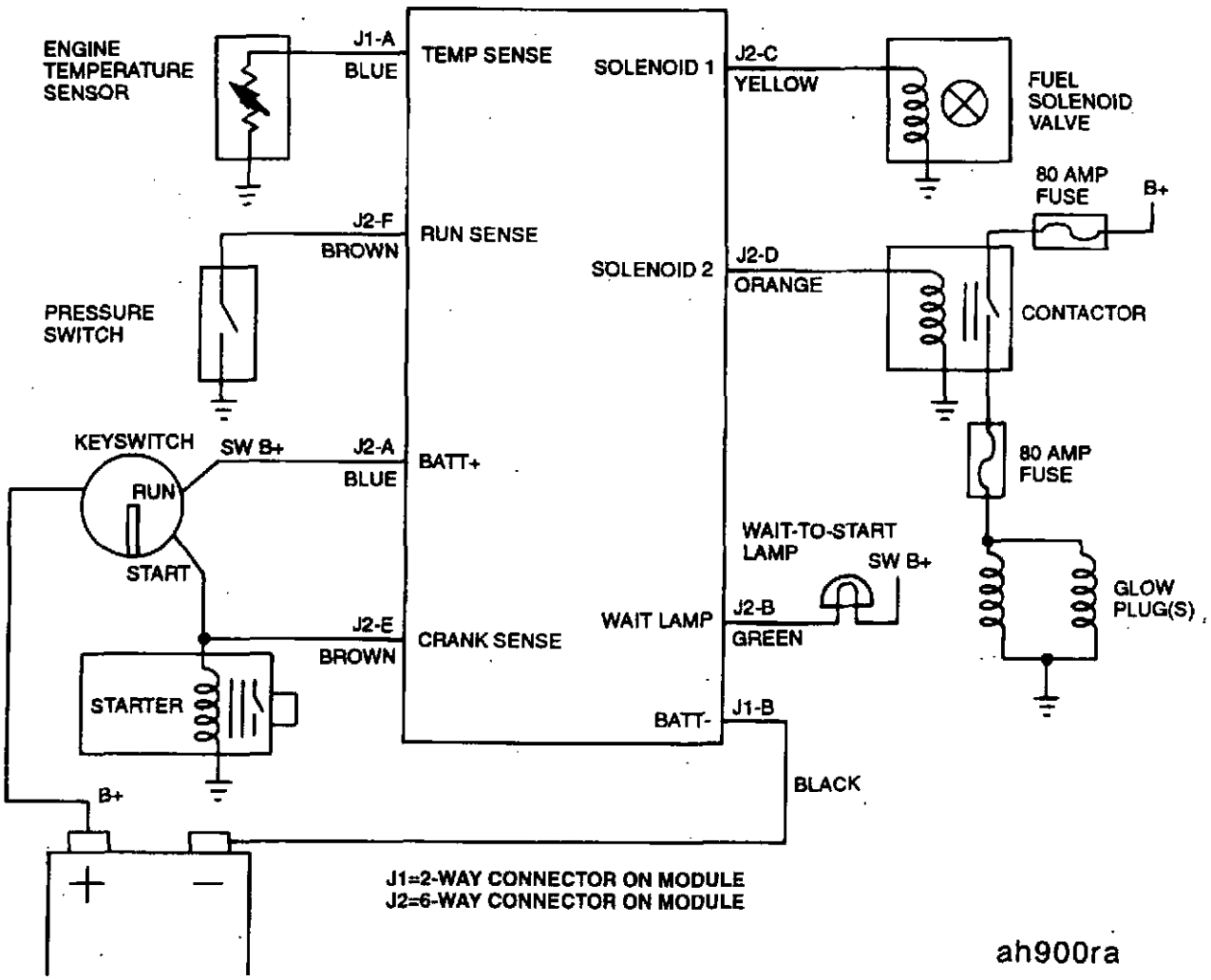
Battery Voltage (Volts)		Preheat Time (Sec)
12 Volt System	24 Volt System	
<9	<20	40
12	24	25
13	25	20
>16	>30	Abort Cycle

Table 2
Post Heat Cycle

Engine Temp. (Deg. F)	Post Heat Time (Min)
Above 45	None
45 to 17	2
Below 17	3



Intake Heater Controller Connection - Diagram



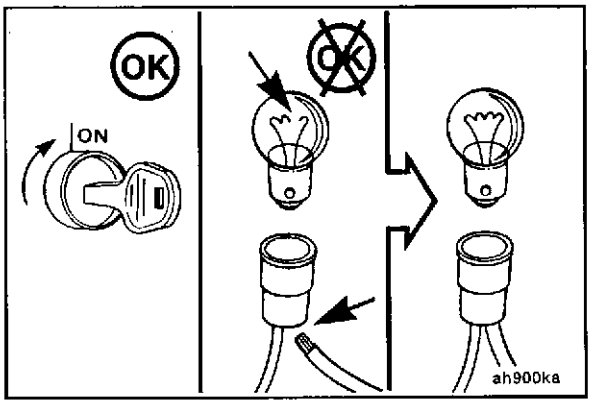
Flame Start System - Checking (3-13)

Wait to Start (WTS) Light - Checking

Turn the key to the "ON" position. The bulb check logic in the controller will turn the WTS light on for 5 seconds.

Visually check the WTS light bulb.

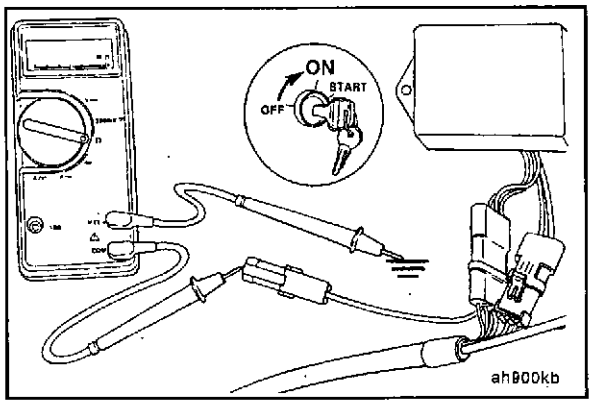
- Check for broken filament on the bulb.
- Check the socket and wiring
  Replace the bulb if necessary.



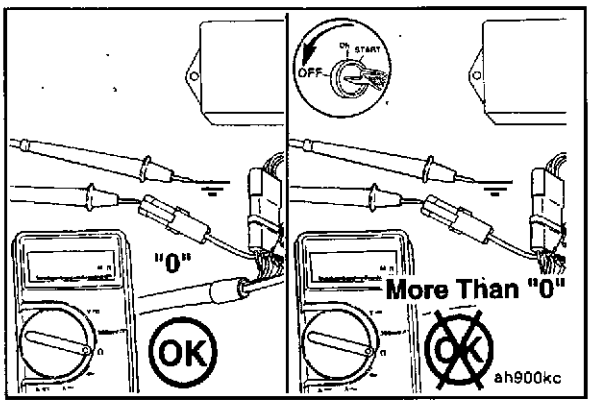
Check the WTS Light Wiring

NOTE: The controller provides a ground signal to the bulb.

- Set the digital multimeter, Part No. 3376898, or equivalent to measure resistance in OHMS.
- Connect the leads of the multimeter to the controller lead of the WTS light and a suitable ground.
- Turn the key switch to the "ON" position.

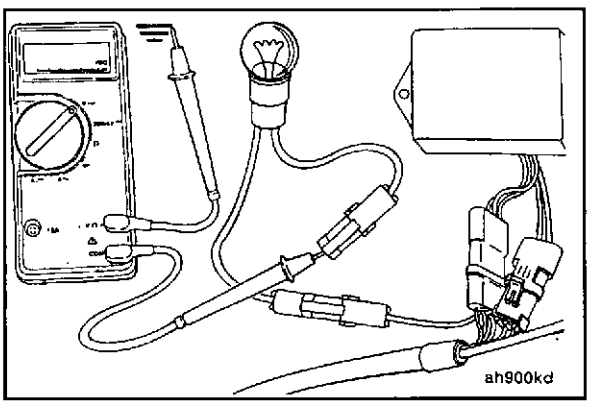


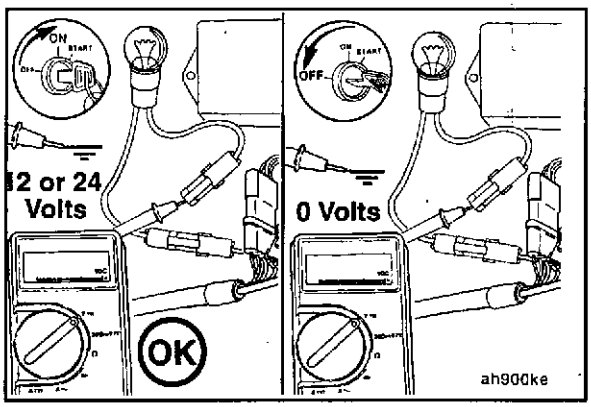
- The multimeter must indicate zero ("0") or very little resistance.
- Check the harness for burning or chafing.
- Check the controller ground if resistance is not close to zero (pin "B") on the 2-pin connector.
- Turn the key switch to the "OFF" position.
  Repair the controller wiring if necessary.



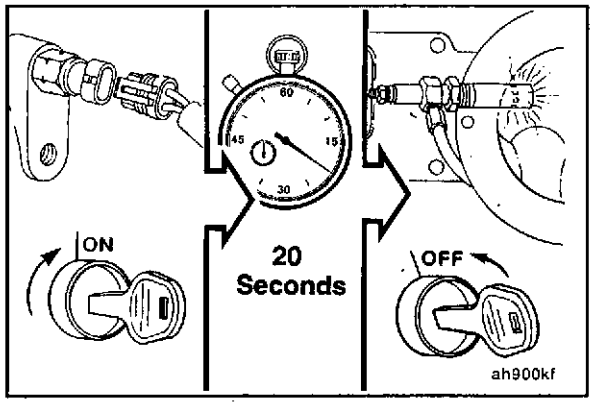
NOTE: The battery positive signal is provided by the chassis.

- Set the digital multimeter, Part No. 3376898, or equivalent to measure the voltage in volts.
- Connect the leads of the multimeter to the chassis lead of the WTS light and a suitable ground.





- Turn the key switch to the "ON" position.
- The multimeter must indicate vehicle system voltage.
- Turn the key switch to the "OFF" position.
- Repair the chassis wiring if necessary.



Flame Plug Electrical Circuit - Checking

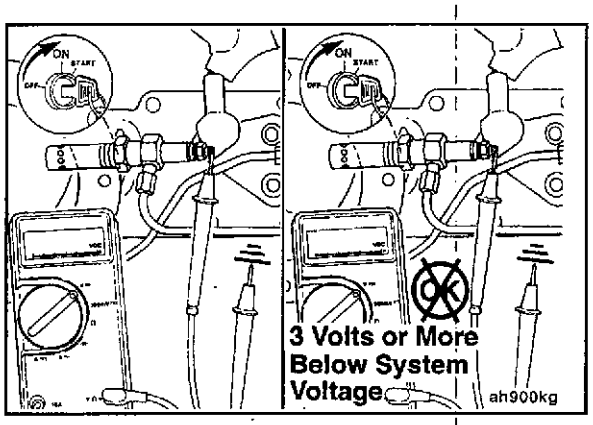
Disconnect the flame plug temperature sensor and install a 10,000 OHMS resistor.

Remove the air intake crossover tube.

Turn the key to the "ON" position. Visually inspect the glow plug. The glow plug should be red in color when functioning properly.

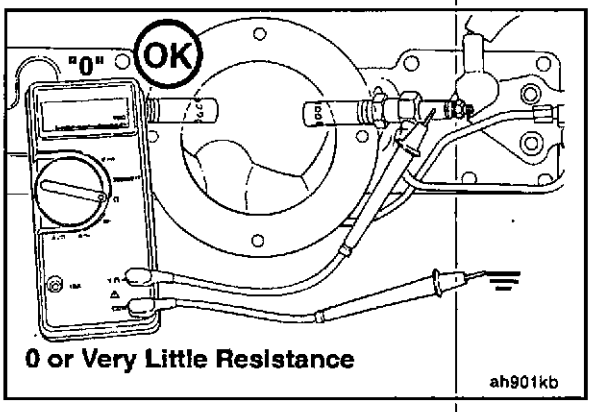
Turn the key switch to the "OFF" position.

If the glow plug is functioning properly, proceed to the Flame Plug Solenoid - Checking.



Voltage Check Between Flame Plug and Ground

- Set the digital multimeter, Part No. 3376898, or equivalent, to measure voltage (VOLTS).
- Connect the leads of the multimeter to the flame plug electrical connection and a suitable ground.
- Turn the key switch to the "ON" position.
- The multimeter must indicate at least 3 volts below the vehicle system voltage.
- Turn the key switch to the "OFF" position.
- If the voltage check is acceptable, proceed to the Flame Plug Electrical Heater - Check.

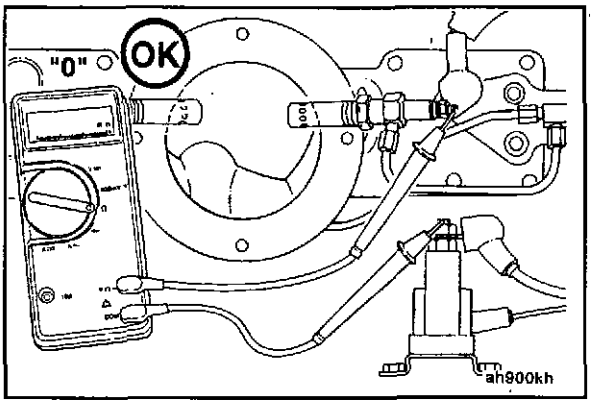


Resistance Check Between the Glow Plug and Ground

- Set the digital multimeter to OHMS.
- Connect the leads to the glow plug and a suitable ground.
- The multimeter must indicate zero (0) or very little resistance.
- Ground the manifold cover properly if resistance is high.

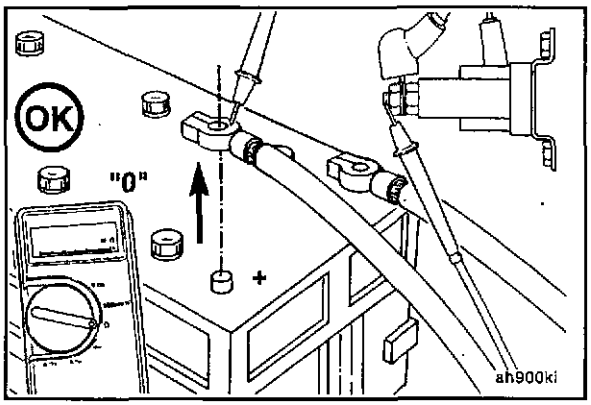
Resistance Check Between the Flame Plug and Relay

- Set the digital multimeter, Part No. 3376898, or equivalent, to measure resistance (OHMS).
- Connect the leads of the multimeter to the flame plug electrical connection and the relay.
- The multimeter must indicate zero ("0") or very little resistance.
- Repair/replace the wiring harness if necessary.

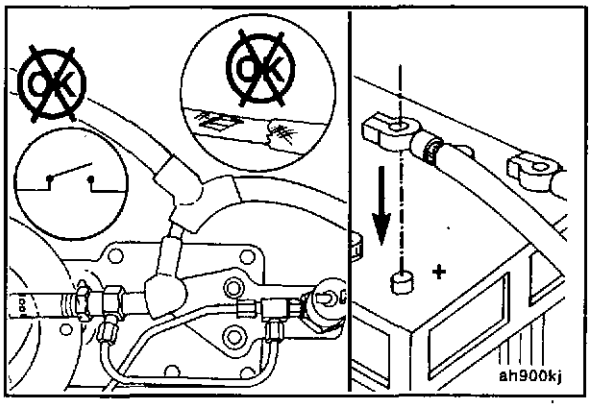


Cable Resistance Check Between Relay and Battery Positive Terminal

- Disconnect the battery positive terminal.
- Set the digital multimeter, Part No. 3376898, or equivalent, to measure resistance (OHMS).
- Connect the leads of the multimeter to the battery cable to the relay and the battery positive cable.
- The multimeter must indicate zero ("0") or very little resistance.
- Repair/replace as necessary.



- Inspect the wiring harness and connectors for chafing or shorts to ground.
- If resistance is high or open, check the fusible link in the wiring harness.
- Repair/replace the cable as necessary.
- Install the battery positive terminal.

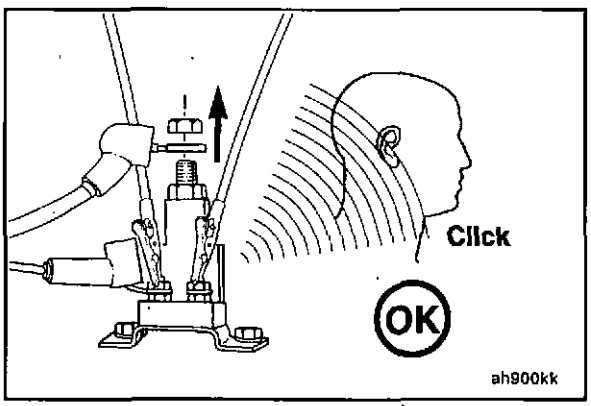


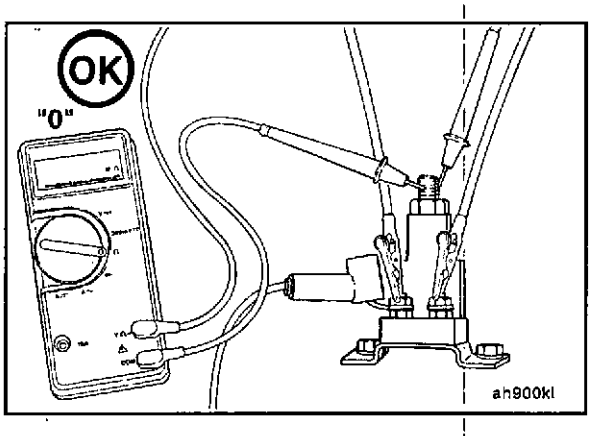
Relay Operation and Resistance - Check

Disconnect the battery lead to the relay.

Apply system voltage and ground to the smaller terminals of the relay.

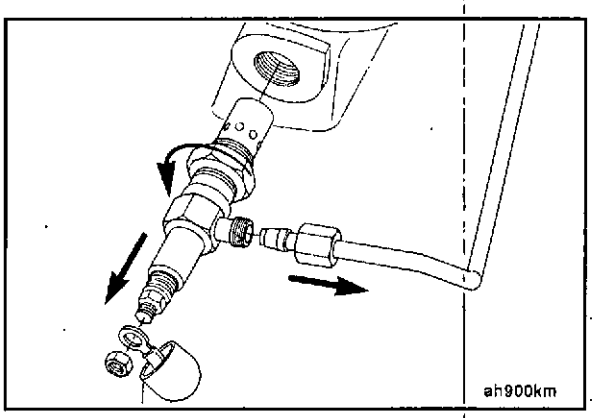
Listen for an audible click to make sure the relay is operating properly.





Apply the system voltage and ground to the smaller terminals of the relay.

- Set the digital multimeter, Part No. 3376898, or equivalent, to measure resistance (OHMS).
- Connect the lead of the multimeter to the high current relay terminal.
- The multimeter must indicate zero ("0") or very little resistance.
- Replace the relay if necessary.



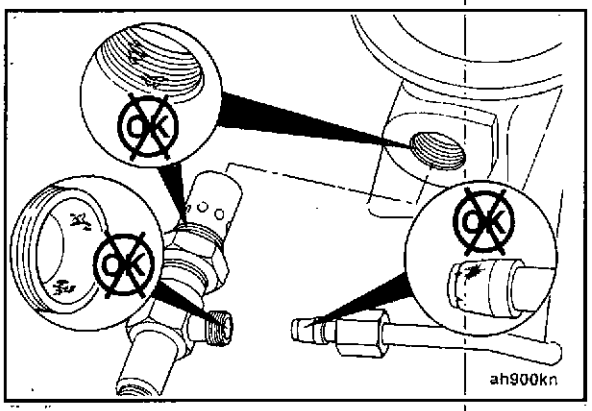
Flame Plug Replacement

NOTE: The electrical connector on the flame plug is susceptible to failures due to excessive torque. Removal or installation torque above 4 N•m [36 in-lb] will fail the delicate electrical heater.

Remove the electrical connector from the plug. Remove the fuel line.

Caution: The flame start system has very small orifices and filter which is susceptible to contamination. When any fuel lines are disconnected, make sure no debris enters the fuel system.

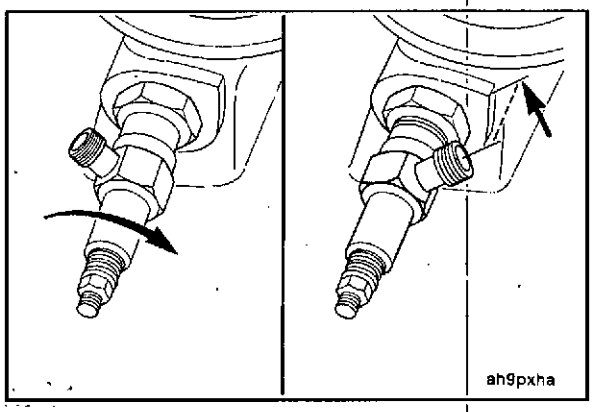
Loosen the flame plug.



Flame Plug Installation

Caution: The flame start system has very small orifices and filter which is susceptible to contamination. When any fuel lines are disconnected, make sure no debris enters the fuel system.

Visually inspect the fuel sealing surfaces on the flame plug and fuel line for scratches or burrs. Replace the flame plug or fuel line if damaged.



Install the flame plug with the jam nut installed.

Bottom out the plug into the manifold and back it out two turns until the plug is aligned with the pointer on the manifold.

Align the fuel plumbing with the flame plug to make sure the fuel tube is centered with the plug.

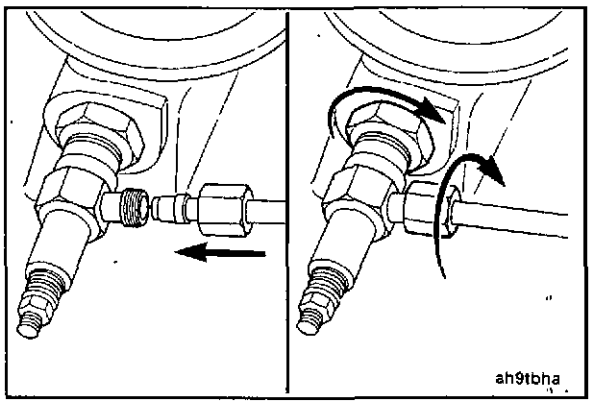
Install the fuel line.

Torque Value: Fuel Line 10 N•m [89 in-lb]
Jam Nut 25 N•m [18 ft-lb]

Install the electrical connections.

Torque Value: 4 N•m [36 in-lb]

Caution: Do not exceed this torque. Damage and or failure to the glow plug will result.

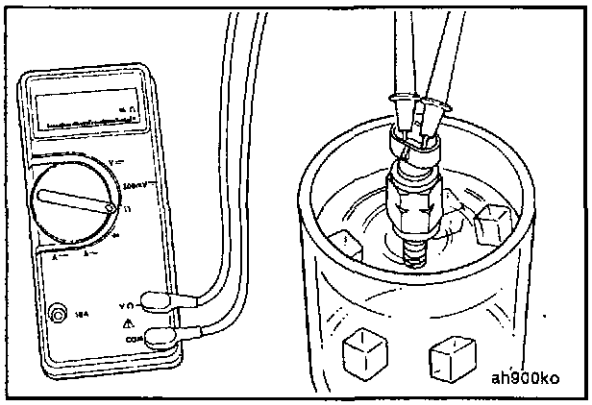


Temperature Sensor - Check

- Set the digital multimeter, Part No. 3376898, or equivalent.
- Connect the leads of the multimeter to the temperature sensor leads.
- Record the resistance at the following conditions:

Temperature C[F]	Resistance Ohms	Measure Value Ohms
Room Temp.	1600	
0° [32°]	800	

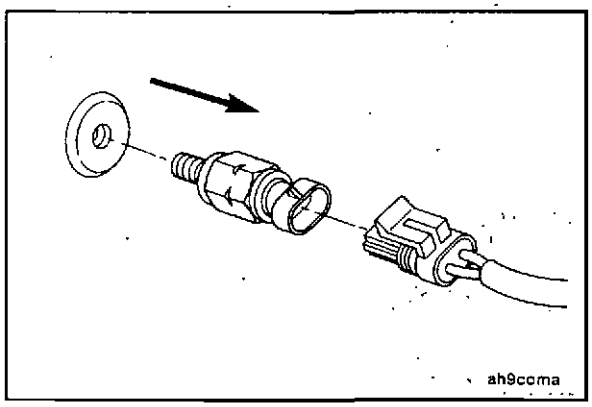
If sensor is 100 OHMS over the specified resistance, replace the sensor. With the key switch "ON", check the resistance across pins J1A and J1B for resistance.



Temperature Sensor Removal

Remove the electrical connection to the temperature sensor.

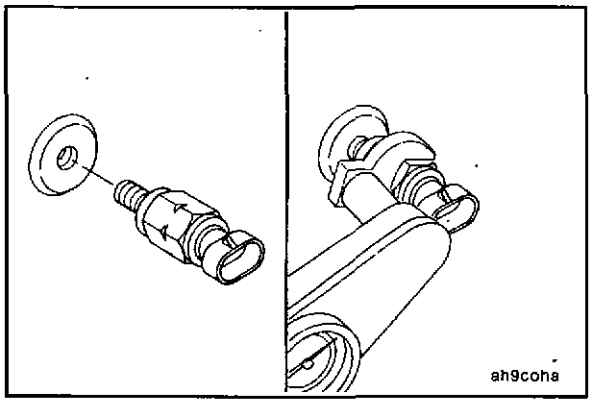
Remove the sensor.

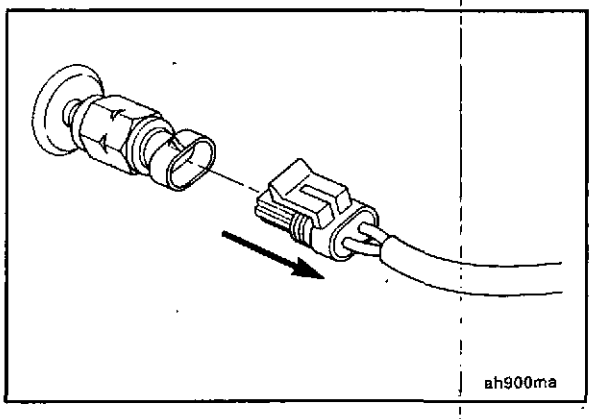


Temperature Sensor Installation

Install the sensor in the reverse order of removal.

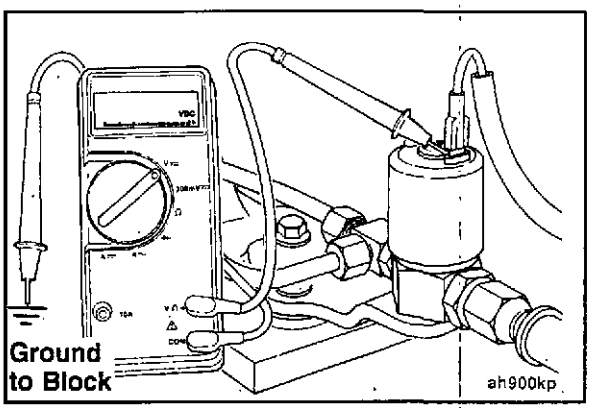
Torque Value: 40 N•m [30 ft-lb]



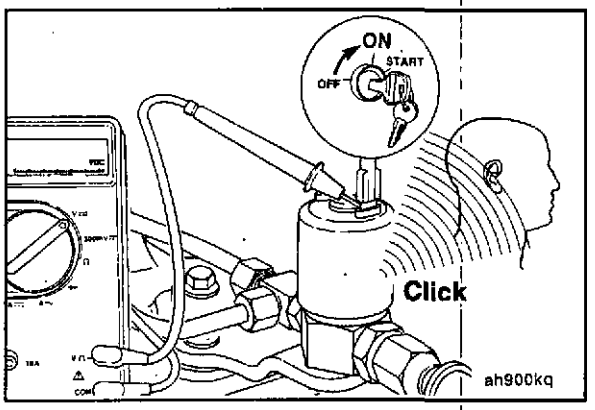


Flame Plug Solenoid - Check

Disconnect the temperature sensor.



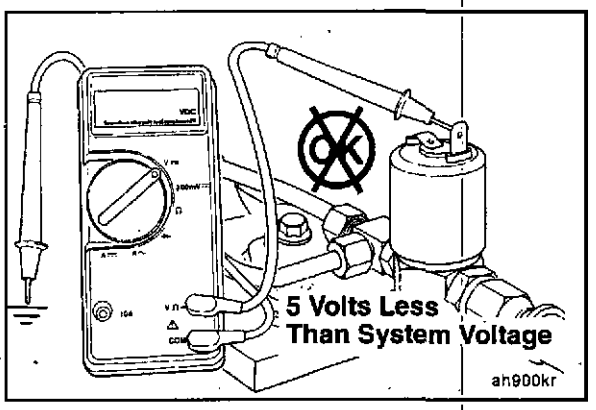
- Set the digital multimeter, Part No. 3376898, or equivalent, to measure the voltage (VOLTS).
- Connect the leads of the multimeter to the flame start fuel solenoid and a suitable ground.



Turn the key switch to the "ON" position.

After the WTS light goes out, attempt to start the engine.

Listen for the solenoid "click".



Measure the fuel solenoid connector voltage.

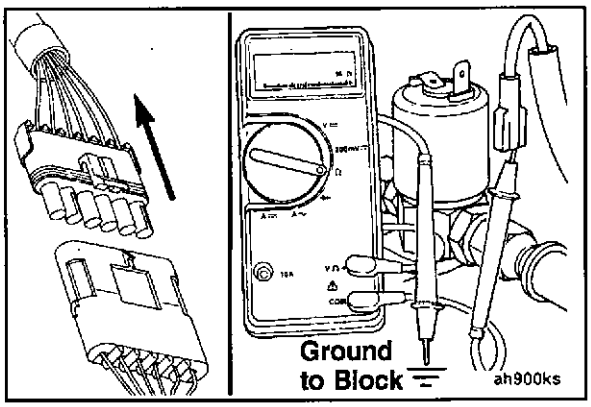
Turn the key switch to the "OFF" position.

If the voltage is 5 volts less than the system voltage, inspect the engine wiring harness and the controller harness for shorts or chaffed insulation.

Disconnect the control module connector.

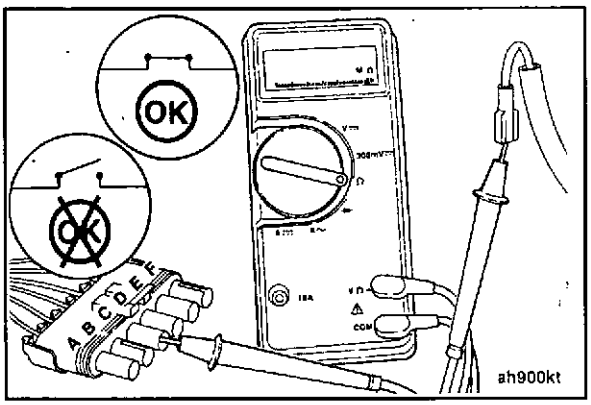
Connect the leads of the multimeter to the flame start fuel solenoid connector and a suitable ground. Resistance must be infinite or open circuit.

If the wiring harness shorted to the ground, replace or repair.



Measure the wiring harness resistance between pin "C" on the harness connector and the solenoid.

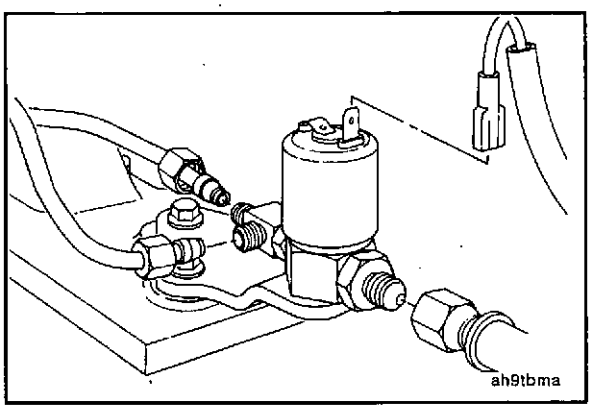
The wiring harness resistance must be zero "0" or close to zero. If not "0", replace or repair the wiring harness.



Flame Plug Fuel Solenoid Operational - Check

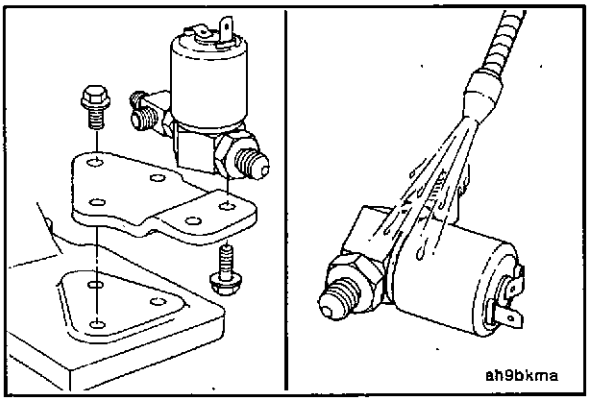
Remove the electrical connector.

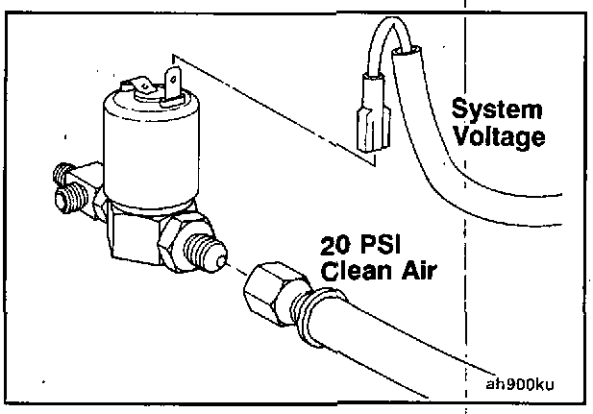
Disconnect the fuel lines from the solenoid valve.



Remove the bracket and solenoid assembly from the intake cover.

Remove the residual fuel and clean the solenoid.

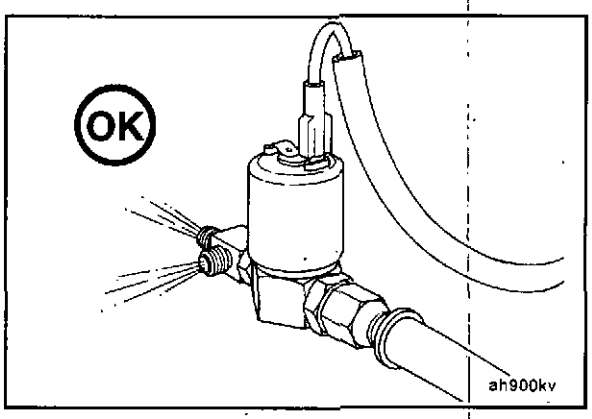




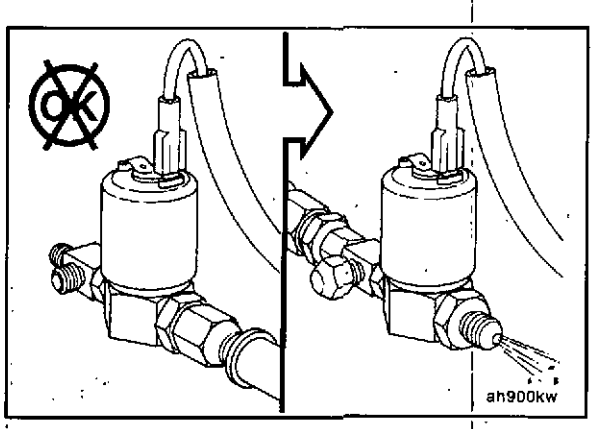
Apply system voltage and a suitable ground to the solenoid.

Apply a clean supply of 20 psi shop air in the inlet side of the solenoid valve.

NOTE: The orifice in the solenoid valve is susceptible to plugging. Make sure no debris enters the valve.

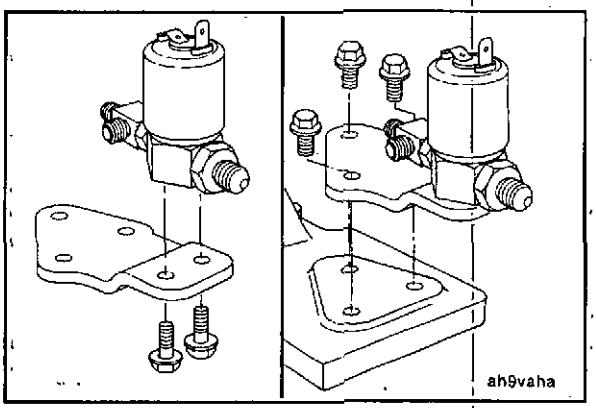


Apply clean shop air to the solenoid and listen/feel for air passage.



If the solenoid is plugged, remove the debris by back flowing the valve with clean shop air.

If the solenoid valve does not open or is still plugged, replace the valve.



Solenoid Valve Installation

8 mm

Install the solenoid valve on the bracket.

Torque Value: 9 N•m [80 in-lb]

Install the solenoid bracket on the intake cover.

Torque Value: 9 N•m [80 in-lb]

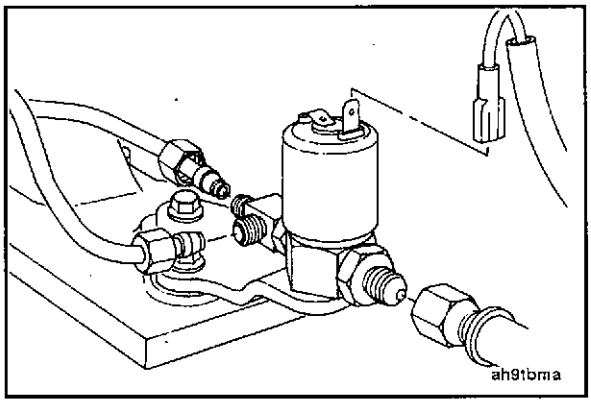
Install the solenoid valve fuel supply line.

Torque Value: 10 N•m [89 in-lb]

Install the solenoid valve fuel lines.

Torque Value: 10 N•m [89 in-lb]

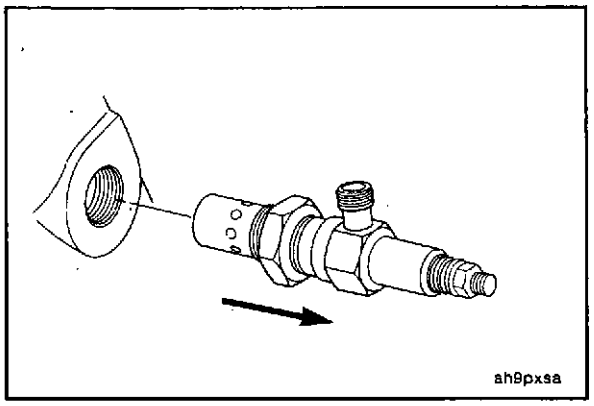
NOTE: To prevent leaks, inspect the sealing surfaces and align the fuel lines to the solenoid before torquing the fuel lines.



Remove the flame plug.

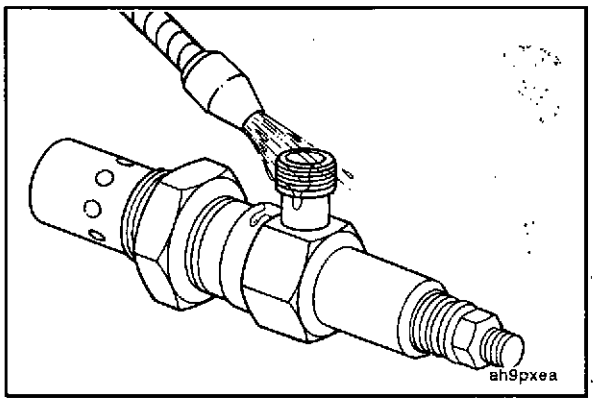
Check the flame plug for plugging and coking.

NOTE: The flame plugs have very small orifices and will fail if plugged with debris. Make sure not to contaminate the plugs.



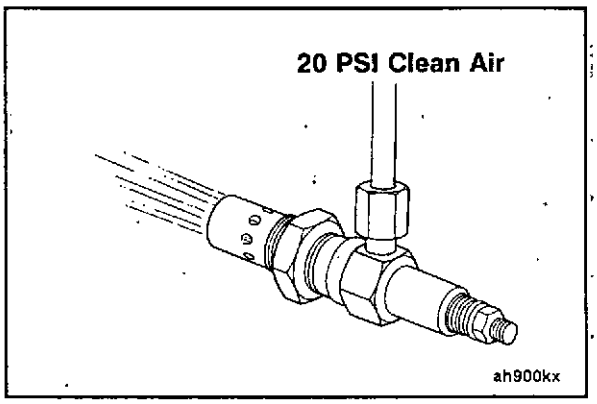
Use a solvent to clean the flame plug filter screen.

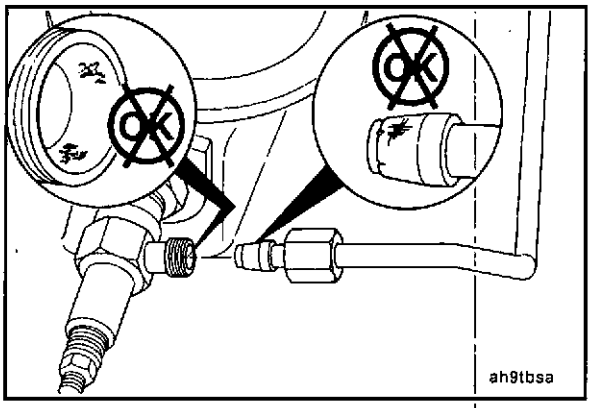
NOTE: Do not remove the filter screen from the flame plug. If the screen cannot be cleaned with a solvent, replace the plug.



Apply 20 psi of clean shop air to the flame plug and listen/feel for air flow.

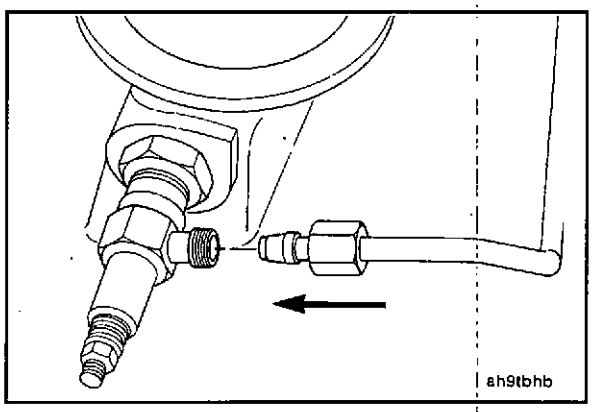
If no air flow is detected, replace the plug.





Fuel Line Leak - Repair

Remove the fuel line and visually inspect the sealing surfaces for scratches or burrs. Replace the damaged fuel line or the flame plug if necessary.

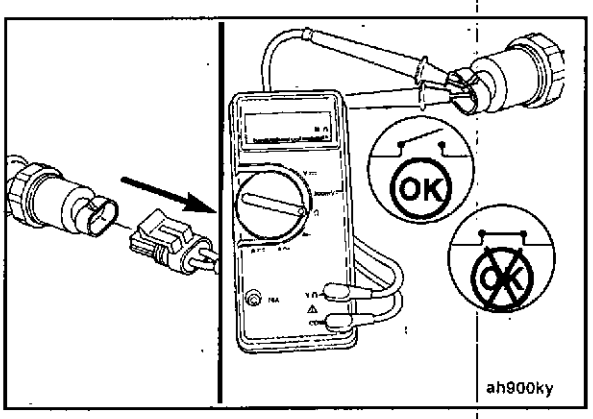


Align the hard-line ends to the end point of the connection.

NOTE: Do not try to force a misaligned fuel line into a connection. This will load one side of the seal and damage the seal.

Install the fuel line.

Torque Value: 10 N•m [89 in-lb]

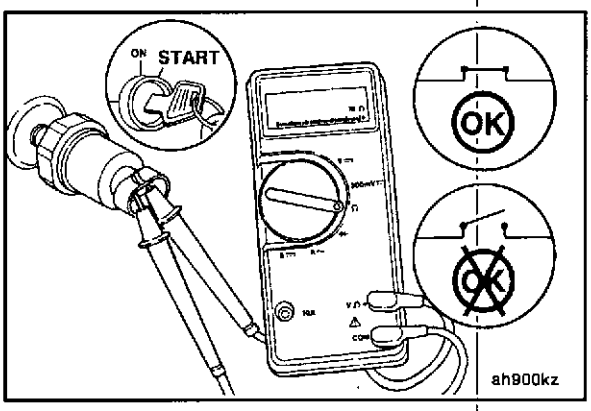


Lubricating Oil Pressure Switch Functional - Check

Disconnect the oil pressure sensor.

Connect the leads of the multimeter to the lubricating oil pressure sensor connector.

The resistance must be infinite or open circuit. If the switch is shorted, replace the lubricating oil pressure switch.

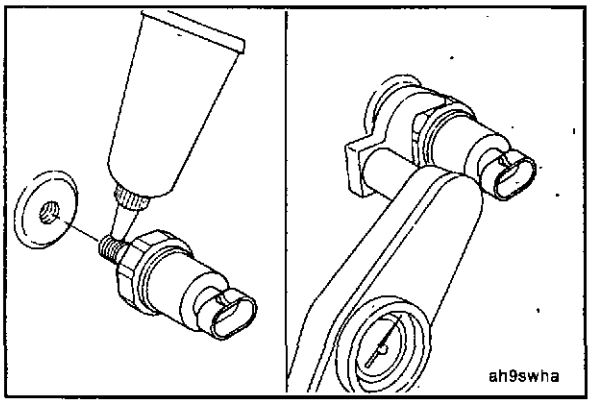


Start the engine (if possible) and measure the lubricating oil pressure switch resistance. If the resistance is not zero "'0'', replace the lubricating oil pressure sensor.

Oil Pressure Switch Installation

Install the lubricating oil pressure switch.

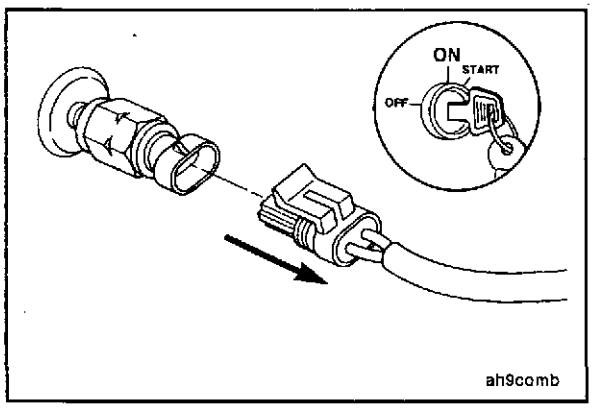
Torque Value: 20 N•m [15 ft-lb]



Controller Logic - Check

Disconnect the temperature sensor connection.

Turn the key switch to the "ON" position.



Connect the leads of the multimeter to pin "A" on the six pin connector and a suitable ground.

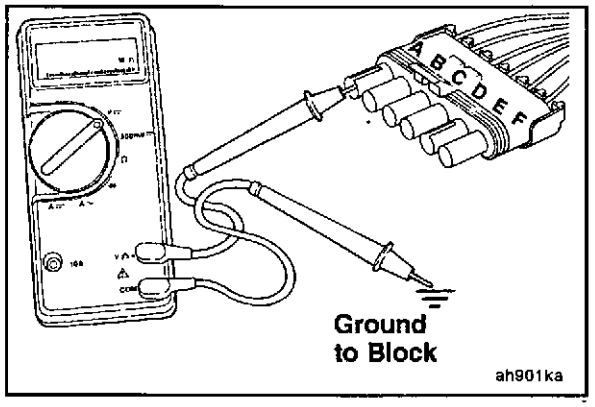
Measure the voltage.

Check for system voltage.

- The controller has an over-voltage protection circuit that will abort all operations if pin "A" has sensed an over-voltage condition. Refer to the chart below:

System Voltage	Over-Voltage Limit
12V	18V
24V	30V

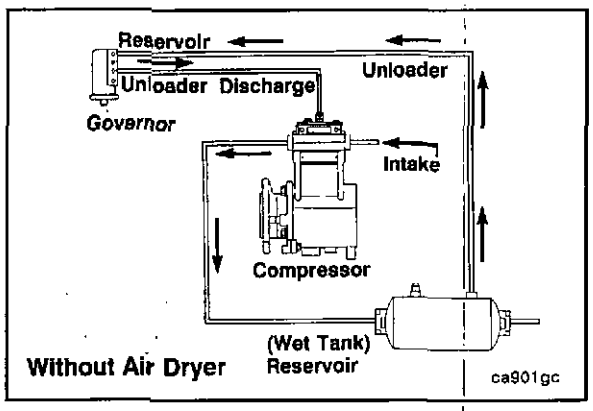
- The WTS light will flash if the temperature sensor is disconnected or failed.
- If the controller does not have an oil pressure signal within 30 seconds after cranking the engine, the controller will abort the cycle.
- If the controller malfunctions, replace the controller.



NOTES

Section 4 - Compressed Air System

Section Contents



Compressed Air System General Information

The compressed air system normally consists of a gear driven air compressor, an air governor, air tanks and all necessary plumbing.

The Holset SS296 single cylinder air compressor is an engine-driven piston-type compressor which supplies compressed air to operate air activated devices. The compressor runs continuously but has a loaded and unloaded operating mode. The operating mode is controlled by a pressure-activated governor and the compressor unloading assembly.

The SS296 air compressor used on C series engines uses an (E-type) unloader. The Economy (E-type) unloader system was designed to reduce pumping losses and engine boost pressure losses through the compressor intake valve while operating in unloaded mode.

When the air system reaches a predetermined pressure, the governor applies an air signal to the air compressor unloader assembly causing the unloader cap to seal off incoming air at the intake valve, and compressed air stops flowing into the air system.

NOTE: System pressure **must** be maintained on the outlet side of the discharge valve to keep the discharge valve closed.

As the air in the air system is used, the pressure drops. At a predetermined pressure the governor exhausts the air signal to the compressor unloader assembly allowing the compressor to again pump compressed air into the air system.

Caution: Vehicles equipped with air dryers vented to atmosphere during unloaded compressor operation, using the Holset (E-type) air compressor, require the installation of an Econ valve to prevent excessive oil consumption.

If the air system pressure is **not** maintained on the discharge valve during unloaded operation, air will be pumped out of the compressor cylinder causing a low pressure (vacuum) condition to form in the cylinder. With the intake valve sealed off by the unloader cap, and the exhaust valve being a one-way pressure actuated valve, no air will be allowed to enter the cylinder. When the compressor cylinder pressure falls below crankcase pressure, oil will be drawn past the piston rings and pumped into the air system.

Other brands of compressors may be used on C series engines. Troubleshooting procedures are very similar for these air compressors compared to the Holset SS296. Refer to the specific air compressor manufacturers manual for detailed repair information and torque specifications.

Compressed Air System Specifications

Holset SS296 Single Cylinder Air Compressor

Compressor Swept Volume @ 1250 RPM ..... 6.2 L per sec. [13.20 CFM]
Piston Displacement ..... 296 cc [18.06 C.I.D.]
Bore ..... 92.08 mm [3.625 in.]
Stroke ..... 44.45 mm [1.750 in.]
Speed ..... 1.135 times greater than Engine Speed
Cooling ..... Engine Coolant
Lubrication ..... Engine Lubricating Oil
Plumbing Line Sizes
- Coolant Inlet and Outlet (Pipe Fitting) ..... 3/8 in NPTF
- Air Inlet (Inside Diameter) ..... 19 mm [0.750 in]
- Air Outlet (Minimum Inside Diameter) ..... 1/2″ NPTF 12.7 mm [0.50 in.]

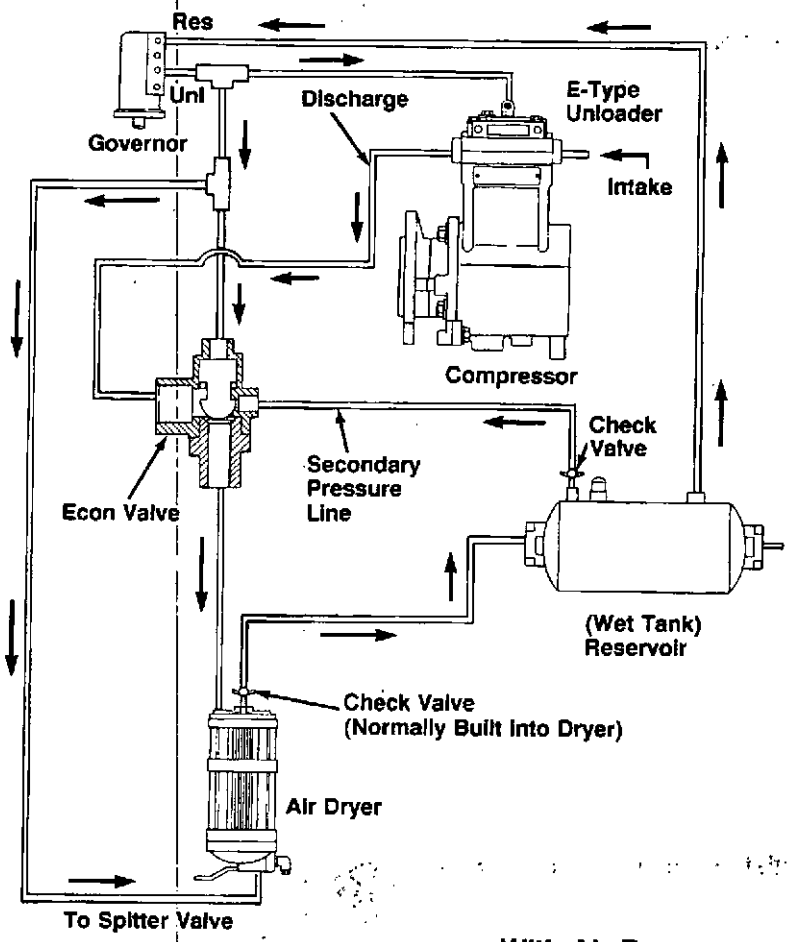
Height, Overall (Approximate) ..... 235 mm [9.25 in.]
Width, Overall (Approximate) ..... 146 mm [5.75 in.]
Length, Overall (Approximate) ..... 267 mm [10.5 in]
Weight (Approximate) ..... 20 kg [44.0 lb]

Holset SS338 Single Cylinder Air Compressor

Compressor Swept Volume @ 1250 RPM ..... [15.0 CFM]
Piston Displacement ..... 338 cc
Bore ..... 98.9 mm [3.875 in]
Stroke ..... 44.45 mm [1.750 in]
Speed ..... 1.135 times greater than Engine Speed
Cooling ..... Engine Coolant
Lubrication ..... Engine Lubricating Oil
Plumbing Line Sizes
- Coolant Inlet and Outlet (Pipe Fitting) ..... 1/2 in NPTF
- Air Inlet (Inside Diameter) ..... 22.2 mm [0.875 in]
- Air Outlet (Minimum Inside Diameter) ..... 1/2 in NPTF 12.7 mm [0.50 in]

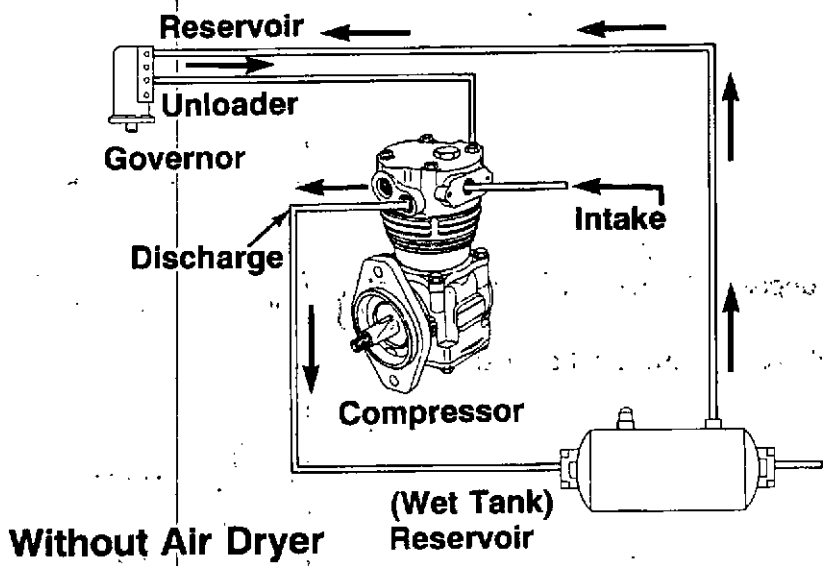
Height, Overall (Approximate) ..... 236.6 mm [9.31 in]
Width, Overall (Approximate) ..... 133.4 mm [5.25 in]
Weight (Approximate) ..... 18 kg [40.0 lb]

Compressed Air System Flow Diagrams



With Air Dryer

ca900gr



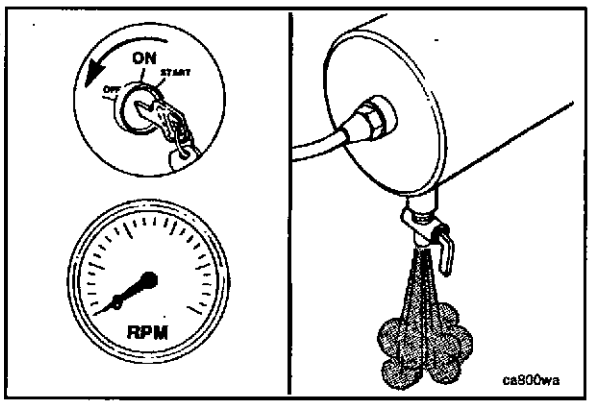
Without Air Dryer

ca900gq

Air Compressor Carbon Buildup - Checking (4-01)

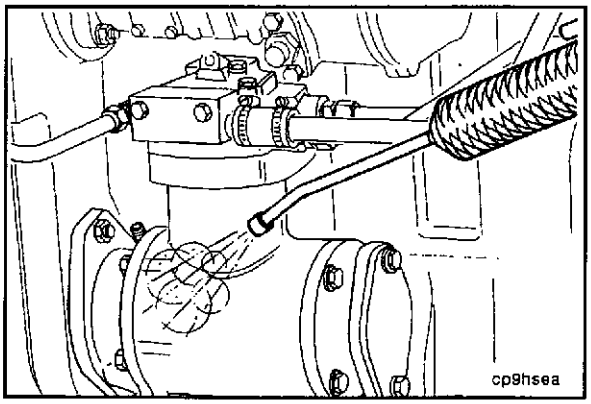
Shut off the engine.

Open the draincock on the wet tank to release compressed air from the system.

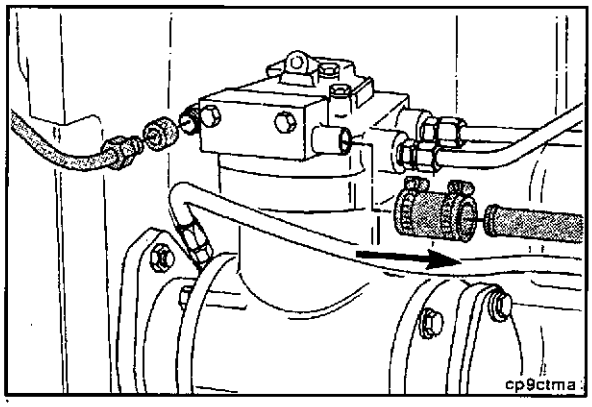


Use steam to clean the compressor.

Use compressed air to dry.

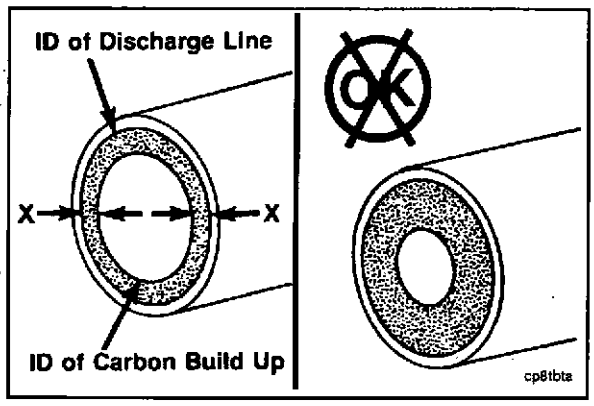


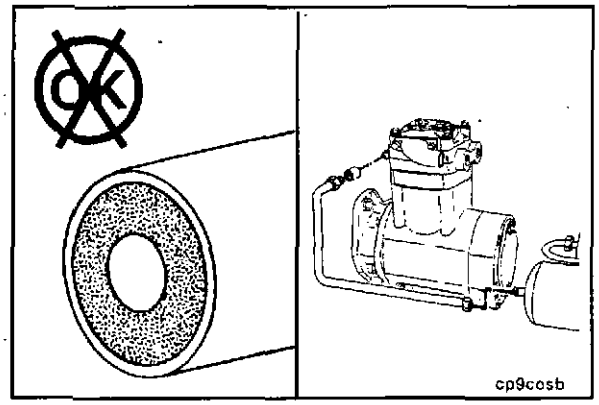
Remove the air inlet and outlet connections from the air compressor.



Measure the total carbon deposit thickness inside the air discharge line as shown.

NOTE: The carbon deposit thickness **must** not exceed 1.6 mm [1/16 inch].

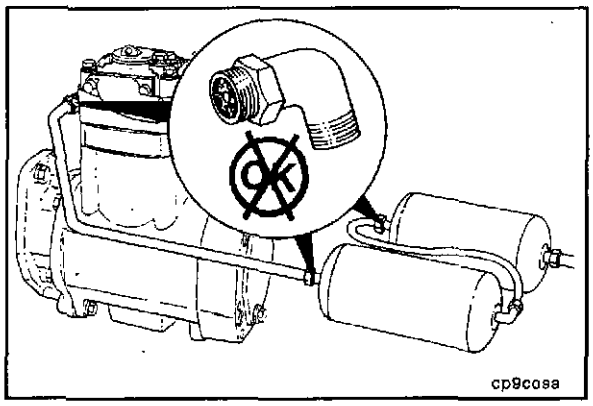




Warning: The air discharge line must be capable of withstanding extreme heat and pressure to prevent personal injury and property damage. Refer to the manufacturer's specifications.

NOTE: If the total carbon deposit thickness exceeds specification:

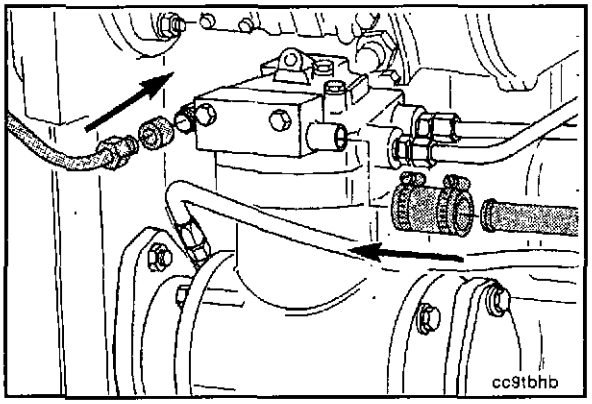
* Remove and clean or replace the air discharge line. Refer to manufacturer's material specifications.
* Remove the air compressor from engine, refer to Procedure 4-03 and inspect unloader components refer to Air Compressor Shop Manual, Bulletin No. 3810242, for detailed instructions on servicing the unloader.



Warning: The air discharge line must be capable of withstanding extreme heat and pressure to prevent personal injury and property damage. Refer to the manufacturer's specifications.

Continue to check for carbon buildup in the air discharge line connections up to the first or wet tank.

Clean or replace any lines and fittings with carbon deposits greater than 1.6 mm [0.06 (1/16) inch]. Refer to the manufacturer's specifications for cleaning or replacement instructions.



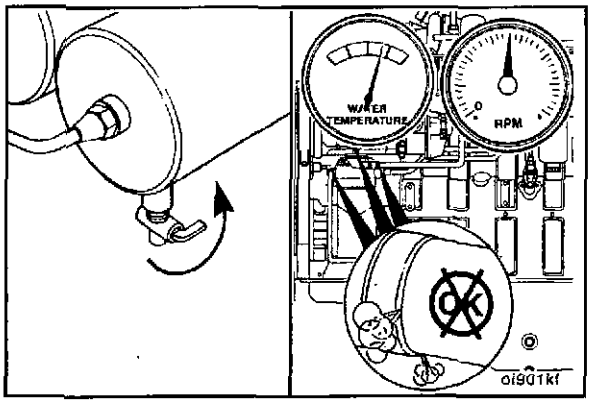
Install and tighten the air inlet and outlet connections.

Torque Value:

Inlet	5 N•m [48 in-lb]
*Outlet	24 N•m [18 ft-lb]

*1/2 NPT fitting in compressor cylinder head.

NOTE: Torque value for the discharge line depends on the line size and type. Refer to vehicle manufacturer for the correct torque value.



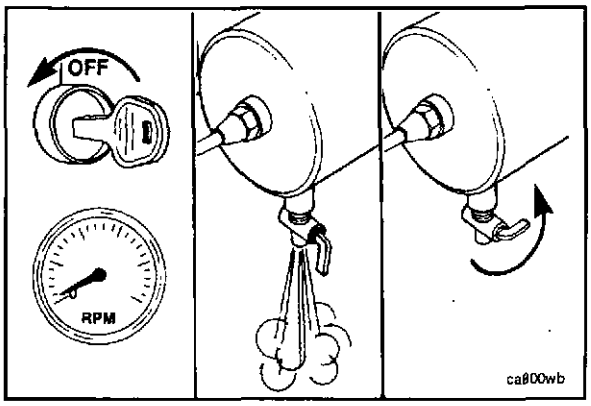
Close the wet tank draincock.

Operate the engine and check for air leaks.

Air Compressor Gasket Leaks - Checking (4-02)

Shut off the engine.

Open the draincock on the wet tank to release air from the system. Close the draincock after the pressure is released.

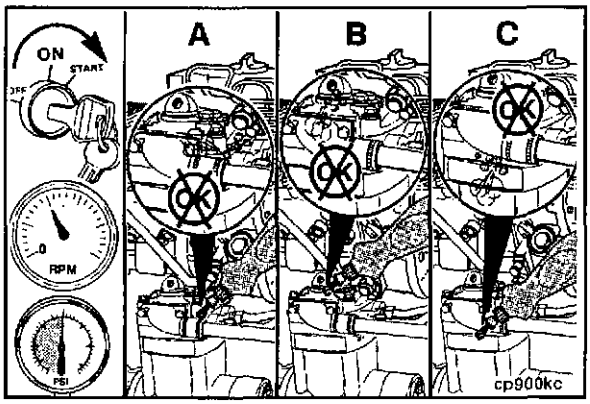


Operate the engine to activate the air compressor.

With the air compressor pumping between 550 to 690 kPa [80 to 100 psi], use a solution of soapy water to check for air leaks in the following areas:

- Air Compressor cover gasket
- Unloader body o-ring
- Air Compressor cylinder head gasket

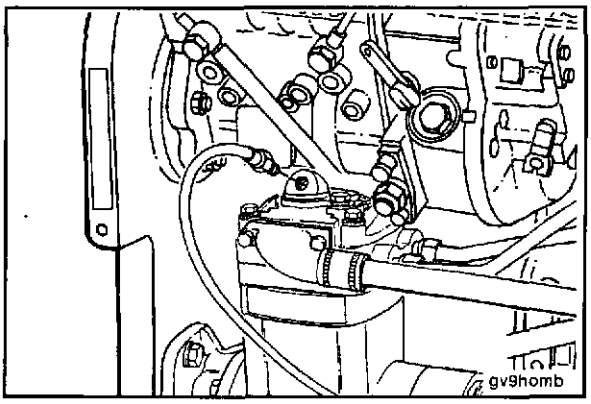
If air leaks are found, refer to Procedure 4-05. The compressor will have to be removed for service.



Air Governor and Compressor Unloader Valve - Checking (4-03)

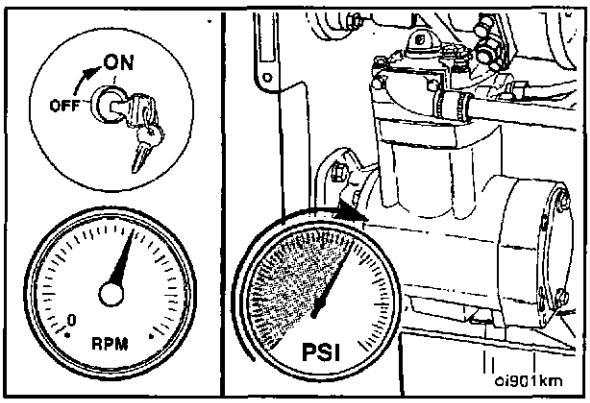
Air Compressor Will Not Pump

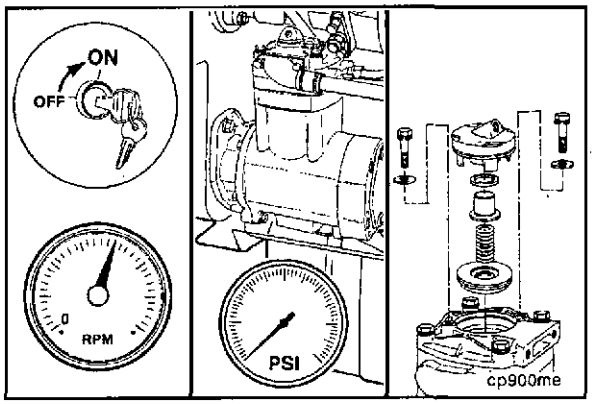
Remove the air governor hose from the air compressor unloader body.



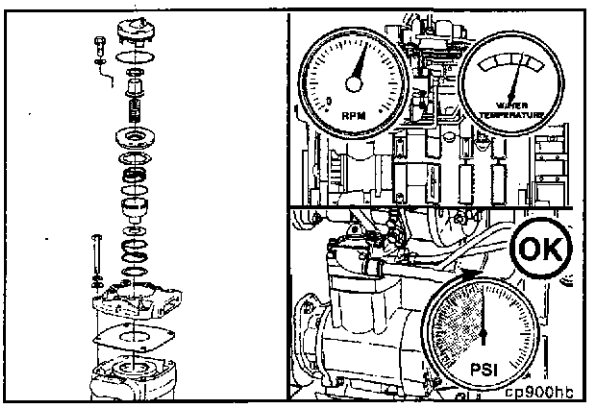
Caution: During this test, Do not exceed maximum vehicle air system pressure or 1035 kPa [150 psi] which ever is lower. Refer to the manufacturer's specifications.

Operate the engine to activate the air compressor.





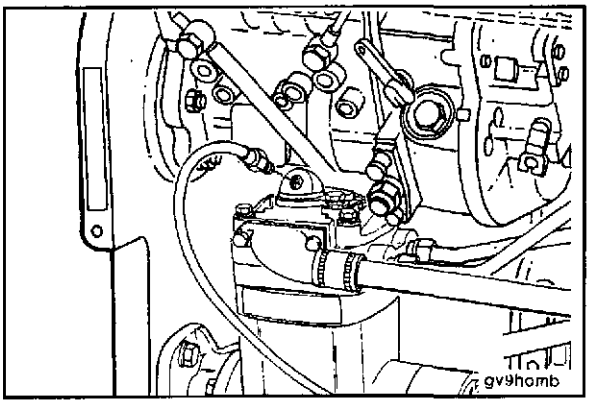
If the air compressor does **not** pump, remove the air compressor, clean and inspect the air compressor unloader valve assembly. Refer to Air Compressor Shop Manual Bulletin No. 3810242.



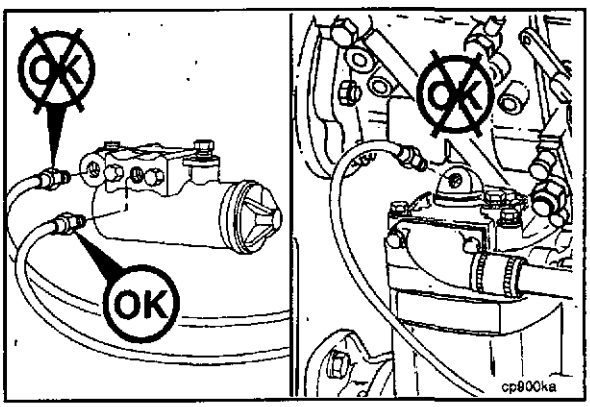
Caution: During this test, Do not exceed maximum vehicle air system pressure or 1035 kPa [150 psi] whichever is lower. Refer to the manufacturer's specifications.

Install the air compressor. Refer to Procedure 4-05.

Operate the engine and check air compressor operation with the air governor removed.



Install the air governor line to the unloader body and tighten.



Air Governor - Checking (4-04)

Air Compressor Pumps Continuously

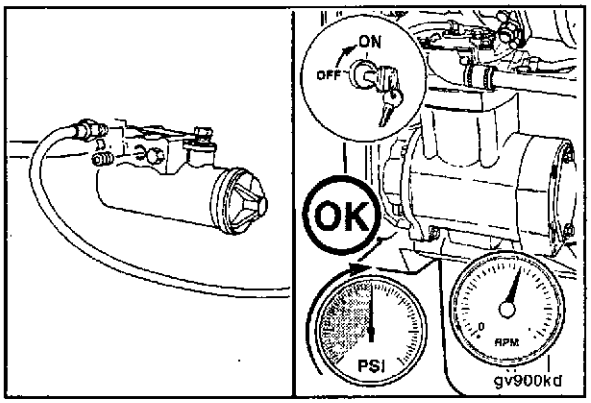
Remove the accessory air lines from the air governor unloader port.

NOTE: Do **not** disconnect the line from the air compressor unloader valve. Do **not** disconnect the reservoir air line from the air governor.

Install pipe plugs in the air governor unloader ports where accessory air lines were removed.

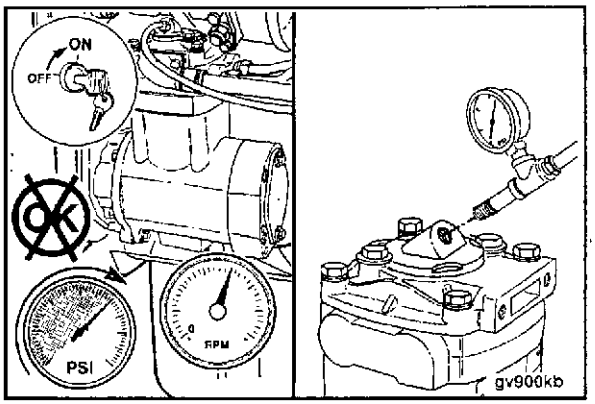
Operate the engine to activate the air compressor.

If the air compressor stops pumping (air pressure stops rising) at the governed air pressure, there is a leak in an accessory or an accessory air line. Refer to the equipment manufacturer's instructions for troubleshooting and repair.



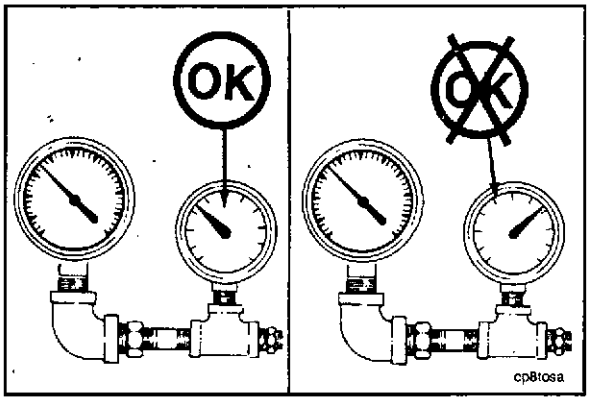
If the air compressor does **not** stop pumping (air pressure continues to rise) at the governed air pressure, connect a regulated shop air pressure line to the air compressor unloader valve port.

NOTE: Be sure the signal line from the air governor to the compressor unloader is **not** leaking.



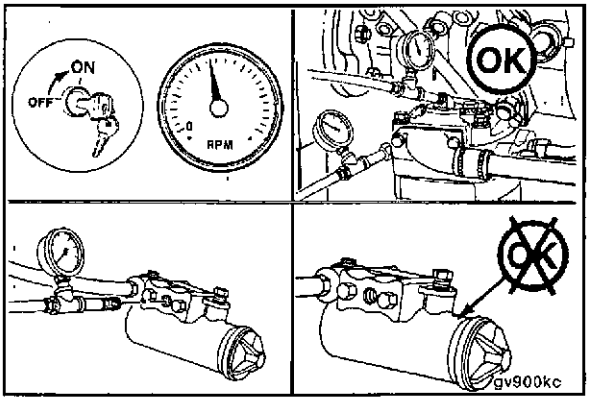
NOTE: Be sure the air pressure gauge is accurate and the supply lines and fittings are in good condition before performing any air pressure checks.

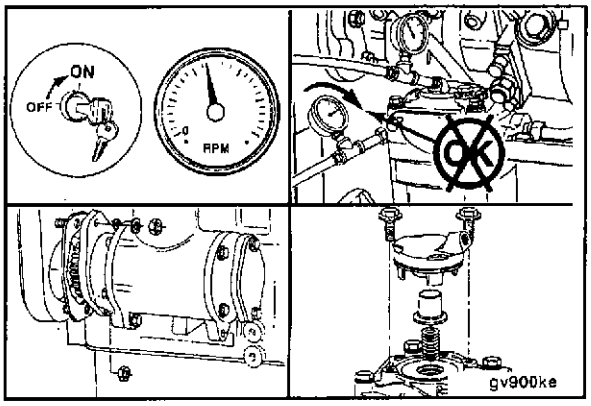
Use a master gauge of known accuracy to check the air pressure gauge.



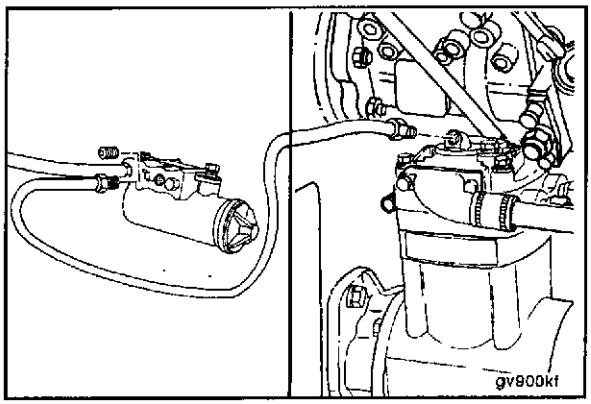
Apply 690 kPa [100 psi] air pressure to the unloader port.

If the air compressor stops pumping (air pressure stops rising) the air governor is malfunctioning and **must** be repaired or replaced. Refer to the manufacturer's instructions.





If the air compressor continues to pump (air pressure continues to rise), the unloader valve is malfunctioning and **must** be repaired or replaced. Remove the air compressor for repair. Refer to Procedure 4-05.

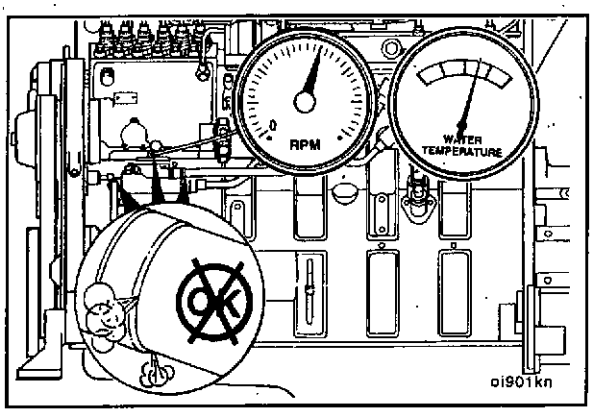


Remove the pipe plug from the governor port used for the accessory air line.

Remove the regulated shop air.

Install and tighten the accessory air line.

Connect the line between the compressor unloader valve and the air governor.



Operate the engine and check for air leaks.

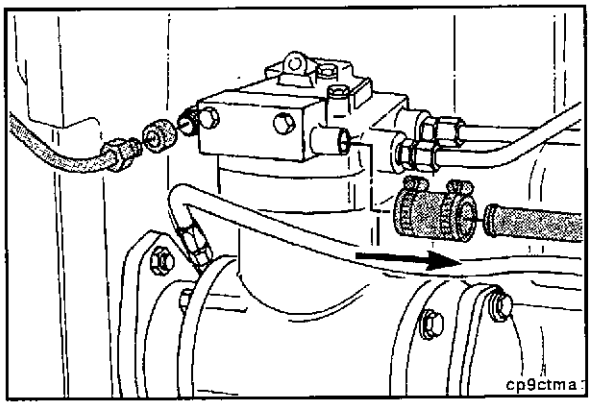
Air Compressor - Replacement (4-05)

Preparatory Steps:

- Steam clean the air compressor and dry with compressed air.
- Drain the engine coolant.

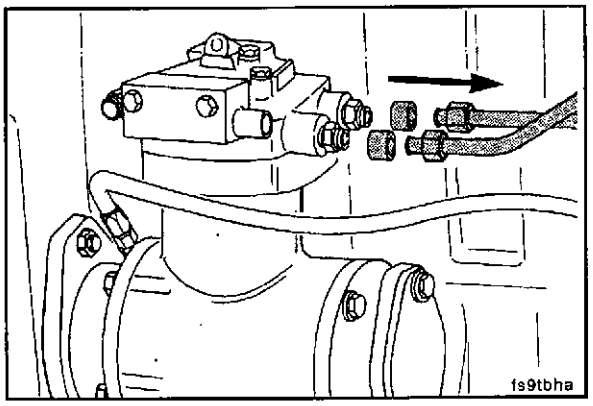
Removal

Remove the air connections from the air compressor.



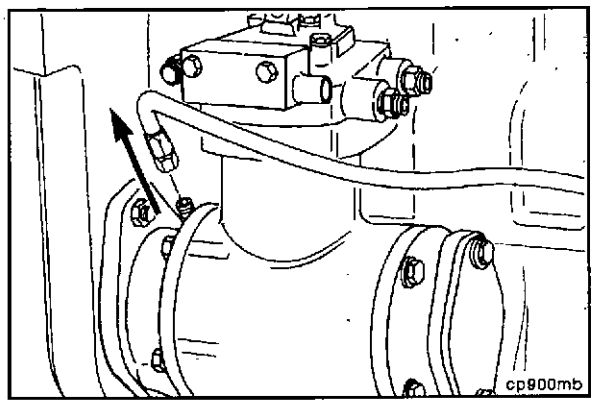
15/16 inch

Remove the coolant lines from the air compressor.



9/16 inch

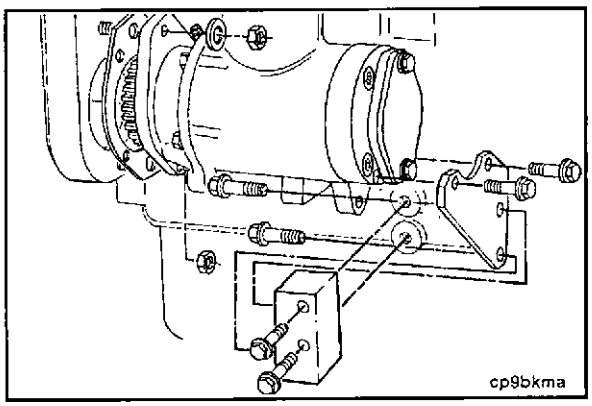
Remove the oil supply line.

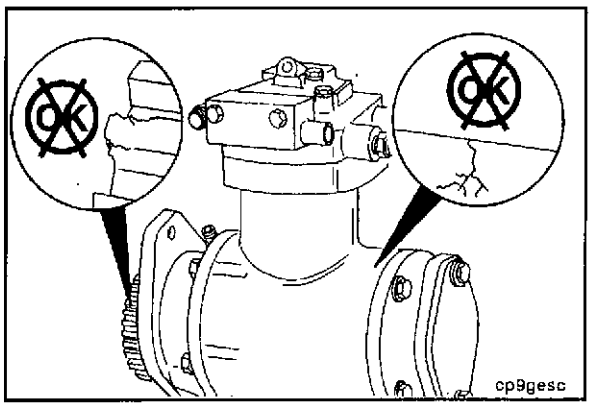


19 mm, 15 mm, 14 mm

Remove the air compressor support bracket and cap-screws.

Remove the air compressor.

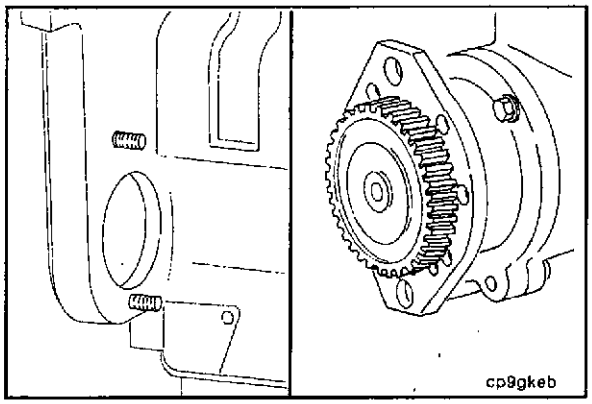




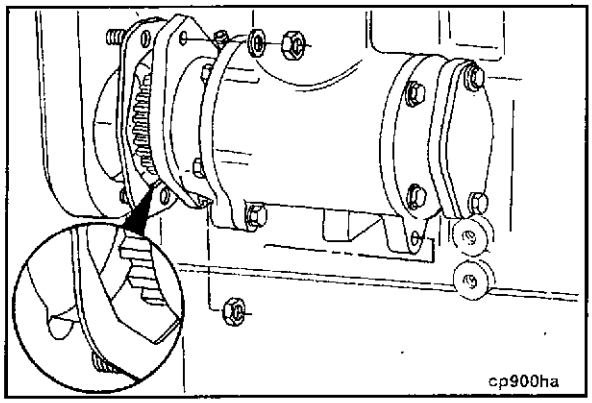
Inspection

Visually inspect the compressor housing for cracks or damage.

Visually inspect the drive gear for cracks or damage.



Be sure the gasket surfaces of the gear housing and air compressor are clean and **not** damaged.



Installation

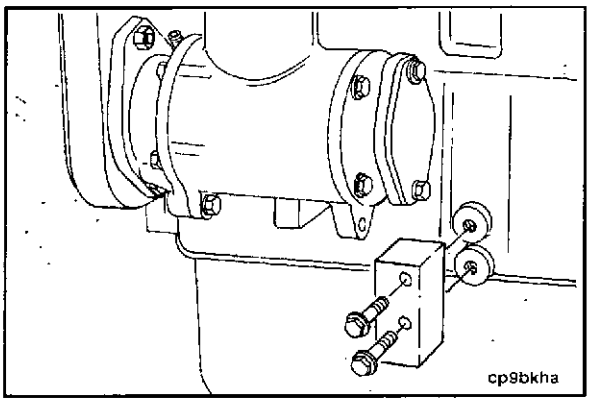
14 mm, 15 mm, 19 mm

Caution: Make sure the oil drain notch in the gear housing is not blocked. The gasket must be installed with the side marked "This Side Toward Gear Housing" is facing the gear housing.

Use a new gasket. Install the air compressor. Tighten the two mounting nuts.

Torque Value: 77 N•m [57 ft-lb]

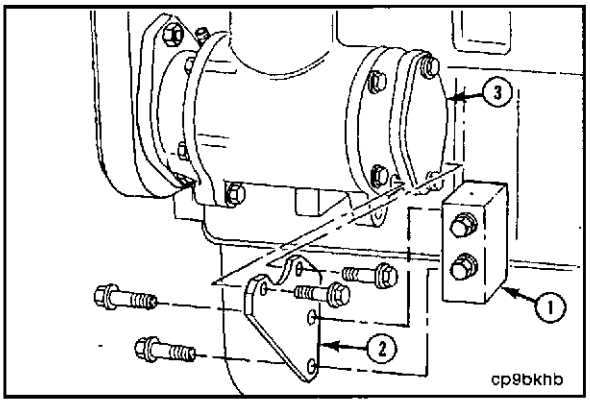
NOTE: It is **not** necessary to time the air compressor on the C Series engne.



Install the mounting spacer to the engine block, use the 40 mm long capscrews and tighten finger tight.

Install the air compressor brace (2) to the mounting spacer (1) and adapter (3) on the air compressor using the 30 mm long capscrews finger tight. Make sure the brace and spacer are aligned and no parts are in a bind. Tighten evenly to the proper torque value.

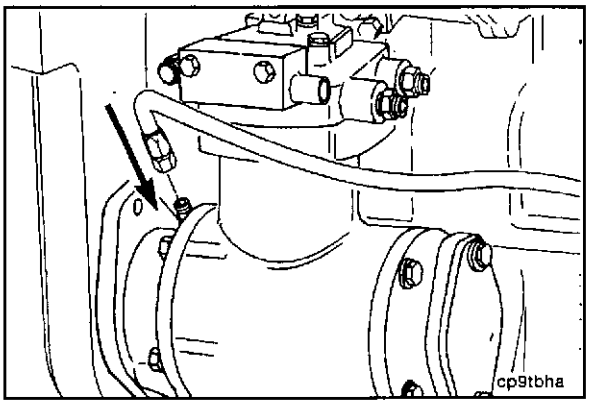
Torque Value: 43 N•m [32 ft-lb]



9/16 inch

Install the oil supply line.

Torque Value: 8 N•m [71 in-lb]

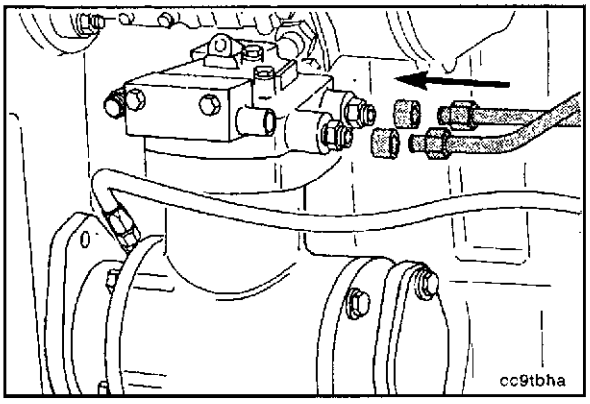


15/16 inch

Caution: If rubber grommets are used on the coolant lines, be sure they are installed carefully to prevent cuts or tears to the grommets which will cause coolant leaks.

Install the coolant lines.

Torque Value: 35 N•m [26 ft-lb]



Install and tighten the inlet and outlet connections.

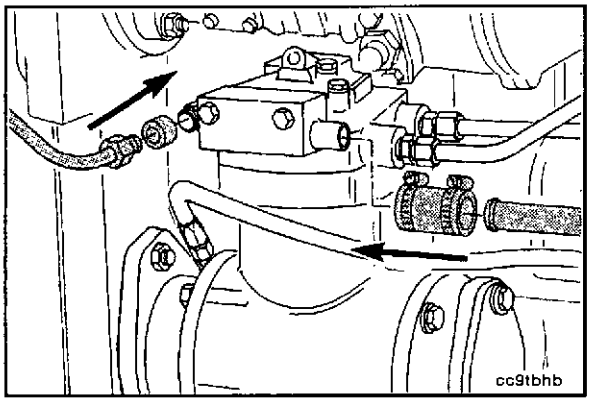
Torque Value:

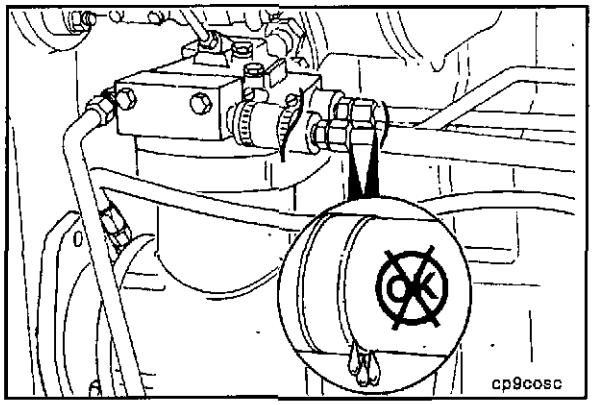
Inlet	5 N•m [48 in-lb]
*Outlet	24 N•m [18 ft-lb]

*1/2 NPT fitting in the compressor cylinder head.

NOTE: Torque value for the discharge line depends on the line size and type.

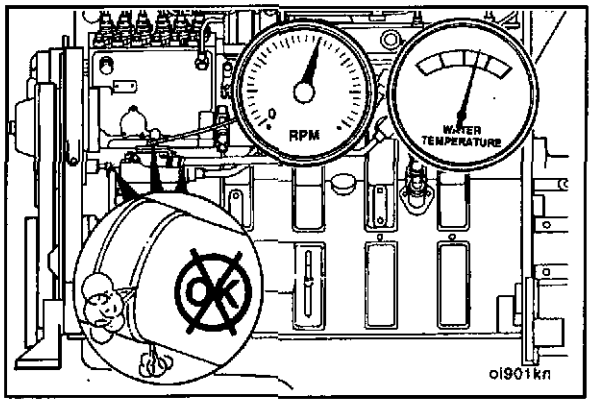
Refer to the vehicle manufacturer for the correct torque value.





Fill the engine cooling system.

Operate the engine to check for coolant leaks and proper operation.



After the system reaches governed air pressure, 690 to 862 kPa [100 to 125 psi] check for air leaks.

Section 5 - Fuel System

Section Contents

Fuel System Components and Flow

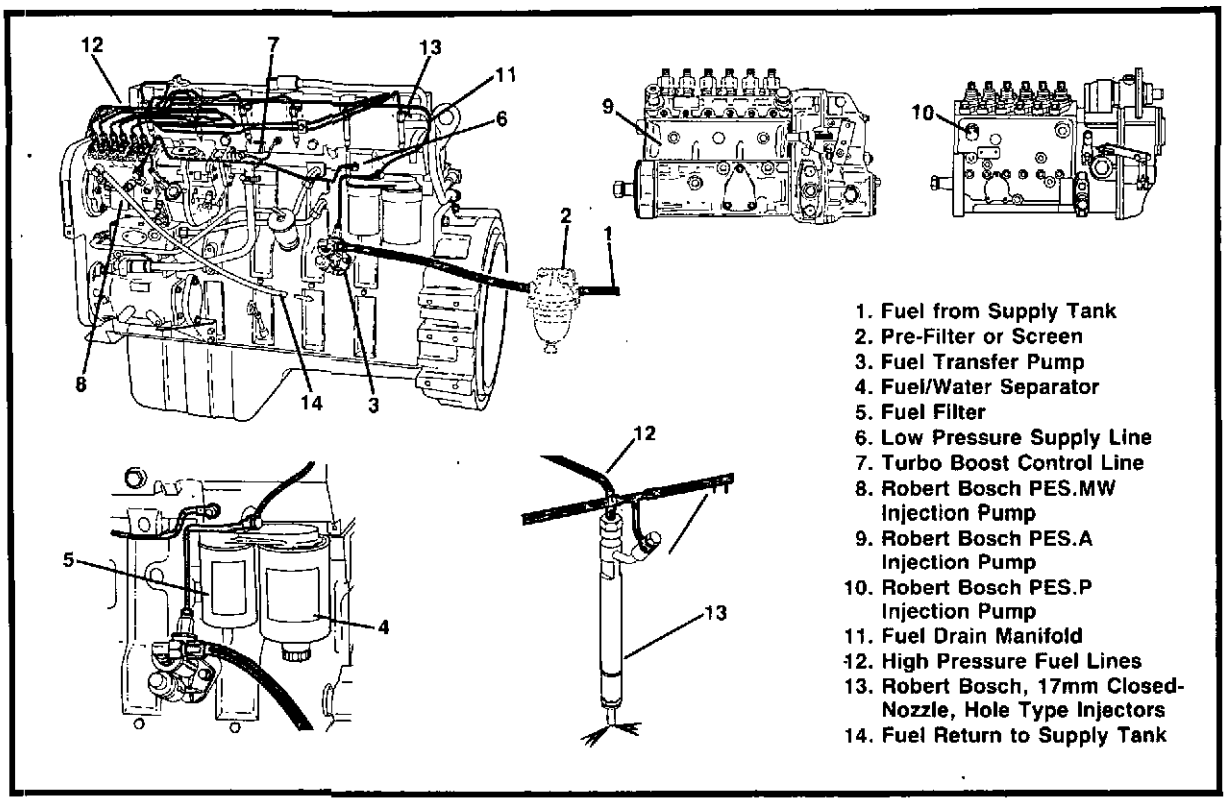
A cam-actuated fuel transfer pump provides positive fuel pressure to the fuel injection pump. Fuel flow begins as the fuel transfer pump pulls fuel from the supply tank. The system should have a pre-filter or screen to remove larger contaminants from the fuel before reaching the fuel transfer pump. The fuel transfer pump supplies low pressure fuel through the fuel filter head and filter to the fuel injection pump for Bosch A, MW, P and EP9 Nippondenso pumps.

The Robert Bosch PES6A fuel injection pump is used on all engine models. The Model PES6MW and PES6A fuel injection pumps are used on the higher rated 6CTA8.3 engines. The PES6P fuel injection pump is used on the C8.3 engines.The fuel injection pump builds the high injection pressures required for combustion and routes the fuel through high pressure fuel lines to each injector.

All C series engines use Robert Bosch 17mm closed-nozzle, hole-type injectors. When the high-pressure fuel reaches the injector, the pressure lifts the needle valve against the spring tension to allow fuel to enter the combustion chamber.

Any leakage past the needle valve enters the fuel drain manifold. The manifold routes leakage from the injectors to the fuel filter head. Fuel from the injection pump vent fitting is returned to the supply tank through the fuel return line.

Fuel System



1. Fuel from Supply Tank
2. Pre-Filter or Screen
3. Fuel Transfer Pump
4. Fuel/Water Separator
5. Fuel Filter
6. Low Pressure Supply Line
7. Turbo Boost Control Line
8. Robert Bosch PES.MW Injection Pump
9. Robert Bosch PES.A Injection Pump
10. Robert Bosch PES.P Injection Pump
11. Fuel Drain Manifold
12. High Pressure Fuel Lines
13. Robert Bosch, 17mm Closed-Nozzle, Hole Type Injectors
14. Fuel Return to Supply Tank

Fuel System Specifications

Fuel transfer pump maximum inlet restriction
6C8.3, 6CT8.3, 6CTA8.3, C8.3 ..... 100 mm Hg [4 in Hg]

Fuel transfer pump output pressure (minimum) at rated speed
High flow ..... 172 kPa [25 psi]
Low flow ..... 83 kPa [12 psi]

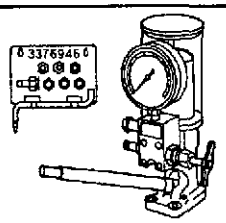
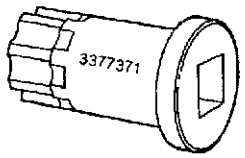
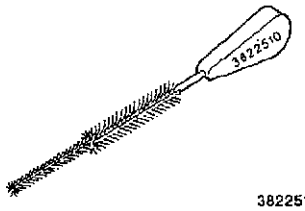
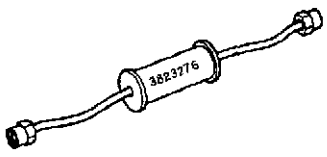
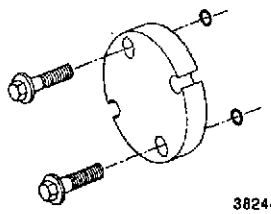
Minimum pressure to fuel pump inlet (all in-line)
High Flow ..... 138 kPa [20 psi]
Low Flow ..... 48 kPa [7 psi]

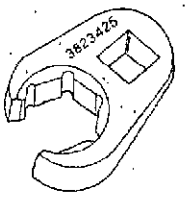
Fuel filter restriction (maximum pressure drop across filters) ..... 35 kPa [5 psi]

Fuel return restriction (maximum) ..... 518 mm Hg [20.4 in Hg]

Fuel System - Service Tools

The following special tools are recommended to perform procedures in Section 5. The use of these tools is shown in the appropriate procedure. These tools can be purchased from your local Cummins Authorized Repair Location.

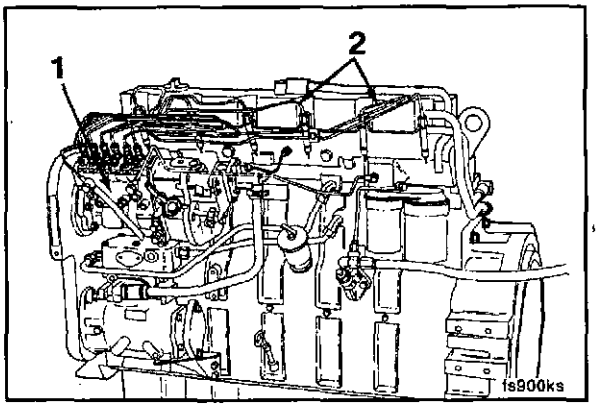
Tool No.	Tool Description	Tool Illustration
3376946	**Injection Nozzle Tester** Used to test injection nozzles.	
3376947	**Injector Nozzle Cleaning Kit** Used to clean injector nozzles.	
3377371	**Engine Barring Tool** Used to rotate the crankshaft.	
3822510	**Injector Bore Brush** Used to clean carbon from injector bores.	
3823276	**Injector Puller** Used to pull injectors.	
3824469	**Fuel Pump Gear Puller** Used to pull the fuel pump gear.	

Tool No.	Tool Description	Tool Illustration
3823425	**Wrench, Crowfoot** Used to torque high pressure fuel lines.	 3823425

Fuel System Diagnosing - Malfunctions (5-01)

The function of the fuel system is to inject a metered quantity of clean, atomized fuel into the engine cylinders at a precise time near the end of the compression stroke of each piston. The components of the system contribute to the delivery of fuel to the cylinders.

1. Fuel injection pump
2. High pressure fuel lines

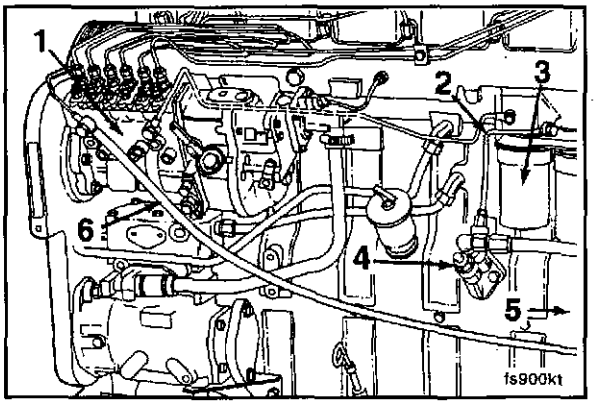


Fuel Transfer Pump

The system design requires an inlet pressure of 131 to 172 kPa [19 to 25 psi] to the fuel injection pump.

The fuel transfer pump capacity is designed to deliver pressure in excess of 138 kPa [20 psi]. The pressure relief valve controls the inlet to the pump by dumping excess fuel back to the supply tank.

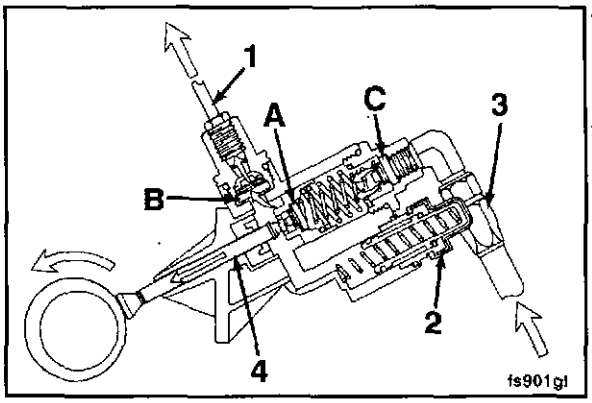
1. Fuel injection pump
2. Fuel supply line
3. Fuel filter
4. Fuel transfer pump
5. Fuel tank
6. Pressure relief valve



The fuel transfer pump is mechanically driven by a plunger running against a special lobe on the camshaft. The fuel transfer pump contains a pumping piston and check valves to control the flow of fuel, and bleed back during engine shutdown.

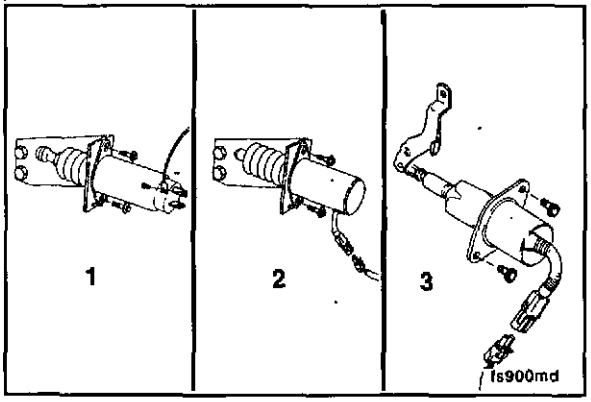
Check valves A, B, C.

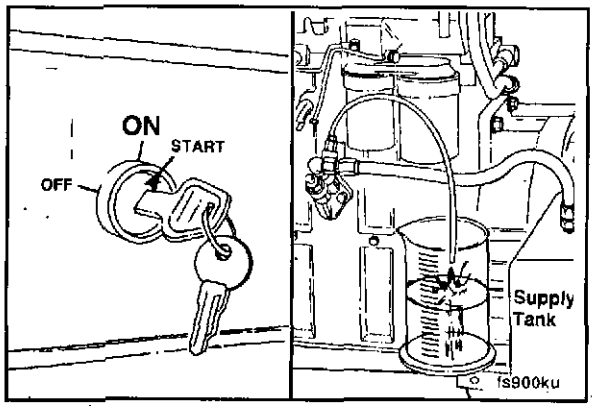
1. Low pressure supply line
2. Priming pump
3. Fuel inlet line
4. Piston



Caution: Make sure the wire to the fuel solenoid is disconnected before performing the following check. Residual fuel in the fuel injection pump may allow the engine to start.

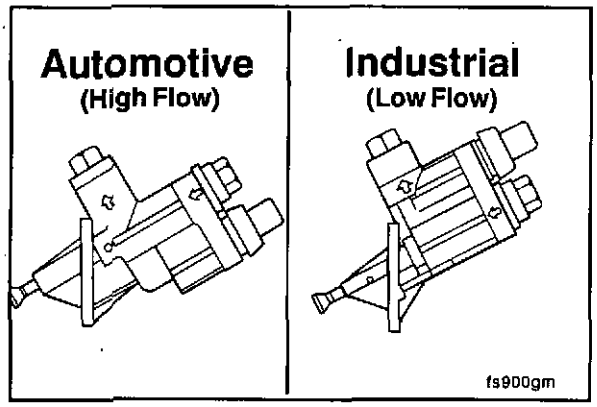
1. Synchro-start
2. Trombetta



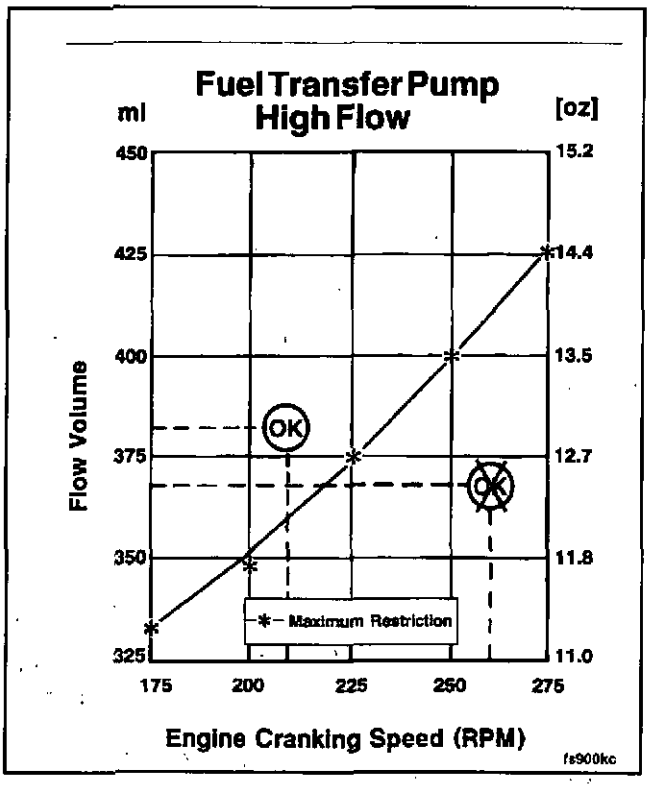


To determine if the fuel transfer pump is delivering the correct amount of fuel.

- Measure the engine cranking RPM with a tachometer.
- Measure the fuel transfer pump output for a 30 second cranking cycle.



- Use the data and the following charts to check the fuel transfer pump performance for both the automotive and industrial fuel transfer pumps.



Automotive Fuel Transfer Pump (High Flow)

Use the chart given in the illustration to find the correct flow volume specification for the automotive fuel transfer pump used with the Robert Bosch PES6P (P7100) fuel injection pump.

- Draw a straight vertical line above the measured cranking RPM.
- Draw a straight horizontal line from the measured flow volume to the engine cranking RPM vertical line to find the intersection point.
- Any intersection point above the required flow line indicates an acceptable flow.
- Any intersection point below the required flow line indicates unacceptable flow and a defective pump or too much line restriction.

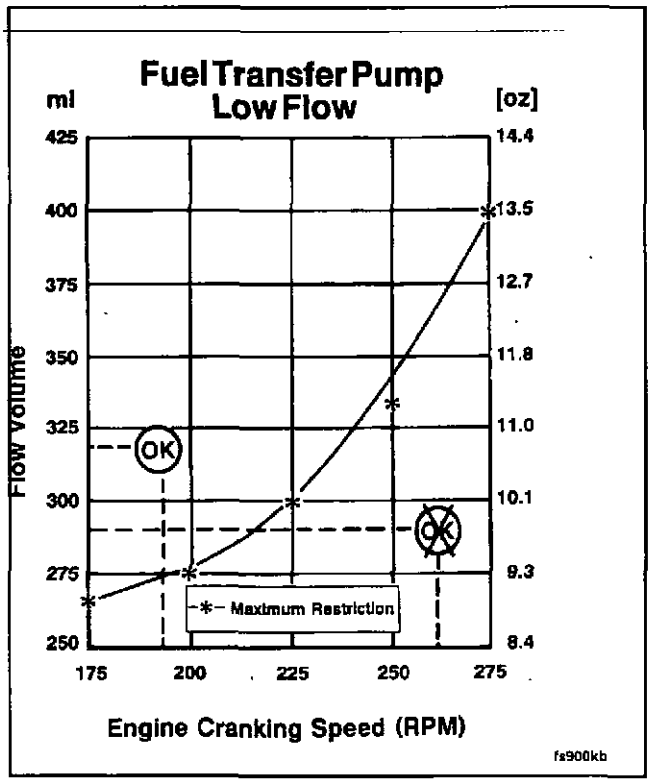
Example 1 Good Pump	Engine cranking speed Flow volume	210 RPM 380 ml [12.9 oz]
Example 2 Bad Pump	Engine cranking speed Flow volume	260 RPM 370 ml [12.5 oz]

Fuel Transfer Pump - Industrial (Low Flow)

Use the chart given in the illustration to find the correct flow volume specification for the industrial fuel transfer pump used with the Robert Bosch PES6A and MW fuel injection pump.

- Draw a straight vertical line above the measured cranking RPM.
- Draw a straight horizontal line from the measured flow volume to the engine cranking RPM vertical line to find the intersection point.
- Any intersection point above the required flow line indicates an acceptable flow.
- Any intersection point below the required flow line indicates an unacceptable flow and a defective pump or too much restriction .

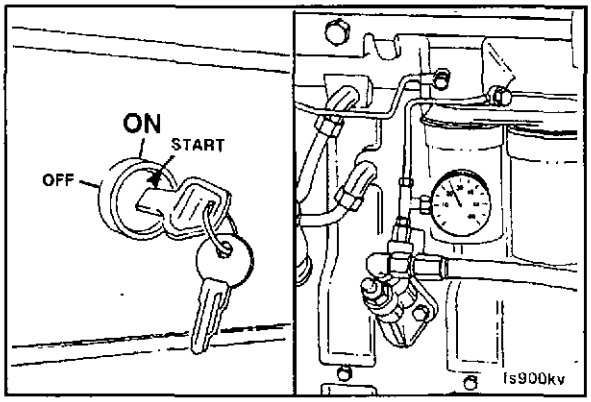
Example 1 Good Pump	Engine cranking speed Flow volume	190 RPM 320 ml [10.8 oz]
Example 2 Bad Pump	Engine cranking speed Flow volume	260 RPM 290 ml [9.8 oz]



A quick check to determine if the fuel transfer pump is delivering fuel is to measure the output pressure.

Fuel Transfer Pump Output at Rated Speed

kPa		psi
172	MIN (High Flow)	25
83	MIN (Low Flow)	12

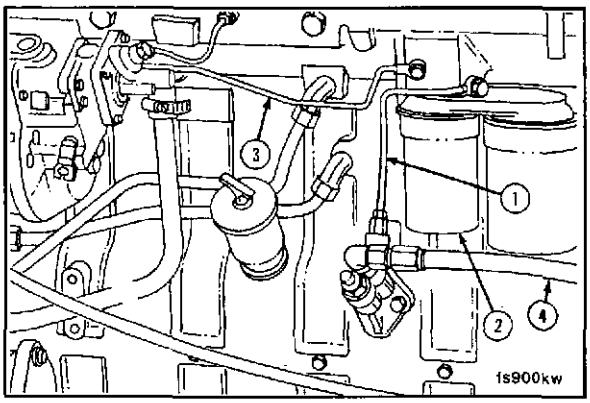


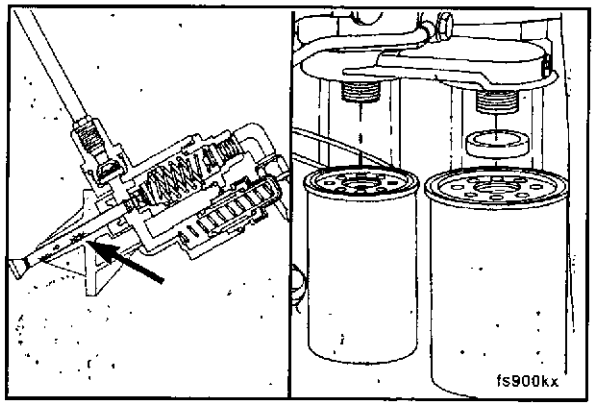
If the required volume is being delivered, look for a restriction between the fuel transfer pump and the fuel injection pump.

1. Supply line to filter
2. Filter
3. Supply line to fuel injection pump

If the required volume is **not** being delivered, measure the transfer pump inlet restriction with a vacuum gauge between the transfer pump inlet and the supply line from the tank. Refer to the fuel system specification for inlet restriction.

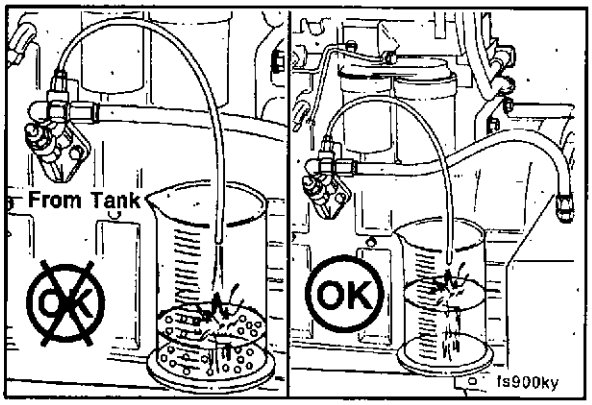
4. Inlet to transfer pump from supply tank.



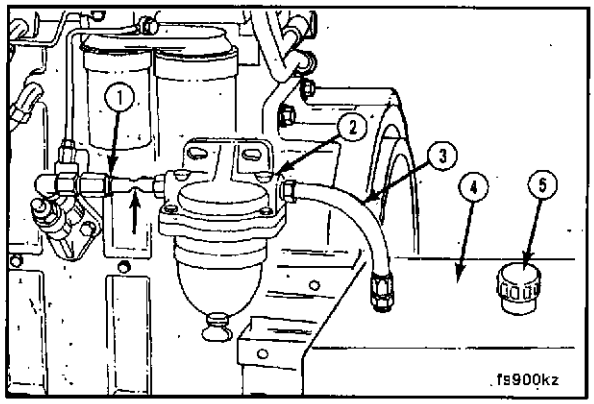


The pressure drop across the filter will increase as the filter removes contamination from the fuel. Therefore, a worn fuel transfer pump will have reduced capacity to force fuel through a dirty filter. This can cause low engine power.

Frequent filter replacement to get full power from the engine can indicate a worn fuel transfer pump.

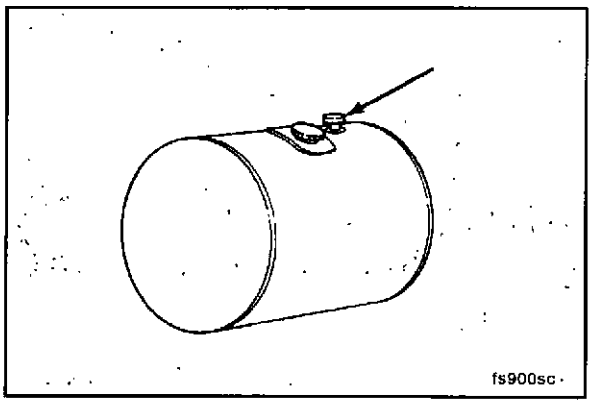


If the fuel is aerated or the volume is low, isolate the fuel transfer pump by connecting the fuel transfer pump inlet to a temporary supply and perform the same check as above.



If the fuel transfer pump delivers the required volume of fuel from a temporary supply, check for restrictions or suction leaks in the fuel circuit to the fuel transfer pump:

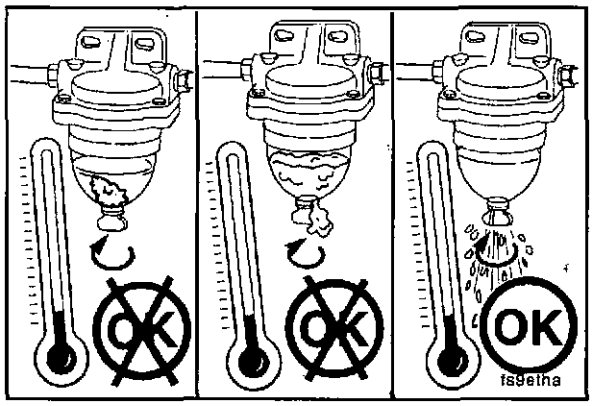
1. Supply line
2. Pre-filter
3. Supply line
4. Supply tank
5. Tank vent



Look for a plugged supply tank vent first.

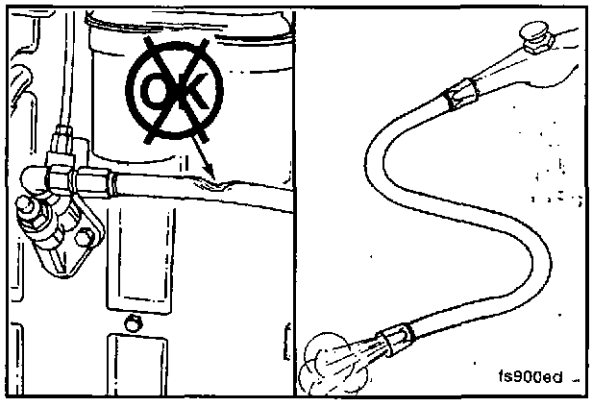
Replace or clean the pre-filter.

In cold weather look for gelled fuel blocking the pre-filter.



Look for kinks that can restrict the supply lines.

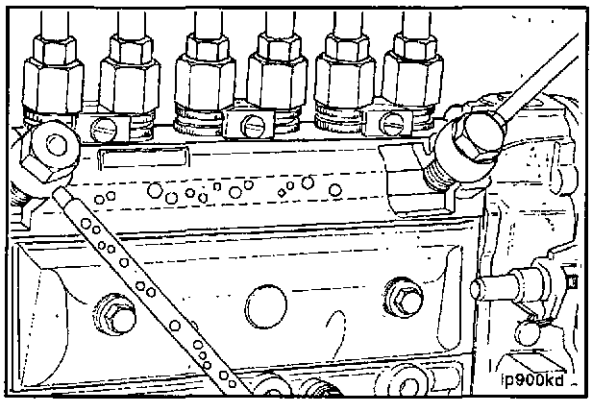
Remove and blow out supply lines.



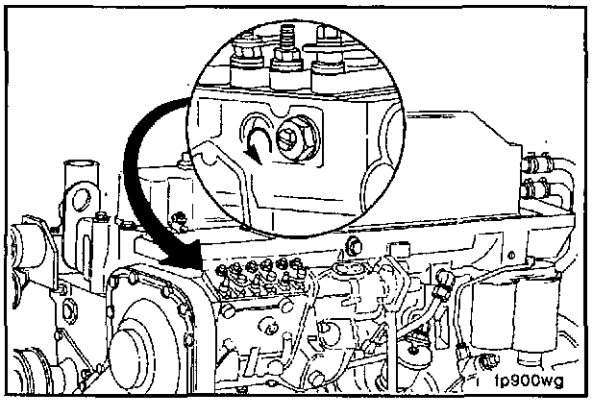
Air in the Fuel System

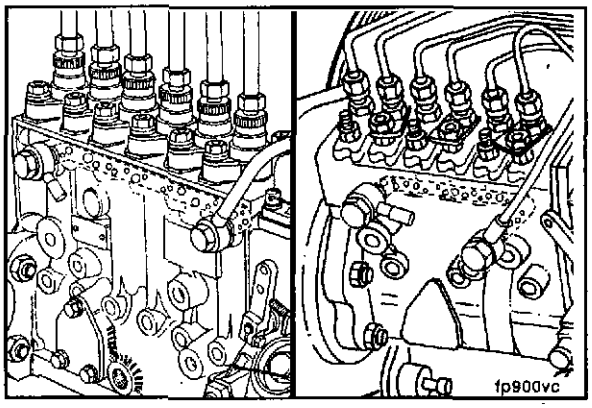
The pressure relief valve arrangement in the supply side of the fuel circuit creates a self-bleeding system on the PES6A fuel injection pump for air introduced during replacement of the supply side components.

Small amounts of air can be bled from the fuel injection pump by operating the hand primer on the fuel transfer pump or by cranking the engine.



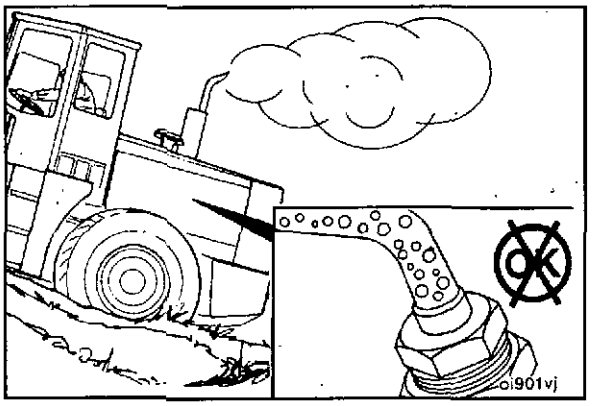
NOTE: PES6MW fuel injection pumps without the fuel drain arrangement on the engine side will require additional venting prior to initial startup, fuel injection pump replacement, or if the engine has been allowed to run out of fuel. Refer to Procedure 5-10 for the discussion.



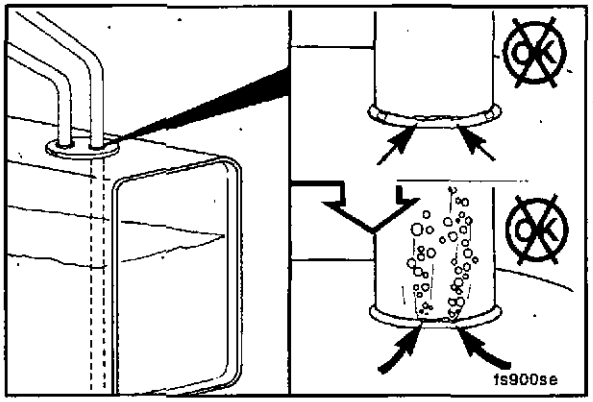


The PES6MW and PES6P fuel injection pumps equipped with engine side fuel drain arrangement creates a self-bleeding system for air introduced during replacement of the supply side components.

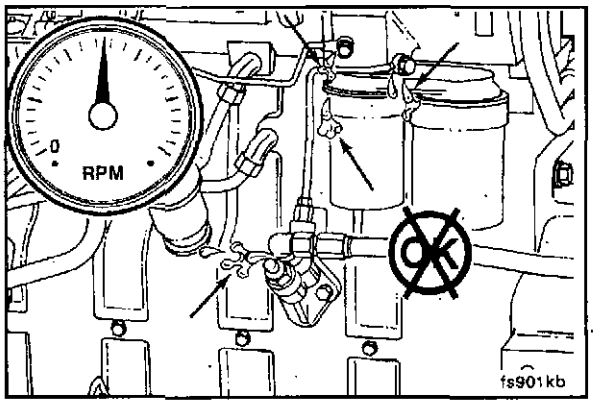
Small amounts of air can be bled from the pump by operating the hand primer on the fuel transfer pump or by cranking the engine.



Air from uncorrected leaks in the supply circuit will make the engine: difficult to start, run rough, misfire, produce low power, and can cause excessive smoke and a fuel knock.



A source, which is often overlooked, for air to enter the fuel system is between the inlet of the pre-filter and the suction tube in the tank. Fuel tanks that have the outlet fitting at the top will have a suction tube that extends to the bottom of the tank. Cracks or pin holes in the weld that joins the tube to the fitting can let air enter the fuel system.

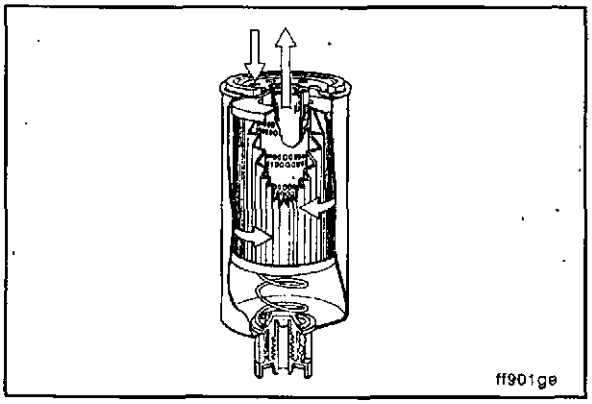


Since the fuel transfer pump provides a positive pressure through the fuel filter and supply line to the fuel injection pump, loose connections or defective seals should show as a fuel leak.

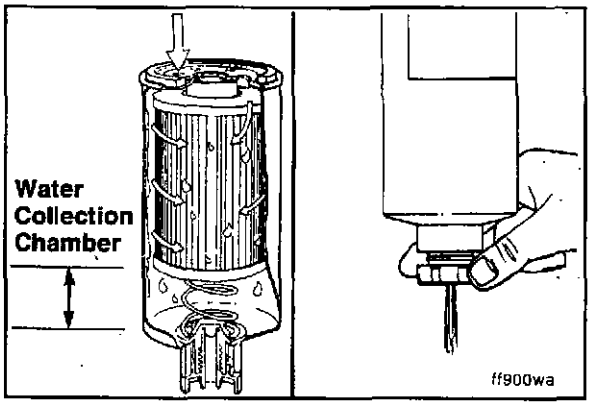
Fuel Water Separator/Filter Unit

Filtration and separation of water from the fuel is important for trouble-free operation and long life of the fuel system. Some of the clearances between the fuel injection pump parts are very close. For this reason the parts can easily be damaged by rust formation, contaminants, or loss of the lubricating film of fuel.

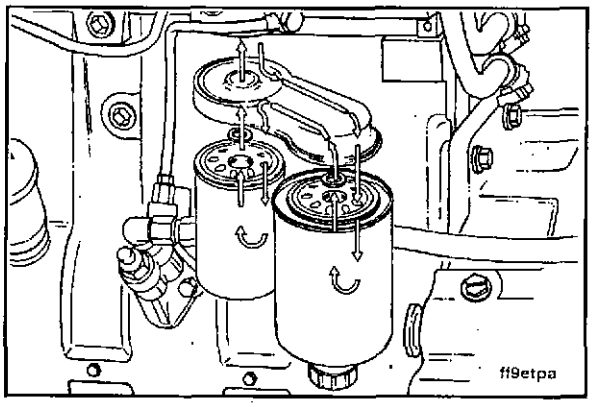
Be sure to use the correct element.



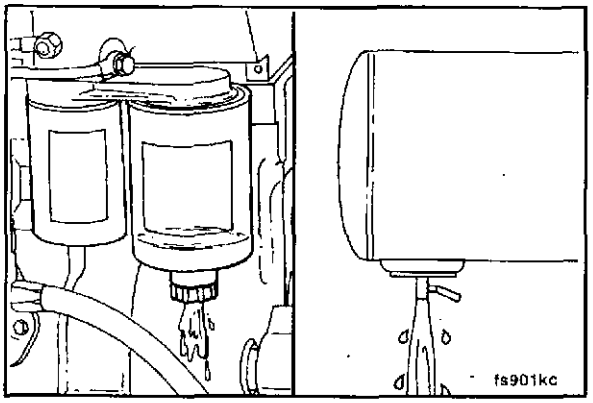
The element has a valve which must be opened daily to drain the collected water.

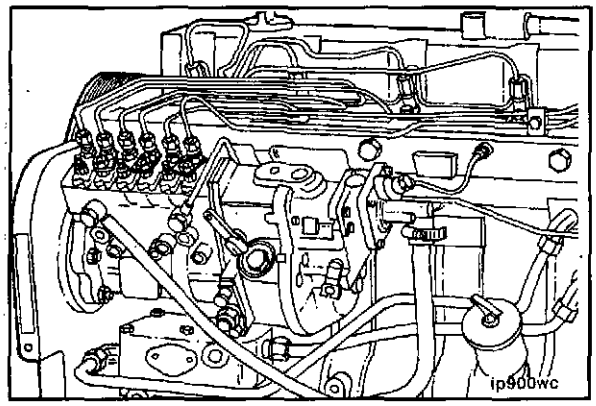


A dual water separator/filter adapter provides additional filtering capacity. The fuel flows through the adapter to a larger combination fuel water separator filter, and back to the fuel filter for final filtering.



Regular maintenance, including draining moisture from the fuel water separator/filter and supply tanks, is essential to keep water out of the fuel.

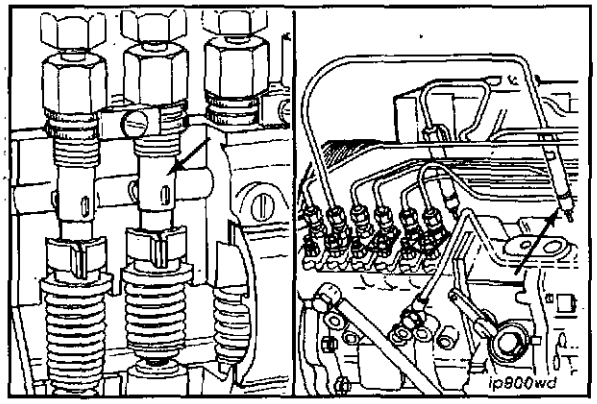




Fuel Injection Pump

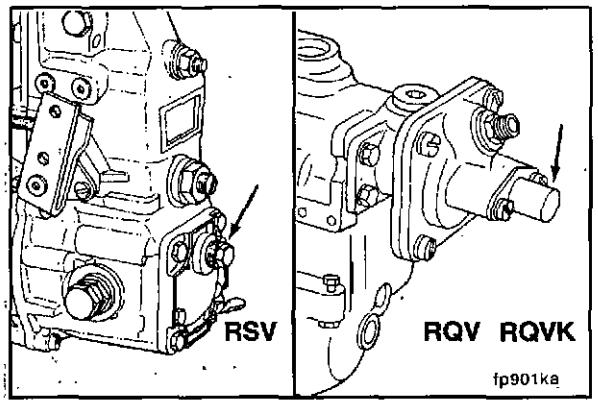
The fuel injection pump performs the three basic functions of:

1. Producing the high fuel pressure required for injection.
2. Metering the exact amount of fuel for each injection cycle.
3. Distributing the high pressure, metered fuel to each cylinder at the precise time.



Individual plungers are used in the fuel injection pumps to develop and distribute the high pressure required for injection.

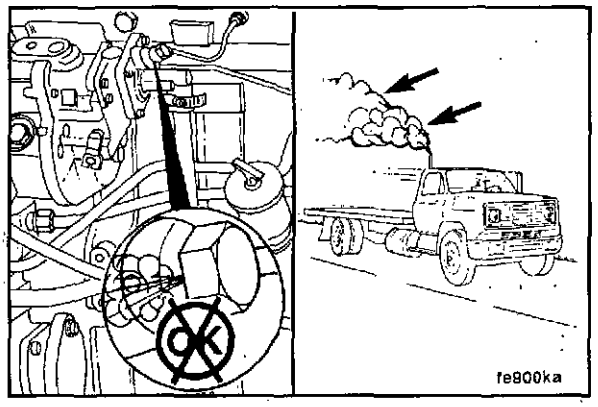
A worn or damaged plunger in the fuel injection pump will affect only one cylinder.



Governor Malfunctions

Balance between the flyweight governor and the control lever position controls the metering of the amount of fuel to be injected.

The fuel injection pump governor performance and setting can affect engine power. Special equipment and qualified personnel are required to verify governor performance. If the seals are broken on the external adjustment screw, the fuel rate may be out of adjustment.



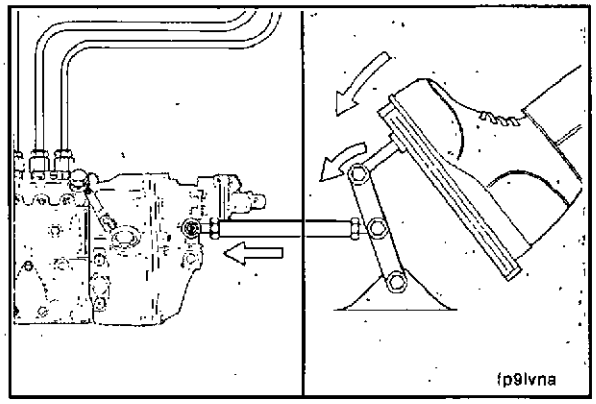
Air Fuel Control (AFC) Malfunctions

Caution: The AFC is a performance part and must not be tampered with after adjustment at the factory. Tampering with the AFC could cause poor fuel economy and failure to meet regulatory emissions laws.

The RQV and RQVK governors are equipped with an air fuel control (AFC) device to help control emissions. The AFC regulates the fuel to air mixture by sensing manifold pressure. A malfunction of the AFC can cause low power and excessive exhaust smoke under load. Leaks at the fittings or a restriction in the tube from the intake manifold to the AFC can also cause low power and excessive smoke.

Fuel Control Lever Travel and Adjustment

The amount of fuel injected and subsequently the speed and power from the engine is controlled by the fuel control lever. Restricted travel of the fuel control lever can cause low power. Always check for full travel of the fuel control lever when diagnosing a low power complaint.

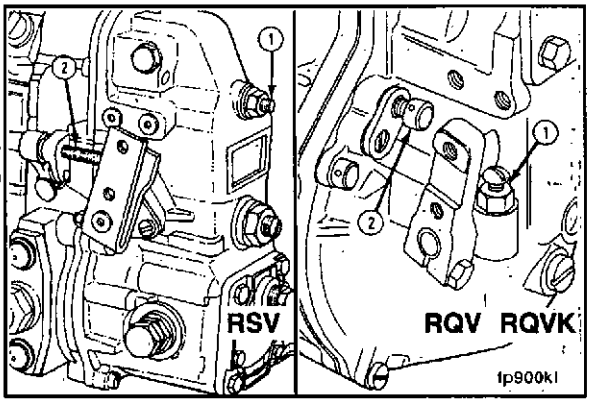


Fuel Injection Pump Idle Adjustment Screws

The idle speed adjustment screw provides a stop for the fuel control lever at low speed. The idle adjustment screw can be used to increase idle speed for accessory loading or, if required, to lower the idle speed.

The high speed adjustment screw is set at the factory and can only be adjusted at a certified fuel pump shop.

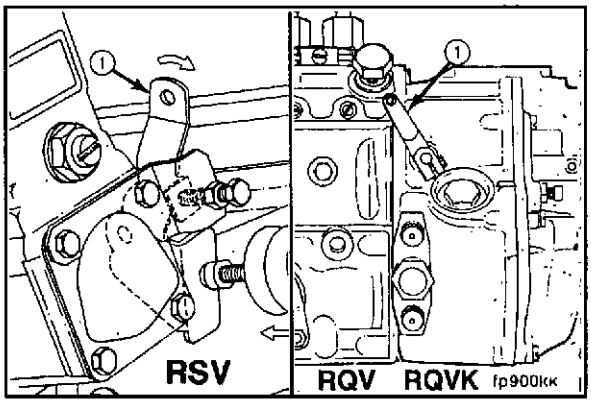
1. Idle Screw
2. High Idle Screw



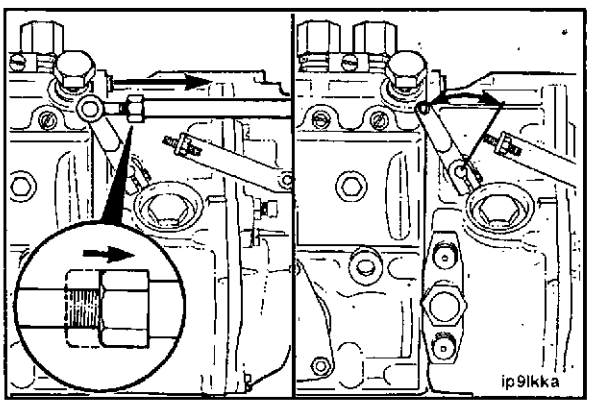
Manual Shut Down Levers

The mechanical shut down lever (1) is located on the governor. These levers are spring-loaded in the run position except the electrical direct link shutdown solenoid. Not all applications will use these manual shut down controls.

Partial actuation of the mechanical shut down lever will affect fuel flow and engine power.



Low power or the inability to stop the engine with the manual shut down control can be corrected by adjusting the cable/rod length to permit stop-to-stop lever travel.

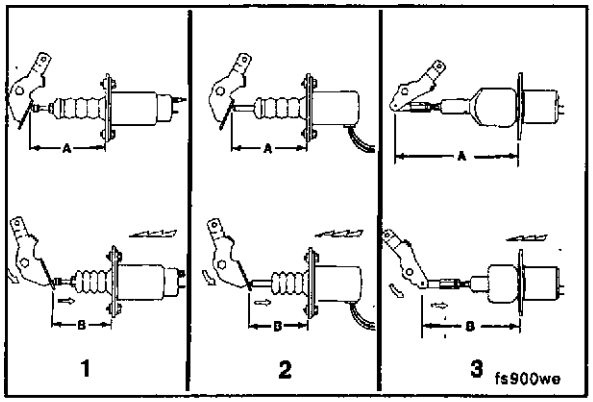


Electrical Shut Down Devices

Engines using the RSV Governor are equipped with either the Synchro-Start or Trombetta cylinder block mounted fuel shutoff solenoid to actuate the shutoff lever. Both 12 VDC and 24 VDC external fuelshut off solenoids are available.

Warning: Solenoid surface temperature can exceed 175°C [347°F] which can cause serious burns to the skin in event of contact.

NOTE: Values are taken at 20°C [68°F] and rated voltage. Minimum values are for 25 mm [1.00 inch] maximum plunger travel. As the temperature of the solenoid increases the voltage and resistance requirements increase, while the amperage requirements decrease.



The solenoid specifications are as follows:

1. Synchro-Start Cylinder Block Mount

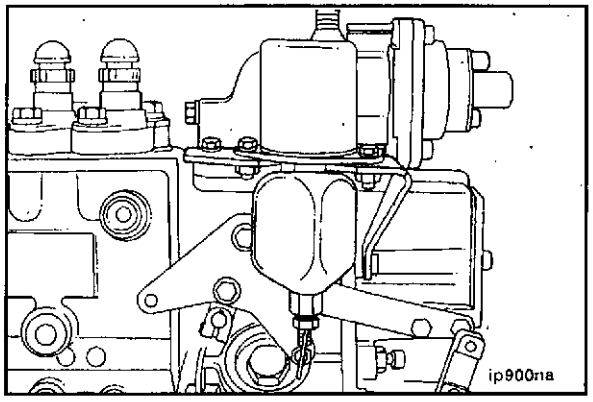
Battery	Min Voltage		Resistance Min Ohms		Min Ampres	
Voltage	Pull-in	Hold-in	Pull-in	Hold-in	Pull-in	Hold-in
12	7.5	3.0	0.28	19.9	44	0.61
24	15.0	6.0	1.04	79.9	23	0.30

2. Trombetta Cylinder Block Mount

Battery	Min Voltage		Resistance Min Ohms		Min Ampres	
Voltage	Pull-in	Hold-in	Pull-in	Hold-in	Pull-in	Hold-in
12	10	4.5	0.17	13.6	58.8	0.33
24	20	9.0	0.68	50	29.4	0.18

3. Direct Link, Cylinder Block Mount

Battery	Min Voltage		Resistance Min Ohms		Min Amperes	
Voltage	Pull-in	Hold-in	Pull-in	Hold-in	Pull-in	Hold-in
12	5.3	2.8	0.22	11.1	55	1.1
24	10.6	5.6	0.82	41.3	29	0.5



Engines using the Robert Bosch PES6P fuel injection pump with the RQVK governor are equipped with the Synchro-Start fuel shutoff solenoid to actuate the shutoff lever. Both 12 VDC and 24 VDC external fuel shutoff solenoids are available.

The solenoid specifications are as follows:

Synchro-Start Governor Mount

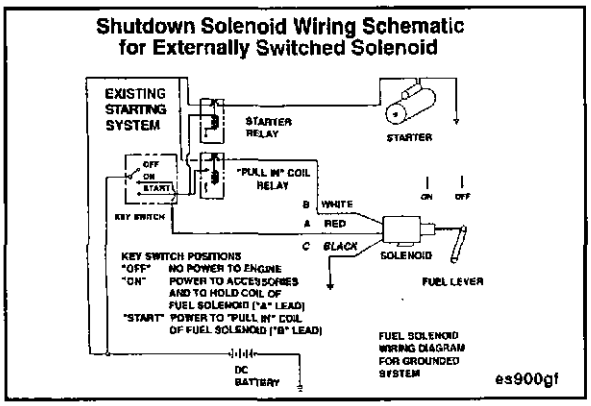
Battery	Min Voltage		Resistance Min Ohms		Min Ampres	
Voltage	Pull-in	Hold-in	Pull-in	Hold-in	Pull-in	Hold-in
12	6.5	4.0	0.22	11.1	55	1.10
24	13.0	8.0	0.82	41.3	29	0.60

Wiring Guidelines:

Refer to the chart below to find the correct gauge size and length of continuous wire for the white (pull-in) wire, which connects to the solenoid wiring. The black (ground) wire **must** be the same gauge as the white (pull-in) wire regardless of its length.

Wire Length			
		Ft. MAX	
cm	Gauge	12V	24V
0 to 137	14	5	9
0 to 213	12	9	14
0 to 335	10	14	23

NOTE: 14 gauge wire is required for the red (hold-in) wire, which connects to the "Run" terminal on the ignition switch.

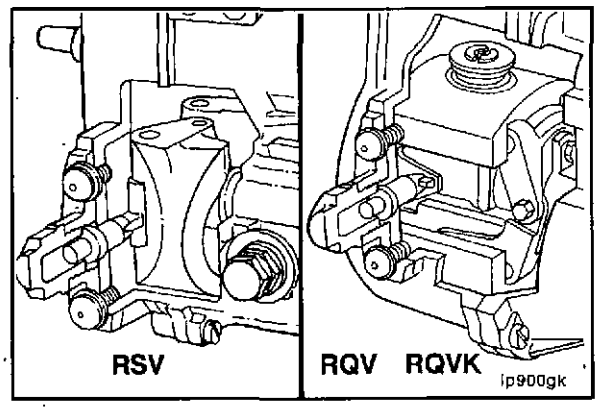


Fuel Injection Pump Timing

Fuel injection pump-to-engine timing is extremely critical. Fuel injection pump timing that is off by only a few crankshaft degrees will cause:

1. Poor performance -- starting and power
2. Excessive smoke and emissions
3. Poor fuel economy
4. Excessive cylinder pressure

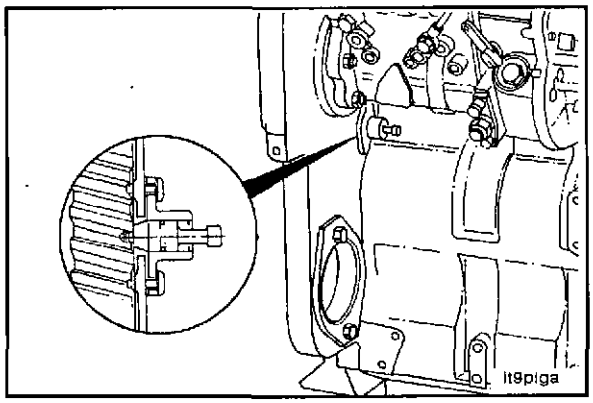
The governors have a provision for locking the fuel injection pump shaft at a position corresponding to top dead center (TDC) for No. 1 cylinder. New and reconditioned fuel injection pumps should be received with the shafts locked in this position.

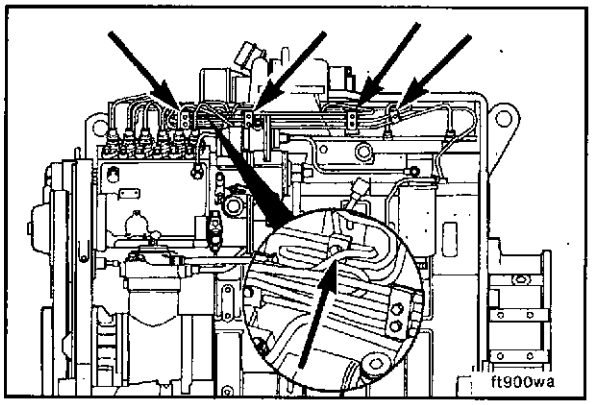


The engine is equipped with an engine timing pin to locate TDC for No. 1 cylinder.

If the timing pin is incorrectly located on the gear housing, the timing procedure will not make sure that the fuel injection pump is timed correctly.

The timing pin assembly is aligned to the gear housing to correspond to a hole in the back side of the camshaft gear when No. 1 cylinder is at TDC. If the gear housing or timing pin assembly is removed, it will be necessary to relocate it (refer to Procedure 7-07).

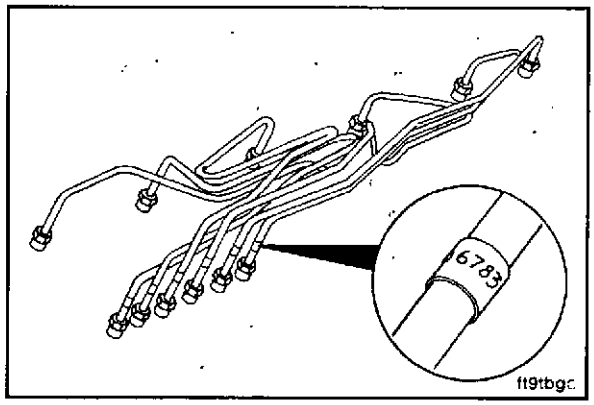




High Pressure Fuel Lines

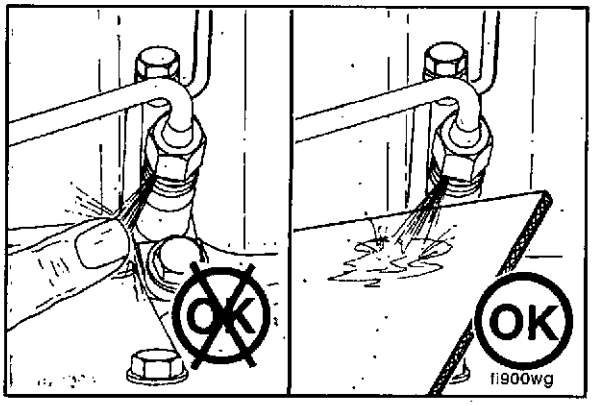
The high pressure fuel lines are designed and manufactured to deliver fuel at injection pressure to the injectors. The high pressure pulses will cause the lines to expand and contract during the injection cycle.

The high pressure lines must be clamped securely and routed so they do not contact each other or any other component.



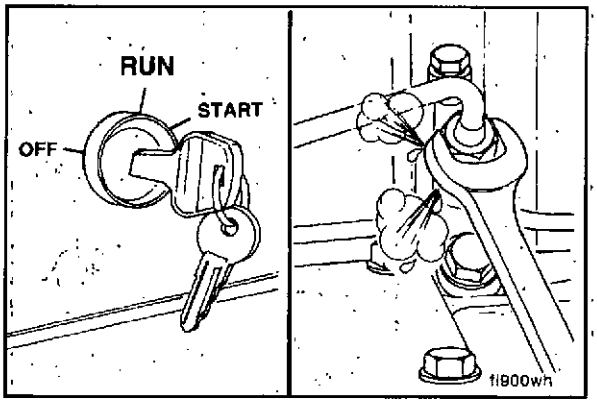
The length, internal size and rigidity of the lines is critical to smooth engine operation. An attached metal tag is used to identify each line with a part number.

Do not weld or substitute lines; use only the specified part number for the engine.



Warning: The pressure of the fuel in the line is sufficient to penetrate the skin and cause serious bodily harm.

Use cardboard to check for cracks and leaks. With the engine running, move the cardboard over the fuel lines and look for fuel spray on the cardboard. Fuel leaks can cause poor engine performance.



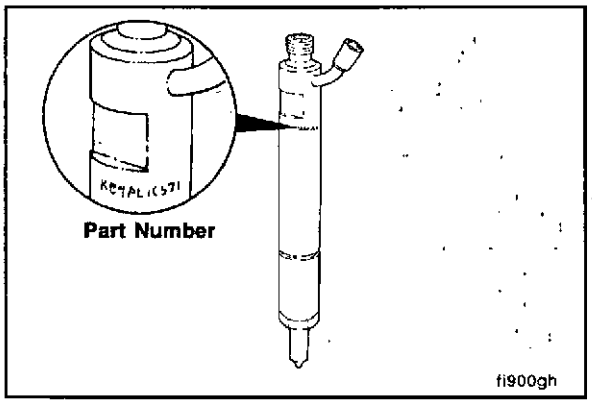
Bleed the air from the high pressure line at the fitting that connects the injector. Bleed one line at a time until the engine runs smooth.

If the air **cannot** be removed, check the fuel injection pump and supply line for suction leaks.

Injectors

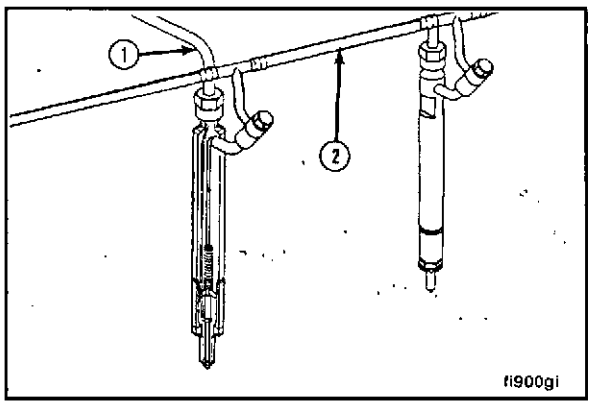
All engines use Robert Bosch, 17mm closed nozzles, hole-type injectors. However, the injectors can have different part numbers for different engine ratings. The last four digits of the Cummins part number are used to identify the injectors.

Use only the specified injector for the engine.



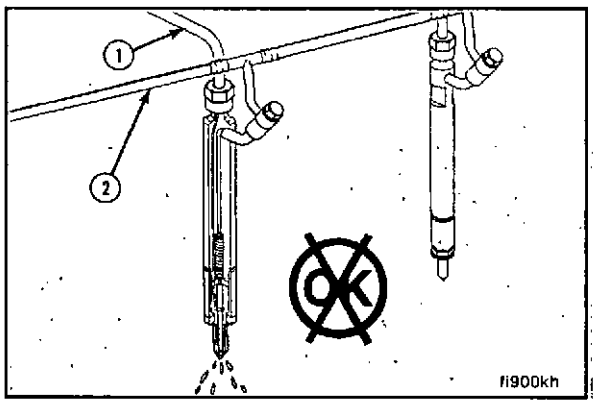
During the injection cycle, high pressure from the fuel injection pump rises to the operating (pop) pressure which causes the needle valve in the injector to lift. Fuel is then injected into the cylinder. A shimmed spring is used to force the needle valve closed as the injection pressure drops below the pop pressure to seal off the nozzle after injection.

1. High pressure fuel line
2. Fuel drain manifold



Failure of the needle valve to lift and close at the correct time or the needle valve stuck open can cause the engine to misfire and produce low power. Fuel leaking from the open nozzle can cause a fuel knock, poor performance, smoke, poor fuel economy and a rough running engine.

1. High pressure fuel line
2. Fuel drain manifold

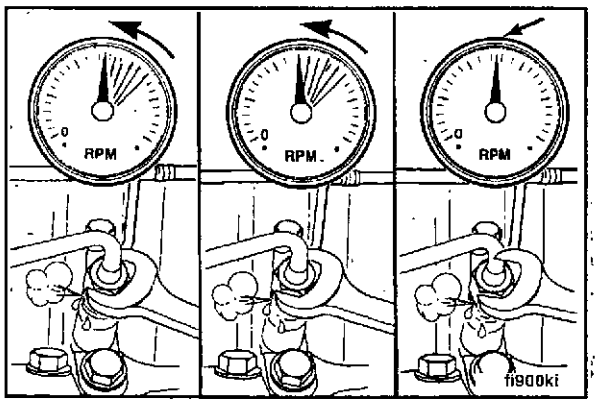


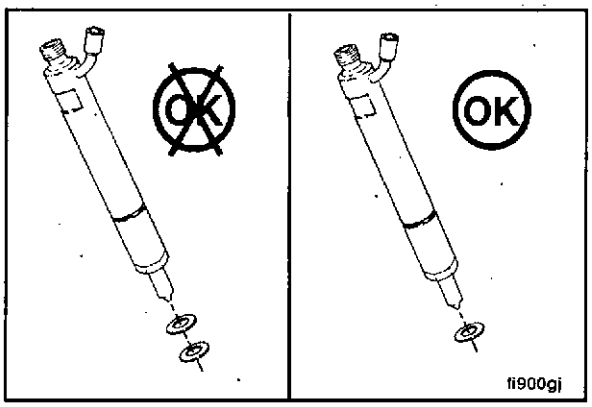
To find which cylinder is misfiring, operate the engine and loosen the fuel line nut at one injector and listen for a change in engine speed.

A drop in engine speed indicates the injector was delivering fuel to the cylinder.

Check each cylinder until the malfunctioning injector is found.

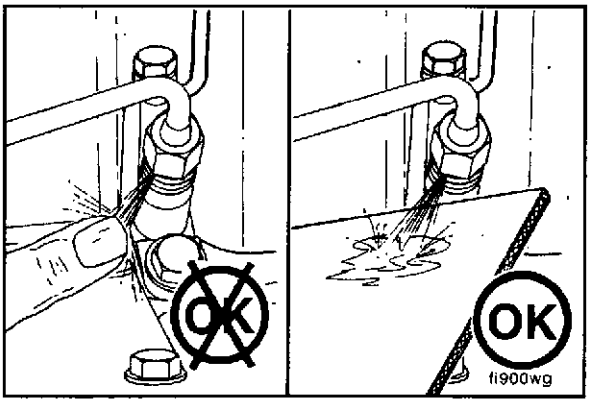
Be sure to tighten the fuel line nut before proceeding to the next injector.





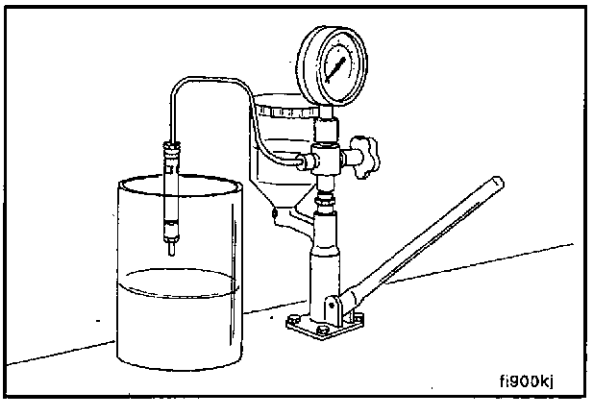
Remove the malfunctioning injector to test or replace it.

Check for an extra sealing washer on the injector.

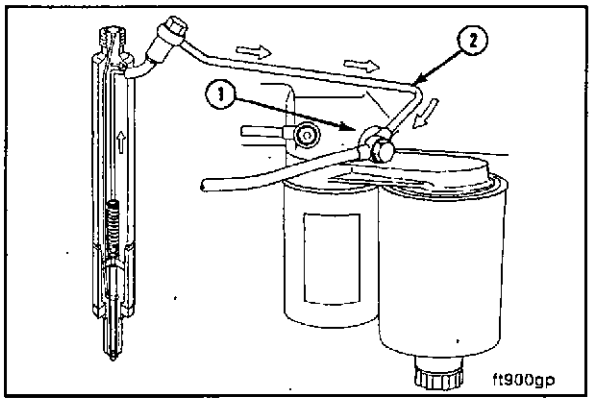


Warning: The pressure of the fuel in the line is sufficient to penetrate the skin and cause serious bodily harm.

If the engine continues to misfire, use cardboard to check for fuel leaks in the high pressure lines. With the engine running, move the cardboard over the fuel lines and look for fuel spray on the cardboard. Fuel leaks can cause poor engine performance.



Carbon build up in the orfices in the nozzle will also cause low power from the engine. Remove and check the spray pattern or replace the injectors.



Fuel Drain Manifold

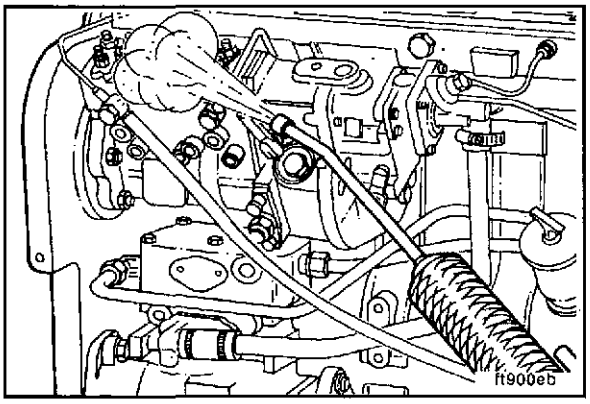
The fuel system is designed to use fuel to cool and lubricate the fuel injection pump plungers and injectors. Fuel is continually vented from the fuel injection pump and a small amount of fuel leaks by the injector needle valve during injection. This fuel is returned to the fuel filter head (1) by the fuel drain manifold (2).

Low Pressure Fuel Line - Replacement (5-02)

Preparatory Step:

Clean debris from fittings.

NOTE: Thoroughly clean all fittings and components before removal. Make sure that the debris, water steam or cleaning solution does **not** reach the inside of the fuel system.



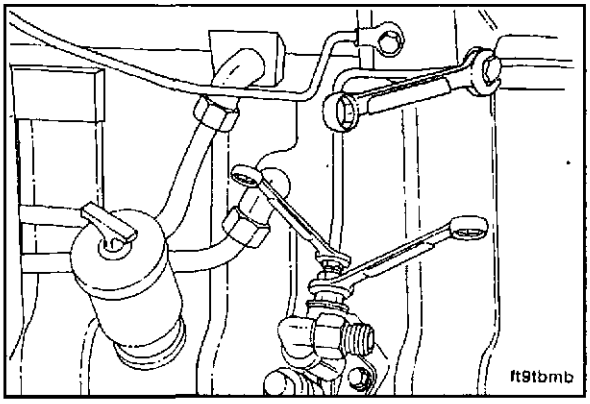
Removal and Installation

14 mm, 17 mm, 20 mm

Disconnect the fuel line from the fuel transfer pump and filter head. Use two wrenches to disconnect the line from the fuel transfer pump.

Install the fuel line to the fuel transfer pump and filter head. Use two wrenches to tighten the connection to the fuel transfer pump. Do **not** over torque, fuel leak may occur.

Torque Value: 24 N•m [18 ft-lb]



Fuel Filter Head Adapter - Replacement (5-03)

Preparatory Steps:

Clean debris.

Removal and Installation

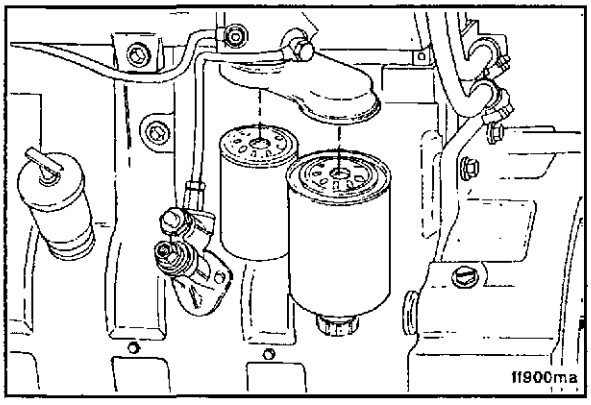
24 mm

Remove the fuel filters.

Remove the retaining nut, fuel filter head adapter and sealing washers.

Install in the reverse order of removal.

Torque Value: 32 N•m [24 ft-lb]

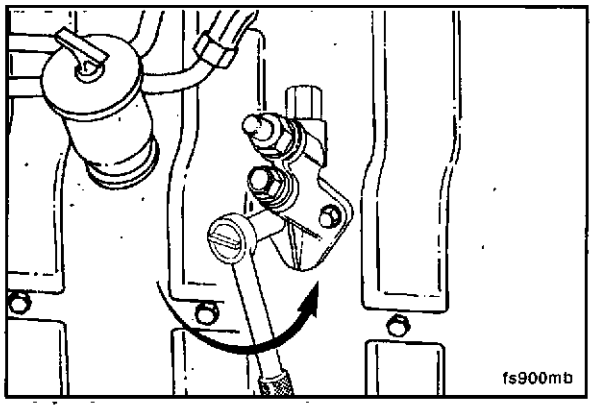


Fuel Transfer Pump - Replacement/ Rebuild (5-04)

Preparatory Steps:

Clean debris.

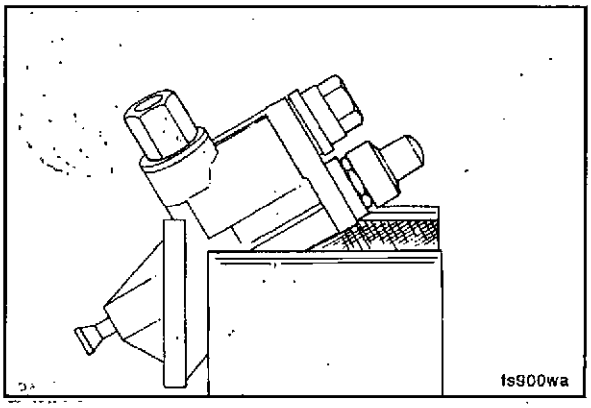
Disconnect the fuel lines.



Removal

10 mm

Remove the fuel transfer pump.



Rebuild

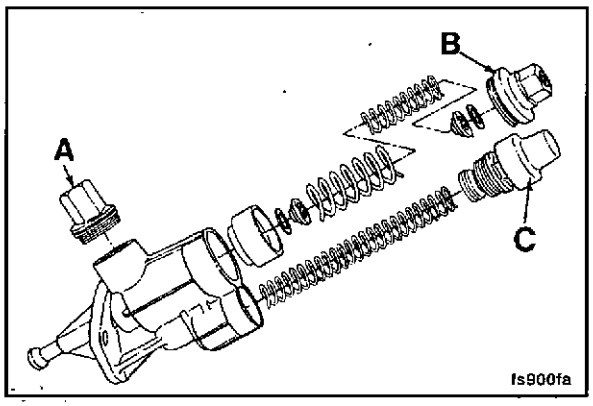
20 mm, 26 mm Wrench

Caution: The hand-prime fitting and inlet fitting are spring loaded. Sudden removal of these two fittings can cause personal injury.

Secure the fuel transfer pump in a vise, taking care not to damage the pump housing.

Remove the rubber boot from the hand-prime fitting.

Remove the three illustrated fittings.



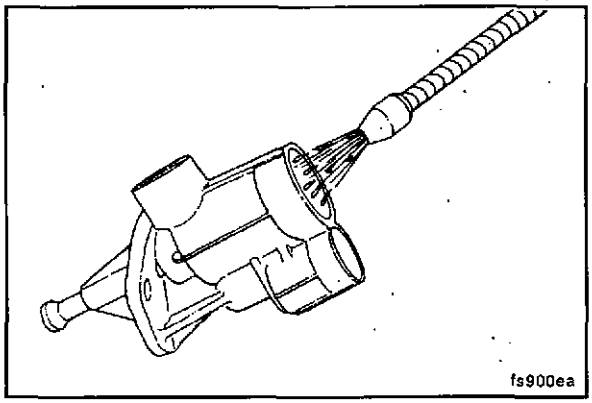
Remove all internal components of the fuel transfer pump.

NOTE: Make sure the check valve gaskets are removed from the inlet fitting.

(A) Outlet Fitting
(B) Inlet Fitting
(C) Hand Primer Fitting

Fuel Transfer Pump Cleaning

Thoroughly flush the fuel transfer pump with a cleaning solution to remove any debris.



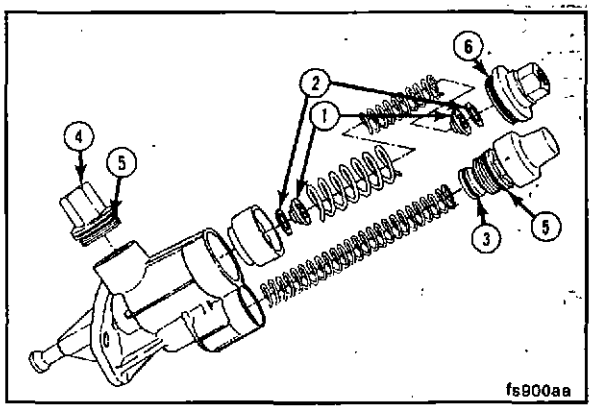
Assembly

20 mm, 26 mm Wrench

Assemble the fuel transfer pump with the new components supplied in the rebuild kit.

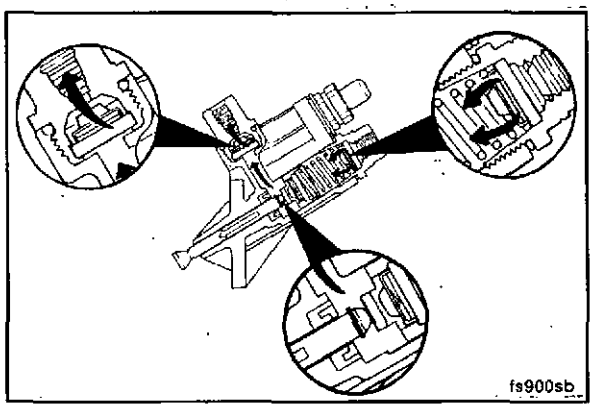
1. Check valves
2. Check valve gaskets
3. O-ring seal
4. Outlet fitting/check valve
5. *O-ring seal (25 mm)
6. *O-ring seal (30 mm) or (25 mm)

* O-ring required is determined by the size of the inlet fitting. Discard unused o-ring.



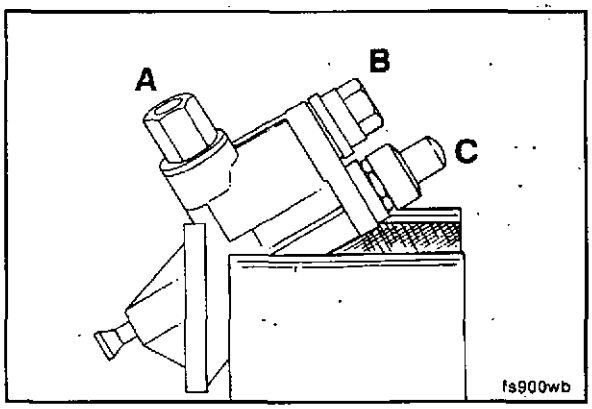
NOTE: Extreme caution must be used to make sure the check valves are installed to open in the direction of the fuel flow.

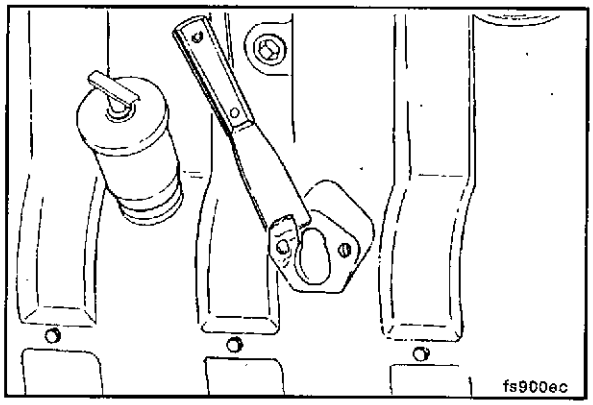
Improper installation of the check valves will result in low power from the engine.



Place the fuel transfer pump in a vise and torque the fittings to the following values:

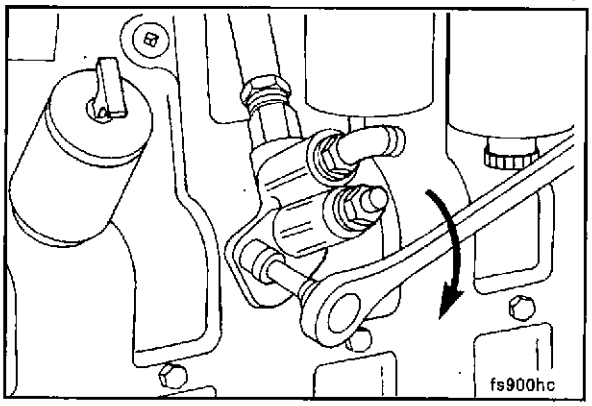
(A) Outlet Fitting	30 N•m [22 ft-lb]
(B) Hand-Prime Fitting	30 N•m [22 ft-lb]
(C) Inlet Fitting	30 N•m [22 ft-lb]





Cleaning

Clean the mounting surface on the cylinder block.



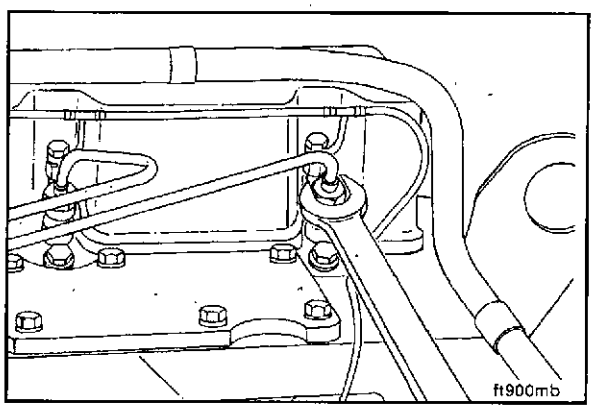
Installation

10 mm

Install the fuel transfer pump and a new gasket.

Connect the fuel lines.

Torque Value: 24 N•m (18 ft-lb]



High Pressure Fuel Lines - Replacement (5-05)

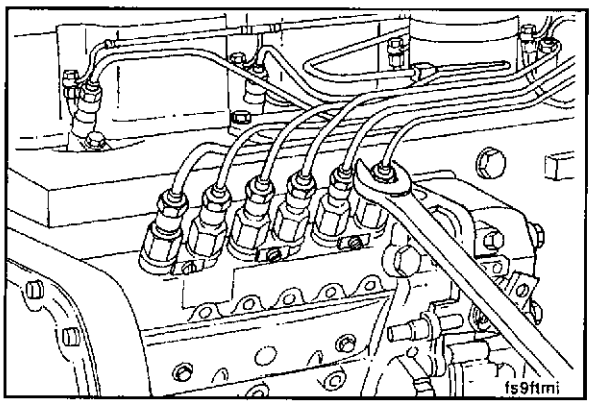
Removal

10 and 17 mm (PES6A and PES6MW Fuel Injection Pump)
10 and 19 mm (PES6P Fuel Injection Pump)

Clean debris from around the fuel lines.

NOTE: If individual lines are to be replaced, remove the vibration isolators from the set of lines containing the line to be replaced.

Disconnect the line(s) from the injectors.



17 mm (PES6A and PES6MW Fuel Injection Pump)
19 mm (PES6P Fuel Injection Pump)

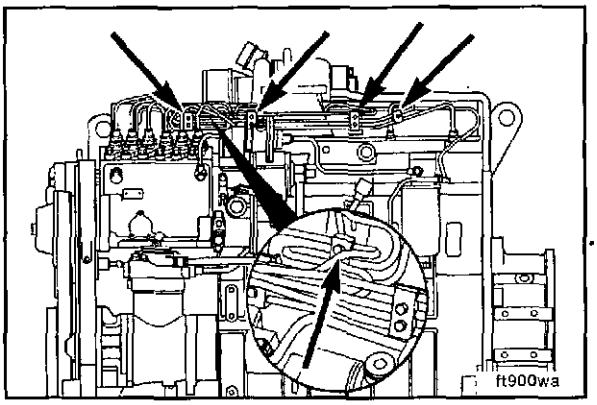
Disconnect the line(s) from the fuel injection pump.

Installation

10 and 17 mm (PES6A and PES6MW Fuel Injection Pump)
10 and 19 mm (PES6P Fuel Injection Pump)

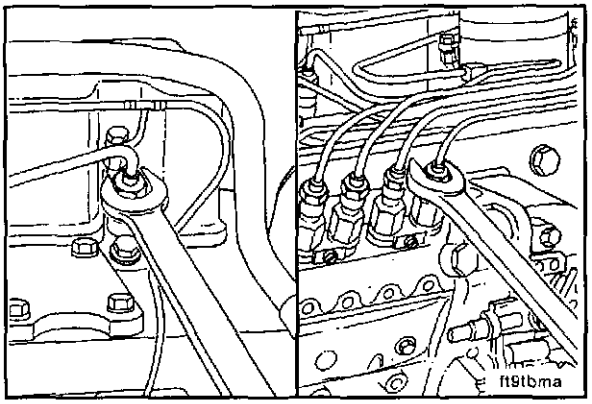
Loosen the vibration isolator capscrews so the fuel lines can be easily moved.

NOTE: To prevent breakage to the fuel lines, they **must** be connected to the injector and fuel injection pump in a "free state" without forcing the connecting nuts. Since the fuel lines are properly sized for specific application, bending should **not** be necessary.



Caution: If removed, install the support clamp in the original position and make sure the lines do not contact each other or another component.

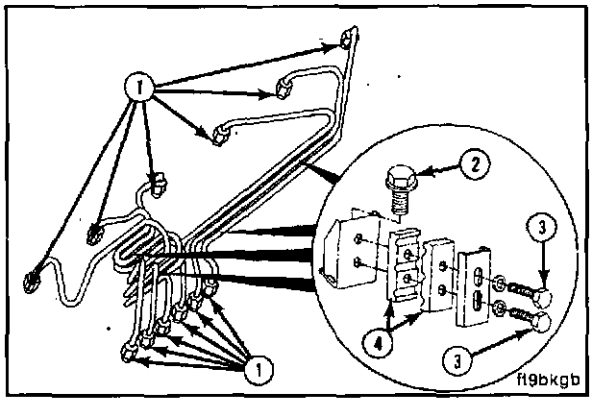
Install the lines in the reverse order of removal.

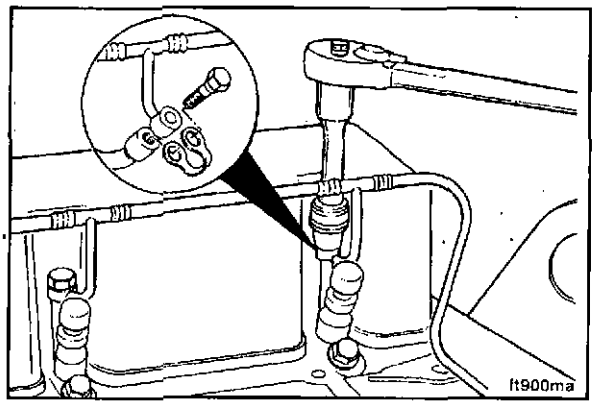


Tighten all fittings and mounting hardware.

Torque Value:

1. Line Fittings 30 N•m [22 ft-lb]
2. Support Bracket Capscrews 24 N•m [18 ft-lb]
3. Vibration Isolator Capscrews 6 N•m [53 in-lb]





Fuel Drain Manifold - Replacement (5-06)

Removal and Installation

10 mm

Clean debris from around the fuel drain manifold.

Remove the banjo capscrews from the injectors and fuel filter head.

Install the fuel drain manifold in the reverse order of removal.

Torque Value:

Filter Head Banjo	15 N•m [11 ft-lb]
Injector Banjo	9 N•m [80 in-lb]

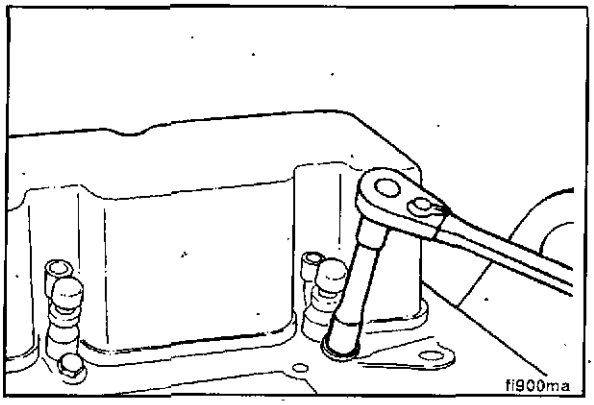
Injector - Replacement (5-07)

Preparatory Steps:

Thoroughly clean around the injectors.

Disconnect the high pressure fuel lines. Refer to Procedure 5-05.

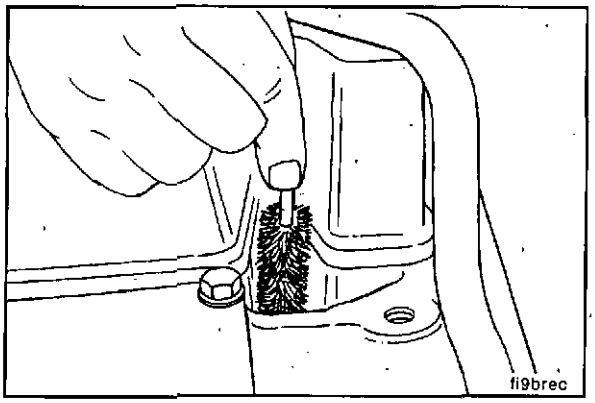
Disconnect the fuel drain manifold. Refer to Procedure 5-06.



Removal

10 and 13 mm, Part No. 3823276 Injector Puller

Remove the injectors.



Cleaning and Inspection

Part No. 3822510 Injector Bore Brush

Clean the injector nozzle bore.

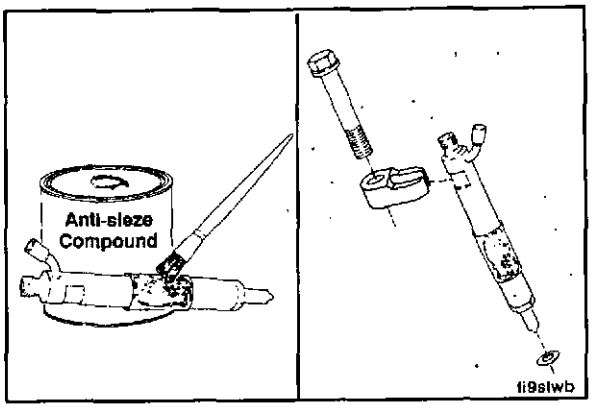
NOTE: If the injector sealing sleeves are melted, it is an indication the engine has been operating in an overheated condition. Refer to the Troubleshooting Logic Chart for "Coolant Temperature Above Normal."

Installation

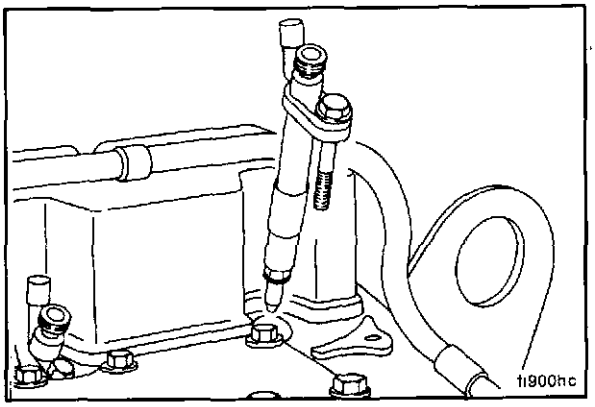
Lubricate the sealing lips of the sleeve with anti-seize compound. Assemble the injector, sealing sleeve, a new copper sealing washer and the holddown clamp.

Use only one washer.

Service Tip: A light coat of clean 15W-40 engine oil between the washer and injector can help hold the washer in place during installation.



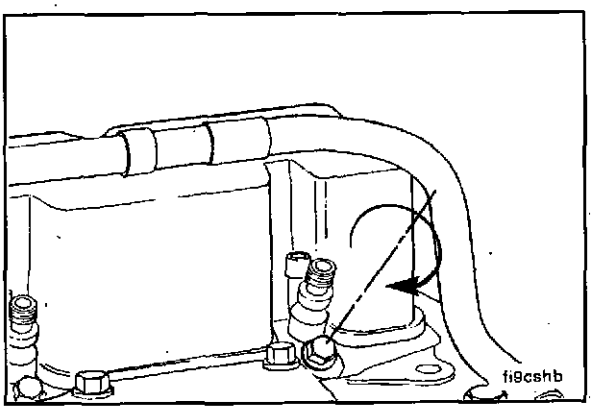
Install the injector assemble into the injector bore. The injector leak-off connection **must** be toward the valve cover.



10 and 13 mm

Install the holddown capscrew.

Torque Value: 24 N•m [18 ft-lb]

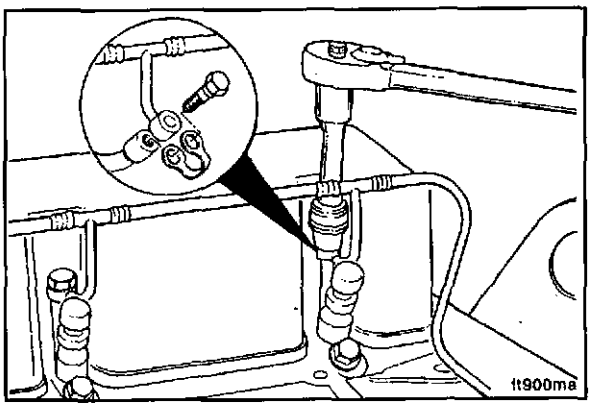


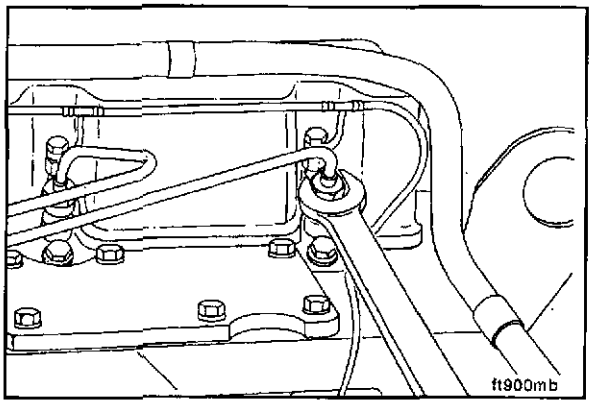
10 mm

Install the fuel drain manifold.

Torque Value: 9 N•m [80 in-lb]

NOTE: The banjo connector seal (siamese washer) **must** be installed as shown in the illustration.





17 mm (PES6A and PES6MW Fuel Injection Pump)
19 mm (PES6P Fuel Injection Pump)

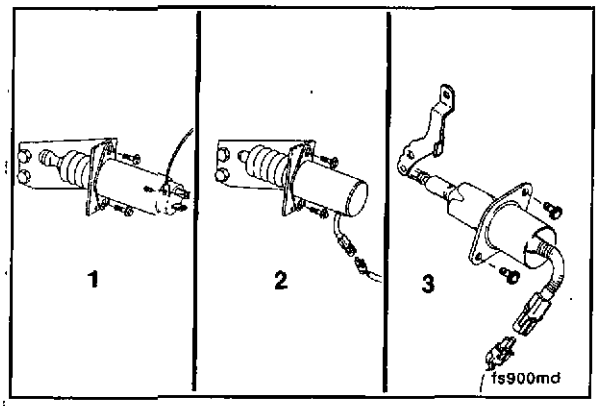
Install the high pressure fuel lines.

Torque Value: 30 N•m [22 ft-lb]

Fuel Shutoff Solenoid - Replacement (5-08)

Preparatory Steps:

Label and disconnect the wiring.



RSV Governor Fuel Shutoff Solenoid - Removal

Cylinder Block Mount

10 mm

Remove the two mounting capscrews and remove the solenoid from the bracket.

1. Synchro-Start
2. Trombetta
3. Direct Link

RSV Governor Fuel Shutoff Solenoid - Installation

Cylinder Block Mount

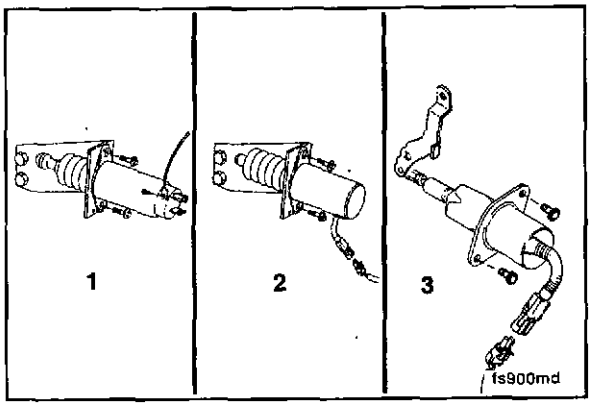
10 mm

NOTE: Make sure the acorn nut is tightened to be snug on the fuel shutoff solenoid shaft (Synchro-Start only).

Install the new fuel shutoff solenoid and connect the wires. Make sure the wiring harness on the Trombetta solenoid is installed in the 6:00 o'clock position.

Torque Value: 10 N•m [89 in-lb]

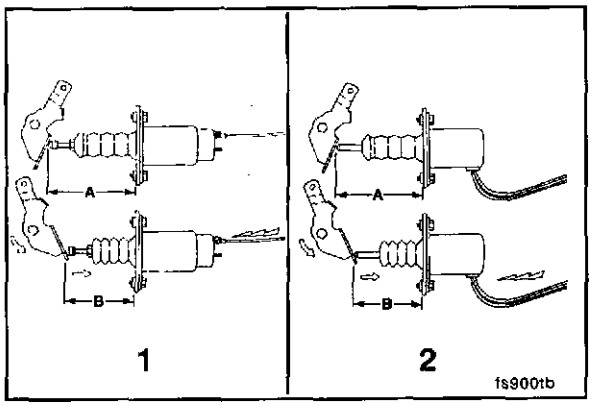
1. Synchro-Start
2. Trombetta
3. Direct Link



Activate the ignition switch and check the plunger travel.

1. Synchro-Start	2. Trombetta
A = 86.6 mm [3.4 in]	A = 91.4 mm [3.6 in]
B = 60.2 mm [2.4 in]	B = 63.5 mm [2.5 in]

The plunger **must** be retracted when the fuel shutoff solenoid is activated to the RUN position "B". The fuel shutoff solenoid **must** operate without binding.

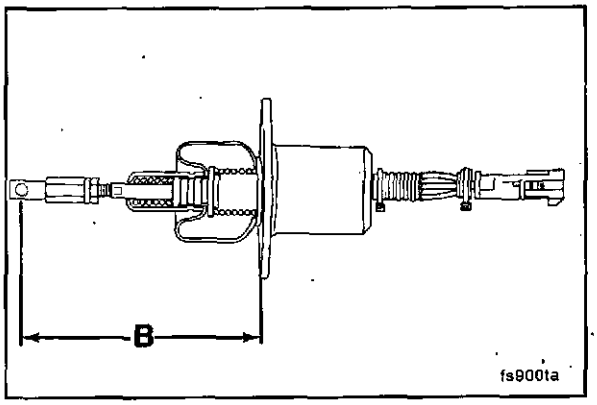


Direct Link Solenoid, Cylinder Block Mounted

- Disconnect the solenoid linkage from the lever.
- Activate the ignition switch and check the plunger travel.
- Measure distance 'B' from the center of the ball socket to the solenoid mounting flange.

  B = 117.1 mm [4.61 in]

  The plunger **must** be retracted when the fuel shutoff solenoid is activated to the RUN position "B". The fuel shutoff solenoid **must** operate without binding.



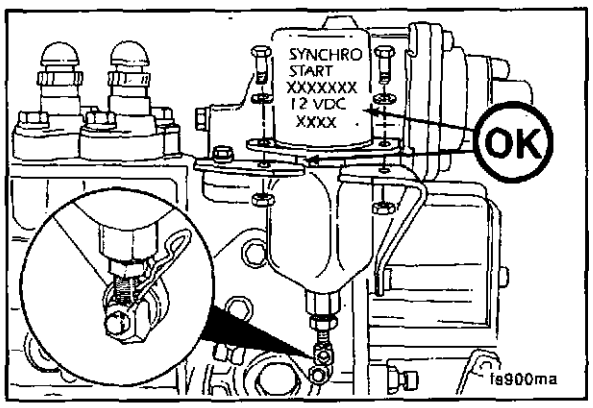
RQVK Governor Fuel Shutoff Solenoid - Removal and Installation

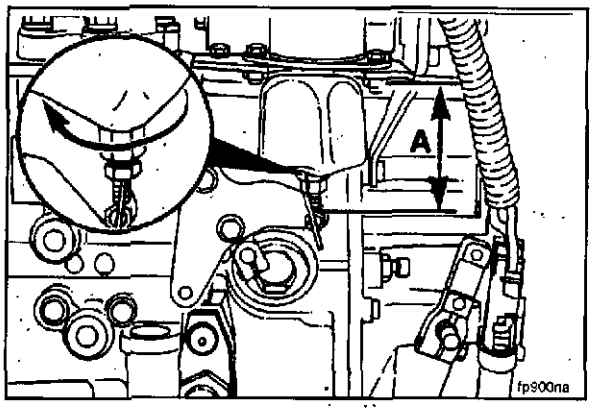
10 mm

Remove the hitch pin clip, mounting capscrews and the fuel shutoff solenoid.

Install the new solenoid in reverse order of removal and connect the wires. Make sure the part number and cable tie block is facing away from the engine.

Torque Value: 10 N•m [89 in-lb]

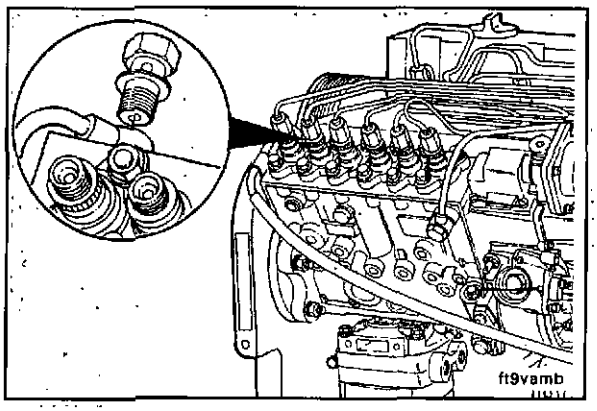




Activate the switch and check the plunger travel.

A = 66.9 mm [2.64 in]

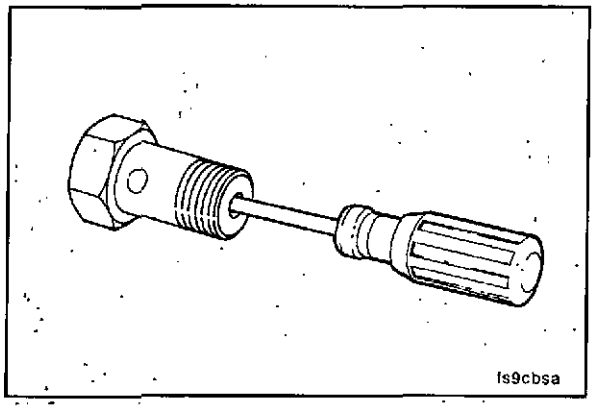
NOTE: Dimension A is measured from the bottom of the mounting bracket to the top of the pivot pin.



Fuel Return Overflow Valve - Replacement (5-09)

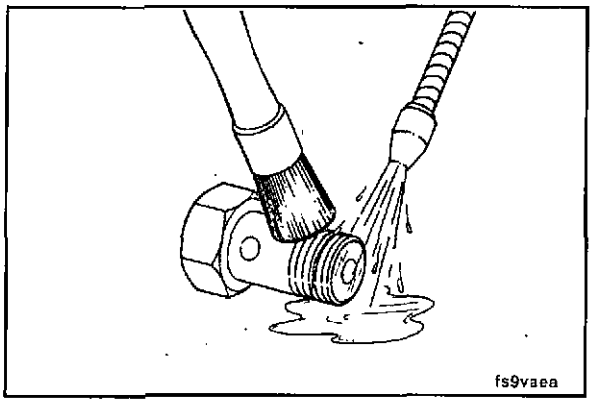
19 mm

Remove the pressure relief valve and copper sealing washers.



Use a small screwdriver to check that the check ball is not sticking in the high pressure relief valve assembly.

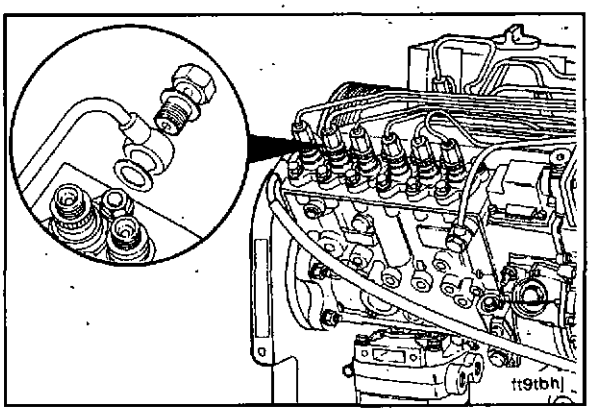
Caution: A sticky check ball will result in engine low power.



Thoroughly flush the high pressure relief valve with cleaning solution.

10 mm, 19 mm

Install the high pressure relief valve assembly in the reverse order of removal.

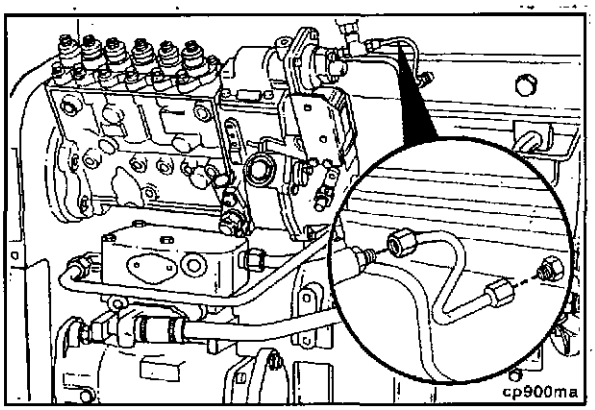


AFC Tube - Replacement (5-10)

Removal

17 mm, 13 mm

Remove the AFC tube.



Installation

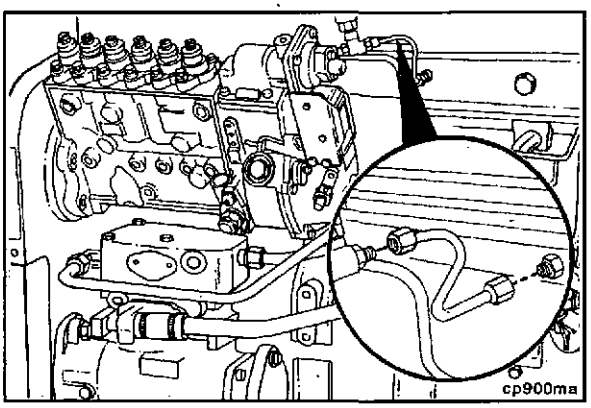
17 mm, 13 mm

Use new copper washers for the banjo fitting.

Install the AFC tube.

Torque Value:

Banjo Fitting	24 N•m [18 ft-lb]
Threaded Fitting	8 N•m [71 in-lb]



Fuel Injection Pump - Replacement (5-11)

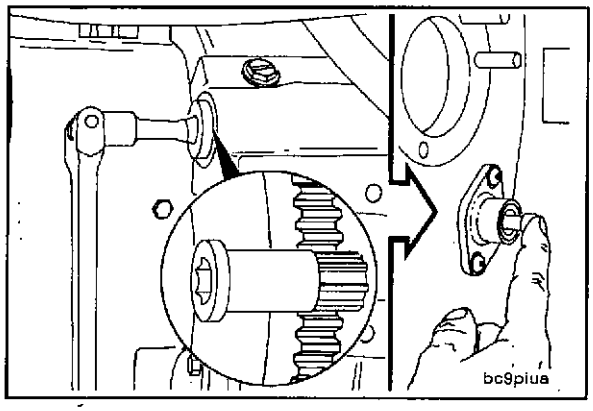
Preparatory Steps:

Clean debris.

Remove all fuel lines. Refer to Procedure 5-05 and 5-06.

Remove control linkage.

Remove fuel shutoff solenoid. Refer to Procedure 5-08.

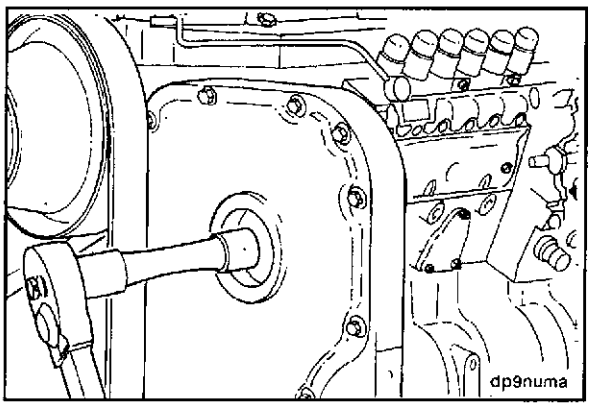


Removal

Part No. 3377371 Barring Tool

Locate TDC for No. 1 cylinder. Push the TDC pin into the hole in the camshaft gear while slowly rotating the crankshaft.

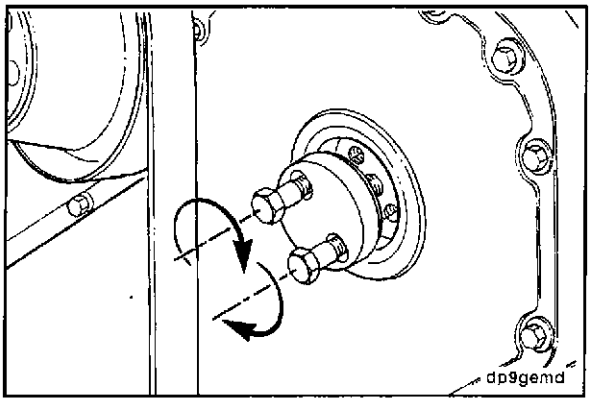
NOTE: Be sure to disengage the pin after locating TDC.



22 mm (PES6A Fuel Injection Pump)
27 mm (PES6MW Fuel Injection Pump)
30 mm (PES6P Fuel Injection Pump)

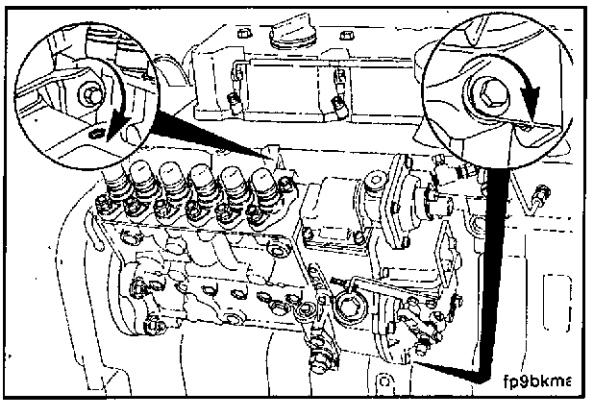
Remove the gear cover access cap.

Remove the nut and washer from the fuel injection pump shaft.



Part No. 3824469 Fuel Pump Gear Puller

Pull the fuel injection pump drive gear loose from the shaft.



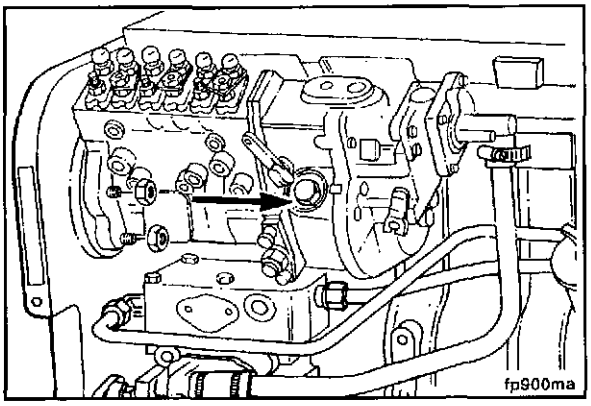
13 mm

Engines equipped with the PES6P fuel injection pump the support brackets **must** be removed.

15 mm

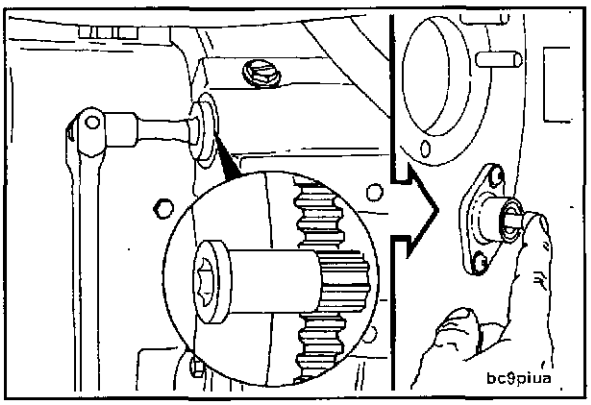
Remove the four mounting nuts.

Remove the fuel injection pump.

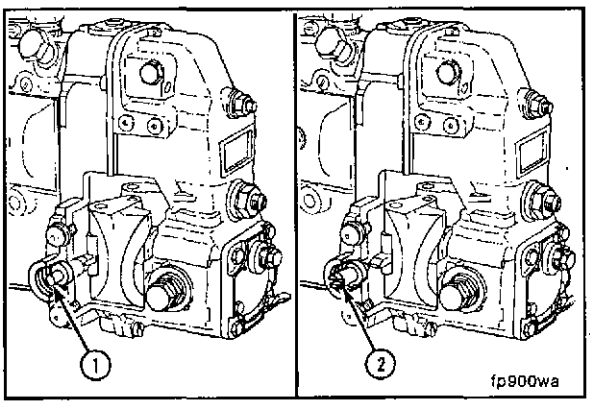


Installation

Make sure the engine has No. 1 cylinder at TDC.

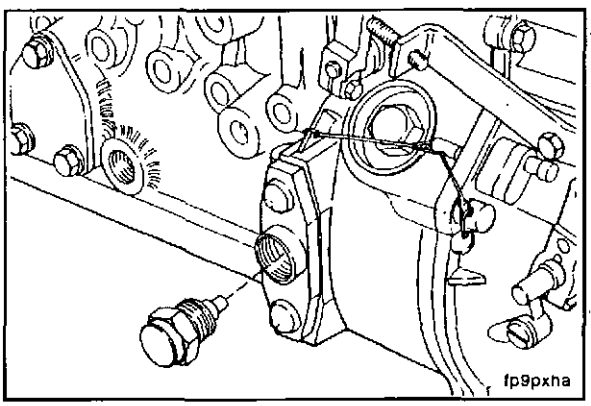


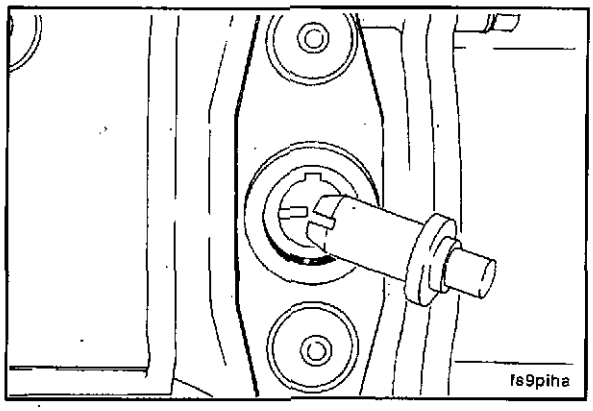
The fuel injection pump also has a timing pin (1), located in the governor housing, to position the fuel injection pump shaft to correspond with TDC for No. 1 cylinder. The timing pin is to be reversed and stored in the housing (2) after the fuel injection pump is installed.



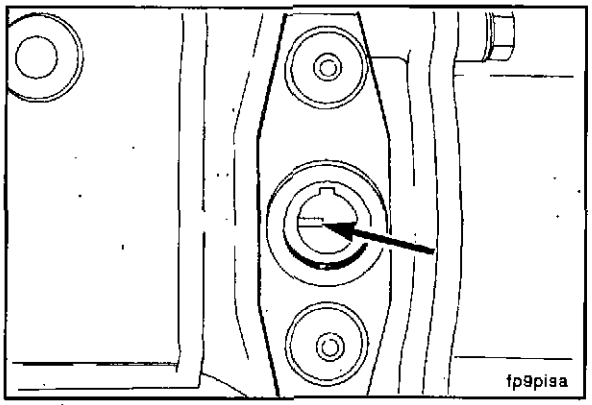
24 mm

Remove the access plug.

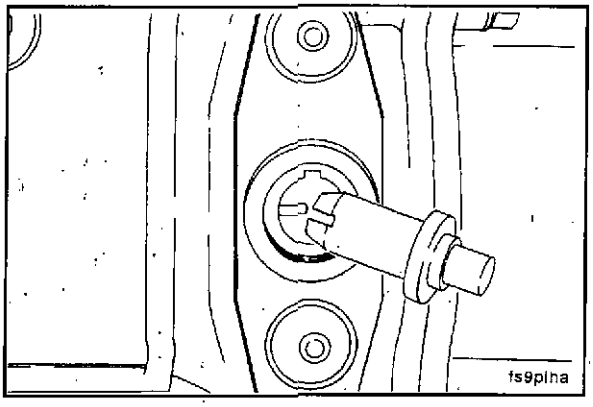




Remove the timing pin.



If the timing tooth is **not** aligned with the timing pin hole, rotate the fuel injection pump shaft until the timing tooth aligns.



Reverse the position of the timing pin so the slot of the timing pin will fit over the timing tooth in the fuel injection pump.

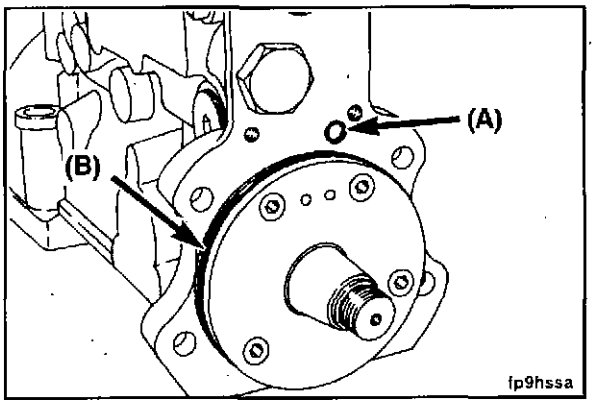
NOTE: PES.P fuel injection pump o-ring is located in the gear housing.

Install and secure the timing pin with the access plug.

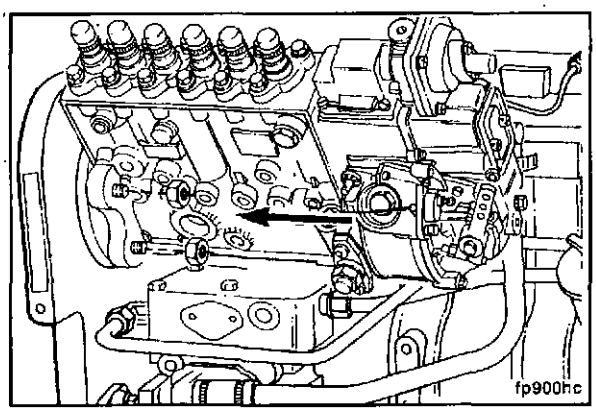
Make sure the o-ring seals for the fill orifice and pilot are correctly installed and are **not** damaged.

Lubricate the mounting flange with clean engine oil.

NOTE: The fuel pump drive gear inside diameter and the shaft outside diameter **must** be clean and dry before installing the gear.



Slide the fuel injection pump shaft through the drive gear and position the fuel injection pump flange onto the mounting studs.



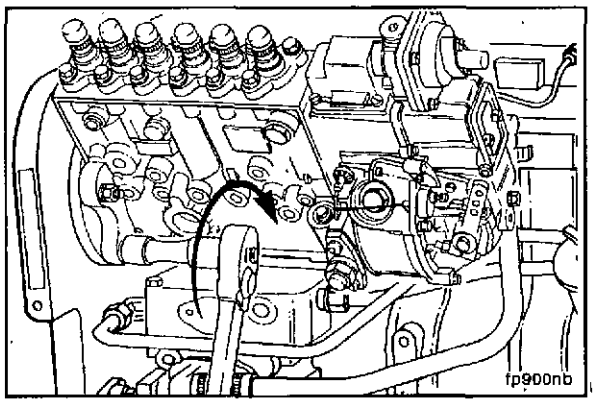
15 mm and 13 mm

Install the mounting nuts.

Install the support bracket if so equipped.

Torque Value:

Mounting nuts	44 N•m [32 ft-lb]
Support bracket	32 N•m [24 ft-lb]

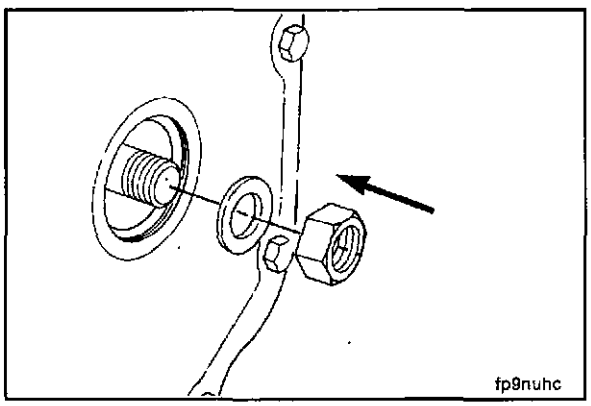


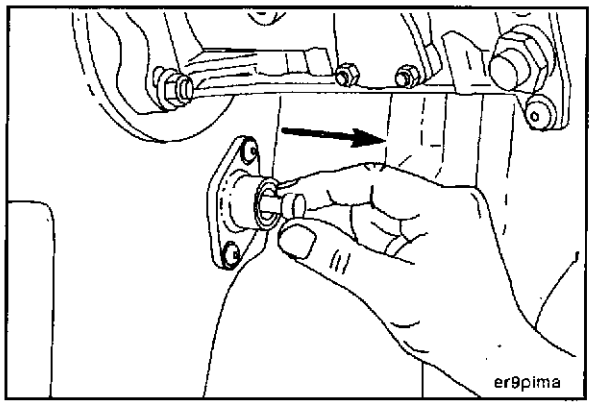
22 mm (PES6A Fuel Injection Pump)
27 mm (PES6MW Fuel Injection Pump)
30 mm (PES6P Fuel Injection Pump)

Install the retaining nut and washer.

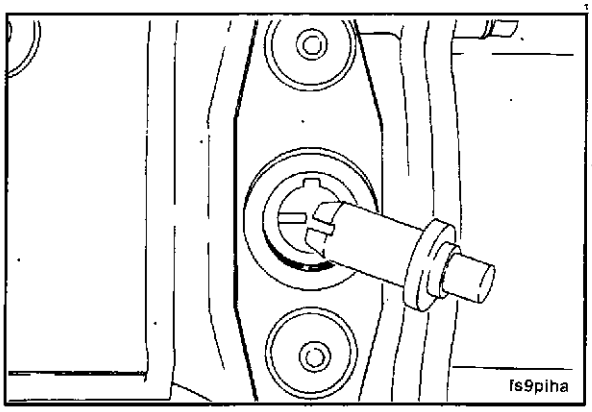
Torque Value: 12 N•m [106 in-lb]

NOTE: To prevent damage to the timing pins, do **not** exceed the torque value given. This is **not** the final torque value for the retaining nut.





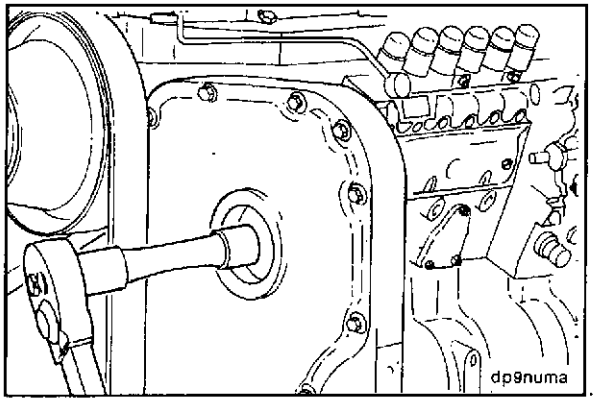
Disengage the engine timing pin.



24 mm

Remove the fuel injection pump timing pin plug. Reverse the position of the timing pin and install the timing pin, plug, and the sealing washer.

Torque Value: 15 N•m [11 ft-lb]



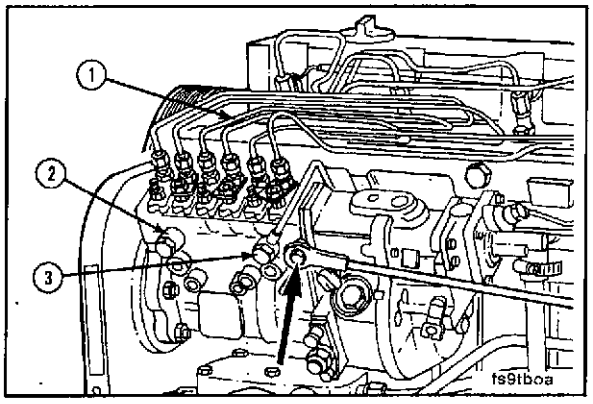
22 mm (PES6A Fuel Injection Pump)
27 mm (PES6MW Fuel Injection Pump)
30 mm (PES6P Fuel Injection Pump)

Tighten the fuel injection pump drive gear nut.

Torque Value:

PES6A Fuel Injection Pump	92 N•m [68 ft-lb]
PES6MW Fuel Injection Pump	104 N•m [77 ft-lb]
PES6P Fuel Injection Pump	165 N•m [122 ft-lb]

Install the gear cover access cap hand tight.



Install the fuel lines and control linkage.

Torque Value:

1.	High Pressure Fuel Lines	30 N•m [22 ft-lb]
2.	Pressure Relief Valve Fitting	32 N•m [24 ft-lb]
3.	Low Pressure Fuel Supply Fitting	32 N•m [24 ft-lb]

Caution: The governor housing must be prelubricated before engine operation. Failure to do so will result in premature governor wear.

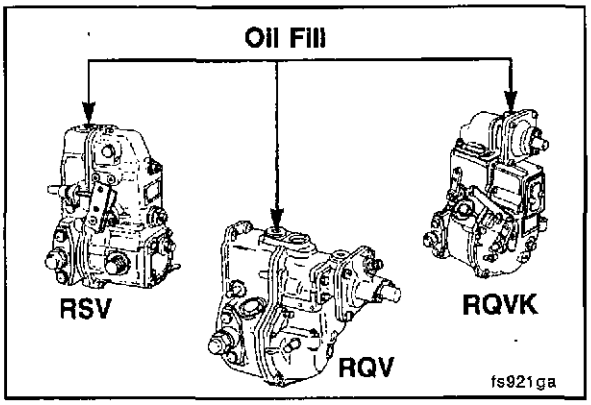
10 mm hex drive

Remove the access plug.

Add the following quantity of clean engine oil:
- RSV 450 ml [0.43 qt.]
- RQV 750 ml [0.71 qt.]
- RQVK 750 ml [0.71 qt.]

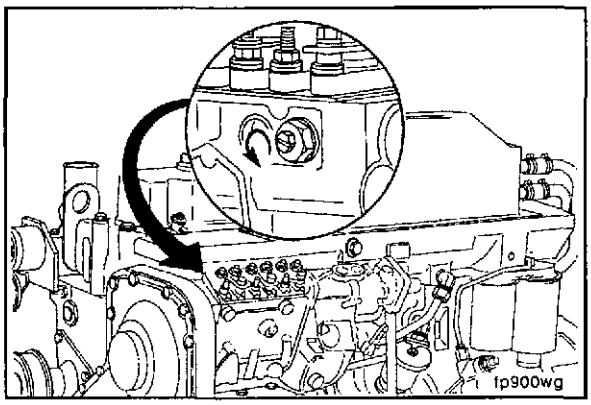
Install the access plug.

Torque Value: 28 N•m [21 ft-lb]



The PES6MW fuel injection pump not equipped with engine side fuel return option **must** be vented after installation. Loosen the vent screw located near the front on the side nearest to the engine. Place the fuel control in the RUN position. Crank the engine so air can bleed from the fuel injection pump. Then, tighten the vent screw.

NOTE: Earlier PES6MW fuel injection pumps were not equipped with a vent screw. Remove the large plug from the location described above to vent the fuel injection pump. PES6A fuel injection pumps are self venting. All PES6P pumps were assembled with the engine side vent option.

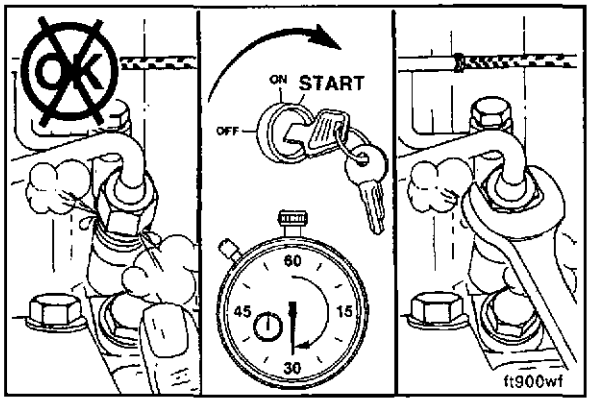


17 mm (PES6A and PES6MW Fuel Injection Pump
19 mm (PES6P Fuel Injection Pump)

Warning: The pressure of the fuel in the high pressure line is sufficient to penetrate the skin and cause serious bodily harm.

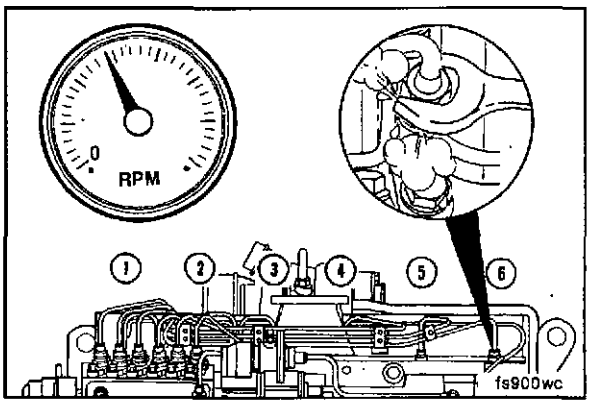
Vent the high pressure fuel lines. Loosen the fitting at the No. 1 injector. Place the fuel control in the RUN position. Crank the engine so air can bleed from the fuel lines, then tighten the fitting.

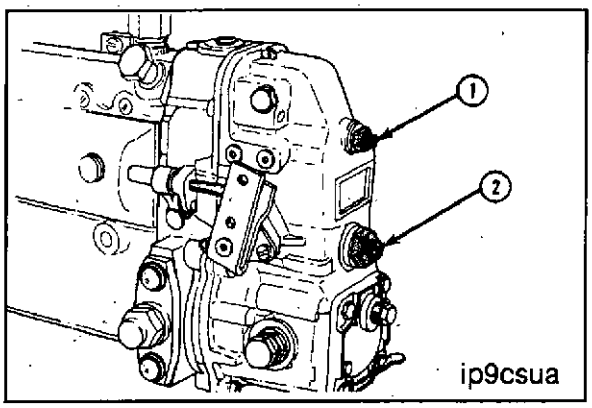
Torque Value: 30 N•m [22 ft-lb]



Warning: The pressure of the fuel in the line is sufficient to penetrate the skin and cause serious bodily harm.

Vent each high pressure line separately until the engine runs smoothly.

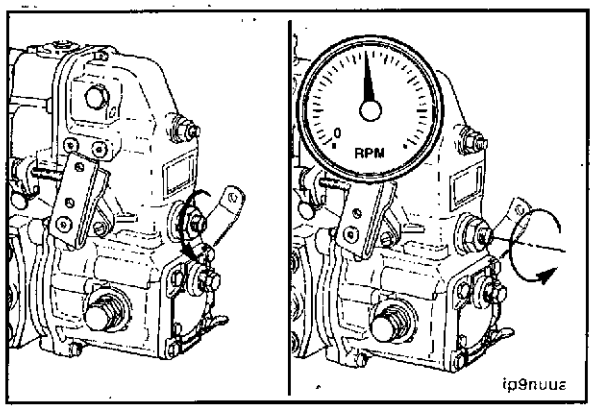




Idle Speed - Adjustment (5-12)

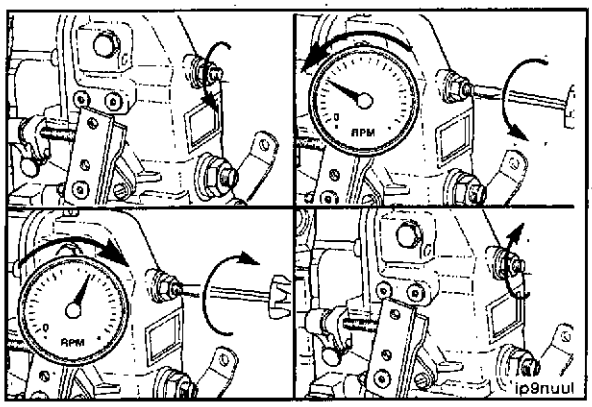
Bosch RSV Governor

Idle speed adjustment for industrial engines requires the setting of both the low idle speed screw (1) and the bumper spring screw (2).



19 mm, Screwdriver and Tachometer

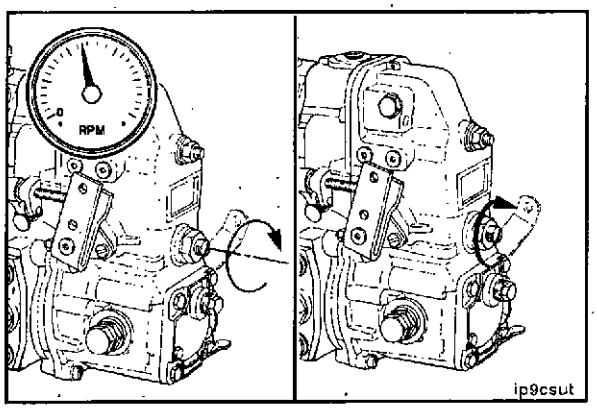
First, loosen the locknut and back out the bumper spring screw until there is no change in engine speed.



13 mm, Screwdriver and Tachometer

Loosen the locknut and adjust the idle speed screw to 20 to 30 RPM less than the desired speed. Turn the idle speed screw **counterclockwise** to decrease RPM; **clockwise** to increase RPM. Tighten the locknut.

Torque Value: 8 N•m [72 in-lb]



19 mm, Screwdriver and Tachometer

Turn the bumper spring **screw clockwise** until the desired idle speed is obtained. Tighten the locknut.

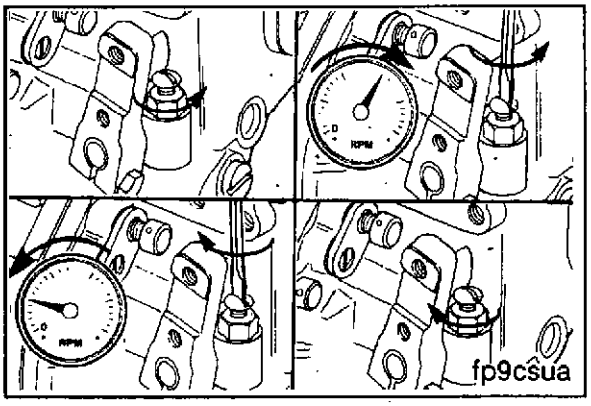
Torque Value: 8 N•m [72 in-lb]

Bosch RQVK Governor

8 and 10 mm, Screwdriver and Tachometer

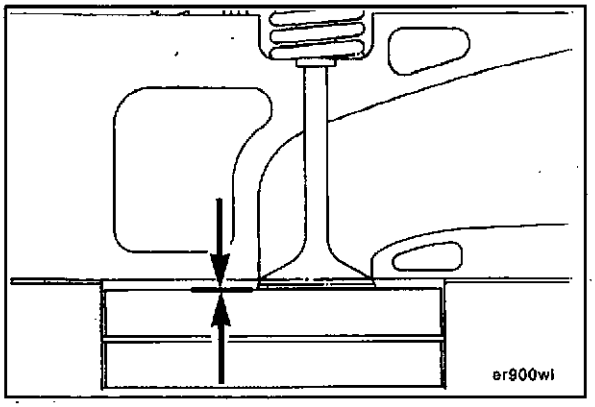
Idle speed adjustment on automotive fuel injection pumps requires setting of the stop screw.

Loosen the locknut and turn the idle speed screw **counterclockwise** to raise the RPM; **clockwise** to decrease the idle speed. Tighten the locknut.

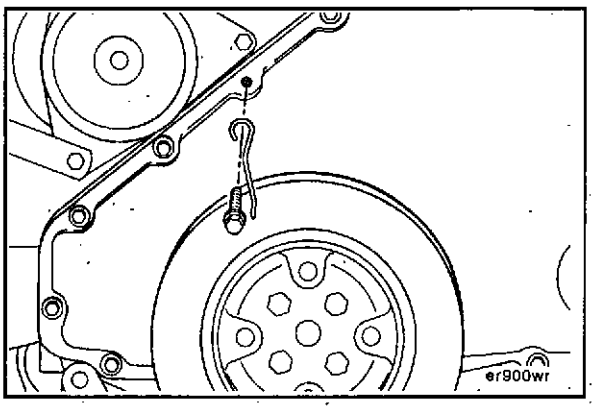


Inline Fuel Injection Pump Spill-Port Timing (5-13)

Use the No. 1 intake valve to make sure the engine is at top dead center (TDC) on the compression stroke for cylinder No. 1. Refer to procedure 7-07.



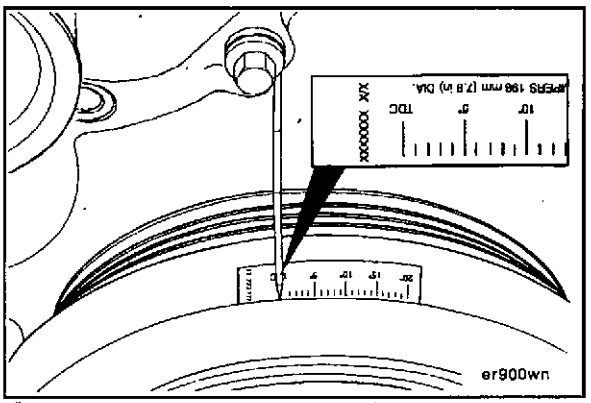
Fabricate a timing mark pointer for the front of the engine. This can be done by forming a piece of wire that can be tightened under one of the gear cover capscrews. Sharpen the wire at the vibration damper end so that it comes to a point for better accuracy.

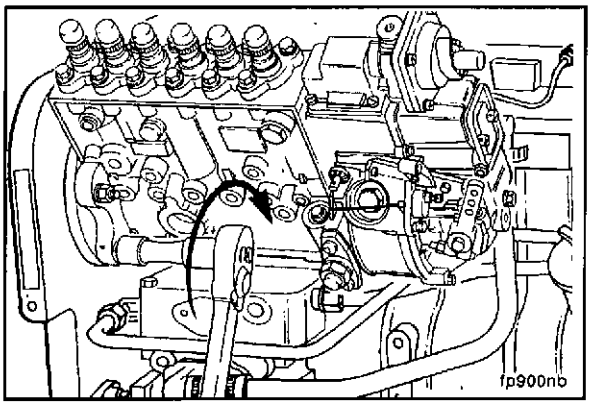


Attach a degree wheel or degree tape to the front of the vibration damper.

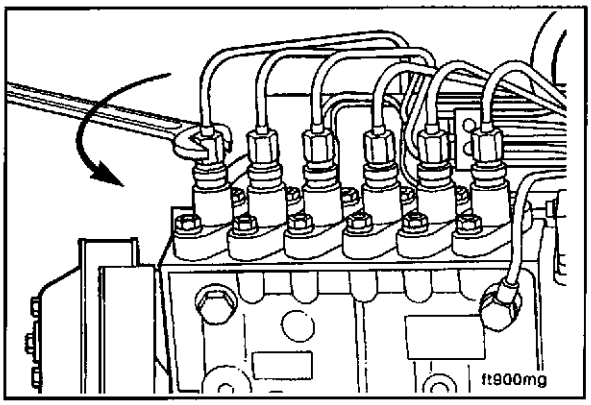
Line the "TDC" mark up with the pointer.

The degree wheel/tape should measure to an accuracy of at least one degree.



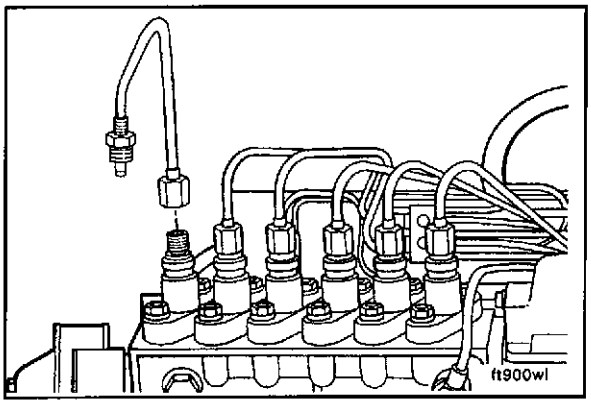


Install the fuel injection pump per the procedures for a new fuel injection pump installation. If the fuel injection pump is already installed, continue the procedures.



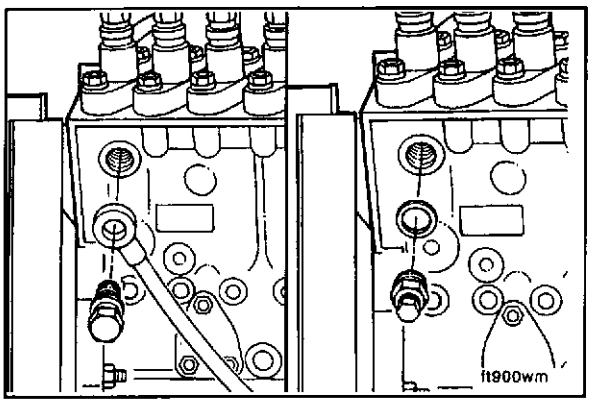
Remove the No. 1 high pressure fuel line from the fuel injection pump.

NOTE: Lines 2 through 6 must not be removed or loosened.



Caution: When attaching the fabricated tube, do not bend the No. 1 high pressure fuel line. This could cause the inside of the fuel line to flake and cause injector failure.

A short length of high pressure line that is compatible with the fuel lines used on the engine should be bent in a "U" shape and installed onto the delivery valve holder of the fuel injection pump. The line is used to observe when the fuel is or is not flowing through the delivery valve holder assembly. Place a container under the tube to catch the fuel or drain the fuel back into the spill port pump.



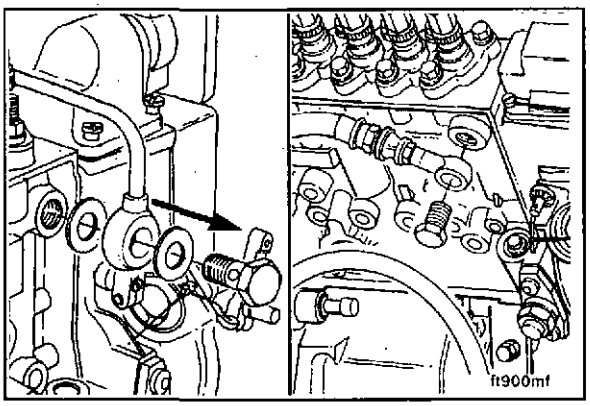
Remove the overflow valve from the fuel injection pump.

Install a 14 mm threaded plug and sealing washer into the fuel return port of the fuel injection pump.

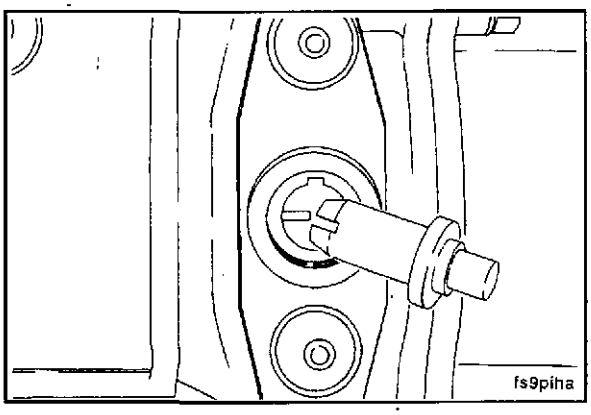
NOTE: The fuel return port is located on the inboard front side of the fuel injection pump for automotive inline application and on the out board front side for most of the industrial applications.

Remove the supply line from the fuel filter head to the fuel injection pump.

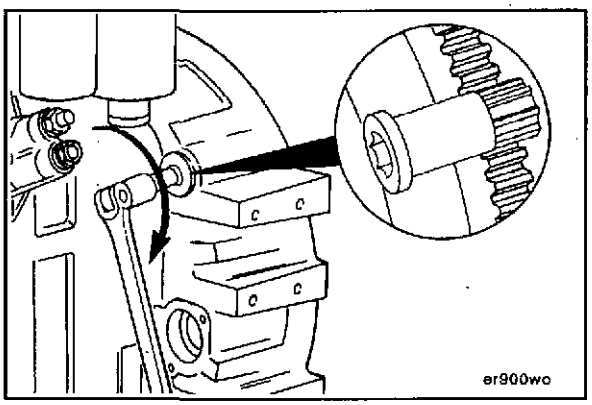
Attach the high pressure outlet hose from the spill port to the fuel injection pump supply port.



Before continuing, make sure the fuel injection pump lock-timing pin is disengaged.



Rotate the crankshaft counterclockwise, as viewed from the front of the engine, to approximately 40 degrees before TDC.

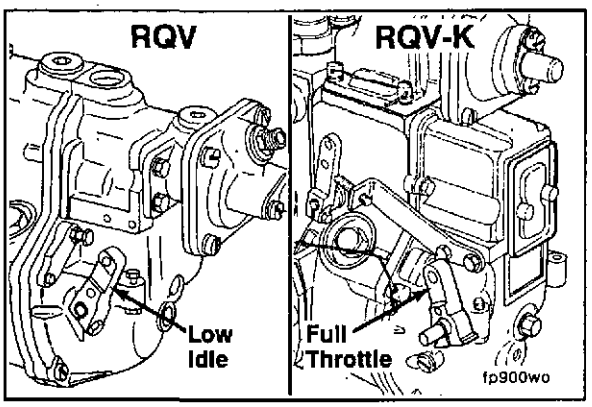


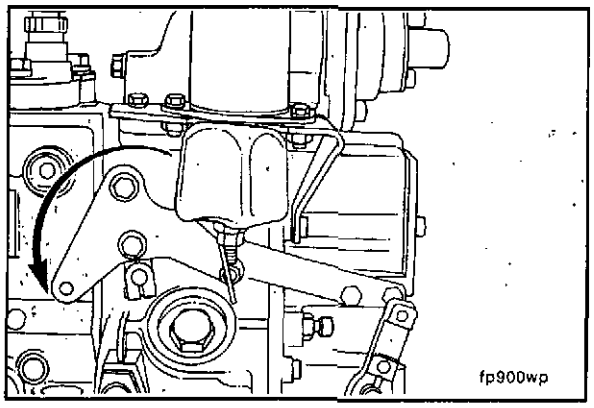
Governor Lever Positioning

Caution: The governor lever must be positioned before pressurizing the fuel injection pump.

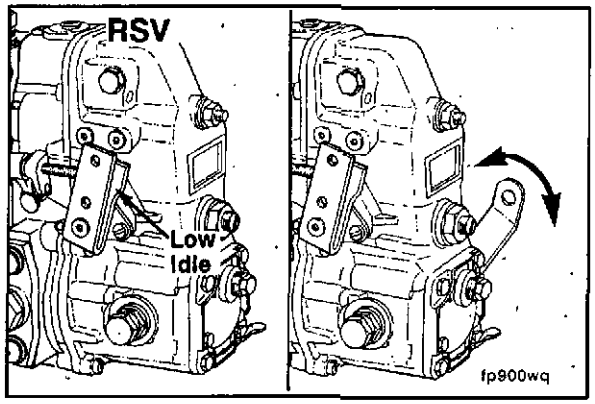
The RQV governor throttle lever must be in the low idle lever position.

The RQV-K governor throttle lever must be in the high idle throttle position.

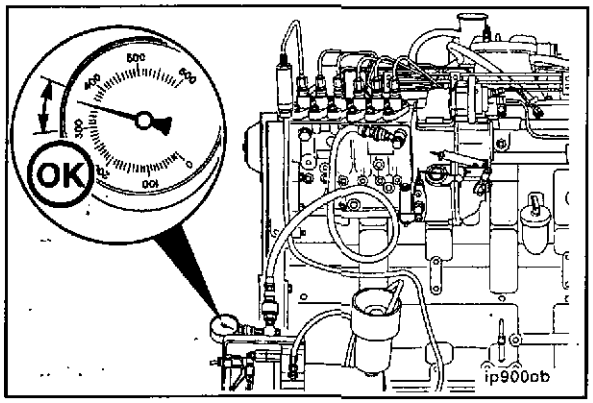




Both the RQV and RQV-K governor require the shut down lever to be in the full run position.



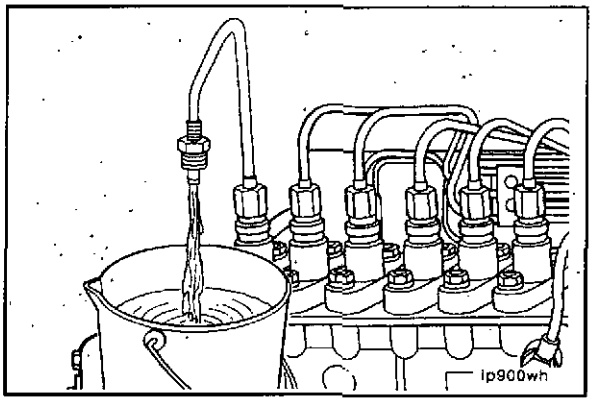
The RSV governor throttle lever must be in the low idle position and the shutdown lever needs to be wired or locked in a suitable fashion to hold the shutdown lever in the 1/2 travel position.



Turn on the spill timing cart pump.

Check the fuel pressure.

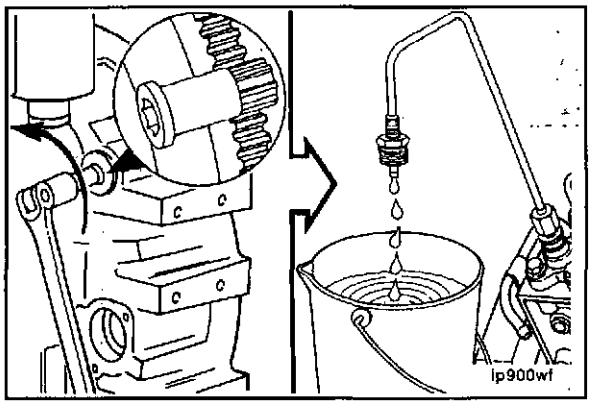
The pressure must be between 300 psi and 370 psi.



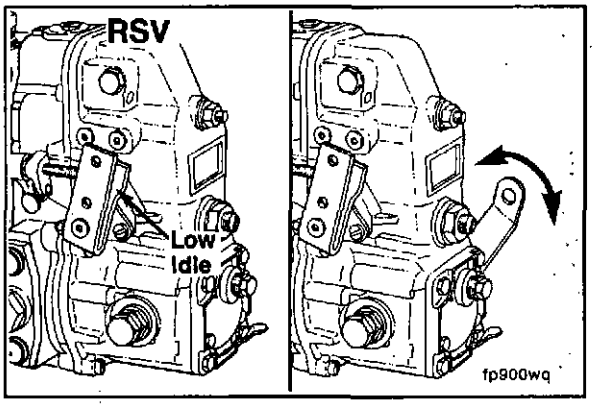
The fuel should be flowing out of the tube attached to the No. 1 cylinder of the fuel injection pump. If the fuel is not flowing, recheck the procedures carefully.

Slowly rotate the crankshaft in the clockwise direction, as viewed from the front of the engine, until the fuel flow from the No. 1 cylinder begins.

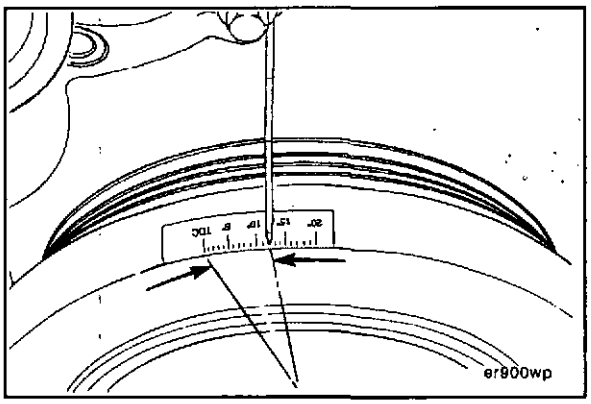
The No. 1 plunger element is now approaching "port closure". Continue to rotate the crankshaft slowly until the flow is reduced to a fast drip (more than one drip per second.) At the point where the steady stream of flow changes from a solid flow to a fast drip, stop. This is the static timing position of the fuel injection pump.



If the flow does not slow down to a drip, check the governor position. Also make sure that the engine is before TDC on the compression stroke. Turn off the spill port pump.

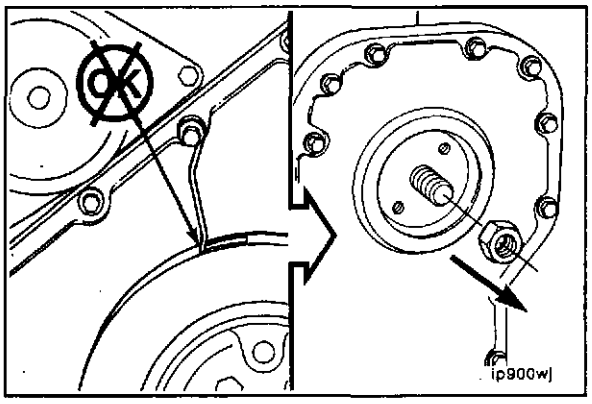


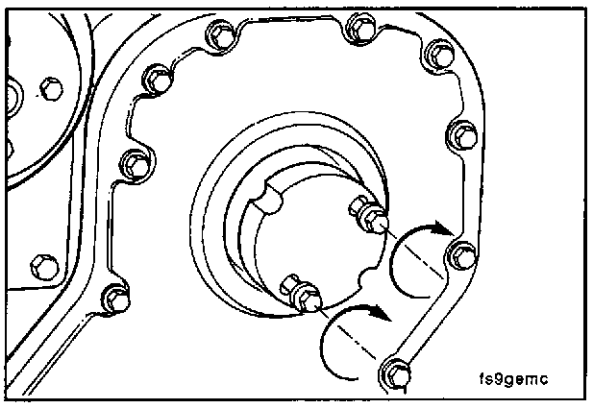
Check the degree wheel on the vibration damper to see what engine degree the timing pointer is indicating. This is spill port static timing. Compare this number to be the timing specification for your particular application.



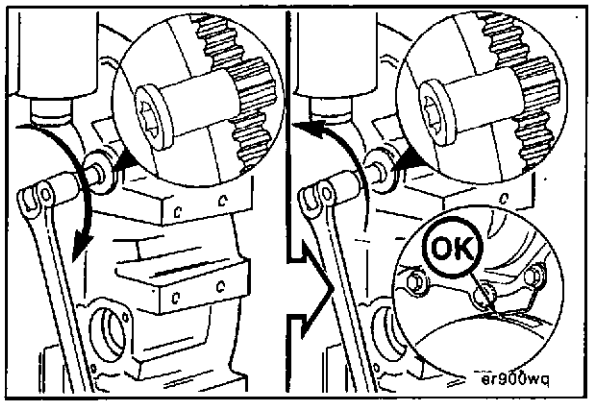
If the fuel injection pump static timing, as measured by the above method, does not agree with the specifications you have been given, remove the large nut that fastens the fuel injection pump camshaft to the fuel pump drive gear. If the crankshaft has rotated, turn on the spill port pump and rotate the crankshaft to find port closure.

Turn off the spill port pump.

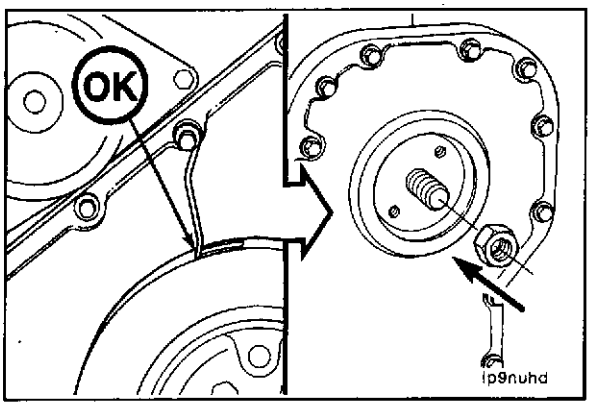




Use a gear puller tool, pull the fuel injection pump drive gear from the fuel injection pump camshaft taper.



Slowly rotate the crankshaft counterclockwise about 40 degrees past the desired static timing specification. Slowly rotate the crankshaft in the clockwise direction until the timing pointer is indicating the desired static timing.

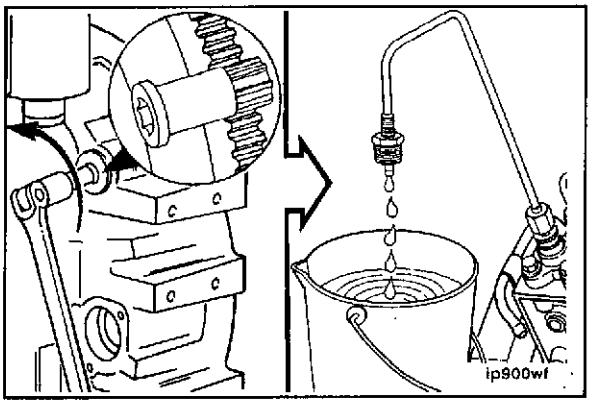


Tighten the fuel injection pump drive nut.

Make sure the static timing has not changed after the fuel injection drive nut is torqued to the required specification.

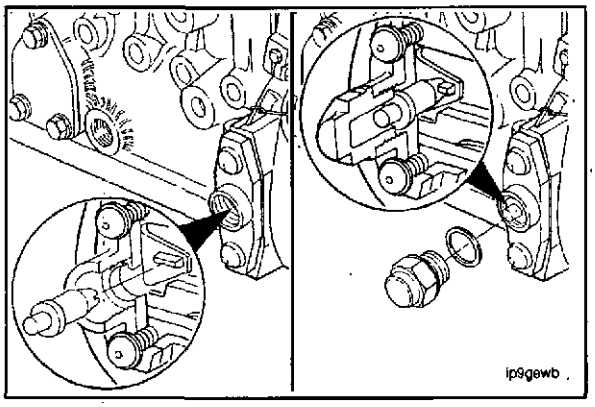
Torque Value:

PES6A Fuel Injection Pump	92 N•m [68 ft-lb]
PES6MW Fuel Injection Pump	104 N•m [77 ft-lb]
PES6P Fuel Injection Pump	165 N•m [122 ft-lb]



Repeat this procedure as needed until the timing is found to be in agreement with the specification.

The fuel injection pump lock timing pin should fit over the injecting pump pointer when the engine is at TDC or on the compression stroke for the No. 1 cylinder. If it does not, the fuel injection pump should be adjusted by an authorized fuel injection pump shop or the fuel injection pump was installed incorrectly.



NOTES

Section 6 - Electrical System

Section Contents

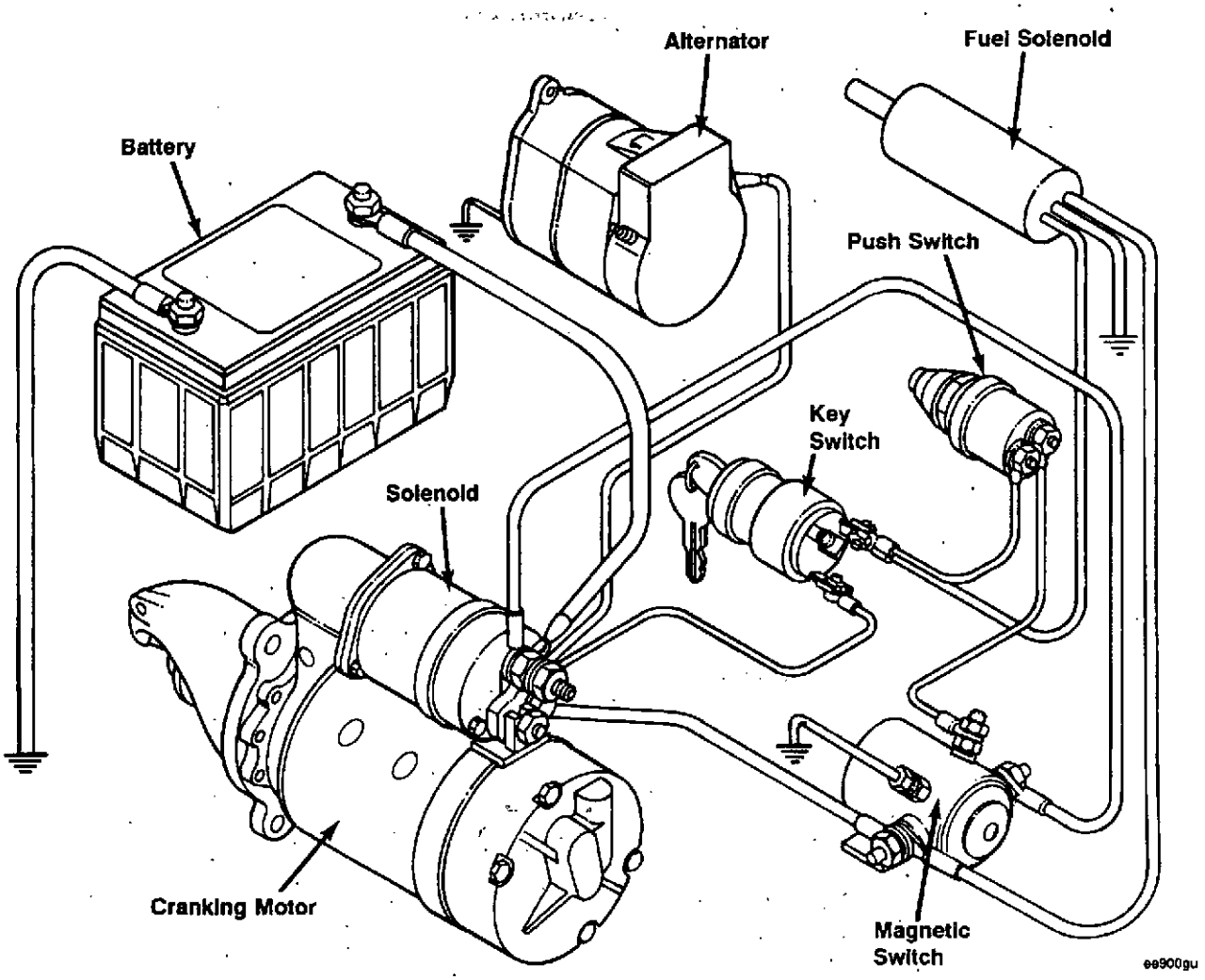
Electrical System Description and Operation

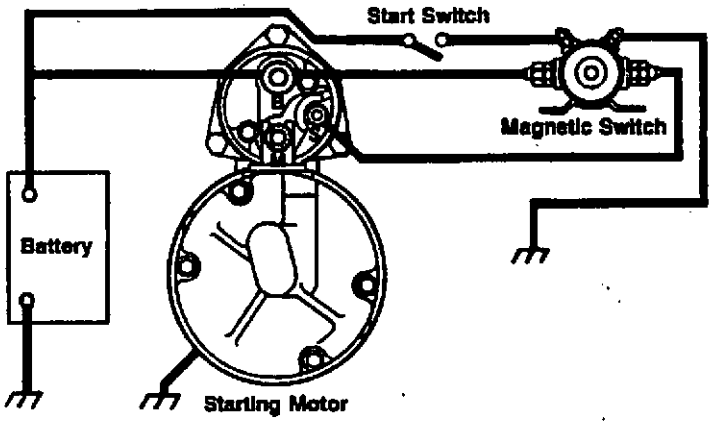
The basic components of the electrical system are the starting motor and the alternator.

If the injection pump uses an electrical fuel shut off valve, refer to the fuel system section of this manual for information concerning the function of the valve.

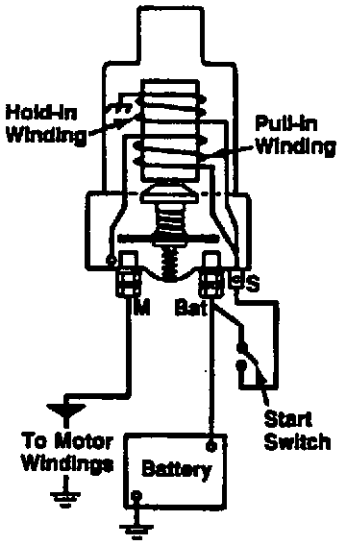
The engine should have temperature and oil pressure sensors connected to indicators and may be wired for automatic shutdown. The engine may also be fitted with a cylinder block heater or oil pan heater.

Cranking and Electrical Circuits





Basic Cranking Circuit

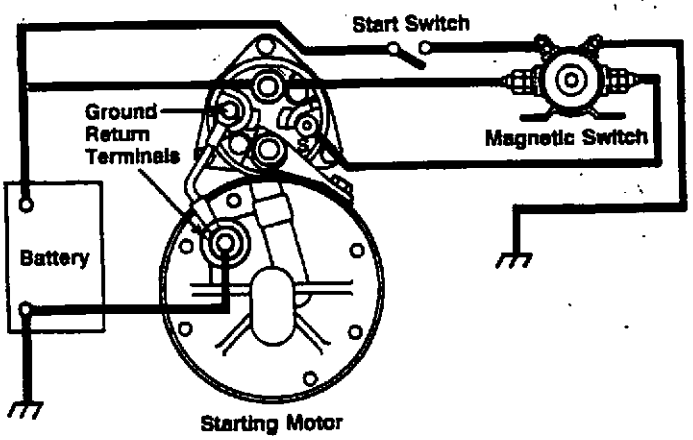


37/41-MT Solenoid Circuit.
(Hold-in winding grounded internally.)

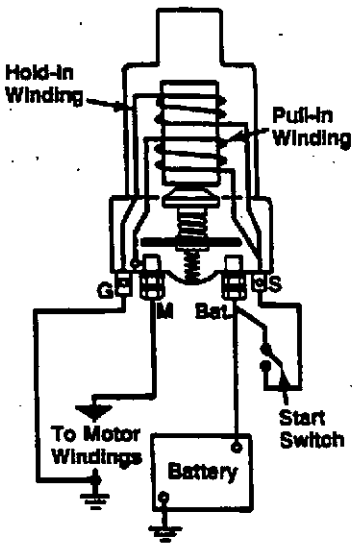
ee900gv

Delco Remy Model 37MT/41MT Starting Motor

(Typical Starting Motor Wiring)



Basic Cranking Circuit

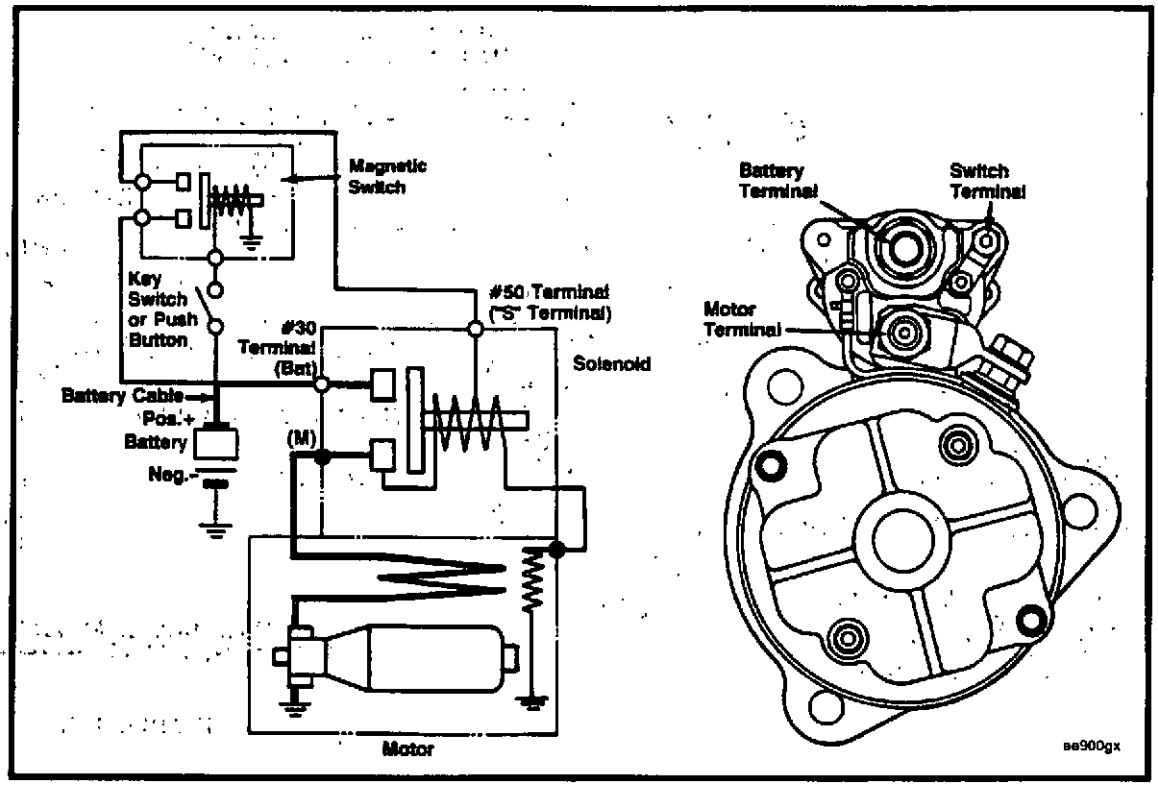


42-MT Solenoid Circuit with ground return terminals.

ee900gw

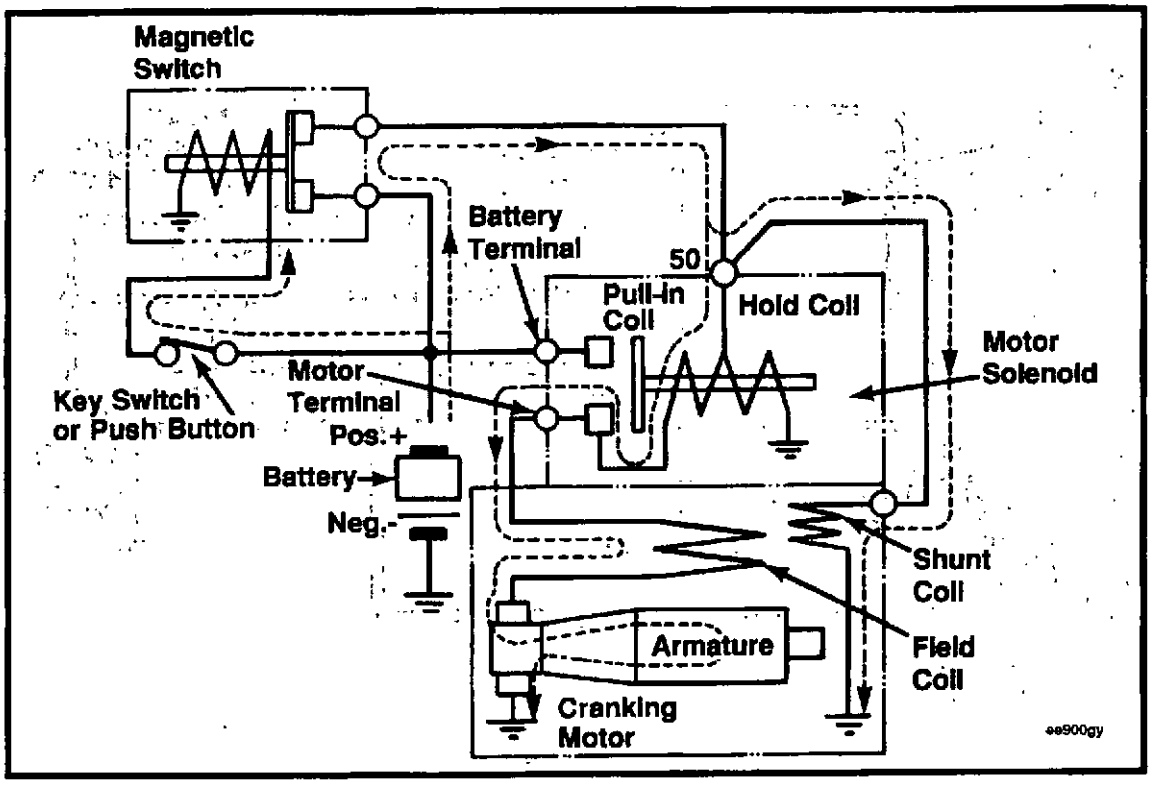
Delco Remy Model 42MT Starting Motor

(Typical Starting Motor Wiring)

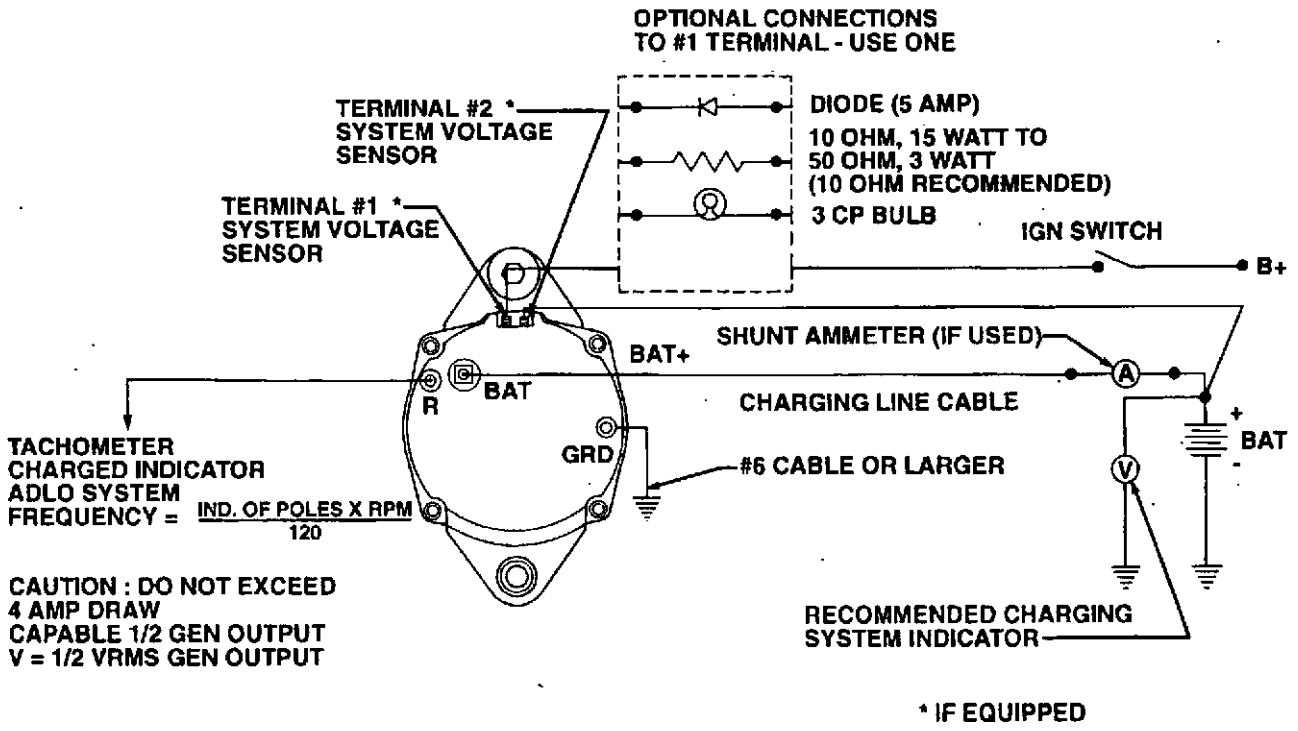


Nippondenso Model F2 Starting Motor

(Typical Starting Motor Wiring)

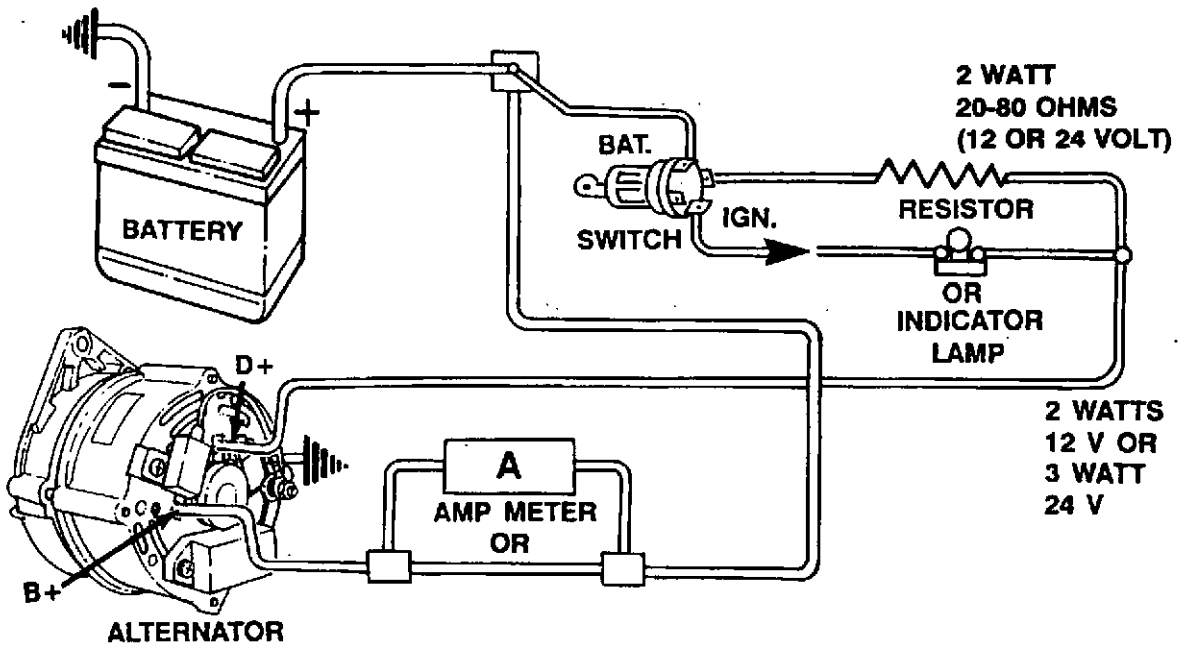


Nippondenso Model F2 Basic Cranking Current Flow

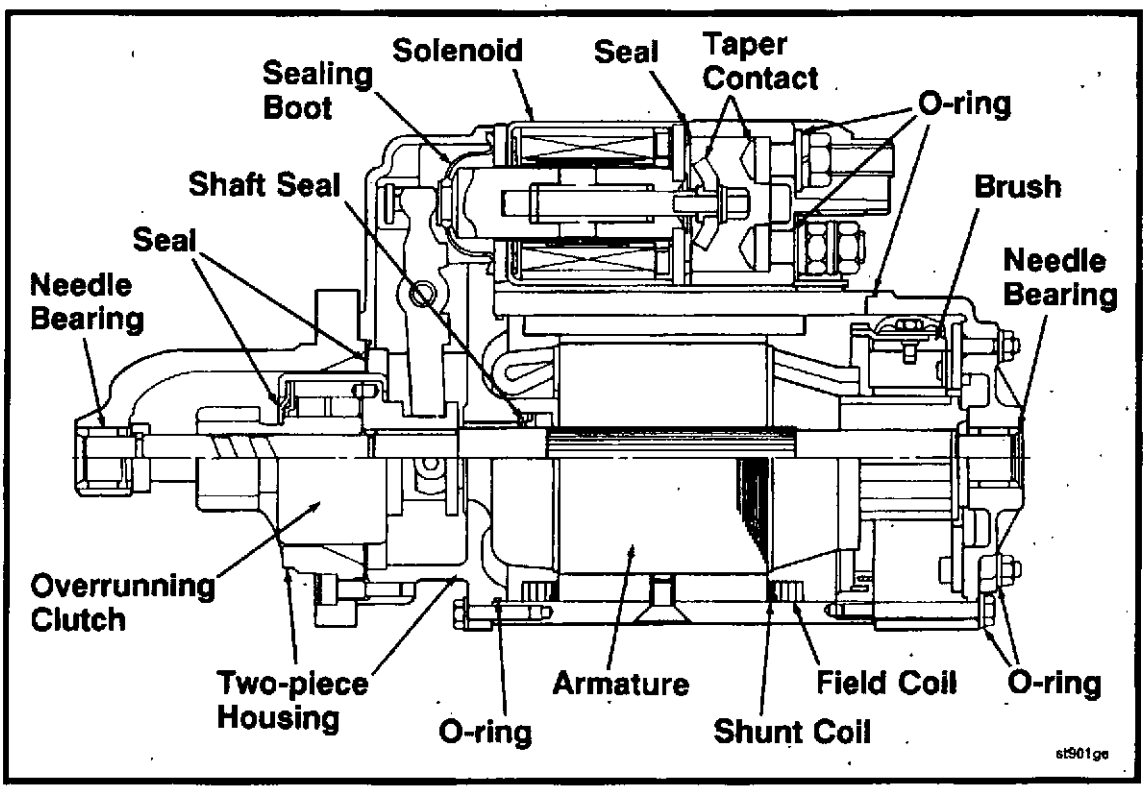


Delco Remy Model 15SI Type 116 Alternator (Wiring Diagram)

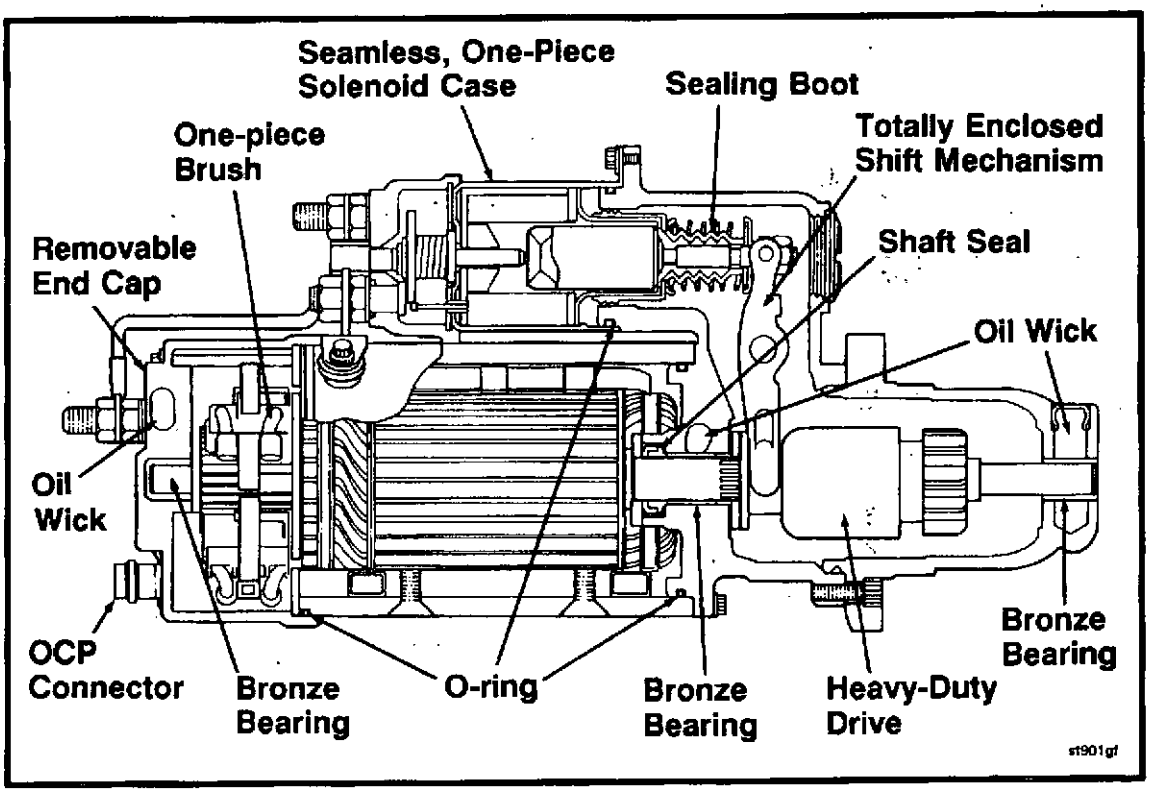
(Typical Delco Alternator Wiring Diagram)



Bosch K1 Model Alternator (Wiring Diagram)



Nippondenso F4 Starting Motor



Delco 42MT Starting Motor

Electrical System Specifications

Minimum Recommended Battery Capacity

- 12 volt system

  -18°C [0°F] Cold cranking amperes 1800

  (Reserve capacity amperes)** ..... (540)

  0°C [32°F] Cold cranking amperes 1250

  (Reserve capacity amperes)** ..... (360)

- 24 volt system*

  -18°C [0°F] Cold cranking amperes 900

  (Reserve capacity amperes)** ..... (270)

  0°C [32°F] Cold cranking amperes 625

  (Reserve capacity amperes)** ..... (180)

* Per battery (Two 12 volt batteries in series)

Ratings are based on -18°C [0°F]

** The number of plates within a given battery size determine reserve capacity. Reserve capacity determines the length of time sustained cranking can occur. Reserve capacity requirements will vary depending upon the electrical accessories the vehicle or equipment may have.

Maximum Allowable Resistance of Starting Circuit

- With 12 V Starter - Ohms ..... (0.0012)
- With 24 V Starter - Ohms ..... (0.0040)

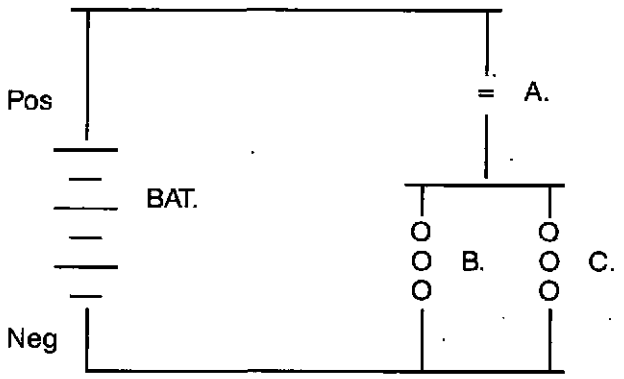
Battery Cables

Total Resistance Not To Exceed 0.001 Ohms for 12V Systems,
0.002 Ohms for 24V Systems

Cable Size	Nominal Resistance In Ohms (Copper Conductor)		Maximum Total Length (sum of both cables)			
			12V		24V	
Gauge	Per Meter	Per Foot	Meter	Feet	Meter	Feet
4	0.000984	0.00030	NR*	NR*	2.03	6.7
2	0.000615	0.000188	1.63	5.3	3.26	10.6
1	0.000492	0.000150	2.03	6.7	4.06	13.4
0	0.000386	0.000118	2.59	8.5	5.18	17.0
00	0.000292	0.000090	3.43	11.3	6.86	22.6
000	0.000232	0.000071	4.32	14.2	8.64	28.4

*Not recommended

Wiring Size Recommendations for Starter Solenoid and Fuel Solenoid Circuit



CIRCUIT DIAGRAM

A. = MAG. SWITCH
B. = STARTER SOLENOID "S" Terminal
C. = FUEL SOLENOID Pull-in winding

TABLE OF RECOMMENDED WIRE GAUGE: (COPPER CONDUCTOR STRANDED WIRE)

Values in table are AWG. size for 12/24 volt systems.

Wire length in circuit:	BAT Pos to A.	A. to B.	*A. to C.	C to Bat. Neg
up to 0.9 m [up to 3 ft.]	10/14	12/14	14/16	14/16
0.9 to 1.4 m [3 to 4.5 ft.]	10/12	10/14	14/16	14/16
1.4 to 2.1 m [4.5 to 7 ft.]	8/10	8/10	12/14	14/16
2.1 to 2.7 m [7 to 9 ft.]	6/8	8/10	10/12	12/14
2.7 to 3.4 m [9 to 11 ft.]	4/6	6/8	10/12	8/10

Wire length in circuit means total length in each individual circuit, e.g: BAT. to A. = One circuit.

For example, in a 12 volt circuit:

BAT. Pos to A. = 2 m; gauge required = 8g.
A. to B. = 2 m; gauge required = 8g.
A. to C. = 3 m; gauge required = 10g.
C to Bat. Neg. = 3 m; gauge required = 10g.

If the system is double pole wiring, (no frame ground), then the fuel & starter solenoid circuit lengths would include the return cable run to the battery negative.

***Special requirements for 3 wire fuel solenoids.**

The pull-in wiring (white lead) should conform to the above chart recommendations A to C.

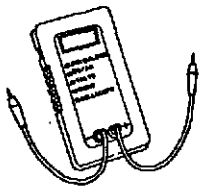
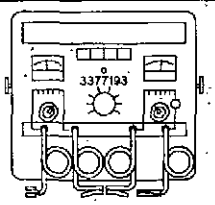
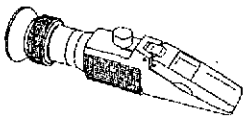
The ground wiring (block lead) **must** be the same gauge as the pull-in wiring (white lead).

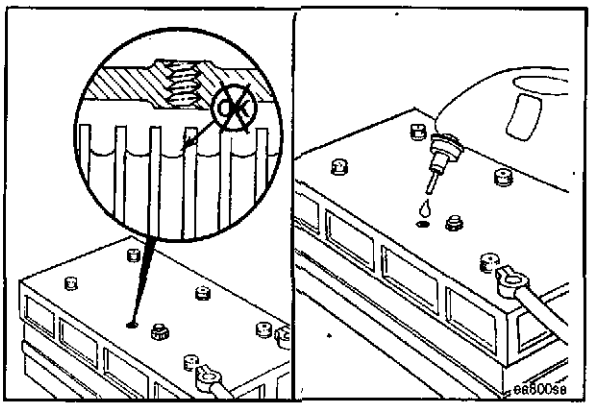
The hold-in wiring (red lead) which connects to the "**Run**" terminal should use a minimum of 14 gauge wire.

Note: Starter solenoids are usually internally grounded through the starting motor. No return lead from the starting solenoid to the battery negative is required.

Electrical System - Service Tools

The following special tools are recommended to perform procedures in Section 6. The use of these tools is shown in the appropriate procedure. These tools can be purchased from your local Cummins Authorized Repair Location.

Tool No.	Tool Description	Tool Illustration
3376898	**Digital Multimeter** Use to measure voltage (volts) and resistance (ohms) in a circuit.	
3377193	**Inductive Charging - Cranking Systems Analyzer** Use to test generators, alternators, relays, starting motors, regulators and batteries. Contains built-in volt meter and ammeter.	
CC-2800	**Refractometer** The Fleetguard® refractometer is used to check the charge condition of a conventional battery.	



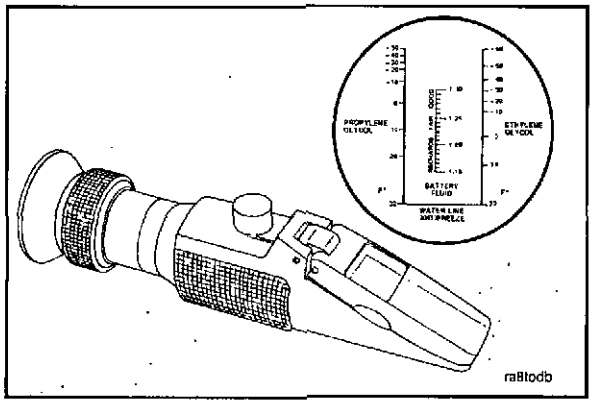
Electrical System - Diagnosing Malfunctions (6-01)

Batteries - Checking

If conventional batteries are used, remove the cell caps or covers and check the electrolyte (water and sulfuric acid solution) level.

NOTE: Maintenance-free batteries are sealed and do **not** require the addition of water.

Fill each battery cell with distilled water. Refer to the manufaturer's specifications.



Part No. CC-2800, Refractometer

Use Fleetguard® refractometer, Part No. CC-2800, to check the condition of the battery.

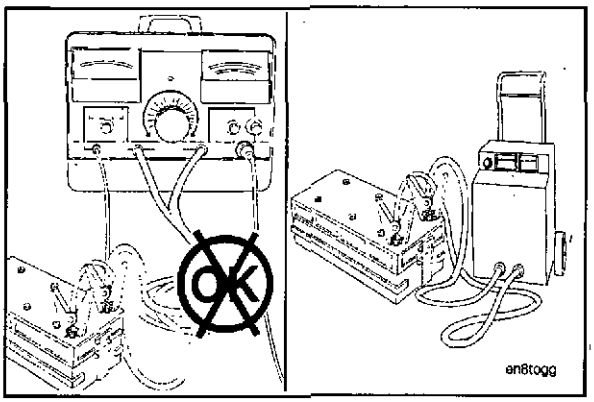
Refer to the battery fluid column in the refractometer to determine the state-of-charge of each battery cell.

NOTE: If the specific gravity of any or all of the cells is below 1.200, the battery **must** be charged.

Battery State of Charge	Specific Gravity @ 27°C [80°F]
100%	1.260-1.280
75%	1.230-1.250
50%	1.200-1.220
25%	1.170-1.190
Discharged	1.110-1.130

ea800ka

Refer to the accompanying chart to determine the battery state-of-charge based on the specific gravity readings.



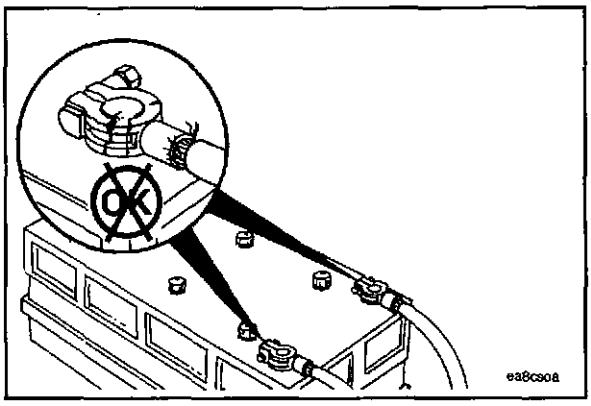
Part No. 3377193, Analyzer

Use Part No. 3377193 Analyzer to load test the state-of-charge of maintenance-free batteries. If the state-of-charge is low, use a battery charger to charge the battery. Refer to the manufacturer's instructions. Replace the battery if it will **not** charge to the manufacturer's specifications or will **not** maintain a charge.

Battery Terminal Connections - Checking

Visually inspect the battery terminals for loose, broken, or corroded connections.

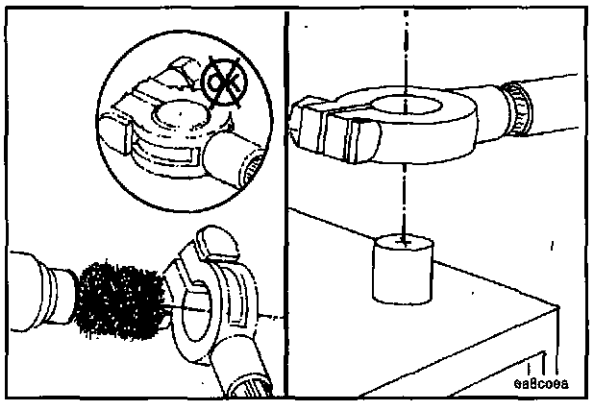
Repair or replace broken cables or terminals.



If the connections are corroded, remove the cables and use a battery cable brush to clean the cable and battery terminals.

Install and tighten the battery cables.

Use grease to coat the battery terminals to prevent corrosion.



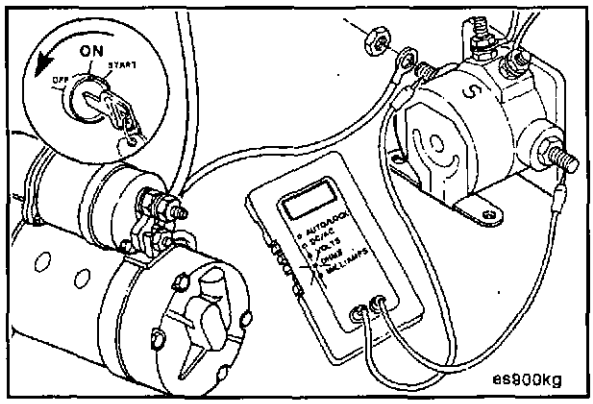
Starting Circuit - Checking

Magnetic Switch - Checking

Warning: Be sure the starting motor switch is in the "OFF" position to prevent electrical shock and personal injury.

Remove the cable connecting the magnetic switch to the starting motor solenoid from the magnetic switch terminal.

Connect the leads of Part No. 3376898 Digital Multimeter to the two large switch terminals.

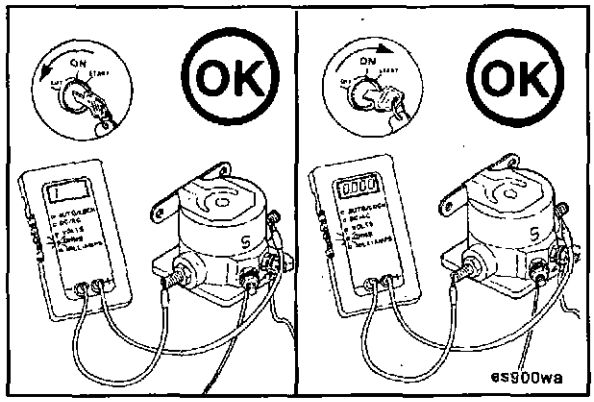


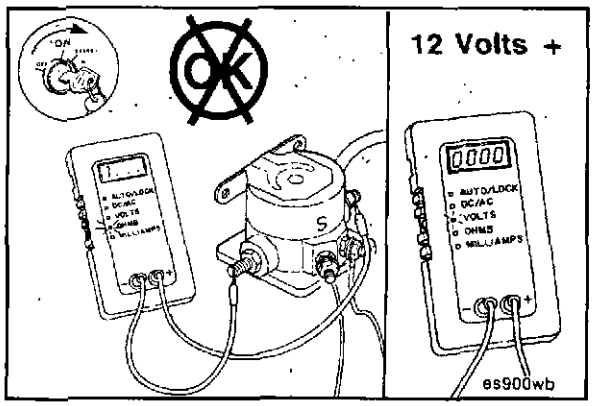
Set the multimeter to measure resistance (OHMS).

With the starting motor switch in the "OFF" position, the multimeter **must** indicate resistance at infinity.

Turn the starting motor switch to the "START" position.

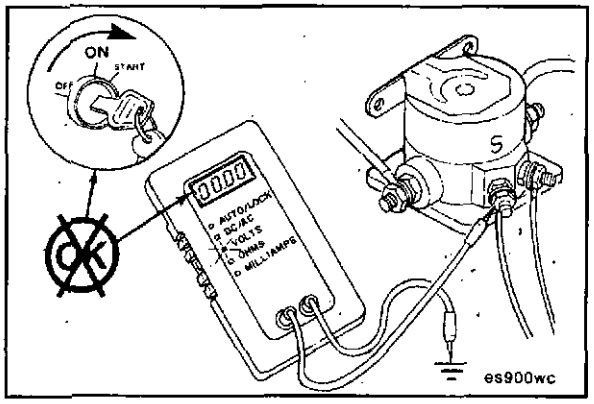
The multimeter **must** indicate zero or very little resistance.



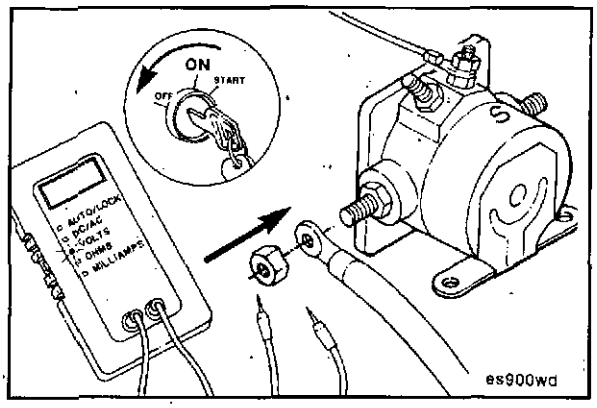


If the multimeter indicates resistance at infinity with the starting motor switch in the "START" position:

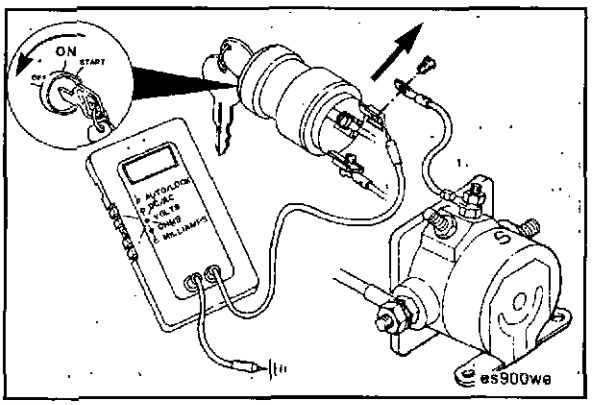
- Turn the starting motor switch to the "OFF" position.
- Set the multimeter scale to read DC voltage.



- Connect one multimeter lead to the magnetic switch terminal marked "S" and the other lead to the ground.
- Turn the starting motor switch to the "START" position.
- If the multimeter indicates no voltage, the magnetic switch is **not** the cause of the complaint. Refer to "Starting Motor Switch - Check" in this Procedure.



- Turn the starting motor switch to the "OFF" position.
- Remove the multimeter leads and connect the magnetic switch to the starting motor solenoid wire.



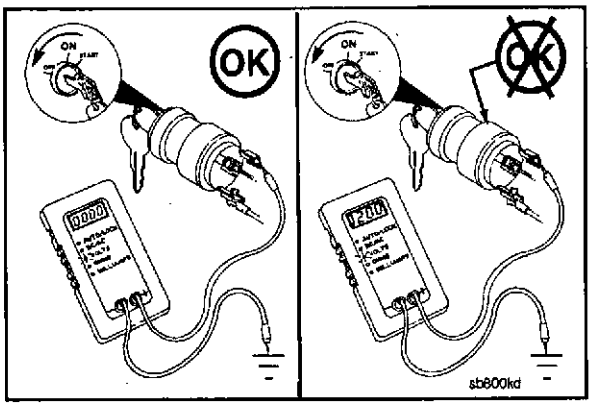
Starting Motor Switch - Checking

Warning: Be sure the starting motor switch is in the "OFF" position to prevent electrical shock and personal injury.

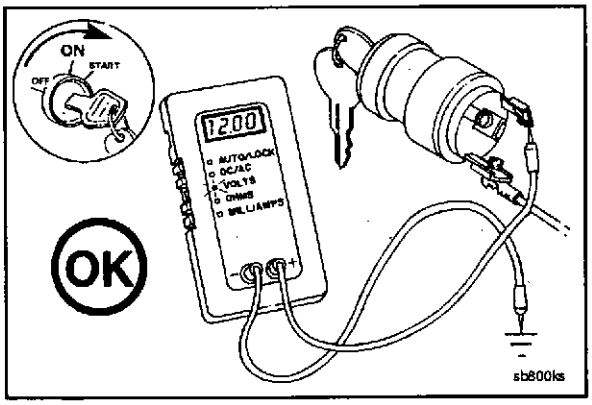
Remove the wire connecting the starting motor switch to the magnetic switch (marked "S" or "Start") from the starting motor switch terminal.

Connect the positive lead of Part No. 3376898 Digital Multimeter to the starting motor switch terminal and the negative lead to a chassis or engine ground location.

NOTE: With the starting motor switch in the "OFF" position, there **must not** be voltage at the starting motor switch terminal. If the meter indicates voltage, the starting motor switch is malfunctioning and **must** be replaced.

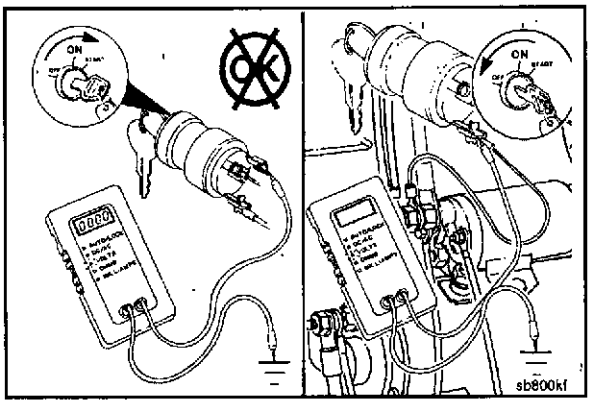


Turn the starting motor switch to the "START" position. The multimeter **must** indicate system voltage.

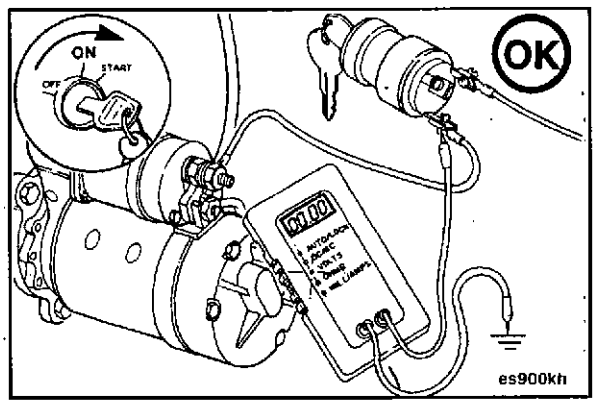


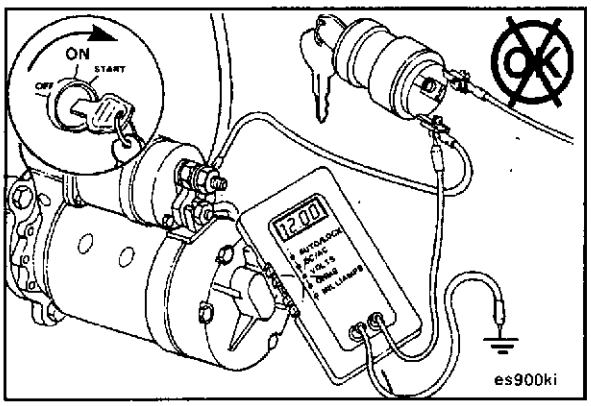
If there is **not** voltage:

- Turn the starting motor switch to the "OFF" position.
- Connect the multimeter positive lead to the starting motor switch terminal having a wire connecting the starting motor switch to the starting motor solenoid "B" terminal.



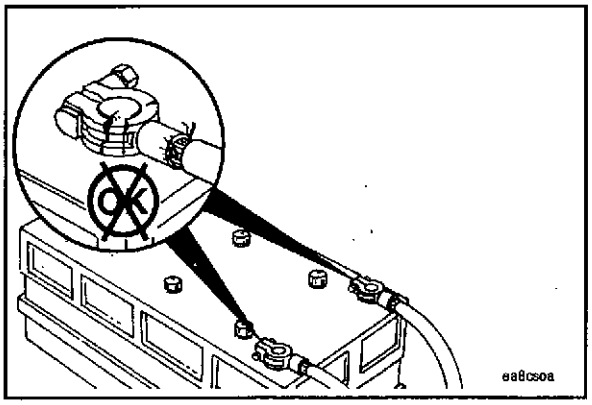
If the meter indicates system voltage at the starting motor switch input terminal, the starting motor switch is defective and **must** be replaced.





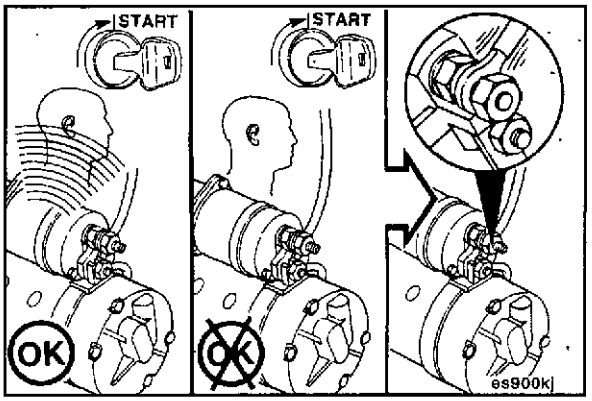
If the meter indicates no voltage, the switch is **not** the cause of the complaint.

Check the wiring from the starting switch to the starting motor solenoid "B" terminal and from the starting motor solenoid to the battery for broken or damaged wires.



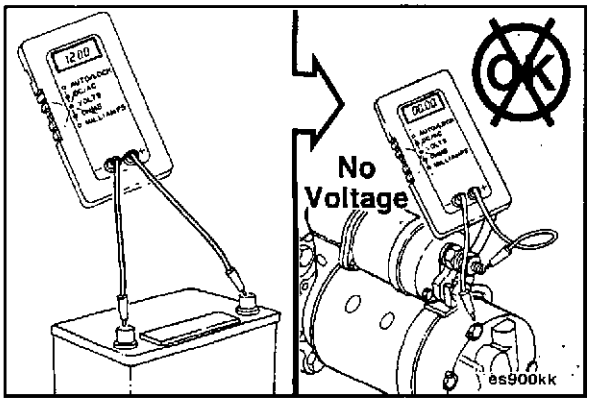
Starting Motor Solenoid and Starting Motor - Checking

Before troubleshooting the starting motor, make sure the battery terminals are **not** loose or corroded. Refer to "Battery Terminal Connections", in this section.



Starting Motor Solenoid

If the starting motor solenoid does **not** make an audible sound, check for loose wiring connections.

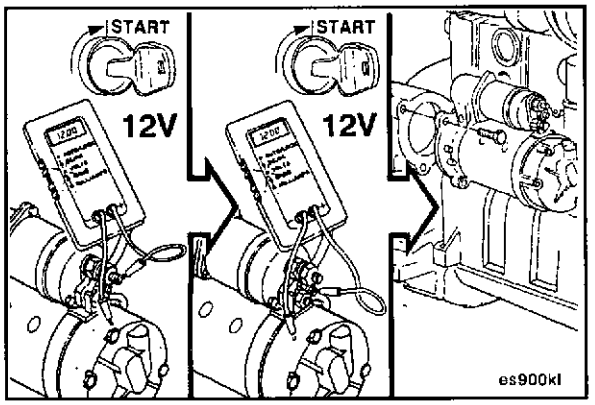


Use a Digital Multimeter such as Part No. 3377161 to set the voltage scale.

Check for system voltage at the starting motor solenoid battery terminal.

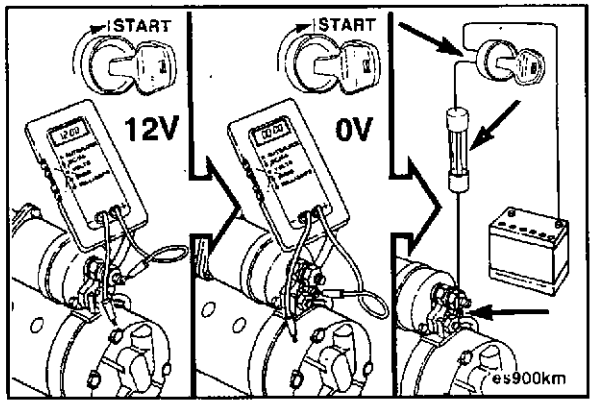
If the multimeter indicates system voltage at the starting motor battery terminal, check the voltage at the starting motor solenoid "S" terminal while the starter switch is energized.

If the multimeter indicates system voltage at "S" terminal, but the starter does **not** engage, the starting motor solenoid is malfunctioning and the starter **must** be replaced.



If the multimeter does **not** indicate system voltage at the "S" terminal, check:

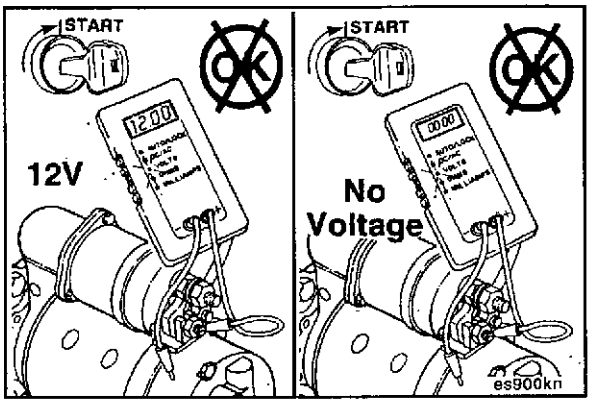
- Fuses
- Voltage to the ignition switch and magnetic switch. Refer to "Starting Motor Switch and Magnetic Switch - Checking" in this section.
- Application safety shutoff systems.



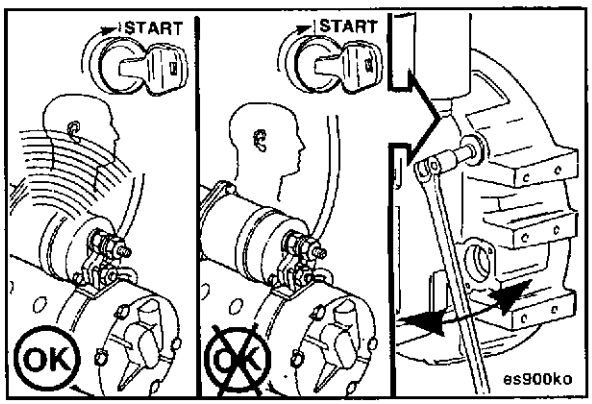
Starting Motor

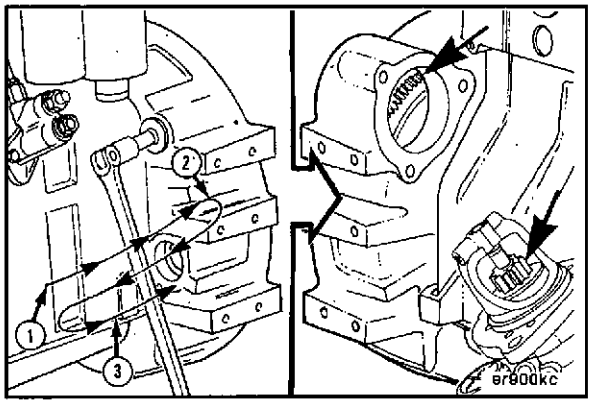
Check for system voltage at the "M" terminal of the starting motor while the starter switch is energized.

- System Voltage: Starting motor is malfunctioning or not adequately grounded and **must** be repaired or replaced.
- No Voltage: Starting motor solenoid is malfunctioning and **must** be replaced.



If the starting motor solenoid makes an audible sound, turn the switch OFF and attempt to rotate the crankshaft in both directions.



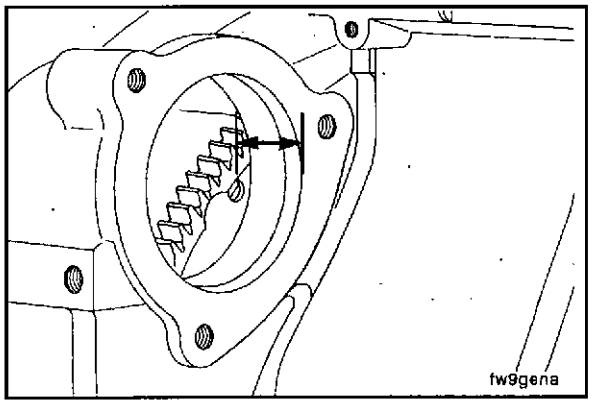


Rotate the crankshaft as follows:

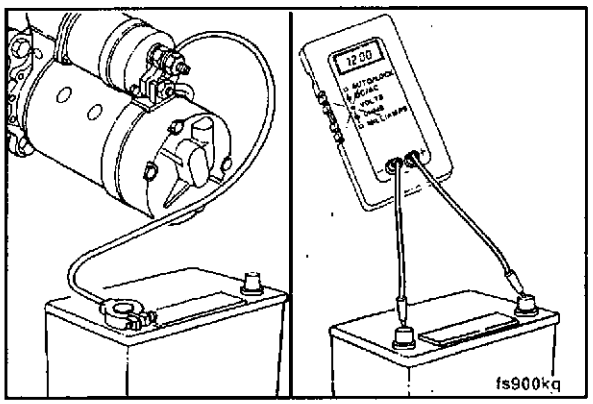
1. Direction of engine rotation.
2. Direction **opposite** engine rotation.
3. Direction of engine rotation.

If the crankshaft will rotate at step No. 3, attempt to start the engine. If the starting motor cranks the engine, check the starting motor pinion gear and flywheel ring gear for damage.

If the starting motor pinion gear or the flywheel ring gear is damaged, the damaged component(s) must be replaced. Refer to Procedures 6-02 and 7-26.



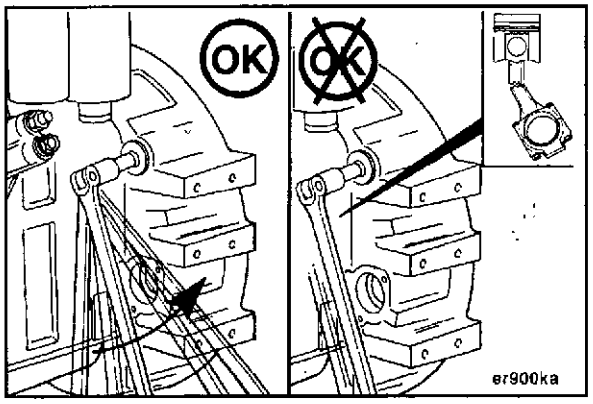
To attain a starter motor mounting surface to ring gear face dimension of 50.8 mm ± 1.5 mm [2.0 in ± 0.060 inch] a starter spacer is used between the starter motor and flywheel housing. If the starter to ring gear spacing dimension is **not** within specification, check to make sure the correct spacer, flywheel or flexplate, and crankshaft to flexplate mounting adapter (if required) is on the engine. This will help determine which component is causing the spacing dimension to be out of specifications.



Engine Cranking Speed Too Slow

Make sure the wiring connections are clean, tight and **not** damaged. Refer to "Battery Terminal Connections", Procedure 6-02.

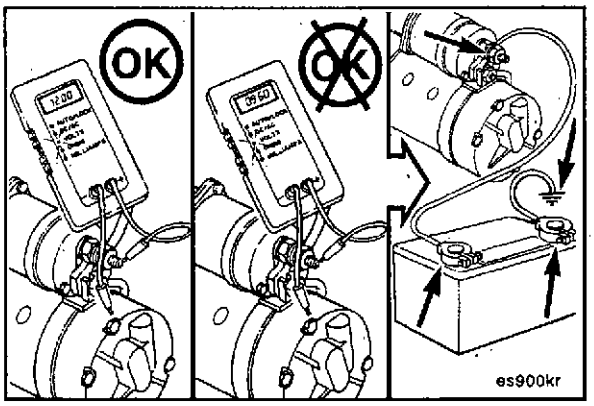
Check the battery voltage. Refer to "Batteries - Checking", Procedure 6-01.



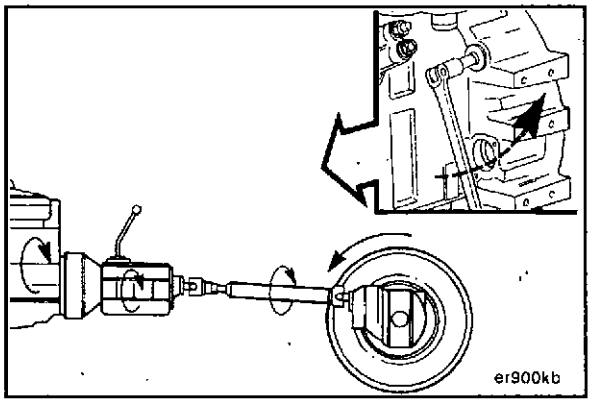
If the crankshaft was **not** rotated to check the starting motor, rotate the crankshaft in the direction of engine rotation to make sure the engine does **not** have an internal malfunction.

If the engine rotates freely, check the voltage at the starting motor during cranking. If the voltage drops more than 2.4 volts, check that all connections are tight. The limit for 24-volt systems is 4.8 volts.

If the cables are adequate size and good condition, but the voltage drop exceeds the limit, replace the starting motor.

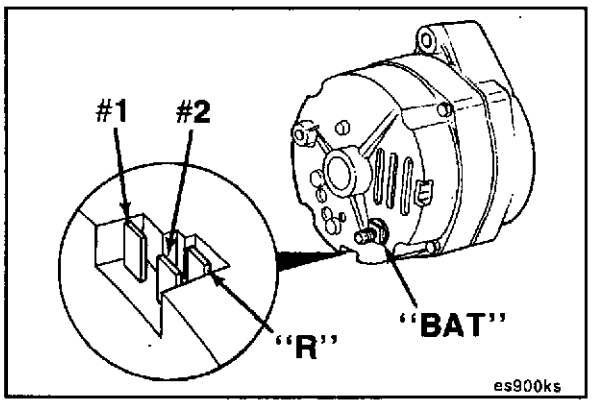


If the crankshaft requires more than a normal effort to rotate, check for excessive load from the driven units and accessories.

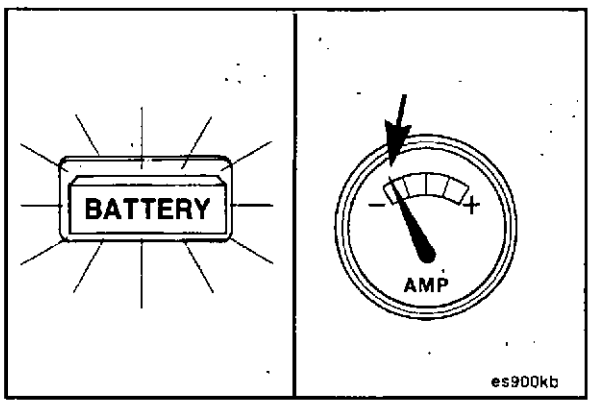


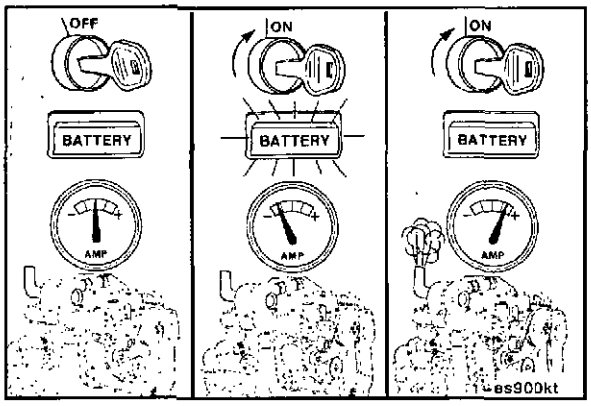
Alternator

The terminals on the alternator are shown in this illustration. The "R" terminal (Delco) or "W" terminal (Bosch K1) provides one-half system voltage and is used to operate accessories such as the tachometer on generator sets.



Trouble with the charging system may be indicated by the indicator lamp or ammeter.

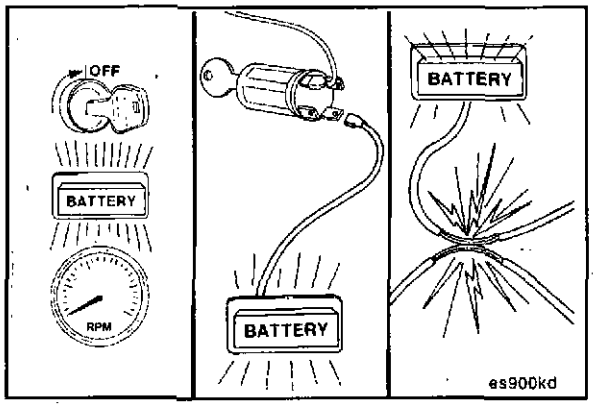




Abnormal Indicator Lamp Operation

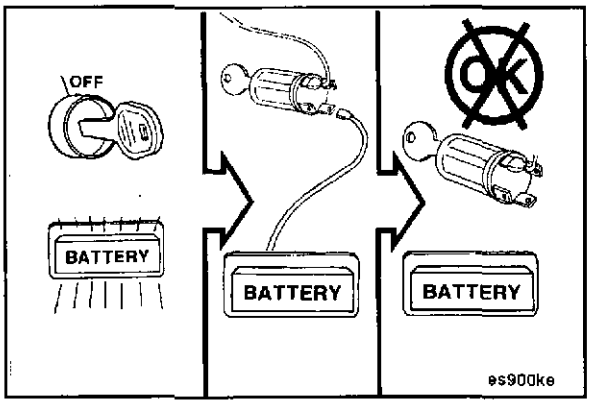
Check the indicator lamp for normal operation as shown below:

Engine	Switch	Lamp	Ammeter
Stopped	Off	Off	0
Stopped	On	On	-
Running	On	Off	+

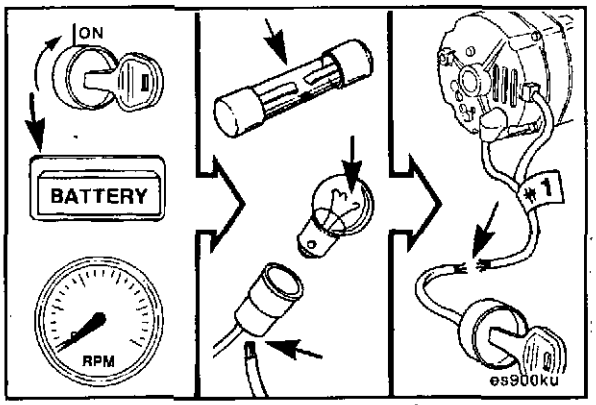


Switch Off, Lamp On, Engine Stopped

Disconnect the lamp lead at the ignition switch. If the lamp stays on, there is a short to a positive wire on the ignition side of the lamp.



If the lamp goes out, there is a short in the switch.

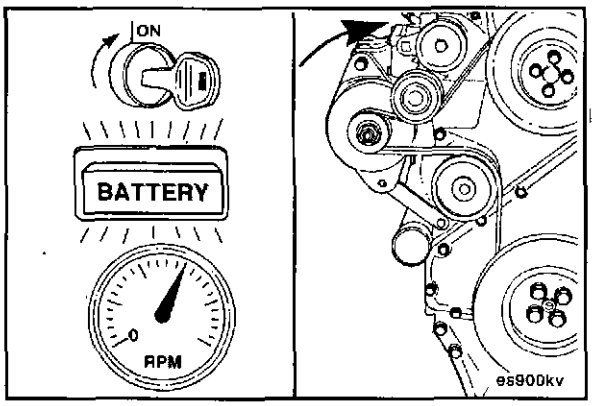


Switch On, Lamp Off, Engine Stopped

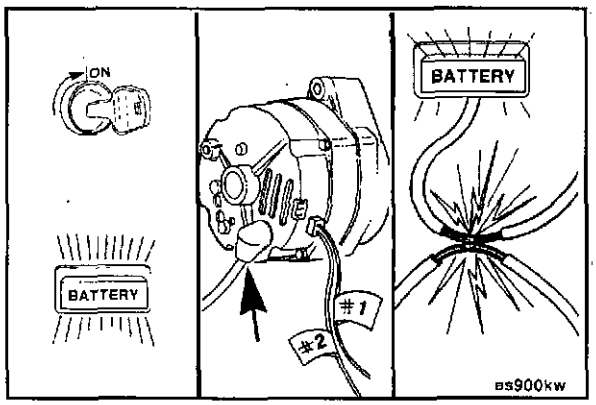
This condition can be caused by an open in the circuit. To determine where an open exists. Check for a blown fuse, a burned out bulb, defective bulb socket, or an open in No. 1 or "D+" lead circuit between alternator and ignition switch.

Switch On, Lamp On, Engine Running

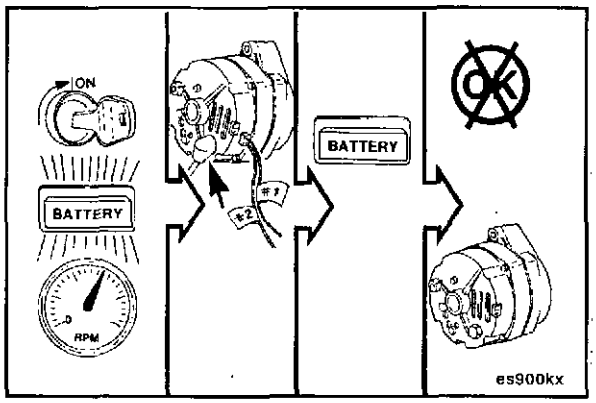
Check the drive belt and alternator pulley to be sure the alternator is rotating.



Disconnect the lead to Terminals No. 1 and No. 2 (Delco) or D+ (BOSCH K1). If the lamp stays on, there is a short to ground on the alternator side of the lamp.



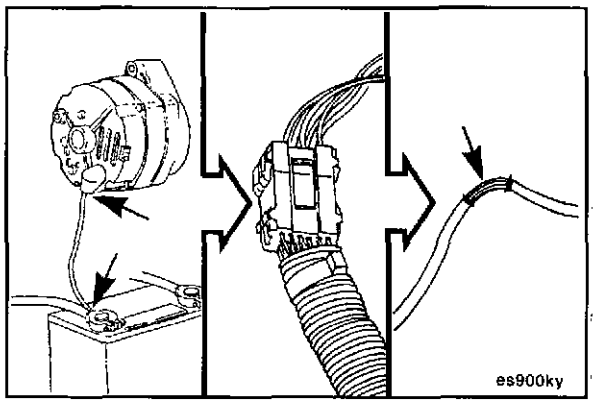
If the lamp goes out, replace the alternator.

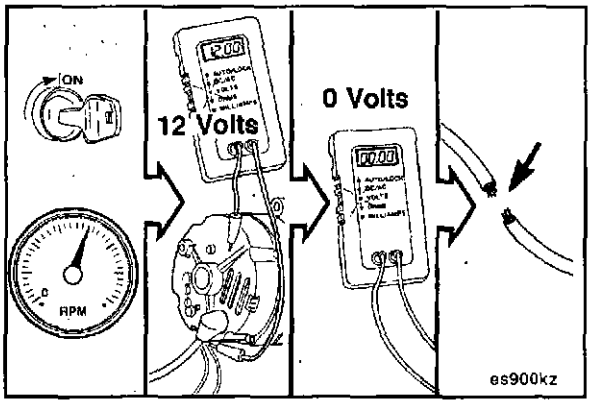


Abnormal Charging System Operation

Check the battery and all wiring connections.

Inspect the wiring for defects. Check all connections for tightness and cleanliness, including the slip connectors at the alternator and firewall, and connections at the battery.





With ignition switch on and all wiring harness leads connected, connect a voltmeter from:

A. Alternator "BAT" (Delco 15SI) "B+" (Bosch K1) terminal to ground.

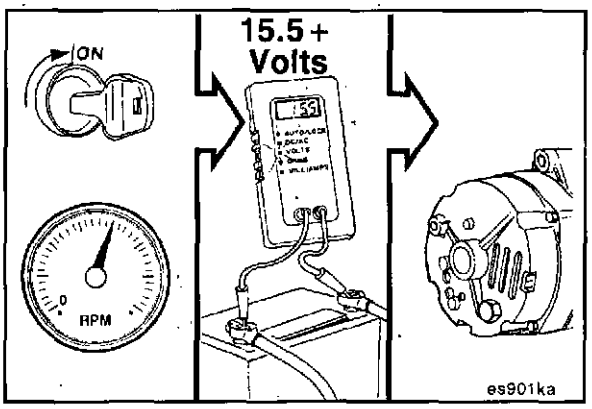
B. Alternator No. 1 (Delco 15SI) to ground.

C. Alternator No. 2 (Delco 15SI) to ground.

D. Alternator D+ (Bosch K1) to ground.

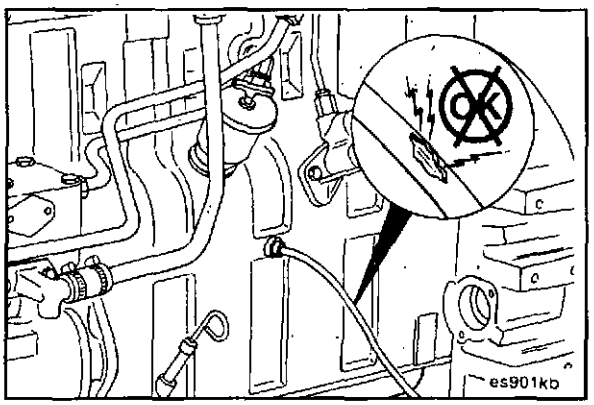
A zero reading indicates an open between the alternator connections and the battery.

Locate and repair the open circuit.



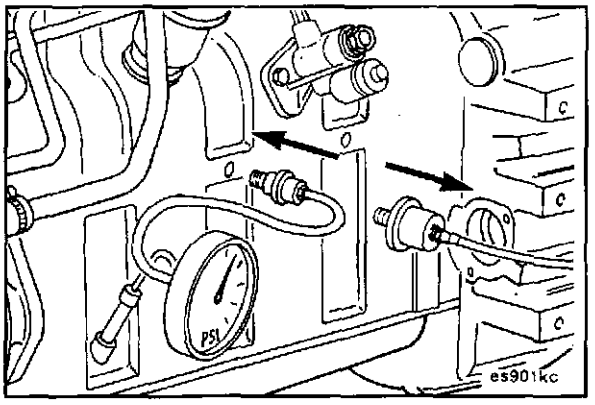
With all accessories turned OFF, connect a voltmeter across the battery. Operate engine at 1500 RPM or above.

If voltage is 15.5 or more, remove the alternator for repair. The limit for 24 volt systems is 28 volts.



Oil Pressure Switch and Temperature Sensor - Checking

When diagnosing problems with either the pressure switch or the temperature sensor, check for loose or corroded connections and broken wires.



Checking the Oil Pressure Switch

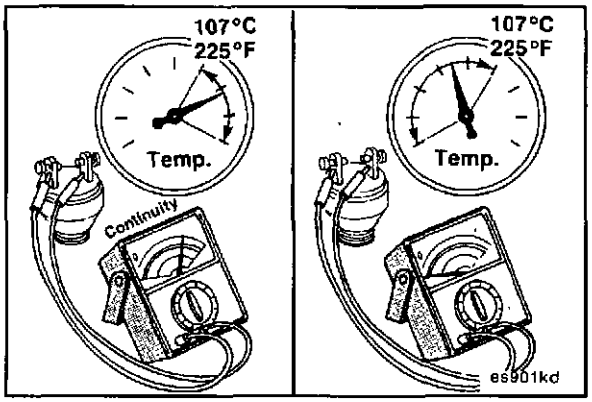
Remove the pressure switch, install a gage, start the engine and measure oil pressure. Minimum oil pressure:

Low Idle (675 to 725 RPM) .... 69 kPa [10 PSI]
High Idle ..... 207 kPa [30 PSI]

Pressure switch is set to actuate when oil pressure drops to 55 kPa [8 PSI].

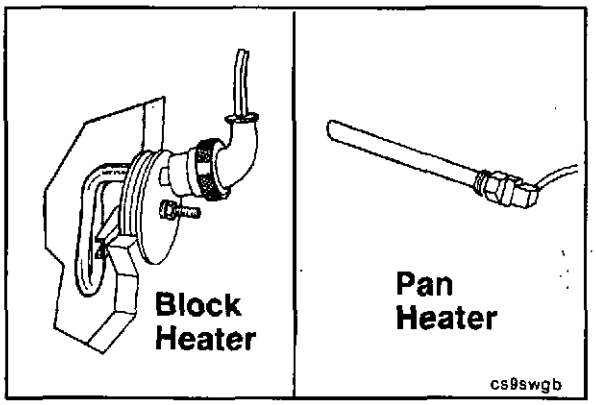
Checking the Temperature Sensor

Check for continuity. The sensor will have continuity only when coolant temperature is above 107°C [225°F].

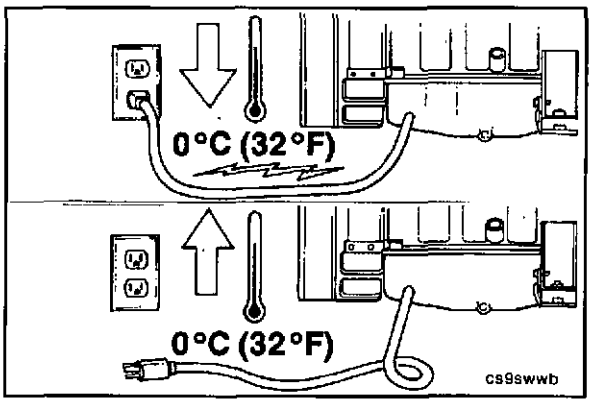


Coolant or Pan Heaters - Checking

When functioning properly, the engine block or oil pan heater should make an audible sound when activated. The adjacent parts should be warm to the touch.



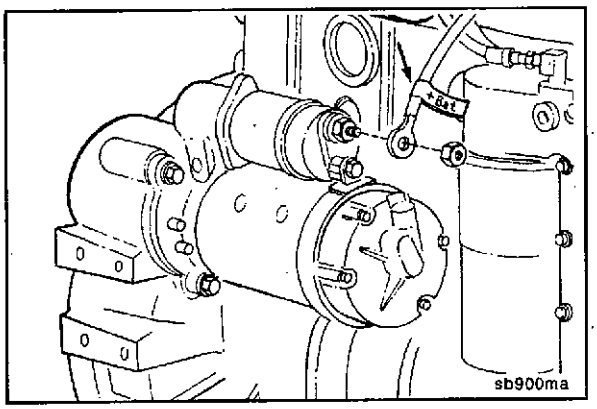
Some heaters will operate continuously when plugged into the correct voltage electrical socket. Operate them only below 0°C [32°F] ambient temperature.



Starting Motor - Replacement (6-02)

Preparatory Steps:

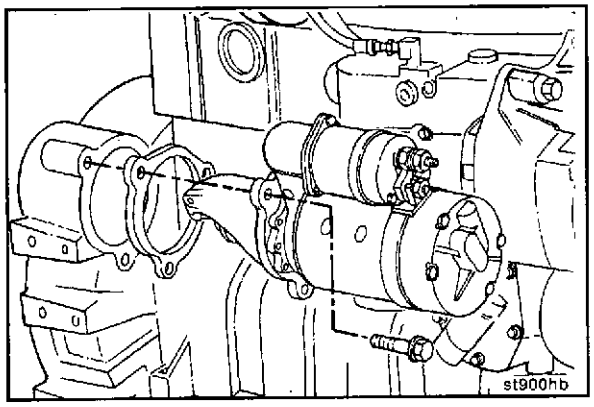
- Disconnect the ground cable from the battery.
- Identify each electrical wire with a tag indicating location.



Removal and Installation

19 mm

Remove the battery cable from the solenoid.



16 mm and 19 mm

Remove the starting motor and spacer.

Install the starting motor and spacer in the reverse order of removal.

Connect the battery cable to the solenoid.

Torque Value: 77 N•m [57 ft-lb]

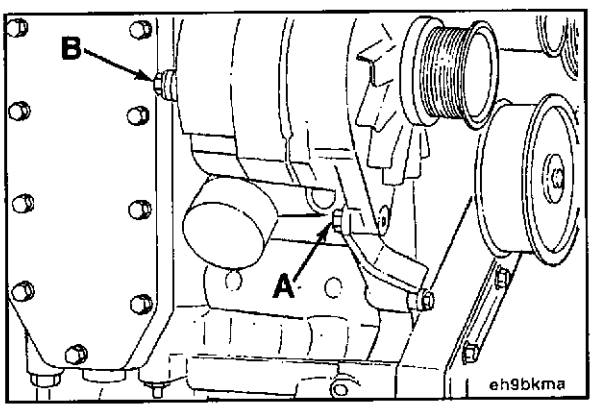
Alternator - Replacement (6-03)

Preparatory Steps:

Disconnect the ground cable from the battery terminal.

Identify each electrical wire with a tag indicating location.

Remove the drive belt. Refer to Procedure 1-03.



Removal

19 mm

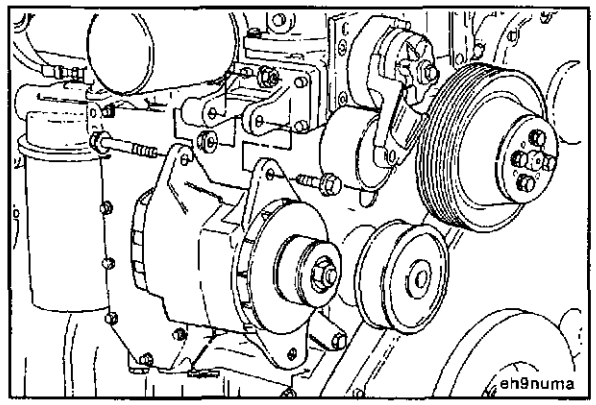
Remove the capscrew (A) from the alternator link.

Remove the capscrew (B) from the tail support bracket.

18 mm, 19 mm

Remove the alternator mounting capscrews and nuts.

Remove the alternator.

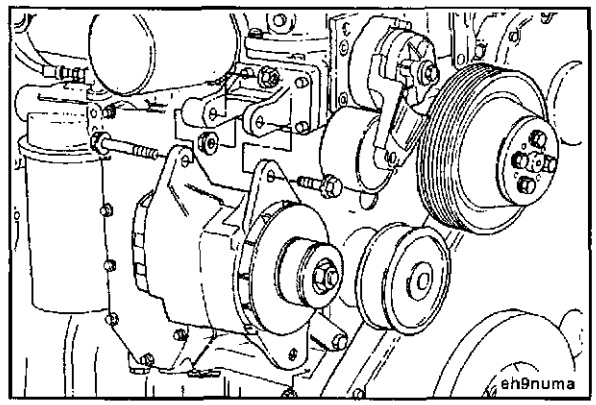


Installation

18 mm, 19 mm

Install the alternator mounting capscrews and nuts.

Torque Value: 77 N•m [57 ft-lb]



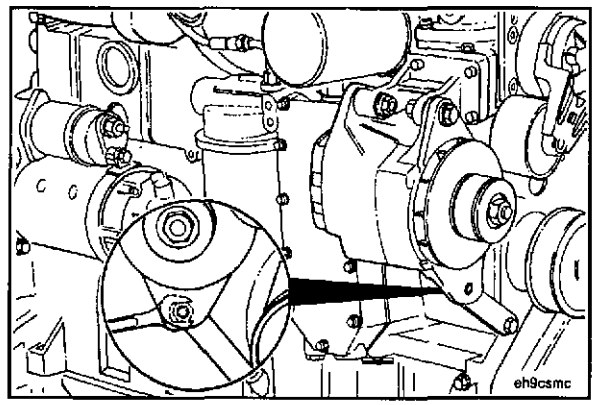
19 mm

Install the alternator link and the tail support bracket.

Torque Value:

(Alternator End) 43 N•m [32 ft-lb]
(Water Pump End) 24 N•m [18 ft-lb]

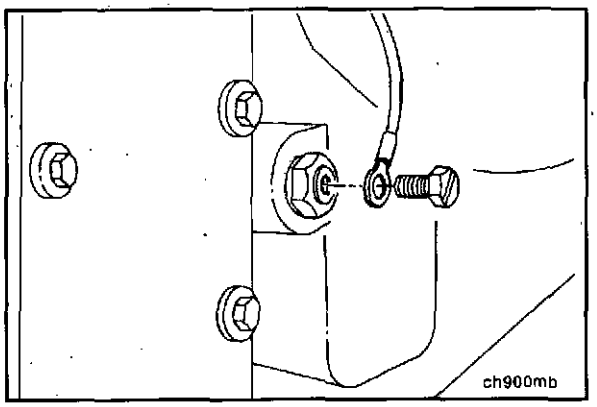
Connect all wires and install the drive belt.



Coolant Temperature Sensor - Replacement (6-04)

Preparatory Step:

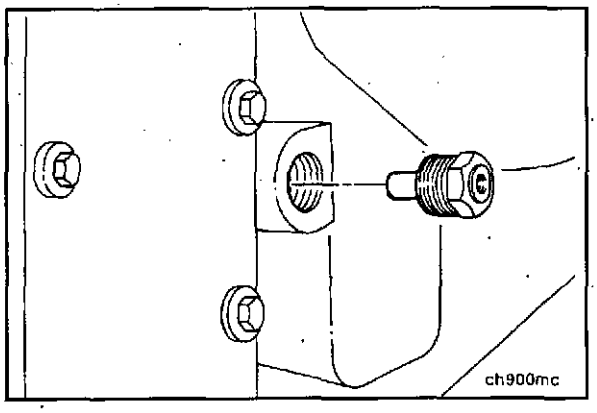
- Drain the coolant. Refer to Procedure 1-01.



Removal

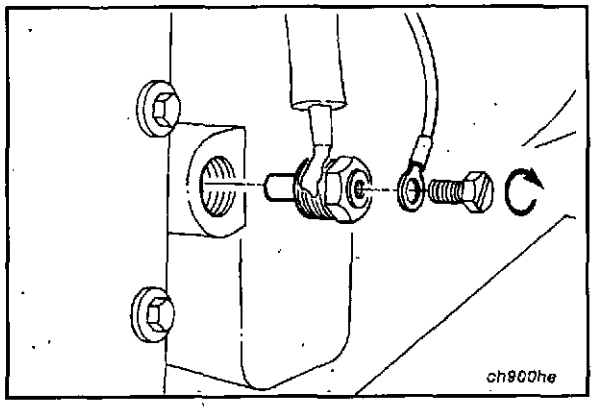
3/8 inch or Screwdriver

Disconnect the temperature sensor wiring.



7/8 inch

Remove the temperature sensor.



Installation

7/8 inch and 3/8 inch or screwdriver

Apply liquid teflon sealant to the threads when installing the temperature sensor.

Connect the wiring.

Torque Value:
(Installed into Cast Iron) 50 N•m [37 ft-lb]
(Installed into Aluminum) 30 N•m [22 ft-lb]

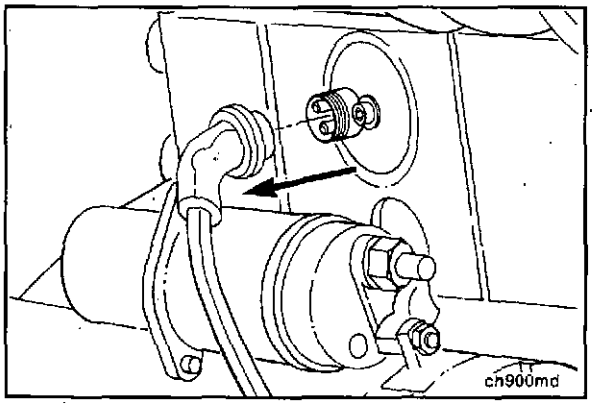
Engine Block and Coolant Heater (750 and 500 Watts) - Replacement (6-05)

Preparatory Step:

- Drain the coolant. Refer to Procedure 1-01.

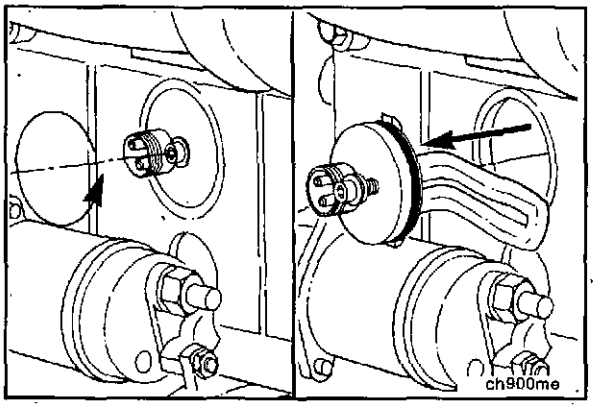
Removal

Disconnect the block heater electrical cord.



4 mm

Loosen the block heater retaining capscrew and remove the block heater from the block.



Installation

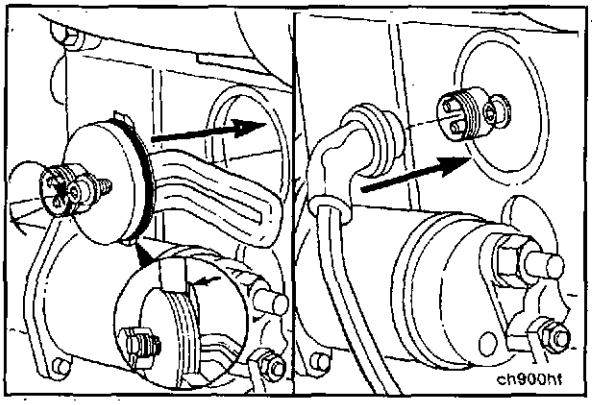
4 mm

Caution: Loss of coolant and engine damage will result if the T-bar is not correctly positioned in the bore.

Apply a coat of engine oil to the o-ring. Slide the heater into the bore. Use a plastic hammer to drive the heater into the bore. Make sure the o-ring is **not** damaged during installation. Tighten the retaining capscrew.

Torque Value: 12 N•m [106 in-lb]

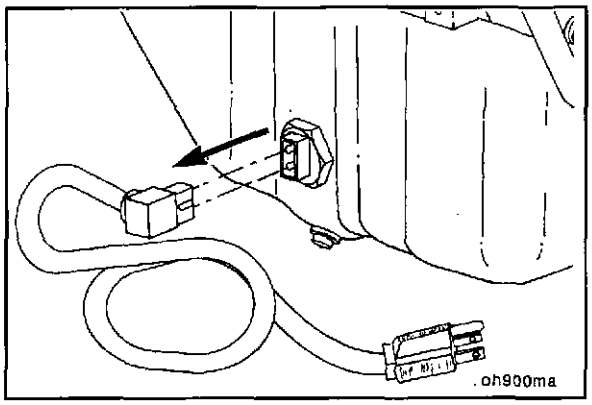
Connect the electrical cord and refill the radiator to the proper level.



Lubricating Oil Pan Heater - Replacement (6-06)

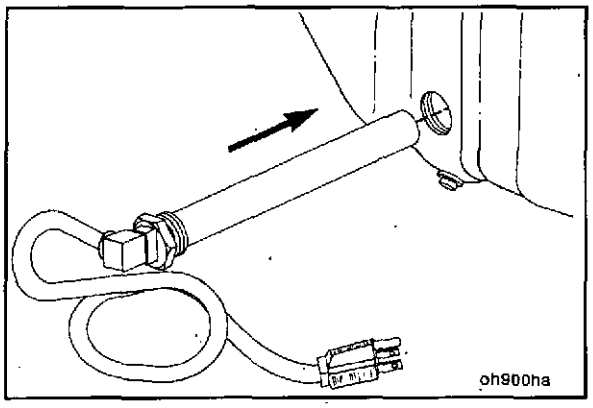
Preparatory Step:

- Drain the engine oil. Refer to Procedure 2-04.



Removal

Disconnect the oil heater electrical cord.

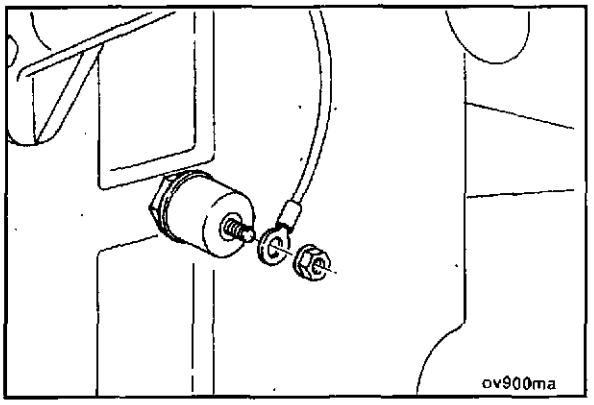


Installation

Ratchet, 27 mm Deep Well Socket, Torque Wrench

Replace the heater element. Refill the engine to the correct oil level.

Torque Value: 120 N•m [89 ft-lb]

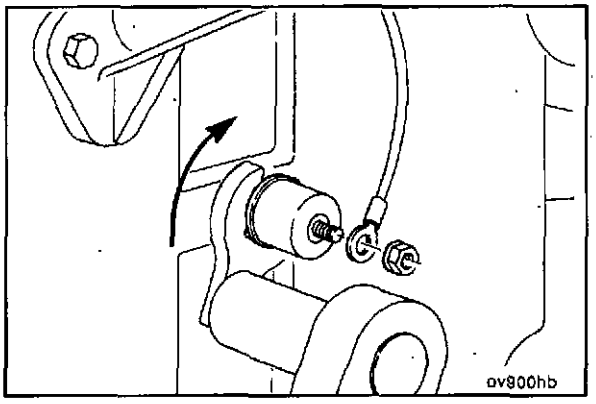


Lubricating Oil Pressure Switch - Replacement (6-07)

Removal

Disconnect the wire from the sending unit.

The sending units illustrated may differ from those installed by the equipment manufacturer.



Installation

Connect the wire to the sending unit.

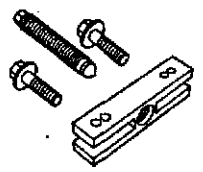
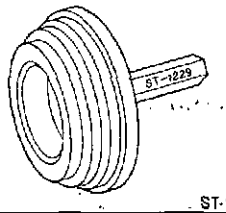
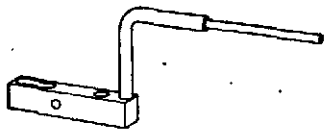
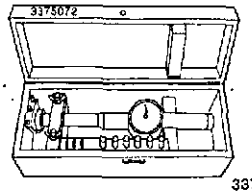
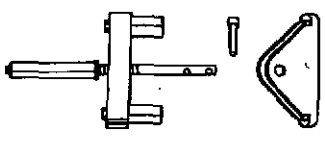
Torque Value:
(Installed into Cast Iron) 16 N•m [12 ft-lb]
(Installed into Aluminum) 10 N•m [89 in-lb]

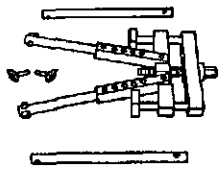
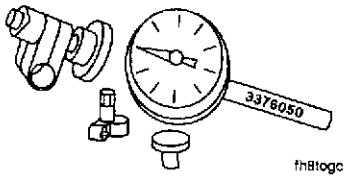
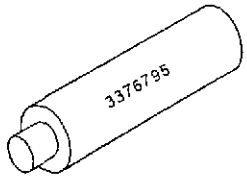
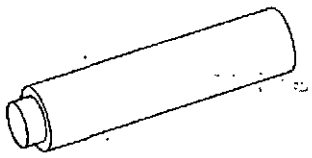
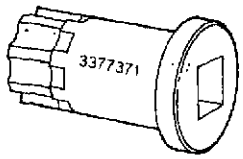
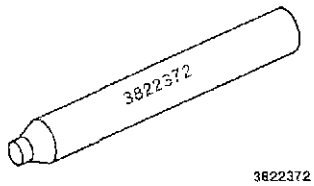
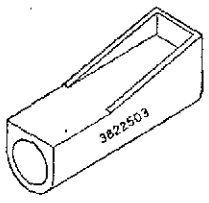
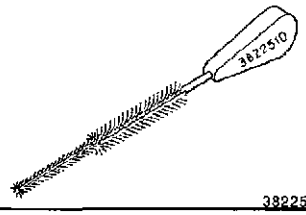
Section 7 - Base Engine Components

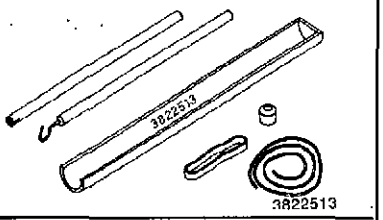
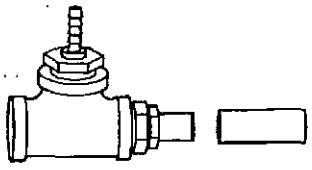
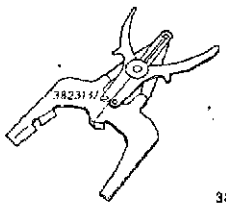
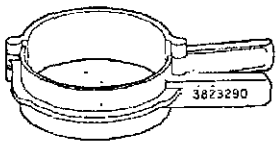
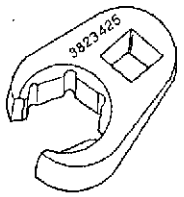
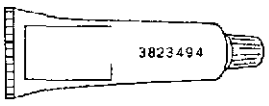
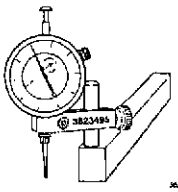
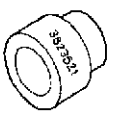
Section Contents

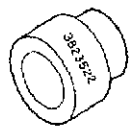
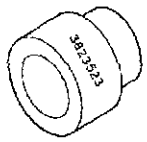
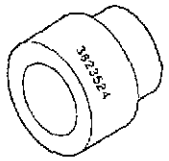
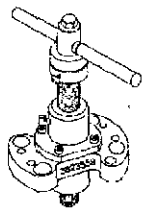
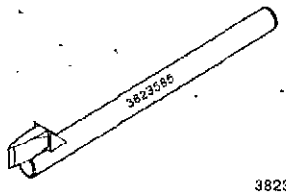
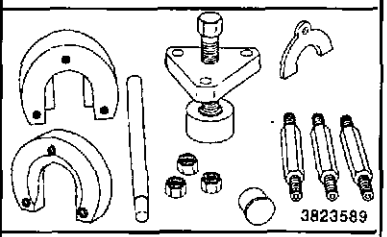
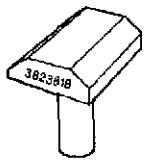
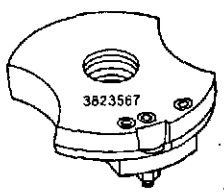
Base Engine Components - Service Tools

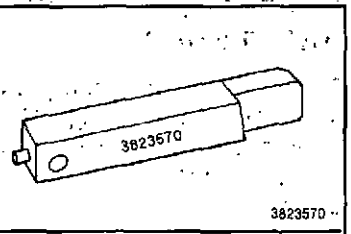
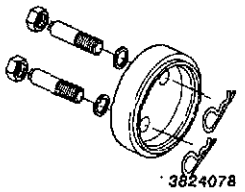
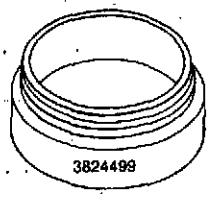
The following special tools are recommended to perform procedures in Section 7. The use of these tools is shown in the appropriate procedure. These tools can be purchased from your local Cummins Authorized Repair Location.

Tool No.	Tool Description	Tool Illustration
ST-647	**Standard Puller** *Used to remove drive pulleys, impellers, air compressor counterweights, etc.*	
ST-1229	**Cylinder Liner Driver** Install cylinder liner in cylinder block.	
ST-1325	**Dial Gauge Attachment** Attaches to crankshaft flange to provide measuring of flywheel and flywheel housing runout with dial bore gauge.	
3375068	**Cup Plug Sealant** Used when installing pipe plugs, cup plugs, etc. on the engine to prevent leaks.	
3375072	**Dial Bore Gauge Kit** Used to measure internal diameter bores from 78.5 mm [3.09 in] to 2.032 mm [8.0 in].	
3375629	***Universal Cylinder Liner Puller*** Remove cylinder liners from cylinder block. Requires Part No. 3822786 Cylinder Liner Puller Plate.	

Tool No.	Tool Description	Tool Illustration
3376015	**Cylinder Liner Puller (Universal)** Remove cylinder liners from the cylinder block. Requires two Part No. 3376649 Puller Arm Extension Feet.	 ck8togr
3376050	**Dial Indicator and Sleeve Assembly** Use with Part No. ST-1325 Dial Gauge Attachment to measure flywheel and flywheel housing runout.	 fh8togc
3376795	**Expansion Plug Driver Handle** Used with all expansion plug drivers larger than 0.375 inch diameter.	
3376816	**Expansion Plug Driver** Install 1.00 inch expansion plug to specified depth. Used with expansion plug driver handle, Part No. 3376795	 ck8togo
3377371	**Engine Barring Gear** Used to engage the flywheel ring gear to rotate the crankshaft.	
3822372	**Expansion Plug Driver** Install 0.375 inch expansion plug to specified depth.	 3822372
3822503	**Cylinder Liner Clamp Set** Used to clamp the liner into the bore of the cylinder block. Note: Requires two cylinder head capscrews (not included in the clamp set).	 3822503
3822510	**Injector Bore Brush** Used to clean carbon from injector bores.	 3822510

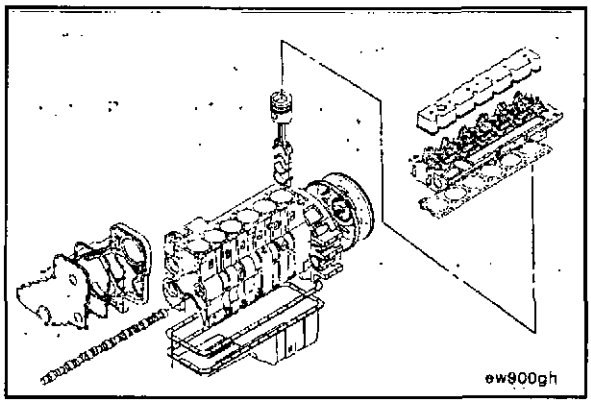
Tool No.	Tool Description	Tool Illustration
3822513	**Tappet Removal Tool Kit** Used to remove and install valve tappets.	
3822566	**Blowby Check Tool** Used with *manometer*, Part No. ST-1111-3, to measure the engine crankcase pressure.	
3823137	**Piston Ring Expander** Used to install piston rings onto pistons without damaging or distorting the rings.	
3823290	**Piston Ring Compressor** Used to compress the piston rings while installing the pistons into the cylinder bores.	
3823425	**Crowfoot Wrench** Used to torque high pressure fuel line nuts on Bosch fuel pump. Size: 17 mm, 3/8 in. drive.	
3823494	**Sealant, Three Bond (150 Gram Tube)** Used for sealing "T" joints and front gear cover.	
3823495	**Gauge Block** Measure cylinder liner protrusion on the cylinder block.	
3823521	**Expansion Plug Driver** Install 0.8125 inch expansion plug to specified depth. Used with expansion plug driver handle, Part No. 3376795.	

Tool No.	Tool Description	Tool Illustration
3823522	**Expansion Plug Driver** Install 1.1875 inch expansion plug to specified depth. Used with expansion plug driver handle, Part No. 3376795.	 3823522
3823523	**Expansion Plug Driver** Install 1.375 inch expansion plug to specified depth. Used with expansion plug driver handle, Part No. 3376795.	 3823523
3823524	**Expansion Plug Driver** Used to install 2.250 inch expansion plug to specified depth.	 3823524
3823559	**Cylinder Liner Counterbore Tool** Used for machining the liner counterbore ledge. Must be used with Part No. 3823567, cutter plate, and Part No. 3823570, cutter bit.	 3823559
3823585	**Crankshaft Gear Splitter** Used to split the crankshaft gear for removal. Does not work on steel gears.	 3823585
3823589	**Camshaft Gear Installation/Removal Tool** Used to remove and install the camshaft gear from the camshaft with the camshaft installed.	 3823589
3823818	**Main Bearing Rollout Tool** Used to remove and install main bearings with the crankshaft installed.	 3823818
3823567	**Cutter Plate** Used with Part No. 3823558, cylinder liner counterbore tool.	 3823567

Tool No.	Tool Description	Tool Illustration
3823570	**Cutter Bit** Used with Part No. 3823567, cutter plate, to machine the cylinder liner counterbore ledge.	
3824078	**Wear Sleeve Installation Tool** Used to install the rear crankshaft lubricating oil seal wear sleeve.	
3824499	**Lubricating Oil Seal Installation Tool** Used to install the front lubricating oil seal in the front cover to a specified depth.	

Base Engine Components - General Information

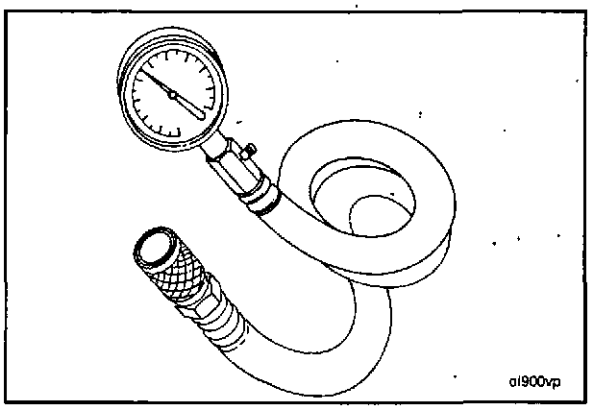
The base engine components section consists of the removal, cleaning, inspection, testing and assembly of all internal and external components **not** previously covered in the troubleshooting and repair of the various engine systems.



Engine Compression - Checking (7-01)

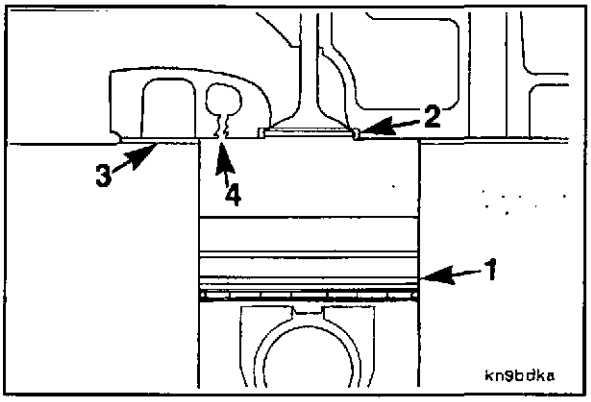
Compression Gauge and Adapter

It is very time consuming and expensive to begin removing internal engine components to diagnose failures. A compression gauge can be used as an aid to check for proper functioning of the following components:



1. Piston ring sealing
2. Intake and exhaust valve sealing
3. Cylinder head gasket sealing
4. Cylinder head cracked

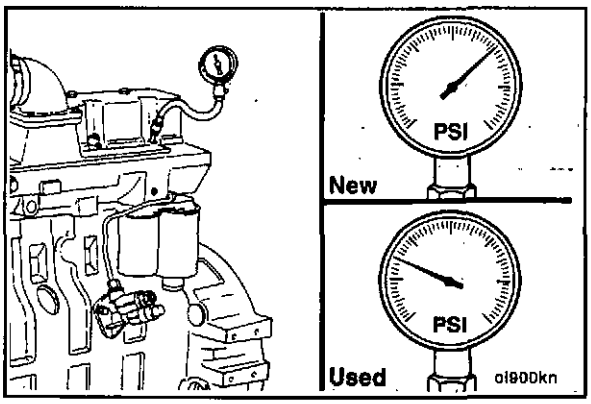
Refer to the appropriate procedure in this section for replacement of failed components.

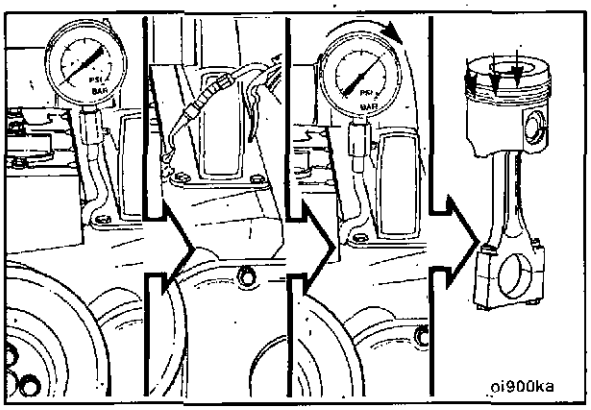


NOTE: Due to variables such as; starter and battery conditions that affect engine cranking speed, it is difficult to establish an absolute value for compression pressure; however, the following values can be used as guidelines:

- New engine (cranking speed @ 250 RPM) 2413 kPa [350 psi]
- Used engine (cranking speed @ 250 RPM) 2068 kPa [300 psi]

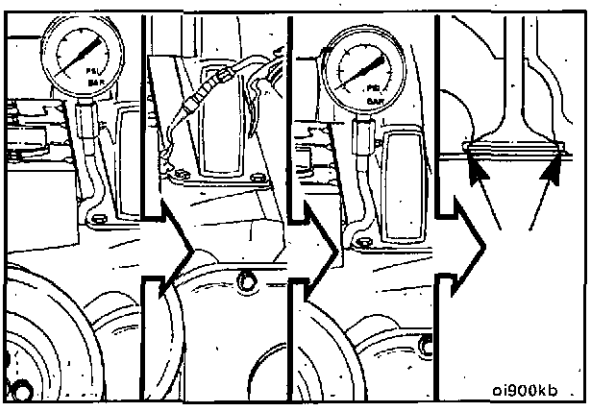
It is recommended that the compression pressure be checked on all cylinders and then compared. All cylinders should be within 690 kPa [100 psi] of each other.





Piston Ring Sealing

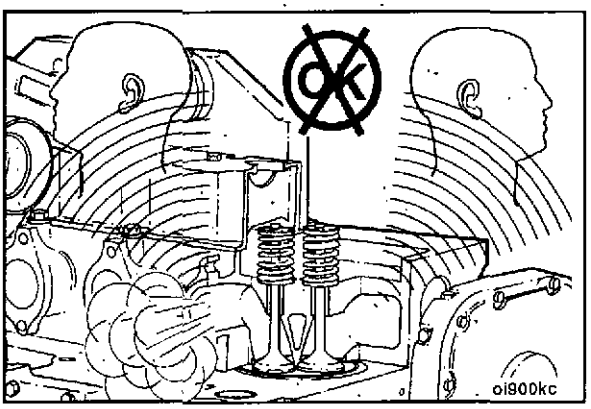
If the compression is low but can be increased significantly by squirting oil into the cylinder, the cause of low compression is inadequate sealing between the rings and the cylinder walls. Refer to Procedure 7-13 for piston ring replacement.



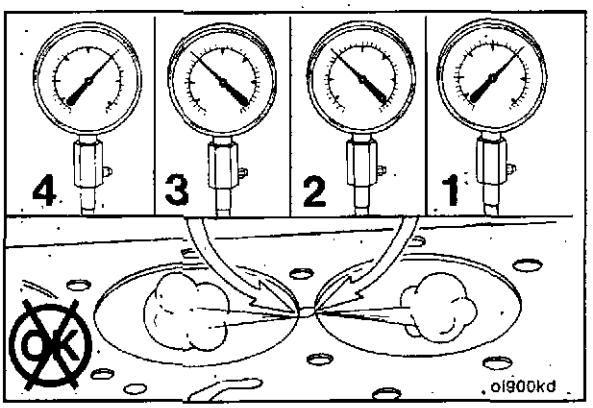
Intake and Exhaust Valve Sealing

If the compression is low on one or more non-adjacent cylinders and the pressure **cannot** be increased by oiling the rings, poor valve sealing is to be suspected.

Refer to Procedure 7-09 for cylinder head replacement.



Valve leakage is often audible from the intake and exhaust manifold.

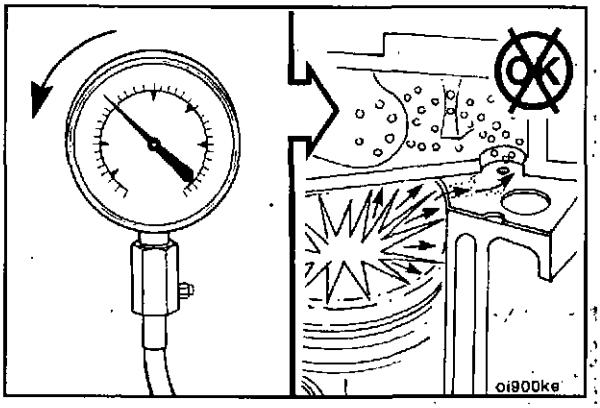


Cylinder Head Gasket Sealing

If the compression is low on adjacent cylinders and the pressure **cannot** be increased by oiling the rings, the cylinder head gasket is probably leaking between the cylinders.

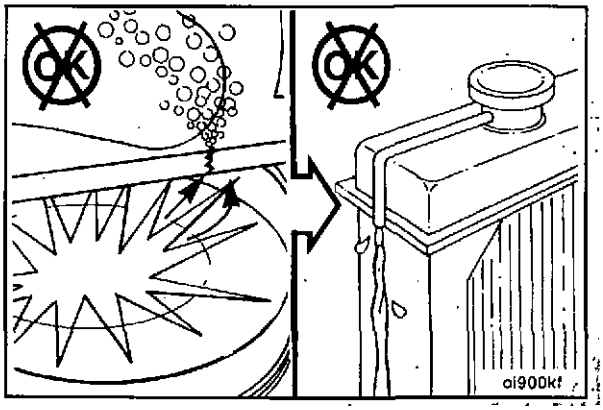
Refer to Procedure 7-09 for cylinder head gasket replacement.

NOTE: Low compression on a single cylinder can be caused by an external leak or a leak to a coolant passage. A leak to a coolant passage of this magnitude will also result in coolant in the cylinder.



A compression leak to the coolant will normally be detected by loss of coolant as the coolant is blown from the cooling system.

Service Tip: Remove the drive belt from the water pump. Run the engine for 1 to 2 minutes and check for coolant being blown from the radiator by compression gasses.



Valve Cover - Replacement (7-02)

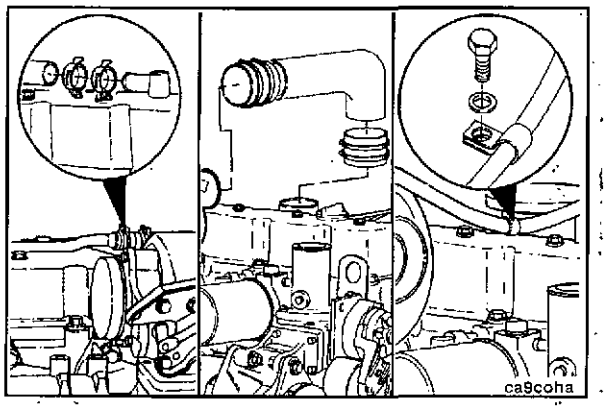
Removal

13 mm, 18 mm

Remove the crankcase breather tube and hose.

Remove the air crossover tube (off-highway vehicles).

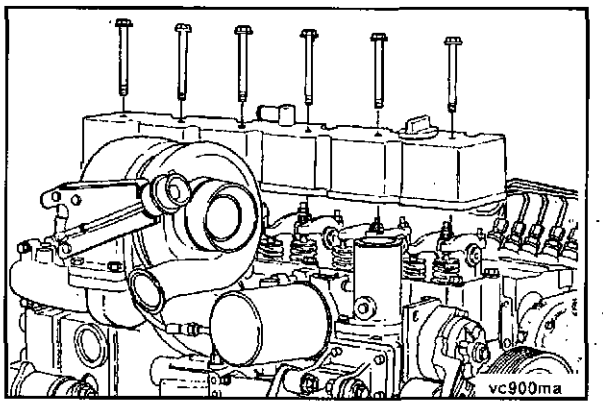
Remove the capscrew from the support bracket for the turbocharger wastegate actuator hose (on-highway vehicles).

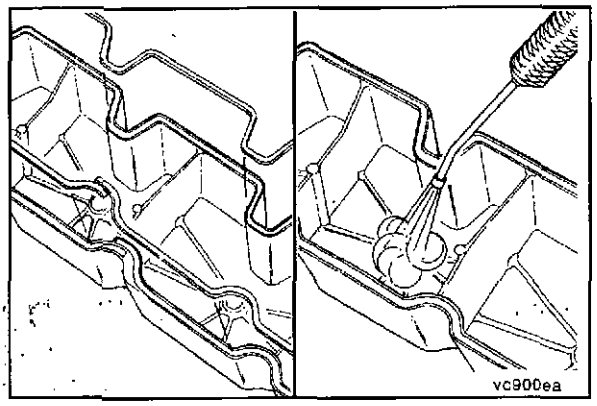


15 mm

Remove the six valve cover mounting capscrews.

Discard the sealing o-rings.





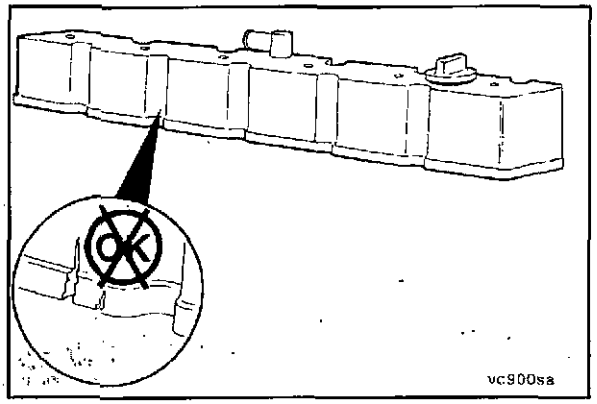
Cleaning and Inspection

Inspect the seal for damage.

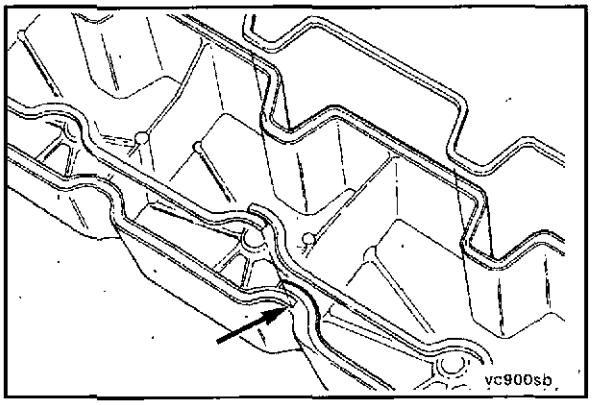
NOTE: The gasket can be reused if it is **not** damaged.

Warning: When using a steam cleaner, wear protective clothing and safety glasses or a face shield. Hot steam can cause serious personal injury.

Steam clean and dry with compressed air.



Inspect the cover for cracks or damage and replace if necessary.



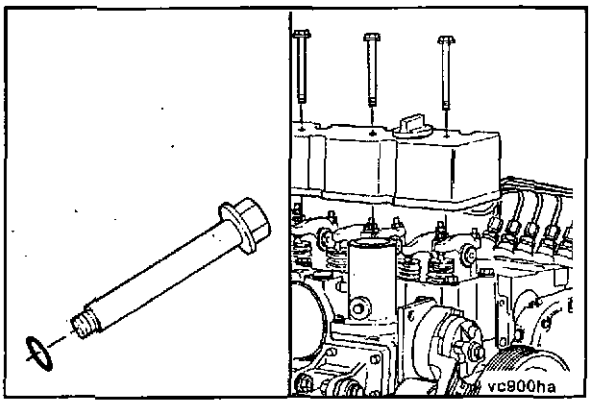
Installation

NOTE: If the seal is **not** damaged, it can be used again.

If the seal is damaged, install a new seal.

Install the rubber seal into the groove in the valve cover. Start the installation at the overlap area shown in the illustration. Do not stretch the rubber seal.

If the seal has more overlap than shown in the illustration, trim the length to provide the correct overlap.



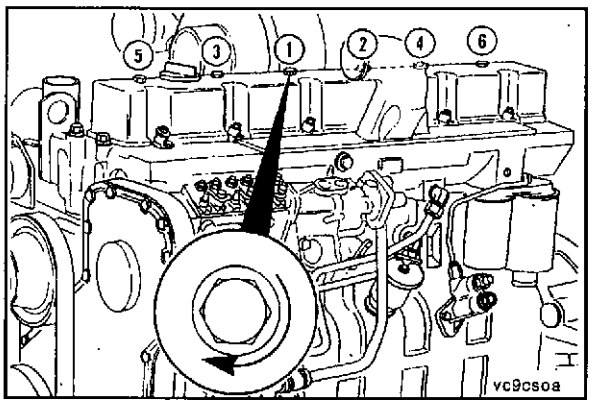
Install new sealing o-rings on the capscrews.

Install the six capscrews into the cover.

15 mm

Tighten the capscrews in the sequence shown.

Torque Value: 24 N•m [18 ft-lb]

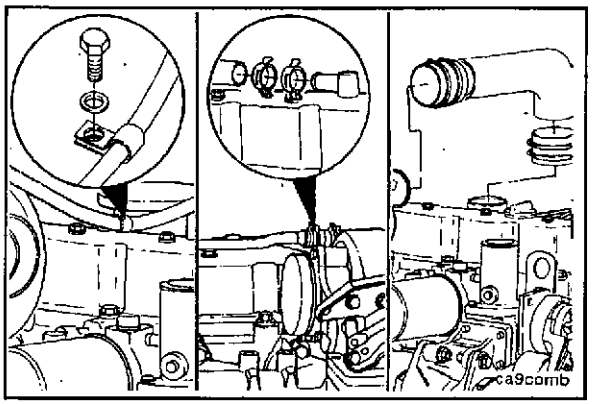


13 mm, 18 mm

Install the capscrew into the support bracket for the turbocharger wastegate actuator hose (on-highway vehicles).

Install the crankcase breather tube and hose. Refer to Procedure 7-03.

Install the air crossover tube (off-highway vehicles).



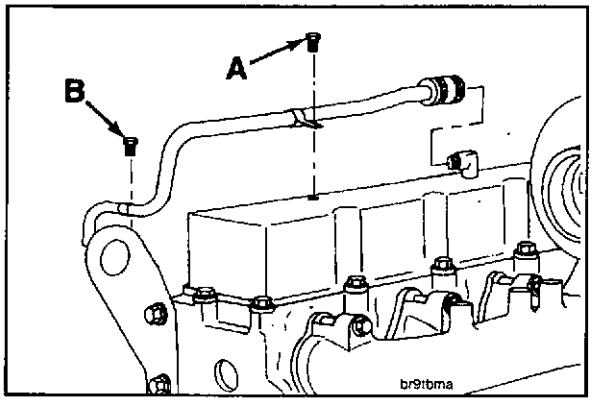
Crankcase Breather Tube - Replacement (7-03)

Removal

13 mm, 18 mm

Remove the two hose clamps from the crankcase breather.

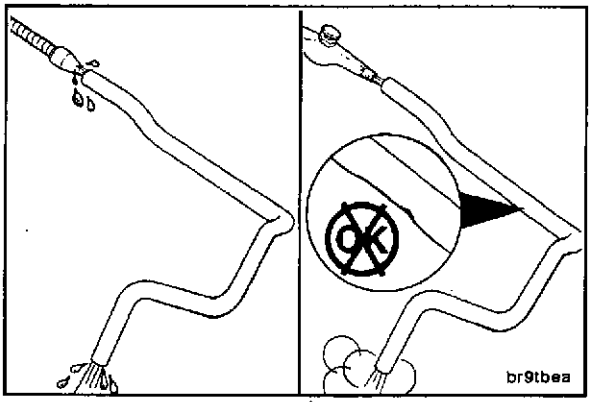
Remove the two breather tube support bracket capscrews (A) and (B).

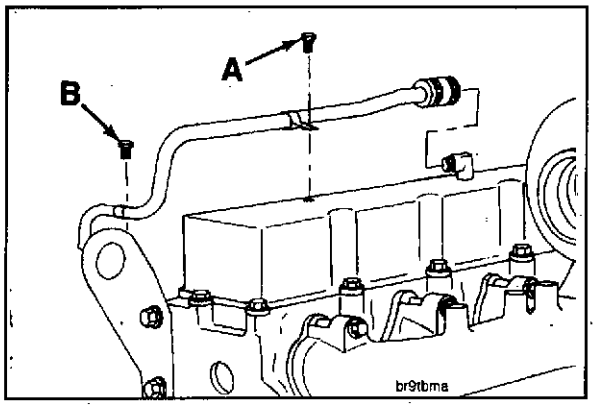


Cleaning and Inspection

Use solvent to clean the hose and tube. Dry with compressed air.

Visually inspect the hose and tube for restrictions, cracks or other damage. Replace the hose and tube if damaged.





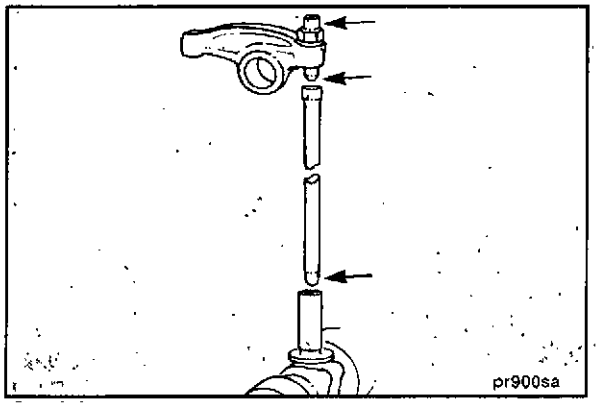
Installation

13 mm, 18 mm

Install the breather tube and hose clamps. Tighten the capscrews for the breather tube support brackets.

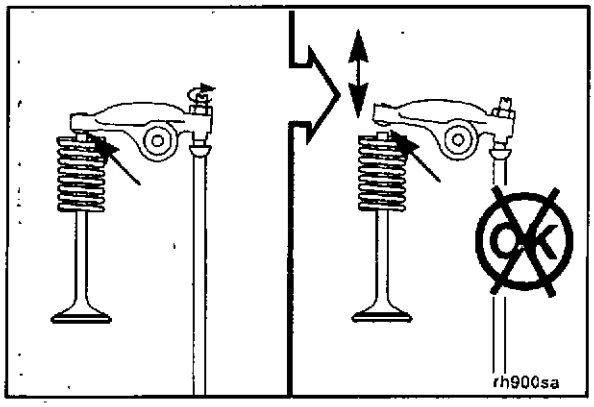
Torque Value:

A = 24 N•m [18 ft-lb]
B = 43 N•m [32 ft-lb]

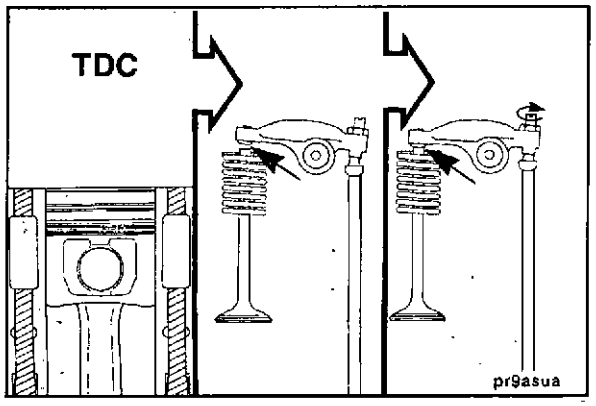


Rocker Lever Diagnosing - Malfunctions (7-04)

The ball end of the push rod fits into the ball socket in the tappet. The other end of the push rod has a ball socket in which the ball end of the rocker lever adjusting screw operates.



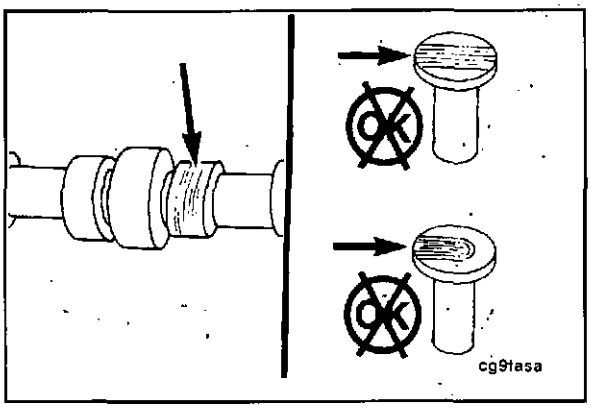
Excessive valve lash can indicate a worn valve stem, push rod, valve tappet or rocker lever.



Valve Lash Specifications

Valve Lash Specifications		
mm		in
0.30	Intake	0.012
0.61	Exhaust	0.024

Loose rocker levers and the need to reset the valve clearance frequently can also indicate cam lobe or tappet wear. If an inspection of the levers, valve stems and push rods does **not** show wear, then tappet and/or cam lobe wear can be suspected. Refer to Procedures 7-22 and 7-24.



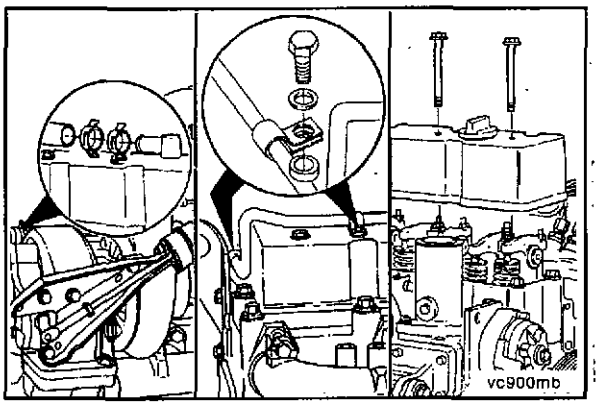
Rocker Lever - Replacement (7-05)

Removal

13 mm, 15 mm, 18 mm

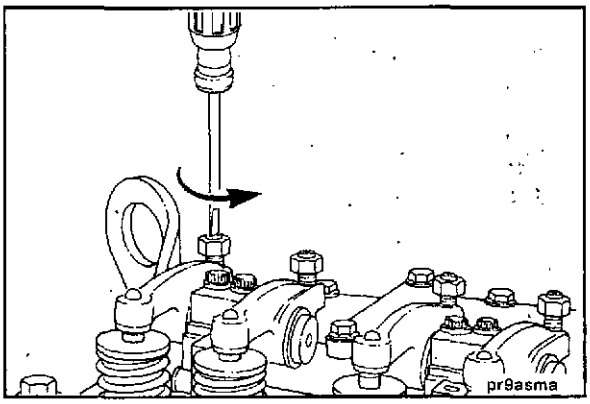
Remove the crankcase breather tube and hose. Refer to Procedure 7-03.

Remove the valve cover. Refer to Procedure 7-02.



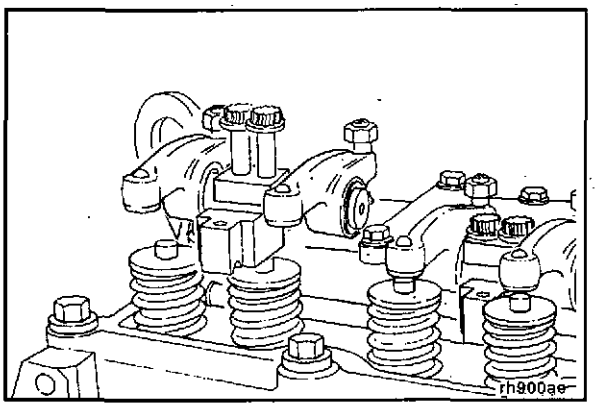
14 mm, Screwdriver

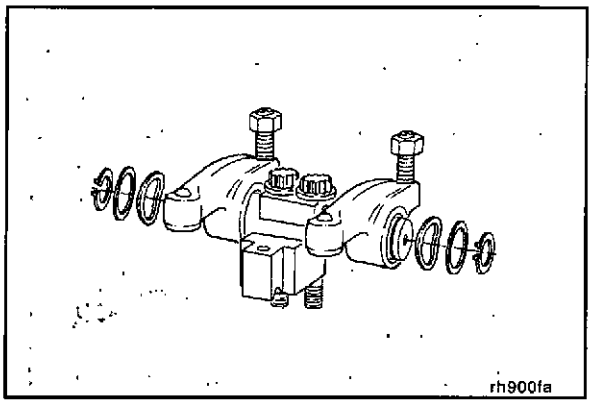
Loosen the adjusting screw locknuts. Loosen the adjusting screws until they stop.



10 mm

Remove the capscrews, retaining clamps, rocker lever assemblies and supports.



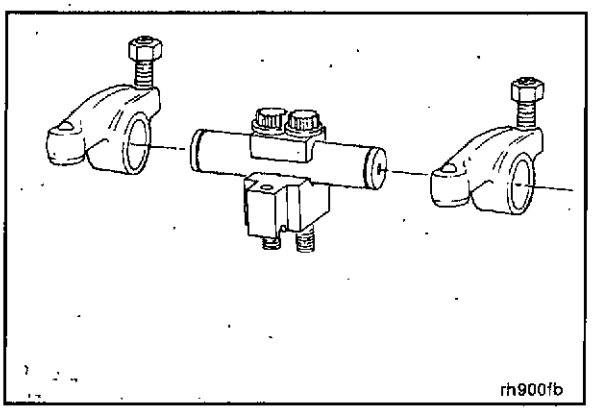


Disassembly

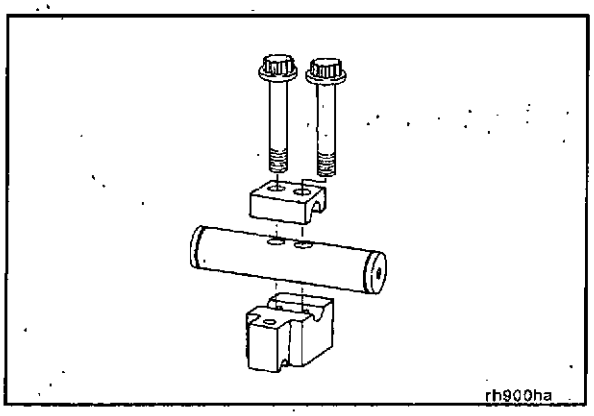
Snap Ring Pliers

If the rocker lever and push rods are to be inspected for reuse, follow these steps:

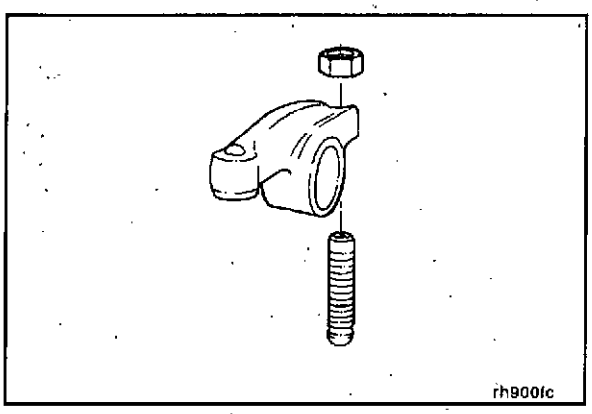
Remove the retaining rings, thrust washers and wavy spring washers.



Remove the rocker levers.



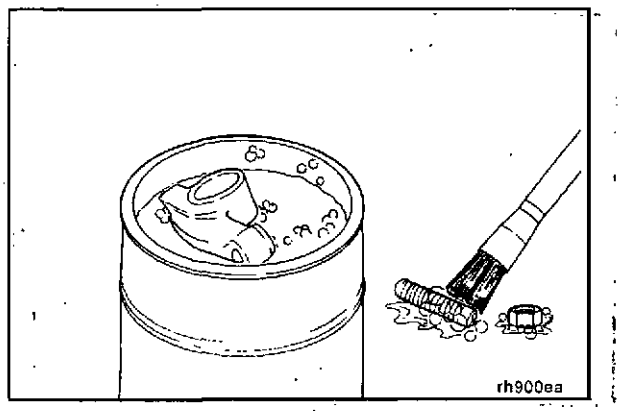
Remove the pedestal assembly.



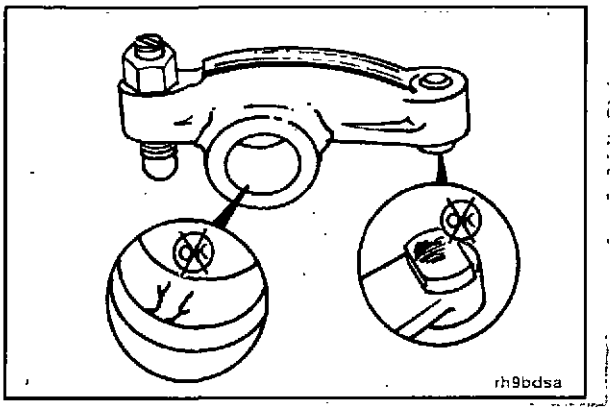
Remove the lock nut and adjusting screw.

Cleaning and Inspection

Clean all parts in a strong solution of laundry detergent and hot water.

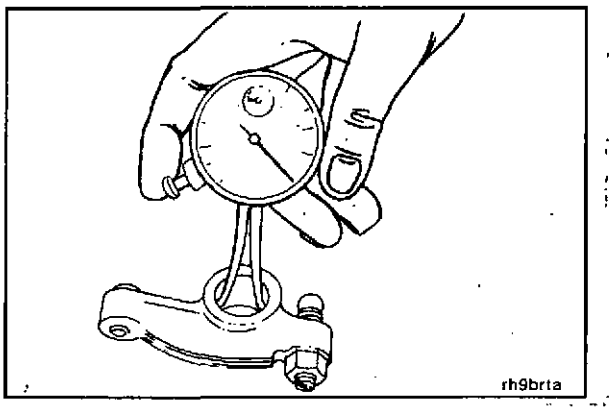


Inspect for cracks and excessive wear in the bore and the contact surface for the valve stem.



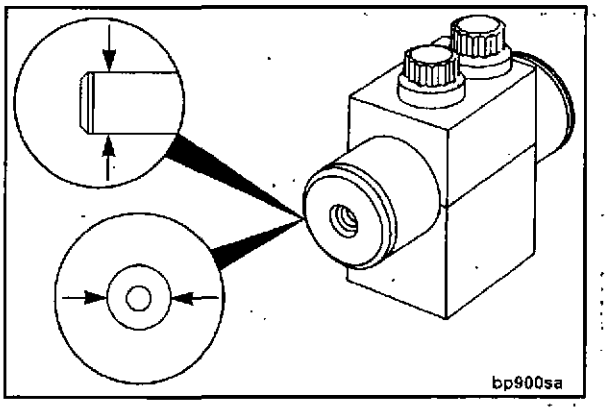
Measure the rocker lever bore.

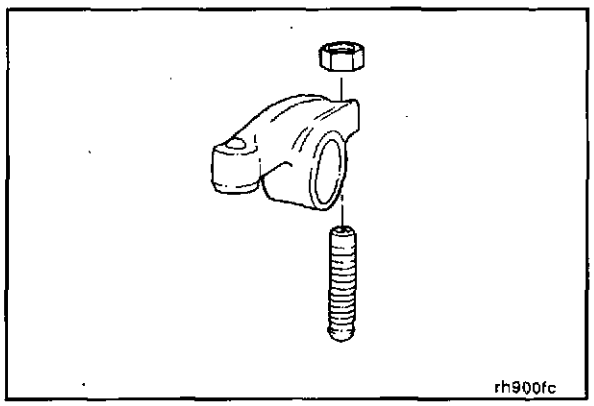
Rocker Lever Bore Diameter		
mm		in
22.301	MAX	0.878



Measure the rocker lever shaft diameter.

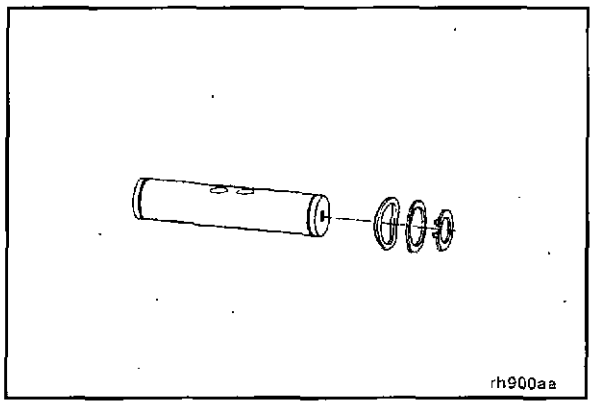
Rocker Lever Shaft Diameter		
mm		in
22.199	MIN	0.874



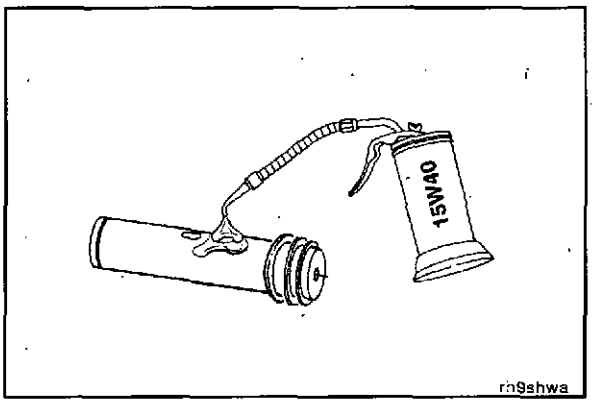


Assembly

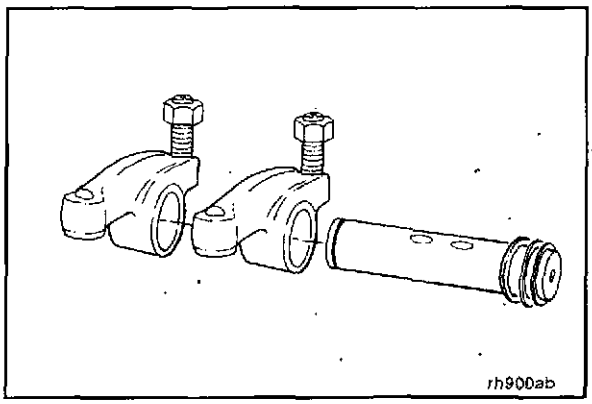
Install the adjusting screw and locknut.



Install a retaining ring, thrust washer and wavy spring washer as illustrated.

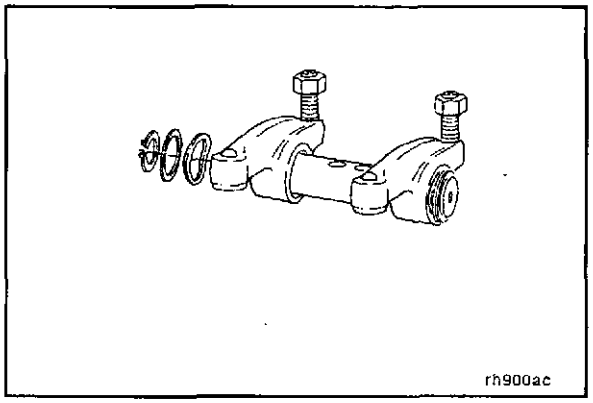


Lubricate the shaft with 15W-40 engine oil.

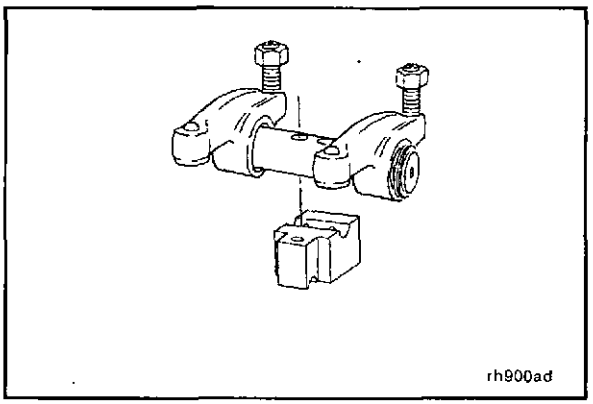


Position the levers on the rocker shaft.

Install the remaining wavy spring washer, thrust washer and retaining ring as illustrated.

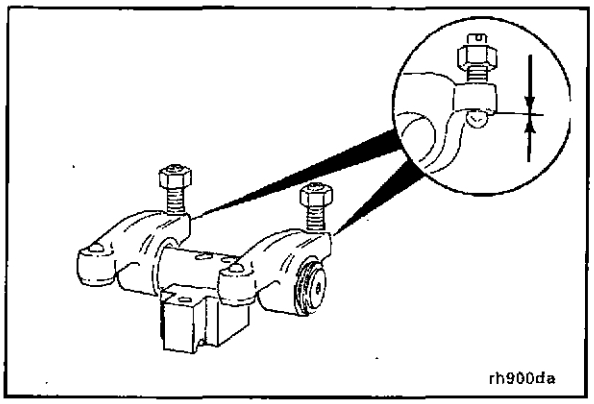


Compress the wavy spring washers and install the bottom half of the pedestal as illustrated.



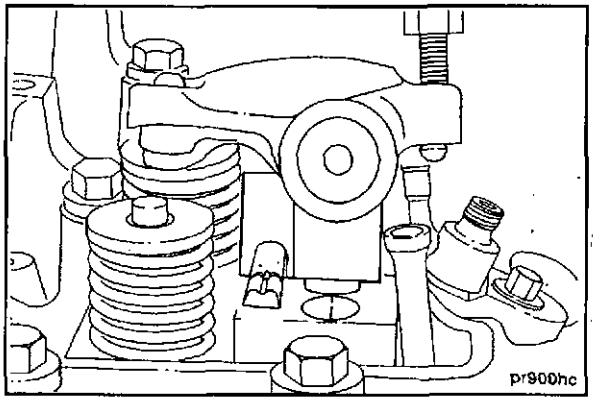
Installation

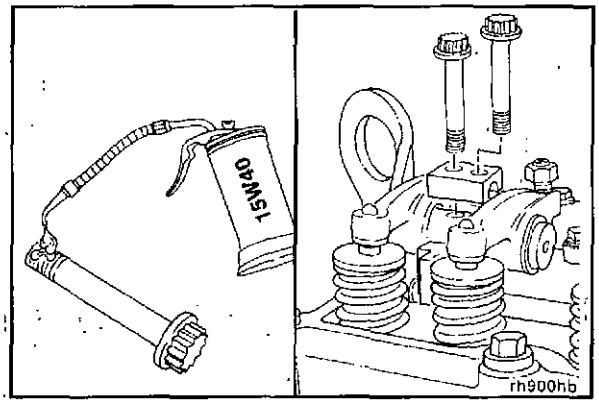
Make sure the rocker lever adjusting screws are completely backed out.



Install the support and rocker lever assemblies over the rocker lever oil manifold.

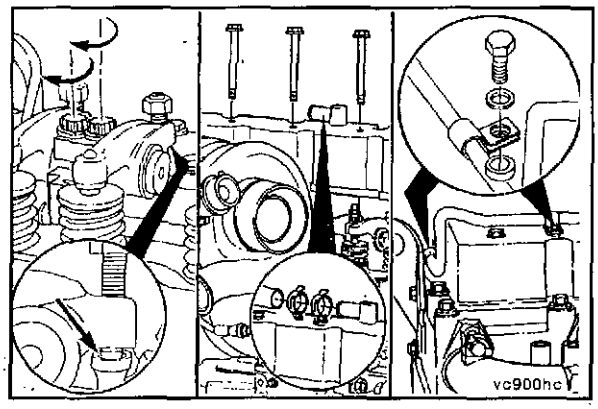
Make sure the dowel rings in the pedestals are installed into the dowel bores.





Use clean 15W-40 engine oil to lubricate the threads and under the heads of the pedestal capscrews.

Install the retaining clamps and capscrews.



10 mm

Tighten the retaining clamp capscrews.

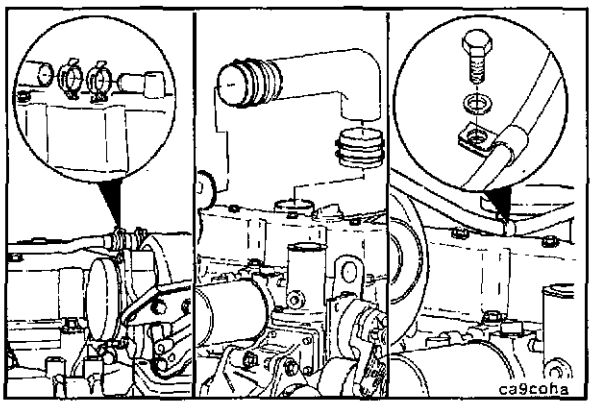
Torque Value: 55 N•m [41 ft-lb]

NOTE: To prevent damage to the rocker lever or push rod make sure the adjusting screw ball is positioned in the socket of the push rods when tightening.

Adjust the intake and exhaust valves. Refer to Procedure 7-06.

Install the valve cover. Refer to Procedure 7-02.

Install the crankcase breather tube and hose. Refer to Procedure 7-03.

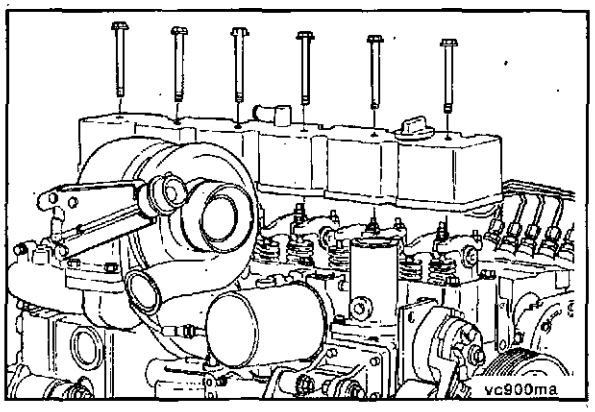


Valve Lash - Adjustment (7-06)

Screwdriver, 13 mm, 18 mm

Remove the air crossover tube (off-highway vehicles).

Disconnect the crankcase breather tube, support clamps, and hose clamps. Remove the crankcase vent tube.

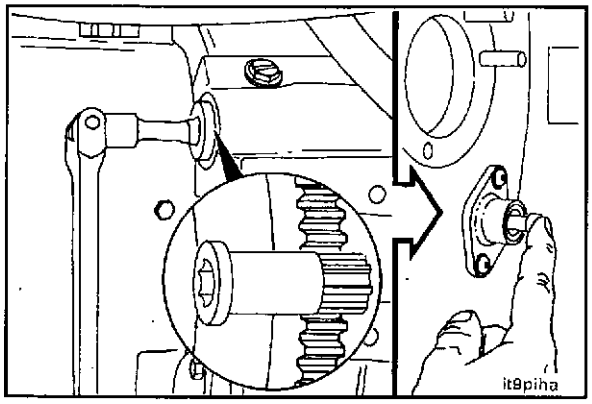


15 mm

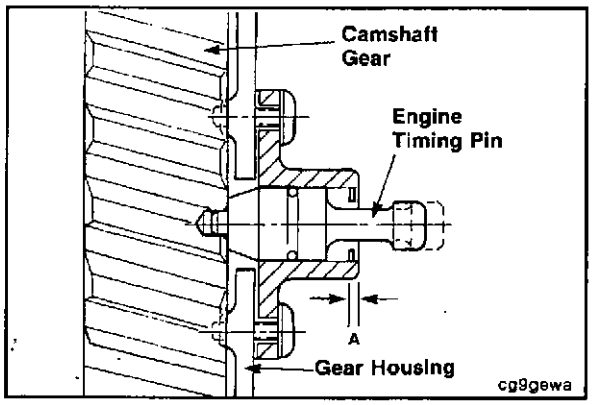
Remove the valve cover.

1/2 Inch Drive, 3377371 Barring Gear

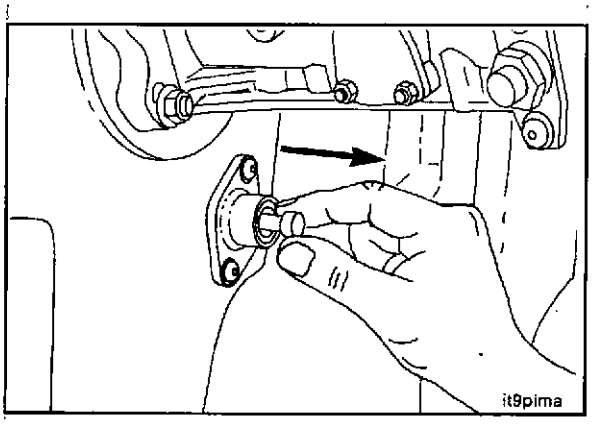
Locate Top Dead Center (TDC) for cylinder No. 1 by rotating the crankshaft slowly while pressing on the engine timing pin.



When the pin engages the hole in the camshaft gear, cylinder No. 1 is at TDC on the compression stroke.



Caution: To prevent damage to the timing pin be sure to disengage the pin after locating Top Dead Center.

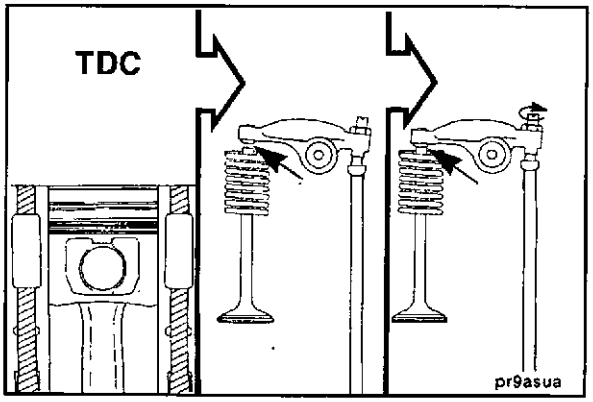


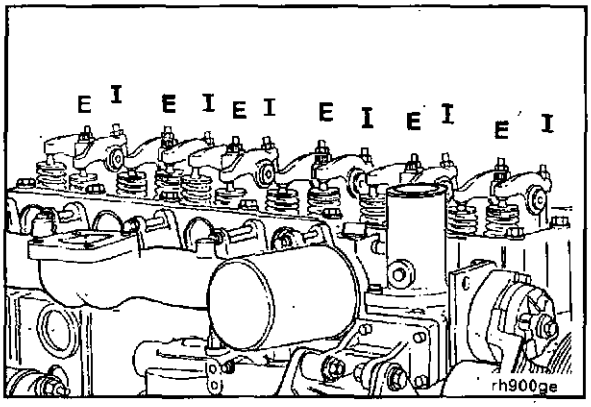
Feeler Gauge

Valve Lash Specifications		
mm		in
0.30	Intake	0.012
0.61	Exhaust	0.024

Check/adjust the valves with engine cold - below 60°C [140°F].

NOTE: The clearance is correct when slight resistance is felt as the feeler gauge is moved between the valve stem and the rocker lever.





Valve Arrangement

Beginning at the front of the cylinder head, the first valve is intake, the second one is exhaust. The same orientation is used for all cylinders.

Chart A						
Cylinder	1	2	3	4	5	6
Intake	X	X		X		
Exhaust	X		X		X	

14 mm, Flat Blade Screwdriver

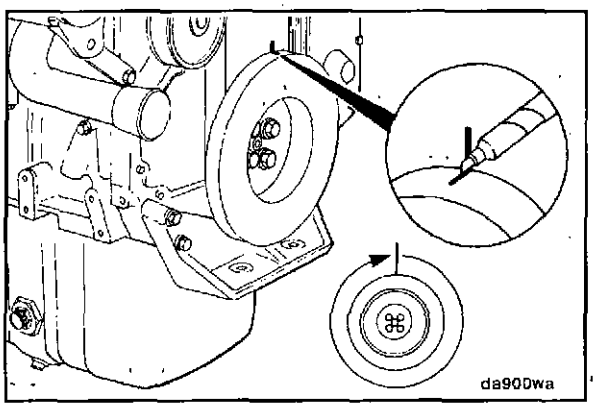
Locate Top Dead Center (TDC) for cylinder No. 1.

Check/adjust the valves indicated for Chart A.

Tighten the locknut.

Torque Value: 24 N•m [18 ft-lb]

Check the valve lash again.



Mark the vibration damper and rotate the crankshaft 360 degrees.

Be sure the timing pin is disengaged.

Chart B						
Cylinder	1	2	3	4	5	6
Intake			X		X	X
Exhaust		X		X		X

14 mm, Flat Blade Screwdriver

Check/adjust the valves indicated for Chart B.

Tighten the locknut.

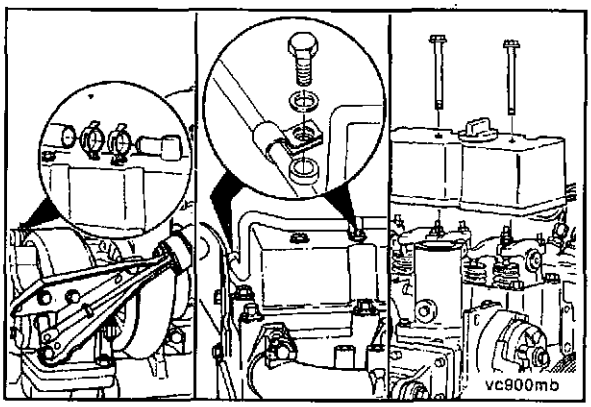
Torque Value: 24 N•m [18 ft-lb]

Check the valve lash again.

Install the valve cover. Refer to Procedure 7-02.

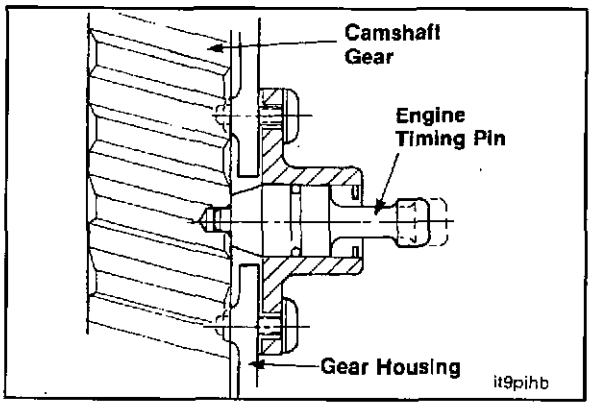
Install the crankcase vent tube and secure with the support brackets and hose clamp. Refer to Procedure 7-03.

Install the air crossover tube (off-highway vehicles).



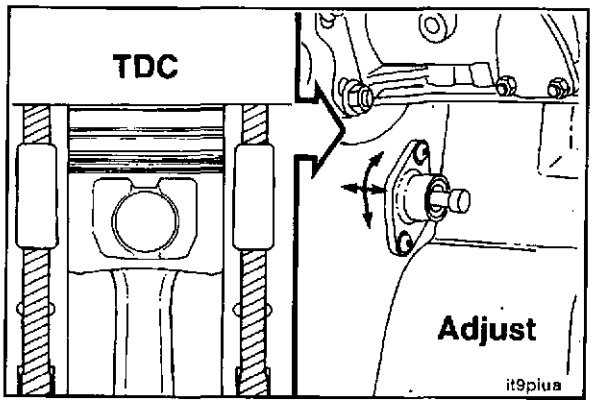
Timing Pin Assembly - Installation (7-07)

The timing pin assembly is precisely located on the gear housing to correspond to Top Dead Center (TDC) for cylinder No. 1.

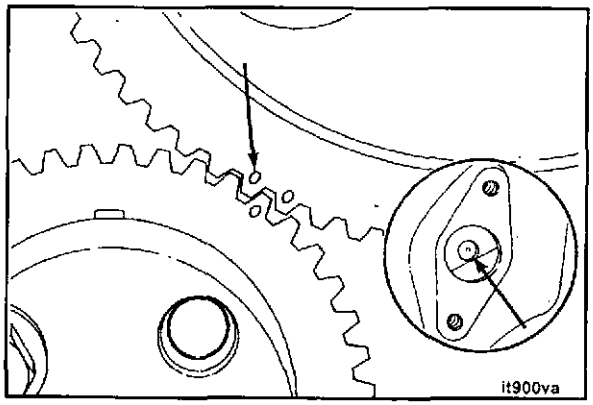


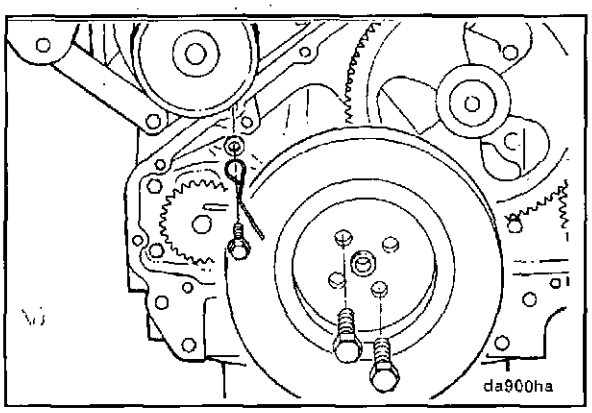
Caution: If a gear housing other than the original housing is installed, the timing pin assembly must be accurately aligned to correspond to TDC for cylinder No. 1.

Failure to locate the timing pin assembly to TDC for cylinder No. 1 will result in incorrect injection timing.



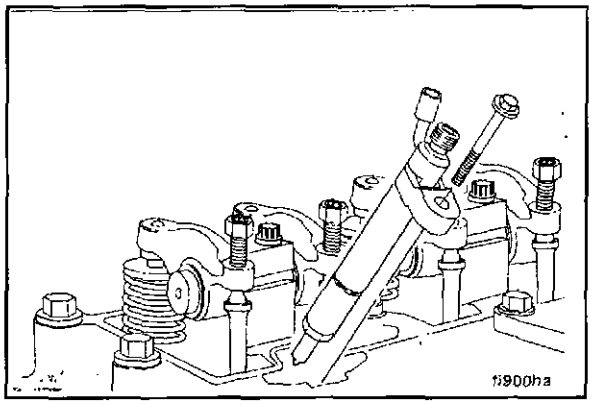
Verify that the No. 1 cylinder is at or near TDC on the compression stroke by rotating the crankshaft until the engine timing pin engages in the cam gear hole or the hole is visible through the gear housing. Disengage the timing pin.





13 mm, 18 mm

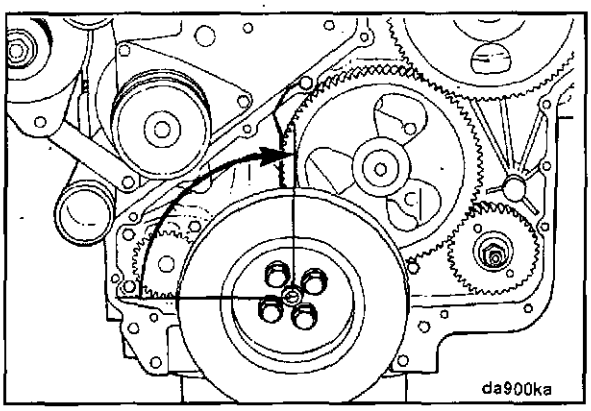
Fabricate and install a wire pointer for the front of the engine. This can be done by forming a piece of wire that can be tightened under one of the gear housing cap-screws. The wire should extend from the gear cover to a place on the crankshaft vibration damper that is easily seen.



10 mm

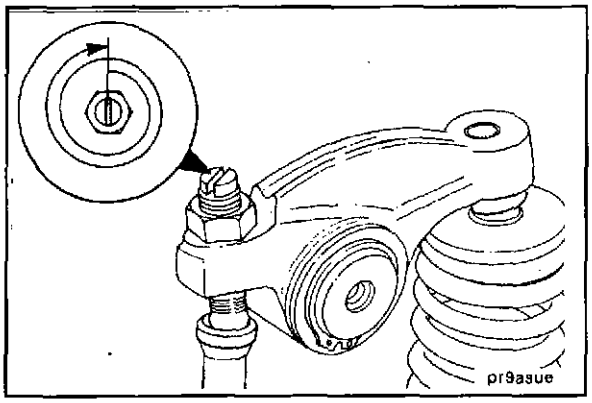
Remove all injector nozzles.

This step is important to release cylinder pressure so the crankshaft can be rotated smoothly to locate TDC for cylinder No. 1.



Part No. 3377371, Engine Barring Gear

Rotate the crankshaft one-quarter revolution in the direction of normal engine rotation.



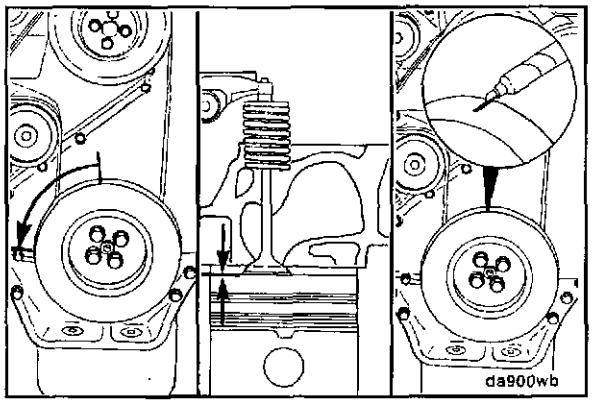
Tighten the adjusting screw for the No. 1 intake valve to zero (0) lash plus 5 turns.

NOTE: Leave the adjusting screw in this position until TDC is established.

Caution: Use extreme care when rotating the crankshaft. Use of too much force could damage the valve or push rod.

Rotate the crankshaft slowly in the opposite direction of normal engine rotation until the piston touches the intake valve.

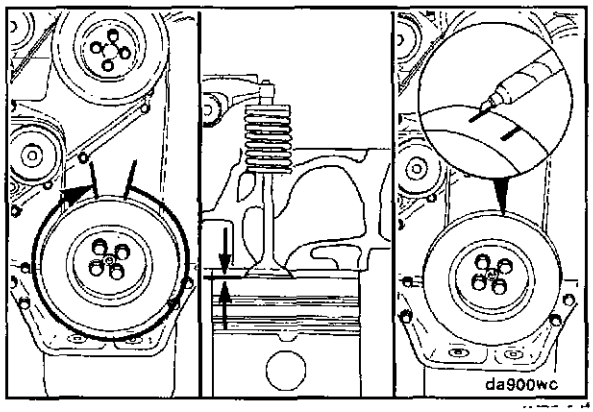
Mark the vibration damper at the wire pointer.



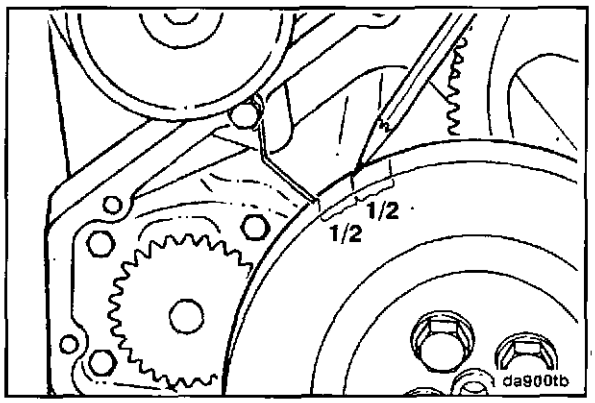
Caution: Make sure that the piston touches the intake valve with approximately the same amount of force as in the previous step.

Rotate the crankshaft in the direction of normal engine rotation until the piston touches the intake valve.

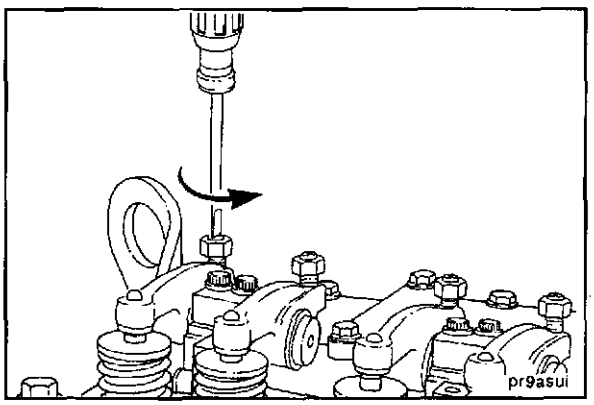
Mark the vibration damper at the wire pointer.

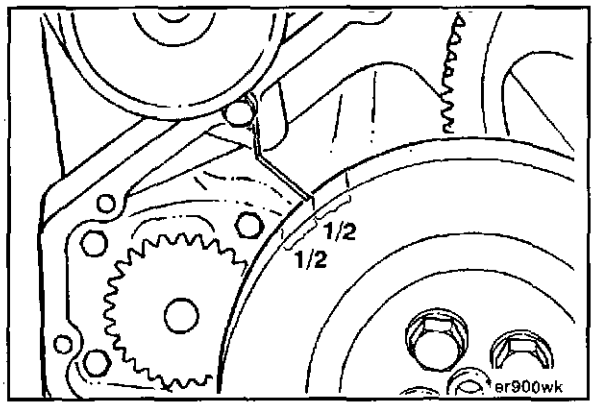


Measure the distance and mark the vibration damper at one-half the distance between the two marks. This mark is the TDC mark.

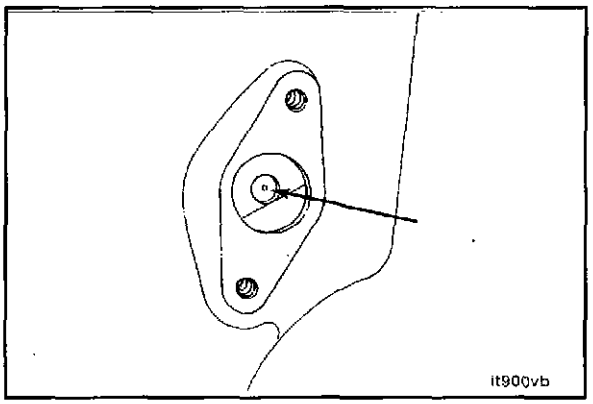


Caution: Completely loosen the intake valve adjusting screw. Failure to do so will result in damage to the intake valve or push rod when the crankshaft is rotated.

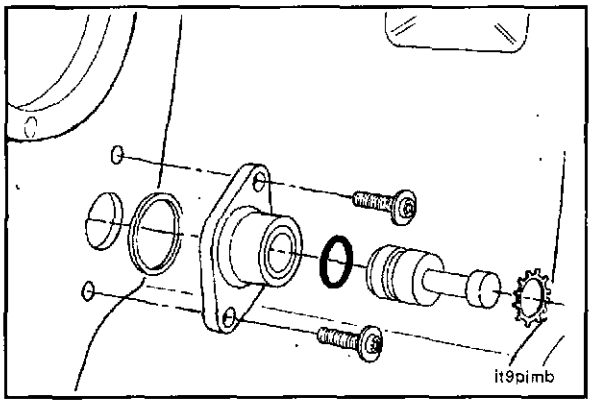




Rotate the crankshaft in the direction of normal engine rotation until the pointer is aligned with the TDC mark, then rotate the crankshaft one additional revolution.

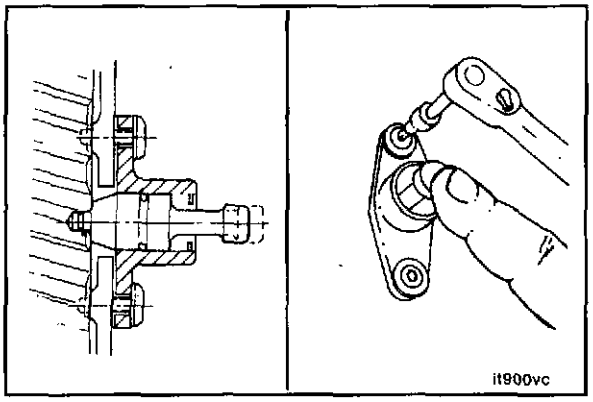


The timing pin hole in the cam gear should be visible or felt through the back side of the gear housing. If not, the crankshaft must be rotated one revolution in the direction of engine rotation.



Install the o-ring into the groove of the timing pin assembly.

Lubricate the o-ring with 15W-40 engine oil.



T-25 Torx™

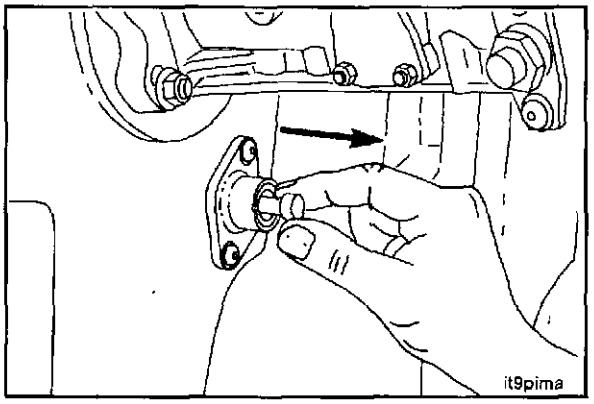
Push the pin into the hole in the cam gear to align the housing.

Hold the pin in while tightening the Torx™ screws.

Torque Value: 8 N•m [71 in-lb]

Check the pin to be sure it did **not** slip out of the camshaft gear hole when the screws were tightened.

Caution: To prevent damage to the pin and gear, be sure the timing pin is disengaged before rotating the crankshaft.

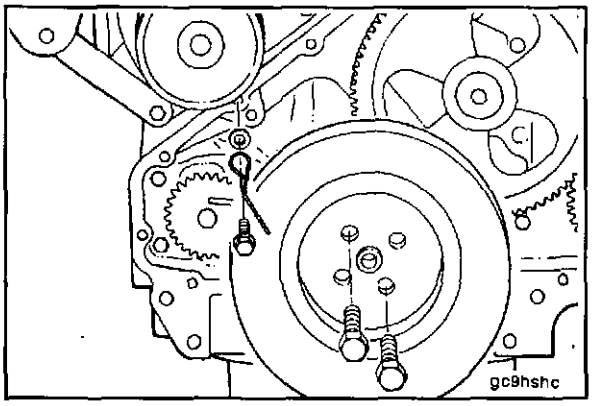


13 mm, 18 mm

Remove the vibration damper and wire pointer.

Install the gear cover. Refer to Procedure 7-17.

Install the vibration damper. Refer to Procedure 7-16.

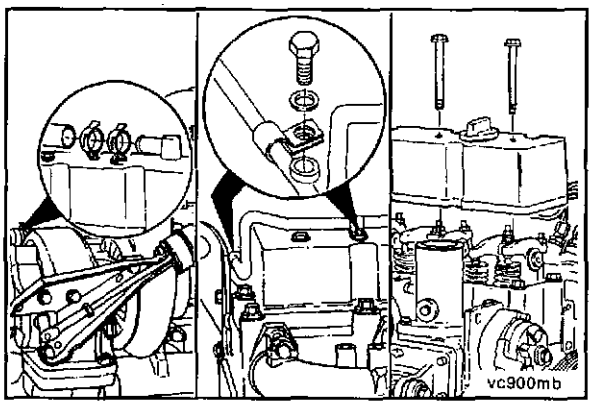


Push Rod - Replacement (7-08)

Removal

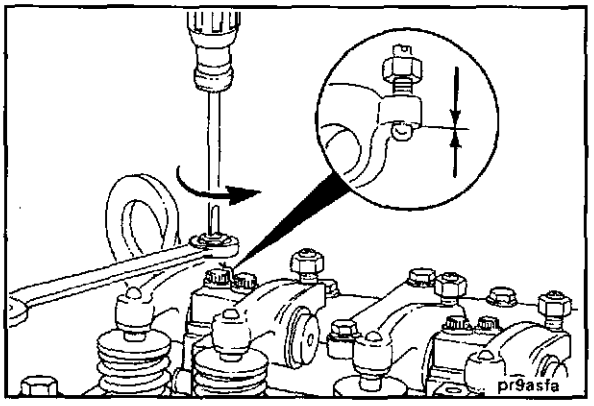
Remove crankcase breather tube and hose. Refer to Procedure 7-03.

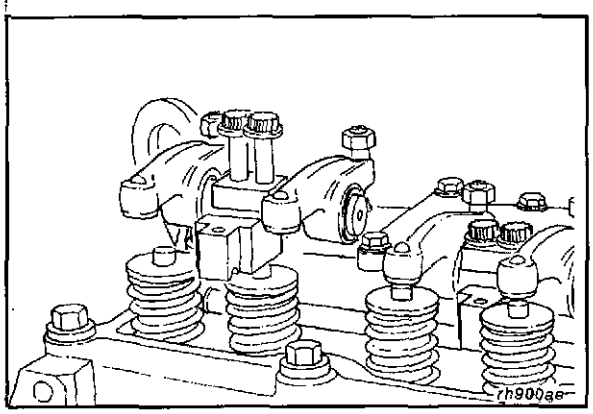
Remove the valve cover. Refer to Procedure 7-02.



14 mm Screwdriver

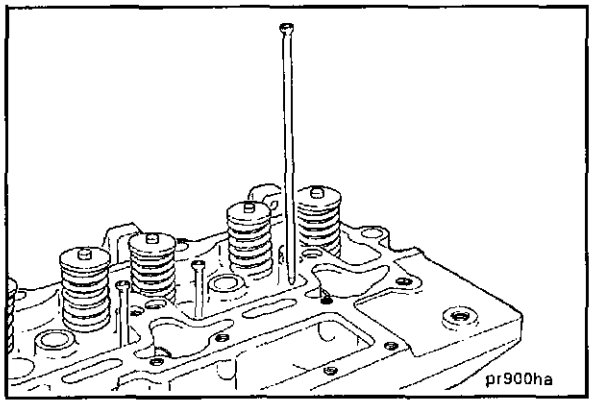
Loosen the rocker lever adjusting screw locknuts and loosen the adjusting screws until they stop.





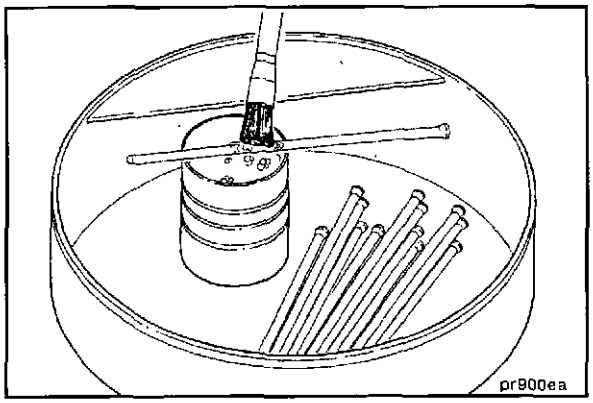
10 mm

Remove the rocker lever assemblies. Refer to Procedure 7-05.



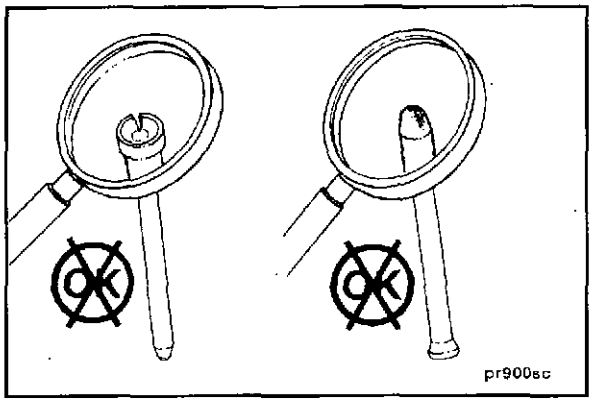
Mark the push rods to identify their location.

Remove the push rods.



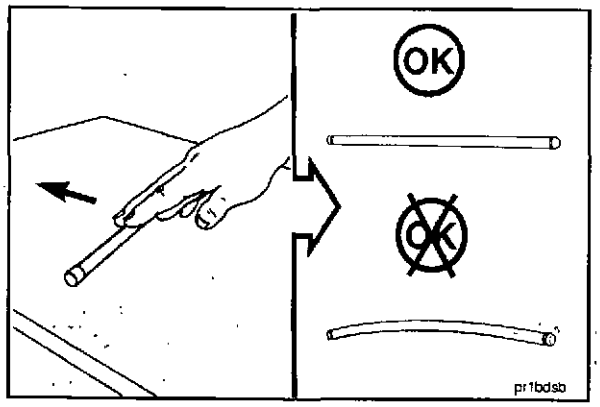
Cleaning and Inspection

Clean the push rods in hot soapy water.



Visually inspect the push rod ball and socket for signs of scoring or other damage.

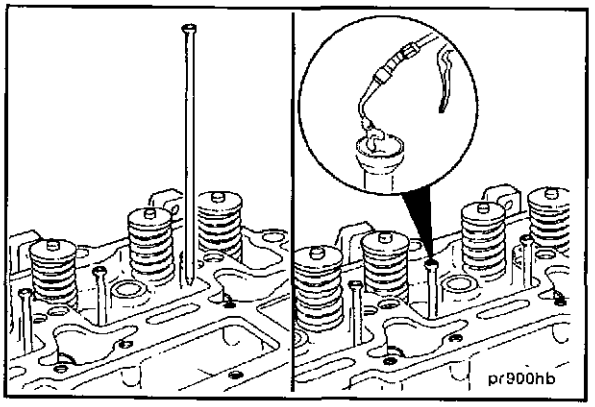
Check the push rods for roundness and straightness.



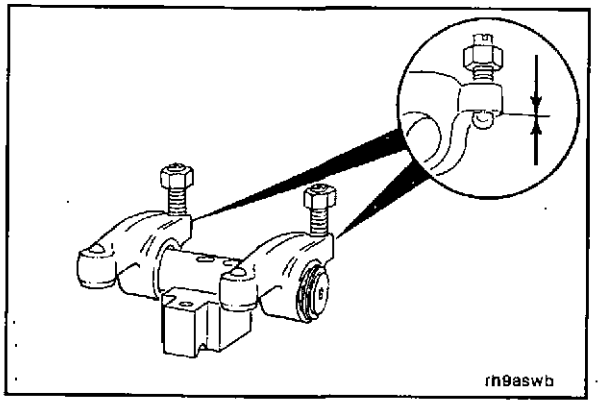
Installation

Install the push rods into the sockets of the valve tappets from which they were removed.

Lubricate the push rod sockets with clean 15W-40 engine oil.



Make sure the rocker lever adjusting screws are completely backed out.



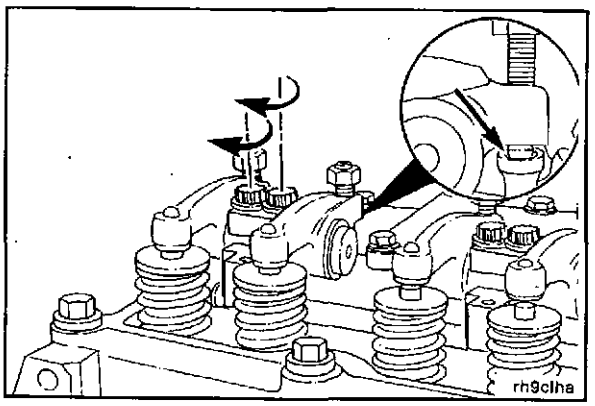
To prevent damage to the rocker lever or push rod, make sure the adjusting screw ball is positioned in the socket of the push rods when tightening.

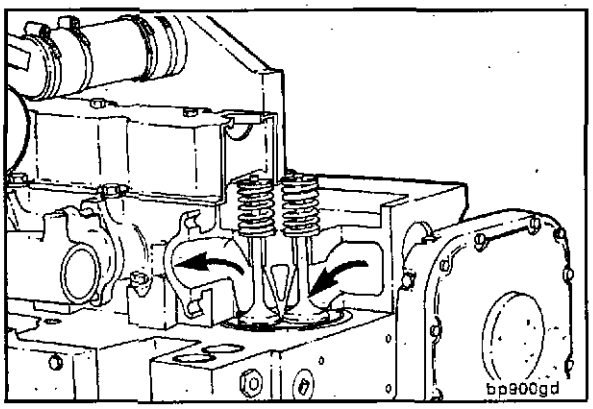
Install the rocker lever assemblies. Refer to Procedure 7-05.

Adjust valve lash clearance. Refer to Procedure 7-06.

Install valve cover. Refer to Procedure 7-02.

Install crankcase breather tube and hose. Refer to Procedure 7-03.

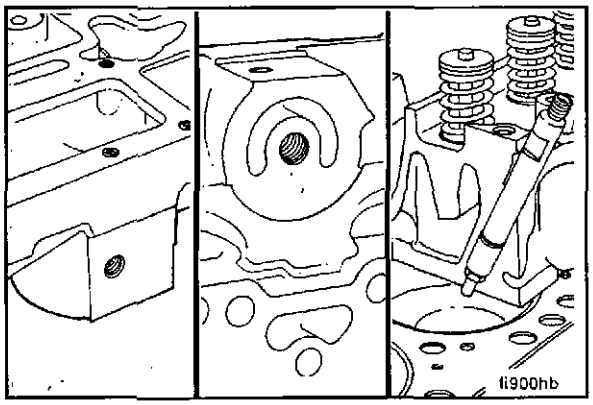




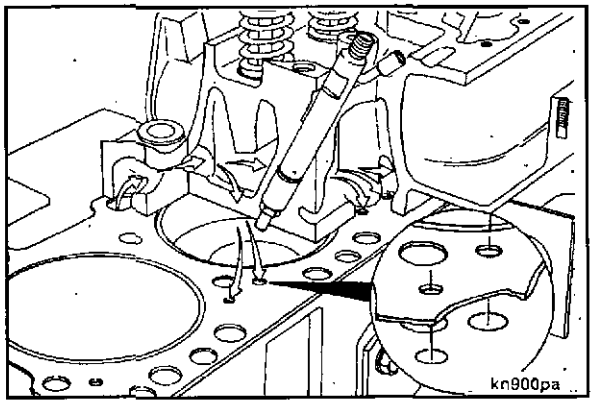
Cylinder Head - Replacement (7-09)

General Information

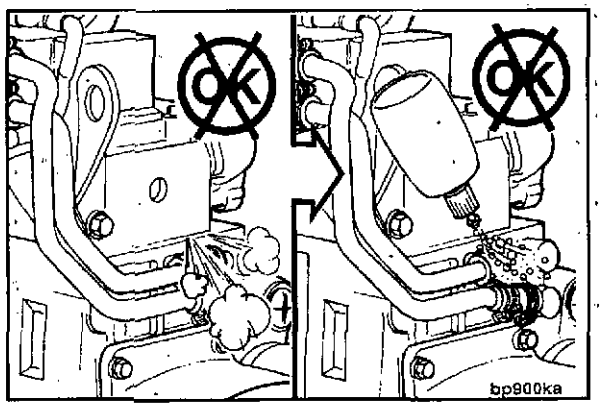
The cylinder head is a one piece, cross flow design with two valves per cylinder. The valve guides and seats are replaceable.



The cylinder head has a cast intake manifold and fuel filter head. The injectors are mounted in the head for direct injection into the cylinders.



The cylinder head gasket is a laminated design with a fire ring to seal the cylinder bores. The gasket also provides orifices to control coolant flow.



Diagnosing Malfunctions

Head Gasket Sealing

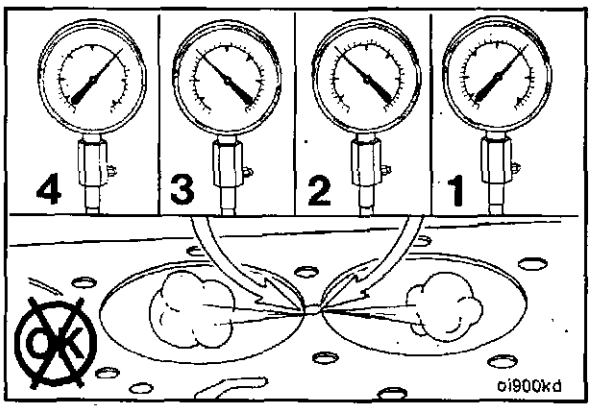
External head gasket leaks can be detected visually. Liquid soap can be used to locate external leaks.

Define the type of leak as follows:

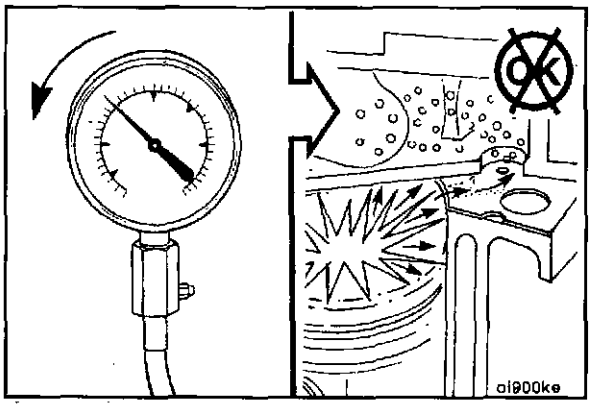
- Lubricating oil
- Coolant
- Compression, refer to Procedure 7-01

Internal head gasket leaks can be detected by performing a compression check. Refer to Procedure 7-01.

If the compression was found low on adjacent cylinders and the pressure **cannot** be increased by oiling the rings, the head gasket is probably leaking between the cylinders.

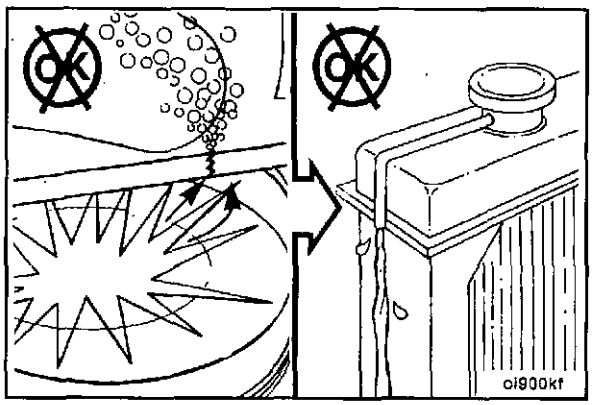


Low compression on a single cylinder can be caused by an external leak to a coolant passage. A leak to a coolant passage of this magnitude will also result in coolant in the cylinder.



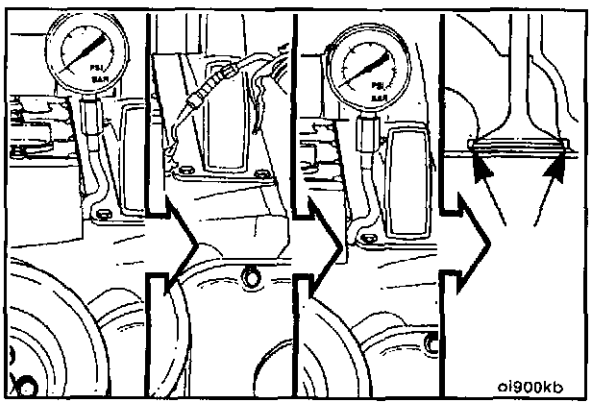
A compression leak to the coolant will normally be detected by loss of coolant as the coolant is blown from the cooling system.

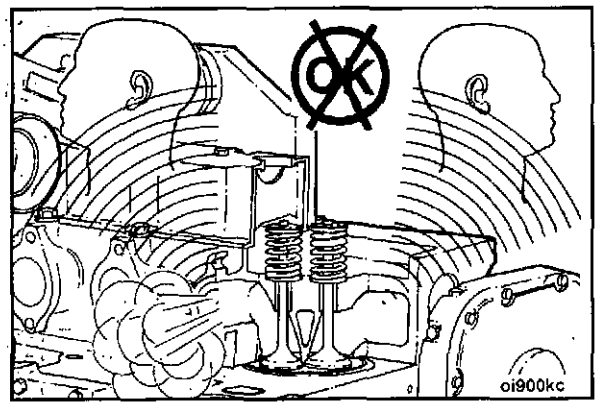
Service Tip: Remove the drive belt from the water pump. Run the engine for 1 to 2 minutes and check for coolant being blown from the radiator by compression gasses.



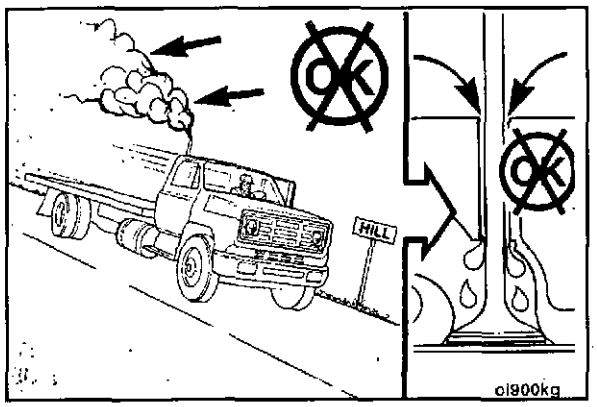
Valve Sealing

If the compression is low on one or more non-adjacent cylinders and the pressure **cannot** be increased by oiling the rings, improper valve sealing is to be suspected.



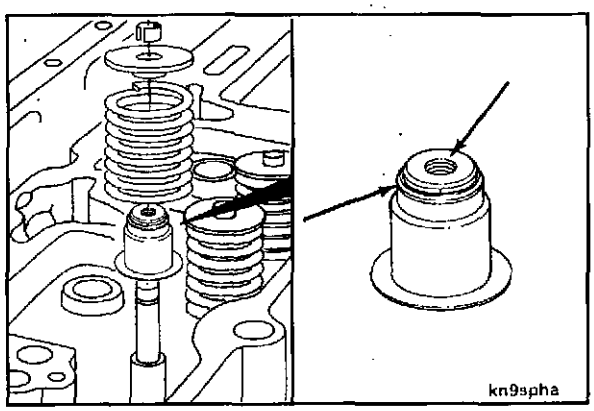


Valve leakage is often audible from the intake and exhaust manifold.



Worn Valve Stem Seals

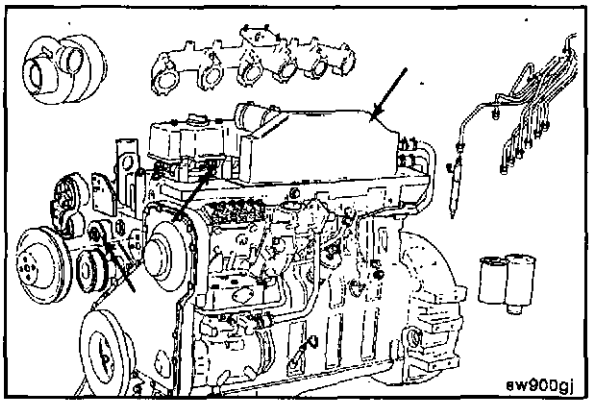
Worn valve stem seals are typically detected by excessive smoke at idle or when the engine is unloaded and the vehicle is going down hill.



Hardening of the material and wear or damage to the sealing surfaces will cause the seal to leak.

Removal

Drain the cooling system. Refer to Procedure 1-01.

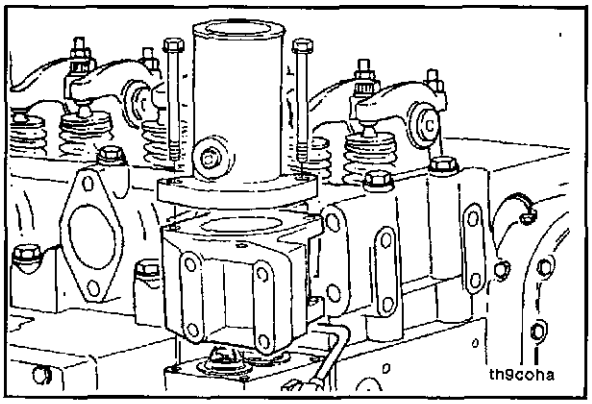


- Remove the turbocharger. Refer to Procedure 3-11.
- Remove the aftercooler or intake cover. Refer to Procedure 3-10.
- Remove the exhaust manifold. Refer to Procedure 3-12.
- Remove the fuel lines and injector nozzles. Refer to Procedure 5-05.
- Remove the valve cover, rocker lever assemblies and push rods. Refer to Procedure 7-08.
- Remove the fuel filters. Refer to Procedure 5-03.
- Remove the fan hub. Refer to Procedure 1-06.
- Remove the alternator. Refer to Procedure 6-03.
- Remove the belt tensioner. Refer to Procedure 1-04.

13 mm

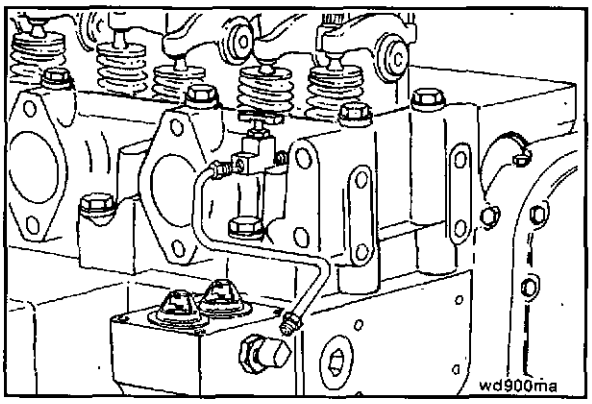
NOTE: In some applications it may be easier to remove the thermostat housing to gain access to the exhaust manifold capscrew for No. 1 cylinder.

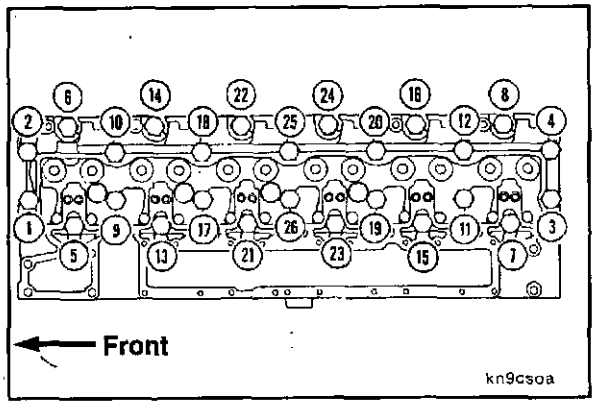
Remove the thermostat housing/coolant outlet assembly.



7/16 inch

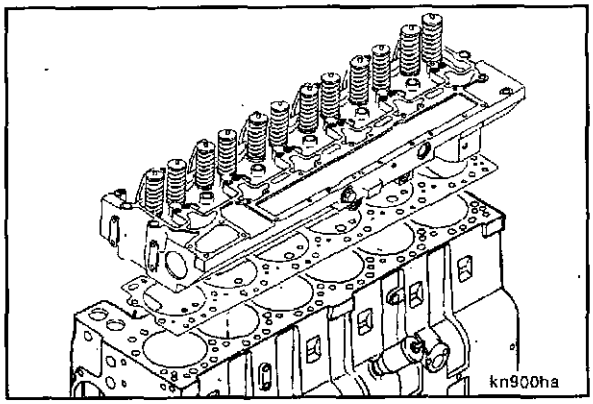
Disconnect the coolant vent tube.





16 mm

Remove the cylinder head capscrews in the sequence shown in the illustration.



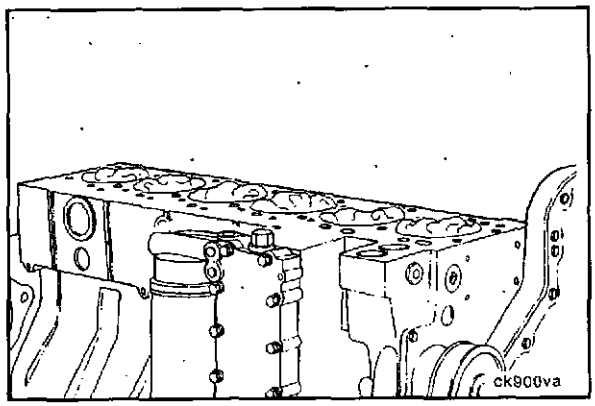
The component weighs 23 kg [50 lb] or more. To avoid personal injury, use a hoist or get assistance to lift the component.

Use a hoist or hydraulic arm to remove the cylinder head.

Make sure the head is removed in a direct upward motion.

Remove the cylinder head gasket.

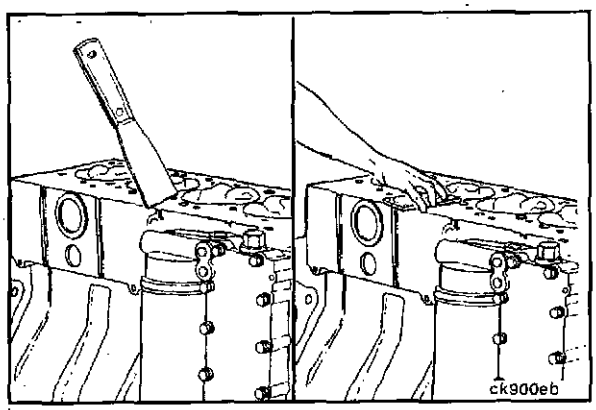
NOTE: Place the cylinder head on wood blocks to prevent damage to the combustion face.



Cylinder Block/Head Deck Cleaning and Inspection

Place clean lint-free rags over the pistons to prevent dirt from falling into the engine.

Plug or cover the coolant and oil passages in the cylinder block deck.



Use a gasket scraper to clean the cylinder block deck surface.

Use Scotch-Brite® 7448, or equivalent, and solvent to remove any residual gasket material from the cylinder block deck surface.

Caution: When using compressed air to clean capscrew holes, always wear safety glasses or a face shield to protect the eyes. Personal injury can result.

NOTE: Make sure the cylinder head capscrew holes are clean.

Use compressed air to clean debris from the capscrew holes.

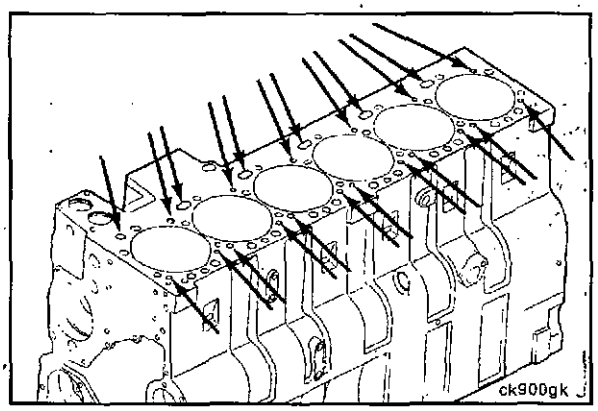
Inspect the coolant passages.

Build-up of deposits in the coolant passages can cause engine overheating.

A large build-up of rust and lime will require removal of the cylinder block for cleaning in a hot tank.

Be sure the coolant passages are clean.

NOTE: Excessive deposits may be cleaned in an acid tank, but the camshaft bushings **must** first be removed to prevent damage.

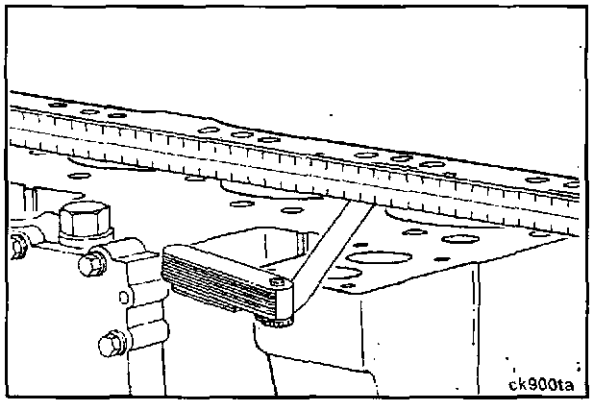


Straight Edge and Feeler Gauge

Visually inspect the top surface for damage.

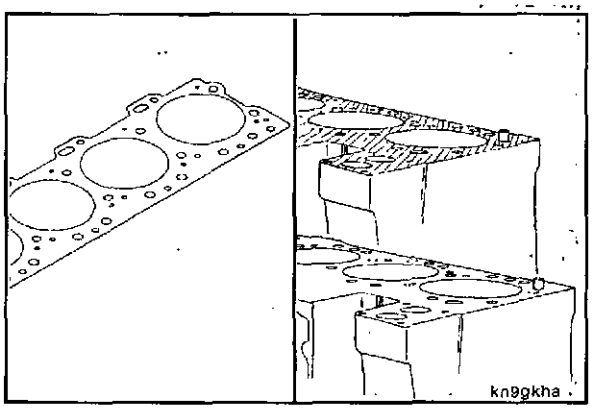
Check the top surface for flatness between each cylinder.

Cylinder Block Flatness Specification		
mm		in
0.075	End-to-End	0.003
0.075	Side-to-Side	0.003



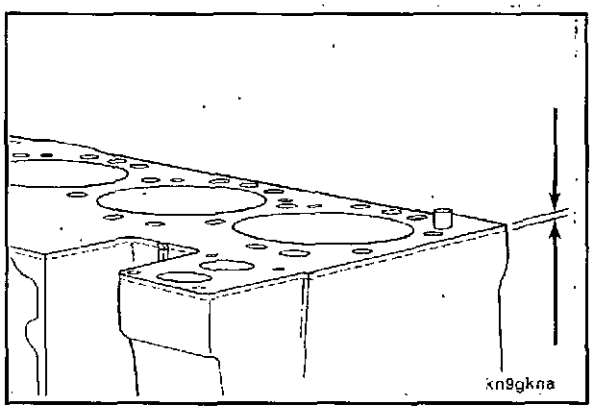
Caution: Do not proceed with the repair if the cylinder block head deck is damaged or not flat. The engine will have to be removed for resurfacing the block.

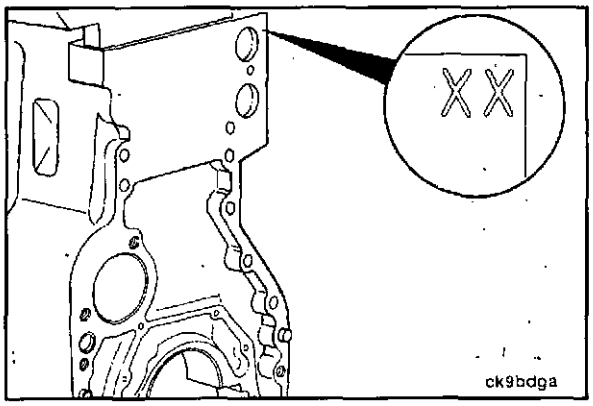
NOTE: The cylinder block head deck can be resurfaced in a machine shop and a thicker surface head gasket installed to keep the piston-to-head clearance the same.



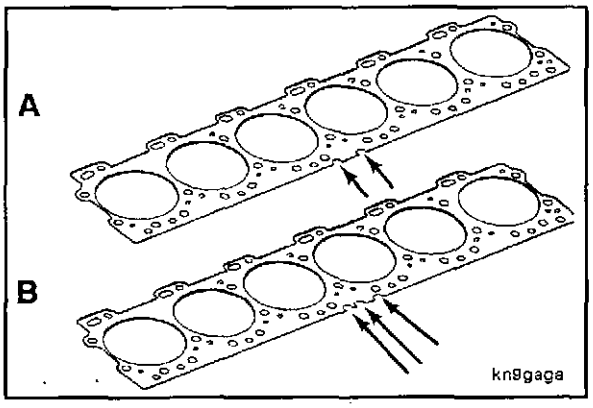
The cylinder block head deck can be resurfaced two times. The first resurface should be 0.25 mm [0.010 inch]. If additional resurfacing is required, an additional 0.25 mm [0.010 inch] can be removed.

Cylinder Block Resurface Limits		
mm		in
0.25	First Resurface	0.010
0.25	Second Resurface	0.010
0.50	Total Allowed	0.020





The upper right corner of the rear face of the block **must** be stamped with an "X" when the block is resurfaced to *0.25 mm [0.010 inch]*. A *second* "X" ***must*** *be stamped* beside the first when the block is resurfaced to 0.50 mm [0.020 inch].

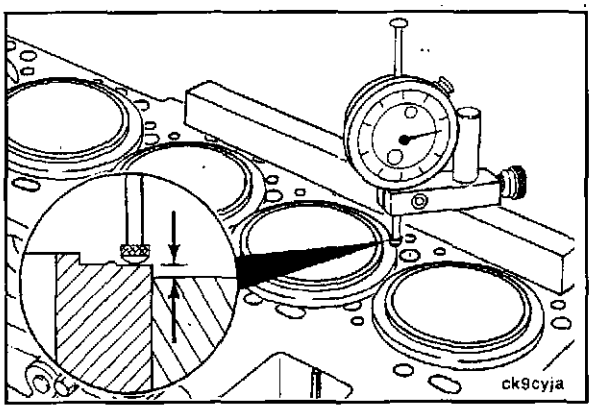


Consult the C Series parts catalog for the correct head gasket to be used with resurfaced blocks to be sure of proper piston to valve clearance.

NOTE: The gaskets are notched to aid in identification. The standard gasket does **not** have a notch.

A = Use where block deck has been resurfaced 0.25 mm [0.010 in] (two notches)

B = Use where block deck has been resurfaced 0.50 mm [0.020 in] (three notches)



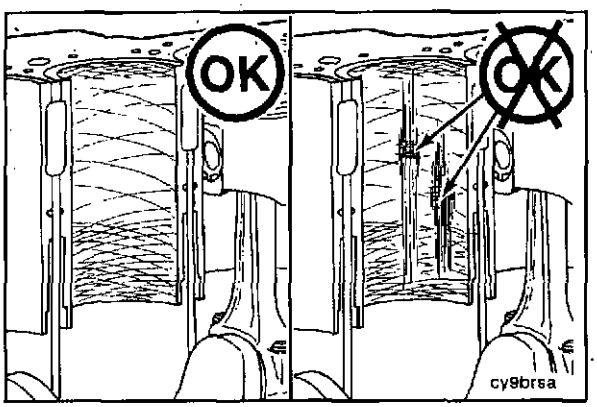
Gauge Block, Part No. 3823495

Liner protrusion is the distance the liner protrudes above the block face. Check the liner protrusion.

NOTE: The liners **must** be checked in the "free state", *without clamps.*

Cylinder Liner Protrusion Specifications		
mm		in
0.025	MIN	0.0010
0.122	MAX	0.0048

NOTE: If the cylinder liner protrusion is below specifications, *it will be necessary to machine the counterbores.*



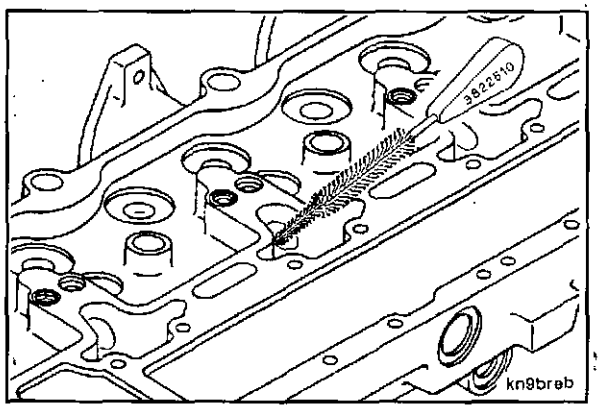
Visually inspect the cylinder liners for cracks, scuffing or scoring.

Cylinder Head - Cleaning and Inspection

Injector Bore Brush, Part No. 3822510

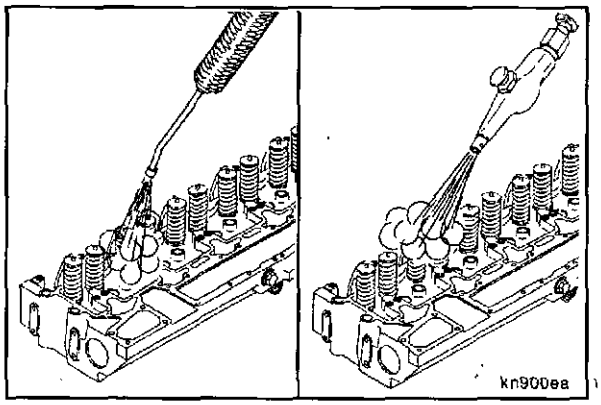
NOTE: Omit the following five steps if a replacement head is to be installed:

Clean the carbon from the injector nozzle seat with an injector bore brush, Part No. 3822510.



Caution: When using a steam cleaner, wear protective clothing and safety glasses or a face shield. Hot steam can cause serious personal injury.

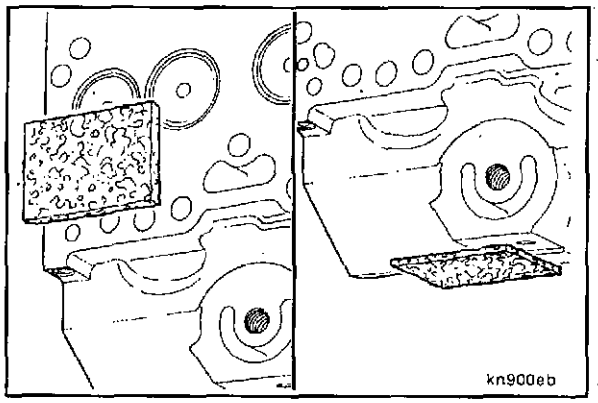
Steam clean the cylinder head and dry with compressed air. Blow out all capscrew holes.



Use Scotch-Brite® 7448, or equivalent, and solvent to clean the cylinder head combustion face.

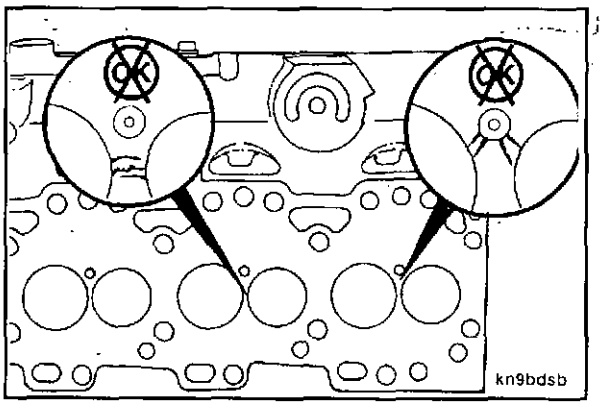
Clean the exhaust manifold gasket surface.

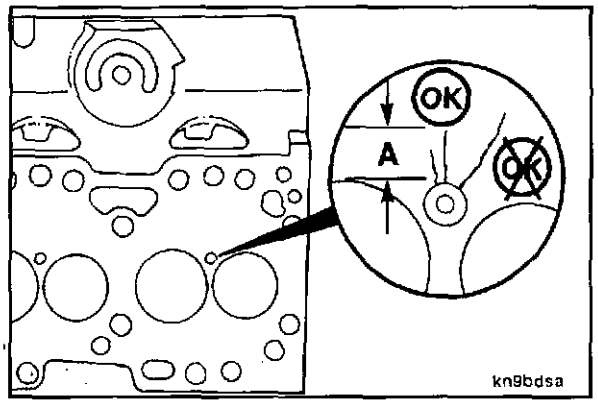
Clean the valve cover gasket surface.



Visually inspect the cylinder head and valves for obvious damage that would prohibit reuse. Check for cracks and damage to the deck surface that would result in loss of sealing.

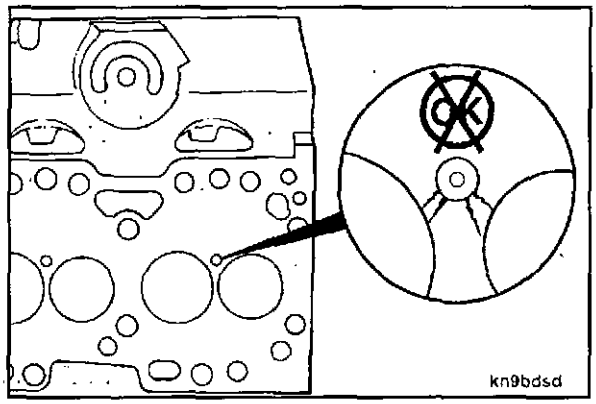
NOTE: If a crack in the cylinder head is suspected, pressure test the cylinder head. Refer to Procedure 7-10.



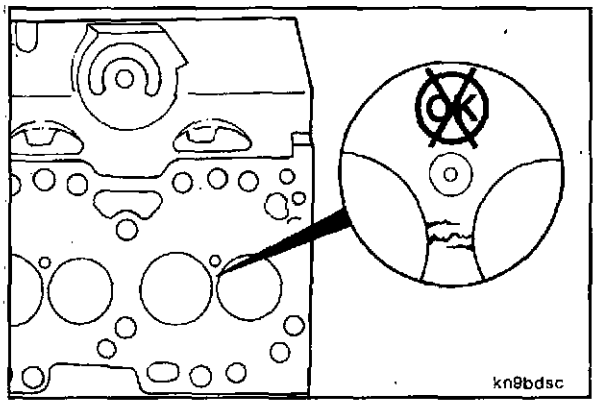


Check for cracks on the combustion face. Cracks that extend from the injector bore away from the valve seats and are **not** over 10 mm [0.394 inch] long are acceptable.

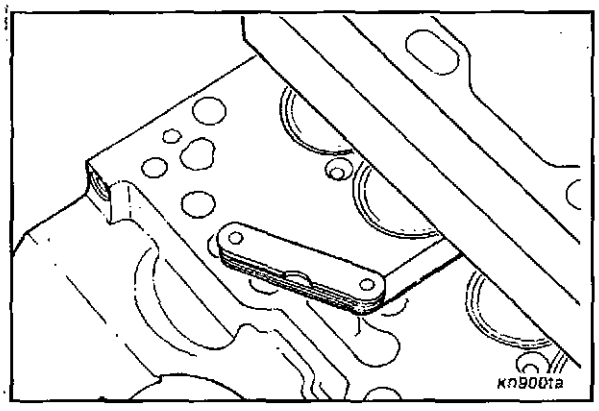
A = 10 mm [0.394 inch]



Any cracks that extend from the injector bore toward the valve seats are unacceptable and the cylinder head **must** be replaced.



Cracks between the valve seats are **not** acceptable and the cylinder head **must** be replaced.



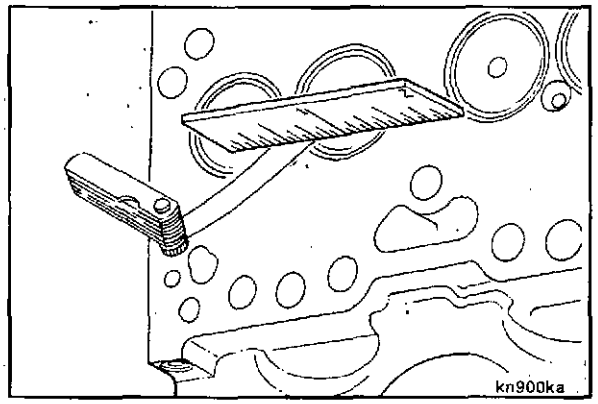
Straight Edge and Feeler Gauge

Use a straight edge and feeler gauge to check the cylinder head combustion surface for flatness.

Cylinder Head Flatness Specifications

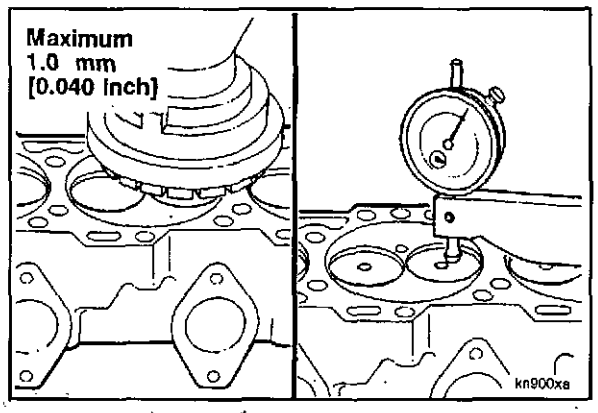
mm		in
0.20	End-to-End	0.008
0.076	Side-to-Side	0.003

Use a small 51 mm [2.0 inch] straight edge and a 0.0254 mm [0.001 inch] feeler gauge to measure local flatness. Check between the cylinder bores and also between the coolant passages. If the 0.001 inch feeler gauge fits under the 2.0 inch straight edge, the cylinder head **must** be replaced or resurfaced.



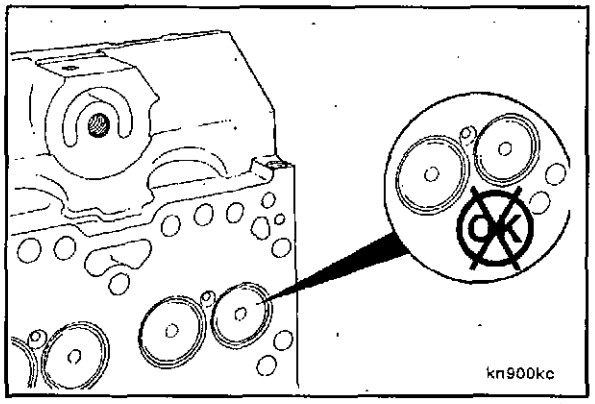
NOTE: A maximum of 1.00 mm [0.040 inch] can be machined from the combustion surface of the cylinder head.

If the cylinder head is machined, place the valve in the respective bore and check the valve depth dimension. If the depth is less than the minimum specification, the valve seat will require machining. Refer to the C Series Shop Manual.



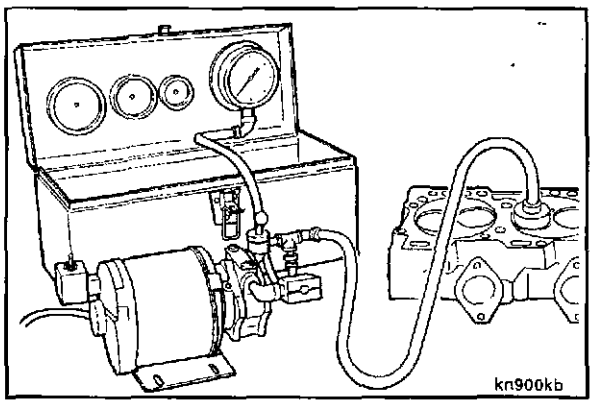
Valve Recess in Cylinder Head			
	mm		in
Exhaust	1.09	MIN	0.043
	1.62	MAX	0.064
Intake	0.59	MIN	0.0023
	1.12	MAX	0.0440

Visually inspect the valves for indications of leakage or burning.

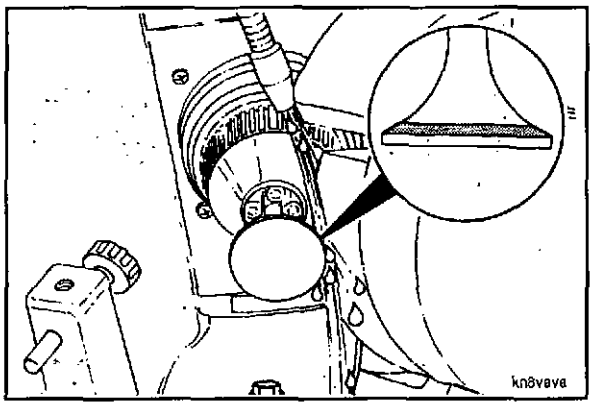


Valve and Seat - Leakage Testing

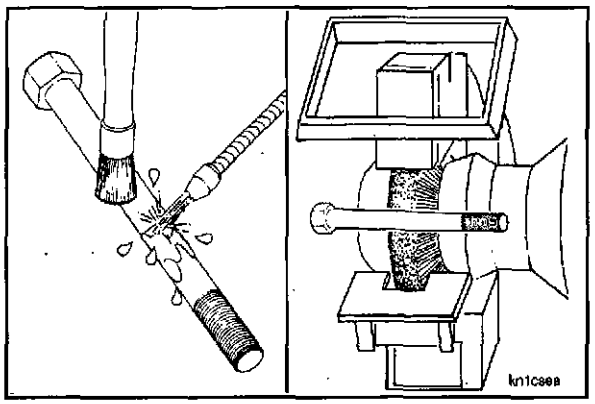
NOTE: If a leaking valve is suspected, vacuum test the valves and valve seats. The vacuum **must** not drop more than 25.4 mm Hg [1.0 inch Hg] in 5 seconds.



Valve to Valve Seat Vacuum		
mm Hg		in Hg
457	Used	18
635	New	25



NOTE: If vacuum does **not** meet the specifications, the face of the valves and the valve seat inserts **must** be resurfaced. Refer to the C Series Shop Manual.

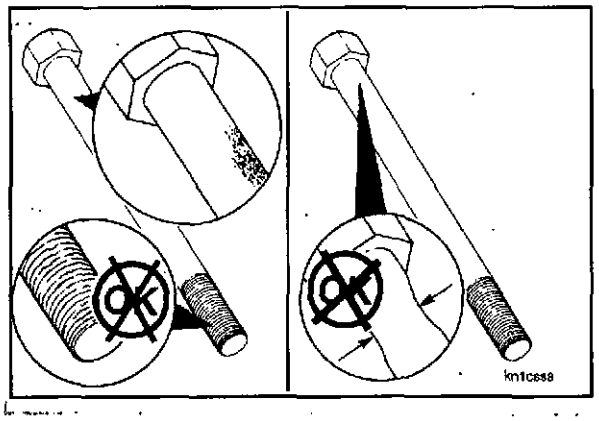


Cylinder Head Capscrews

Caution: Do not use caustic or acid solutions to clean the cylinder head capscrews.

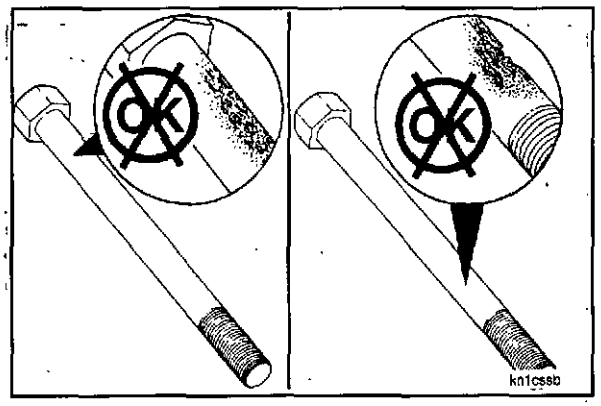
Use a petroleum-based solvent to clean the capscrews.

Clean the capscrews thoroughly with a wire brush, a soft wire wheel, or use a non-abrasive bead blast to remove deposits from the shank and the threads.



Visually inspect the cylinder head capscrews for damaged threads, corroded surfaces, or a reduced diameter (due to capscrew stretching).

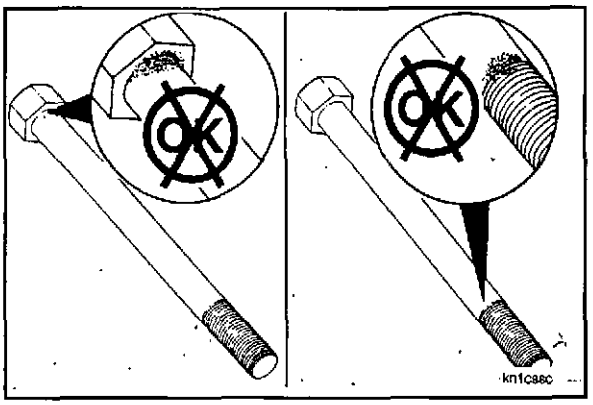
NOTE: Do **not** reuse a capscrew that has damaged threads or a reduced diameter from having been stretched.



Do **not** reuse cylinder head capscrews under the following conditions:

- Visible corrosion or pitting exceeds 1 sqcm [0.155 sq. inch] in area. Example:
  - Acceptable 3/8- x 3/8-inch
  - Unacceptable 1/2- x 1/2-inch
- Visible corrosion or pitting exceeds 0.12 mm [0.005-inch] in depth.

- Visible corrosion or pitting is located within 3.2 mm [1/8-inch] of the fillet.
- Visible corrosion or pitting is located within 3.2 mm [1/8-inch] of the threads.
- Stretched beyond "free length" maximum. Refer to the measurement procedure below:

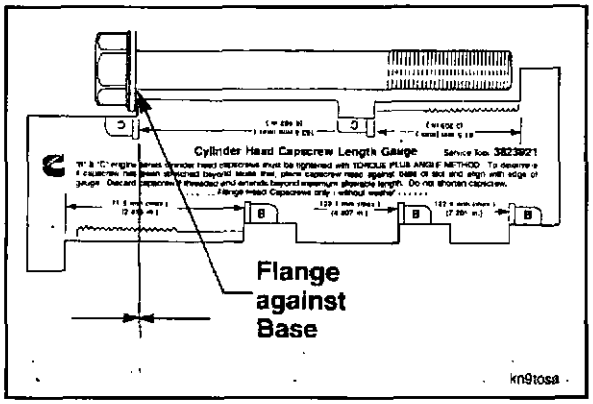


Free Length - Measurement

Part No. 3823921, Capscrew Length Gauge

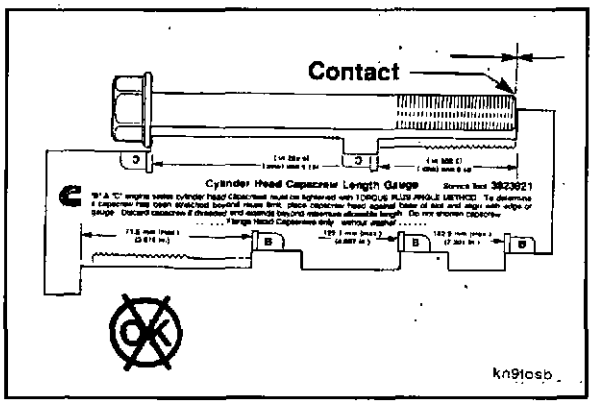
NOTE: If the capscrews are **not** damaged, they can be reused throughout the life of the engine unless the specified "free length" is exceeded.

To check the capscrew free length, place the head of the capscrew in the appropriate slot with the flange against the base of the slot.

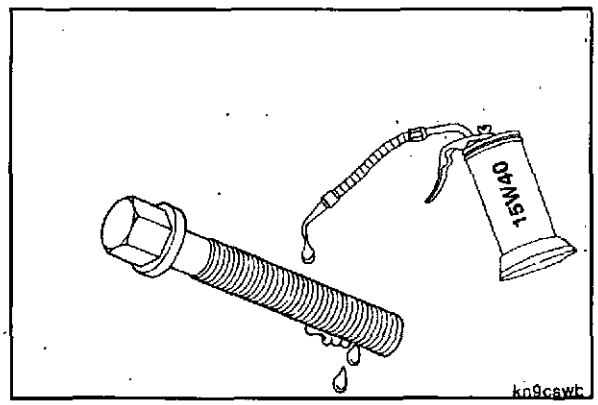


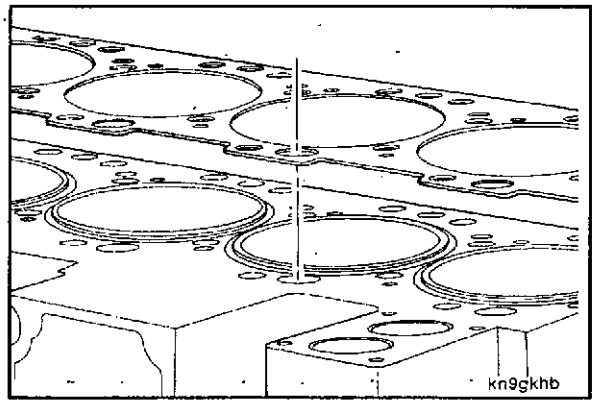
Capscrew Free Length		
mm		in
81.5	Short	3.2
162.6	Long	6.4

If the end of the capscrew touches the foot of the gauge, the capscrew is too long and **must** be discarded.



Immediately after cleaning and inspecting, apply a film of clean engine lubricating oil to all capscrews that are to be used again.



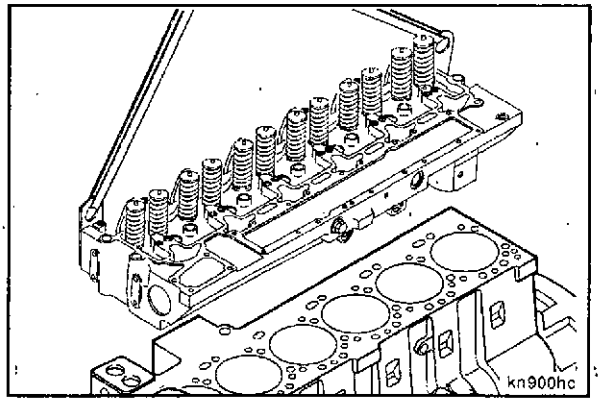


Installation

NOTE: Make sure the new head gasket is correctly aligned with the holes in the cylinder block.

The cylinder block and head **must** be clean and dry.

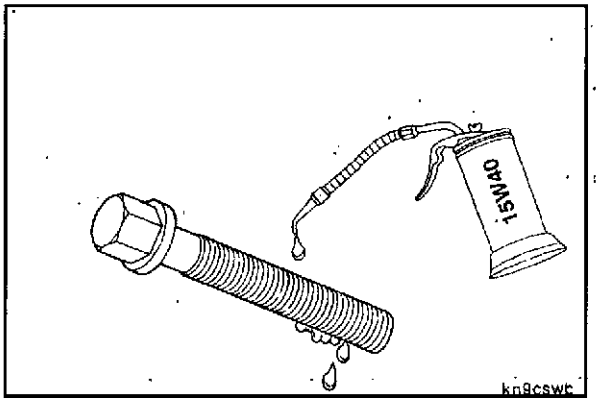
Position the gasket onto the dowels.



Caution: Do not drop the cylinder head on the cylinder head gasket. The gasket material can be damaged.

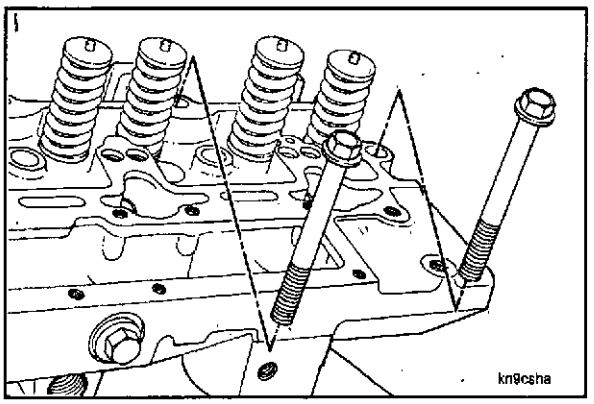
Carefully install the cylinder head onto the gasket and cylinder block.

NOTE: Make sure the cylinder head is installed onto the dowels in the cylinder block.



Use clean 15W-40 oil to coat the cylinder head capscrew threads and underneath the head flange.

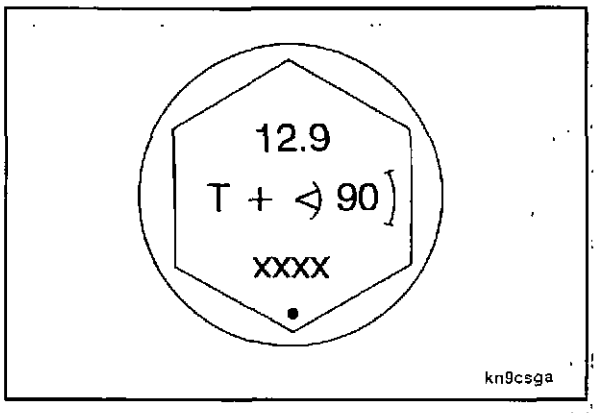
Allow the excess oil to drain from the capscrew threads.



Install the capscrews in the cylinder head.

NOTE: Be sure to install the six capscrews into the holes underneath the injectors.

NOTE: The top of the cylinder head capscrew is identified with an angle marking. The cylinder head capscrews **must** be tightened by using the three-step "torque plus angle" method, described as follows:

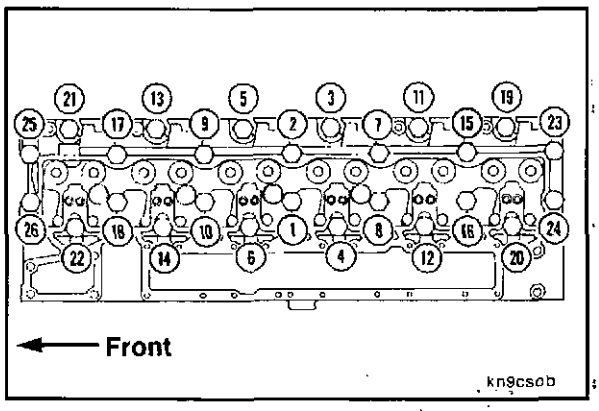


16 mm

1. Follow the numbered sequence and tighten all capscrews:

Torque Value: (Step One) 70 N•m [52 ft-lb]

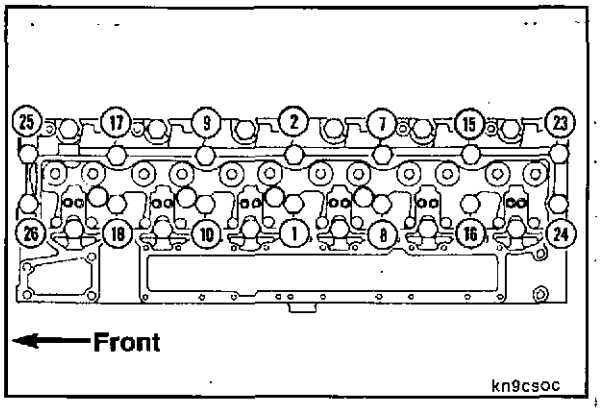
Follow the numbered sequence and check the torque on all capscrews again.



2. Follow the numbered sequence and tighten only the 12 long capscrews:

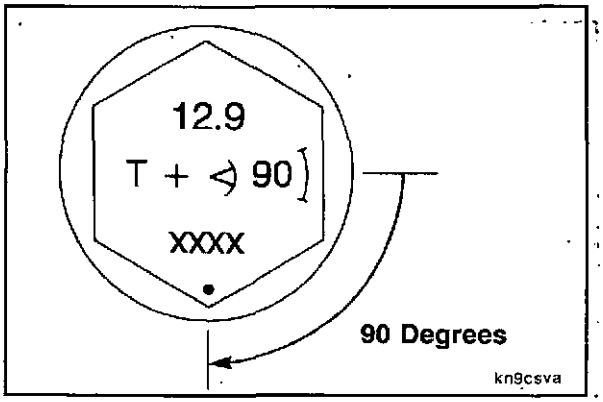
Torque Value: (Step Two) 145 N•m [105 ft-lb]

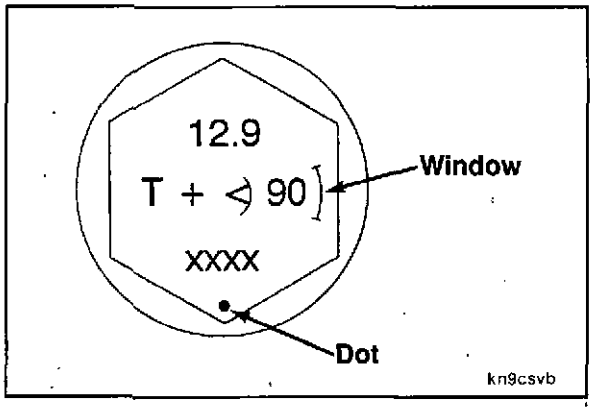
Follow the numbered sequence and check the torque on all long capscrews again.



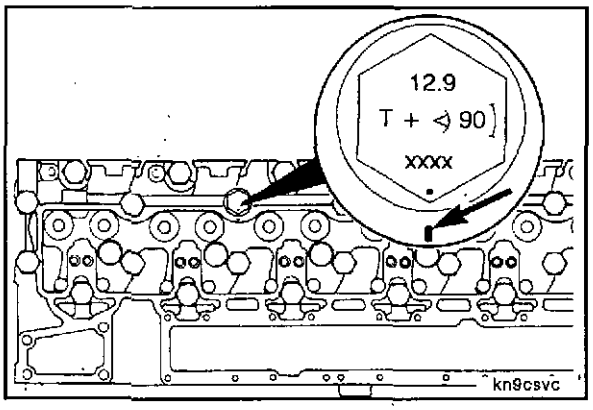
3. Torque Value: (Step Three)

Follow the numbered sequence and turn all the capscrews 90 degrees as indicated on the capscrew head.

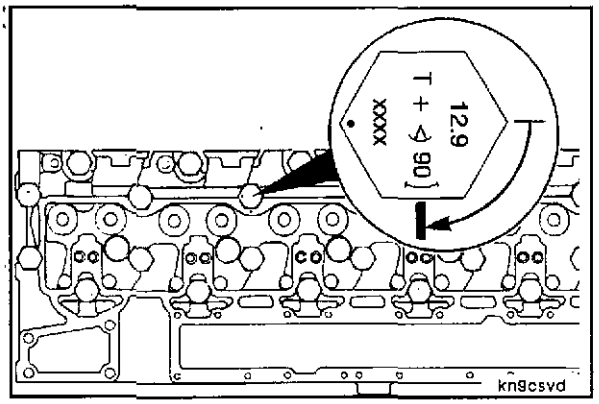




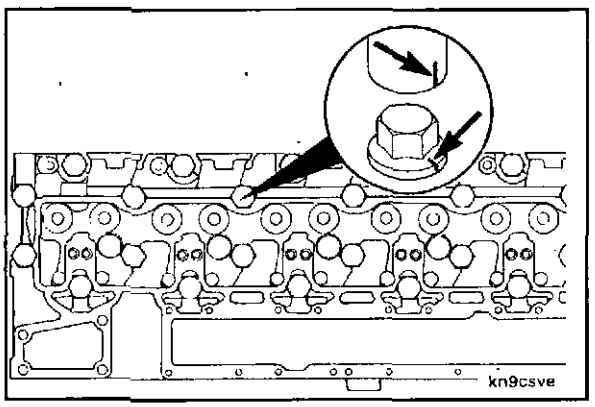
To accurately turn the capscrew to the desired angle, a small "dot" and a "window" are marked on the capscrew head.



Mark the cylinder head adjacent to the dot on the capscrew head. This mark will serve as an indexing aid.



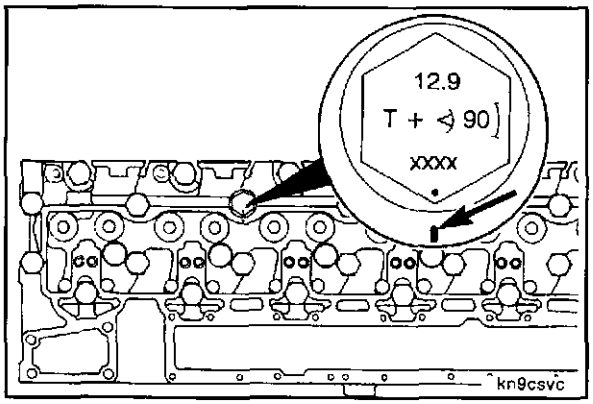
Rotate the capscrew until the mark, that has been made on the cylinder head, falls into the "window" on the capscrew head.



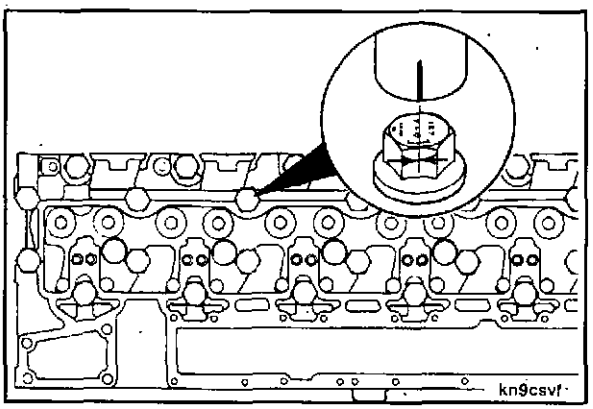
Service Tip:

Use a permanent marker to mark the socket corresponding to one of the flats of the socket hex.

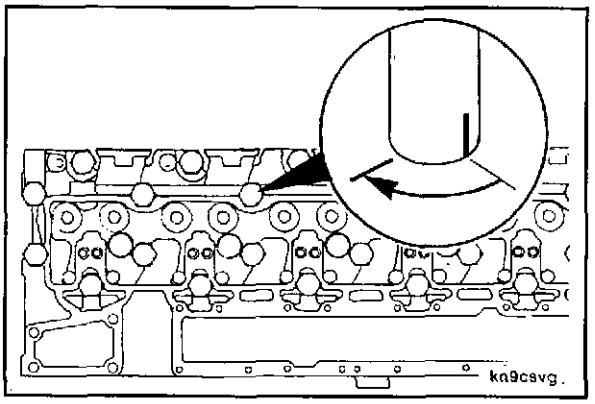
After the torque has been completed, mark the cylinder head at the location of the dot.



Position the socket on the capscrew such that the mark on the socket is at the same point as the window on the capscrew.



Turn the socket until the mark of the socket aligns with the mark on the cylinder head.



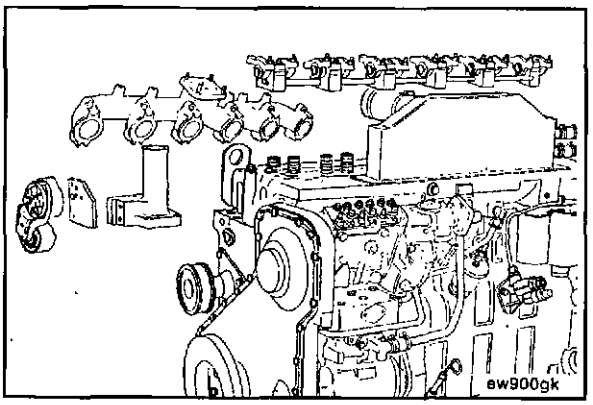
Install the thermostat housing. Refer to Procedure 1-08.

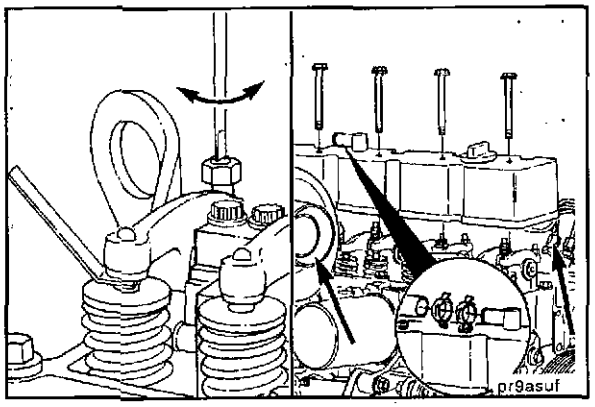
Install the belt tensioner and bracket. Refer to Procedure 1-04.

Install the exhaust manifold. Refer to Procedure 3-12.

Install the rocker lever oil manifold. Refer to Procedure 7-05.

Install the rocker assemblies. Refer to Procedure 7-05.





Adjust the valve clearance. Refer to Procedure 7-06.

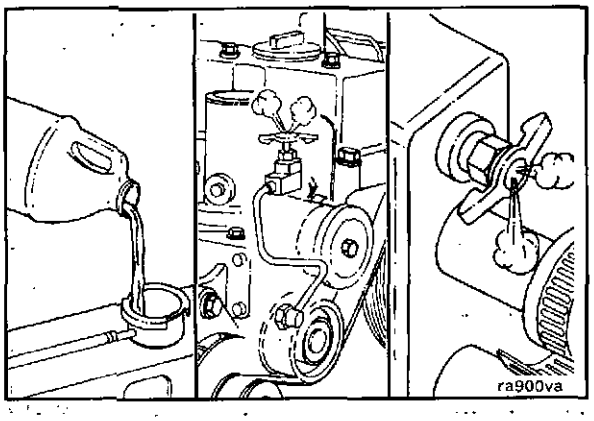
Install the valve cover. Refer to Procedure 7-02.

Install the injectors. Refer to Procedure 5-07.

Install the fuel lines. Refer to Procedure 5-05.

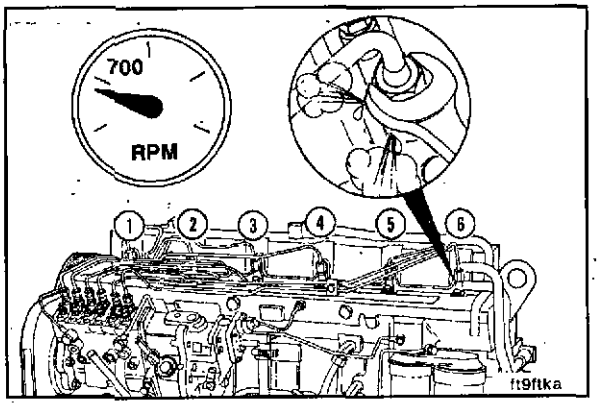
Install the turbocharger. Refer to Procedure 3-11.

Install the crankcase vent tube. Refer to Procedure 7-03.



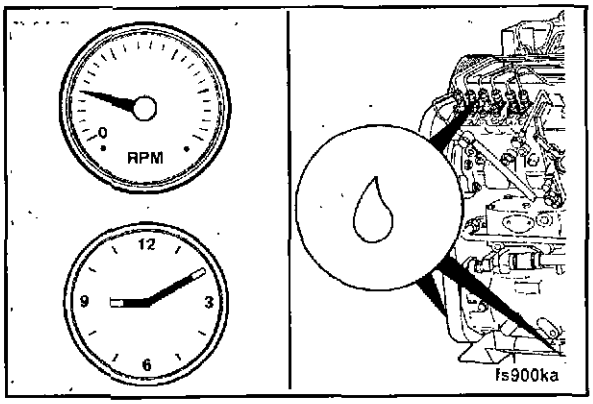
Fill and vent the cooling system.

Refer to Procedure 1-01.



Vent the high pressure fuel lines.

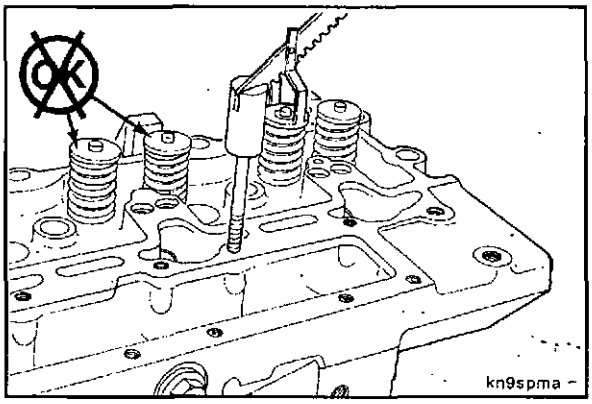
Refer to Procedure 5-05.



Operate the engine at idle 5 to 10 minutes to check for leaks and proper operation.

Cylinder Head - Pressure Test (7-10)

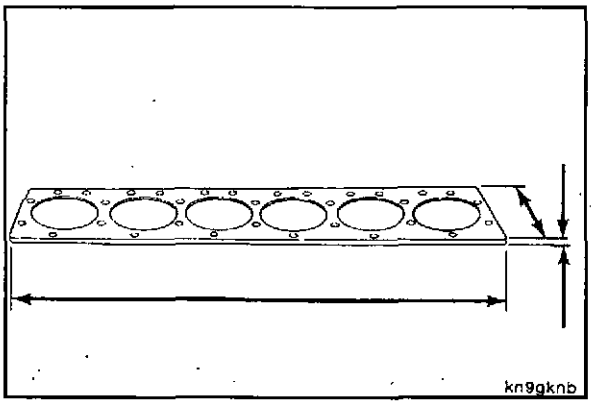
Caution: Do not pressure test the cylinder head with the valves and valve springs installed. Water entering the cylinder head cannot be dried thoroughly and will damage the valve guides and valve stems. Refer to the C Series Shop Manual for cylinder head disassembly procedures.



NOTE: A cylinder head test fixture can be fabricated from a flat piece of steel or aluminum. Refer to the following table for test fixture dimensions:

Test Fixture Dimensions

mm		in
16	Thickness	0.625
851	Length	33.5
190	Width	7.5



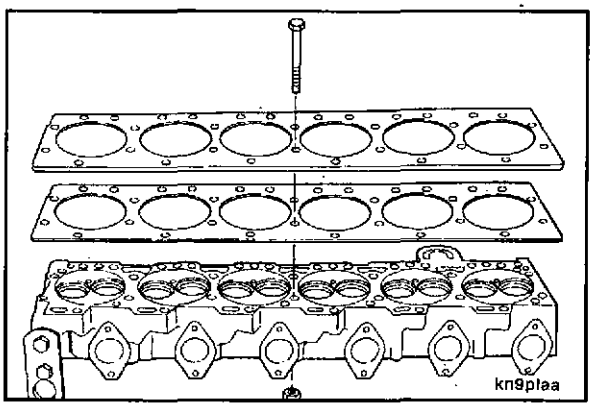
NOTE: Use the cylinder head gasket as a pattern for drilling the capscrew holes.

Install the cylinder head water test fixture.

- Install a new head gasket
- Install the test plate
- Install the 26 cylinder head capscrews and M14 X 2.0 nuts

Tighten the nuts.

Torque Value: 45 N•m [35 ft-lb]



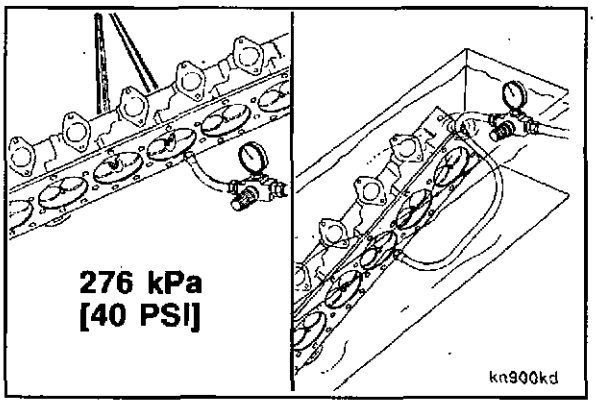
Connect a regulated air supply hose to the text fixture plate. Apply air pressure.

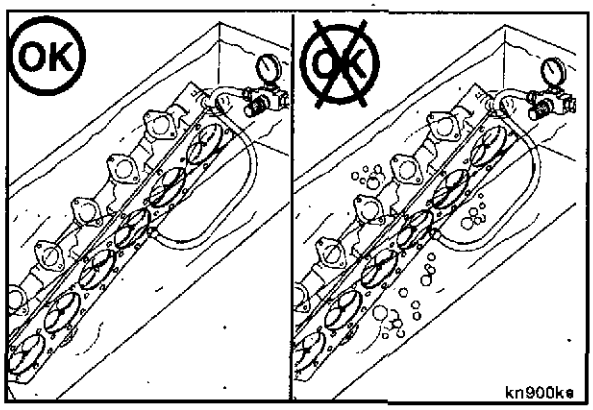
Air Pressure: 276 kPa [40 psi]

Use a nylon lifting strap and a hoist to place the cylinder head in a tank of heated water.

Temperature: 60°C [140°F]

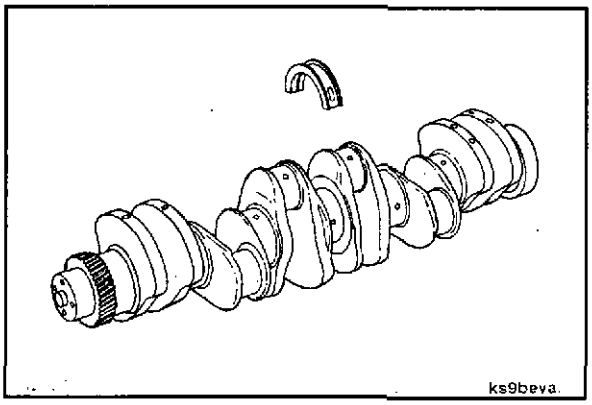
Completely submerge the cylinder head in the water.





Visually inspect for air bubbles rising from the water.

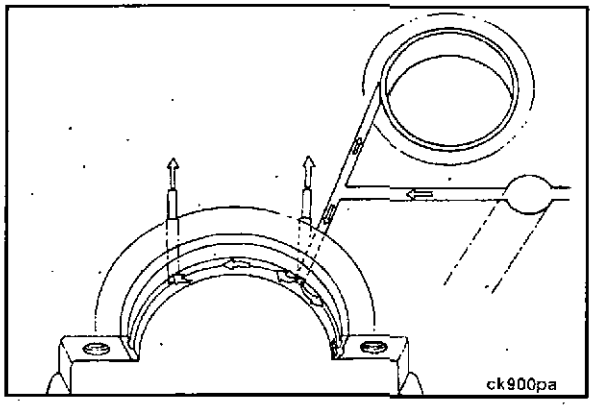
If air bubbles are seen, replace or rebuild the cylinder head. Refer to the C Series Shop Manual for rebuild procedures.



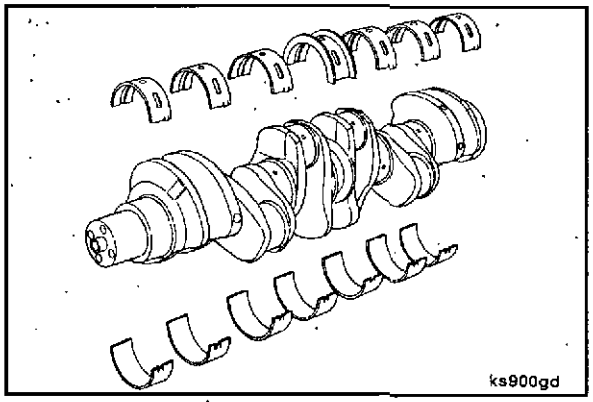
Main and Thrust Bearings - Replacement (7-11)

General Information

The engine has seven main bearings. The lower bearing shells are all the same. All of the upper bearing shells are the same except for the No. 4 journal. The No. 4 journal uses a flanged upper bearing shell. The flanges on the bearing control the end thrust of the crankshaft.



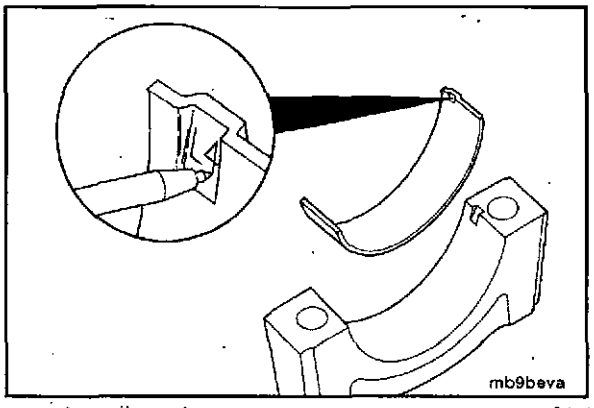
The upper bearings are grooved and have two oval holes in them. One hole aligns with the drilling from the main oil rifle, the other hole supplies oil to the piston cooling nozzles.



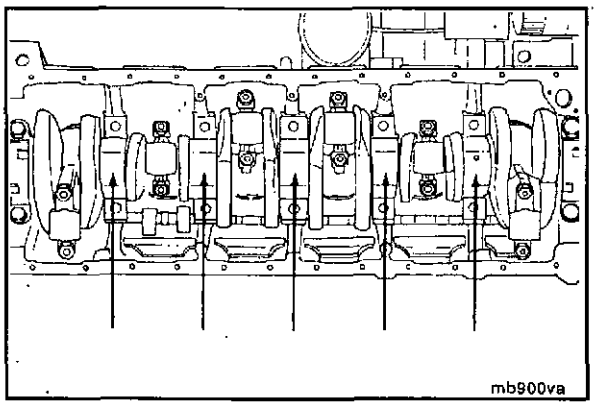
The following oversize service main and thrust bearing combinations are available for crankshafts that have been machined undersize, either on the main journal or thrust bearing face:

Main Bearing Journal Diameter	Thrust Bearing Face Thickness
STD	STD
-0.25 mm [-0.010 inch]	STD
-0.50 mm [-0.20 inch]	STD
-0.75 mm [0.030 inch]	STD
-1 mm [-0.040 inch]	STD
STD	+0.25 mm [+0.010 inch]
STD	+0.50 mm [+0.020 inch]
-0.5 mm [-0.020 inch]	+0.50 mm [+0.020 inch]

Mark the bearing shell with the letter "L" (lower) and the journal number it was removed from.

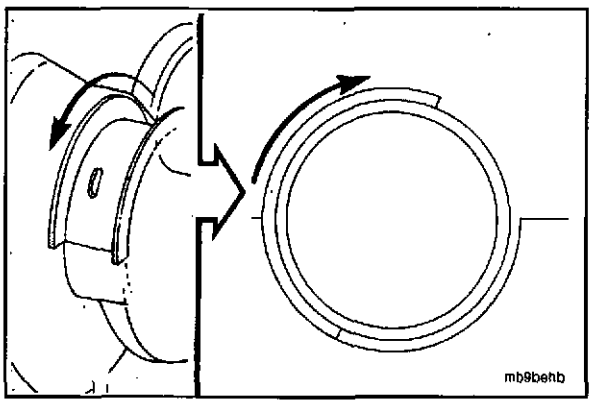


If the main bearings are to be removed, remove all bearing caps except for cylinders No. 1 and 7.



Caution: do not damage the crankshaft when removing the thrust bearing.

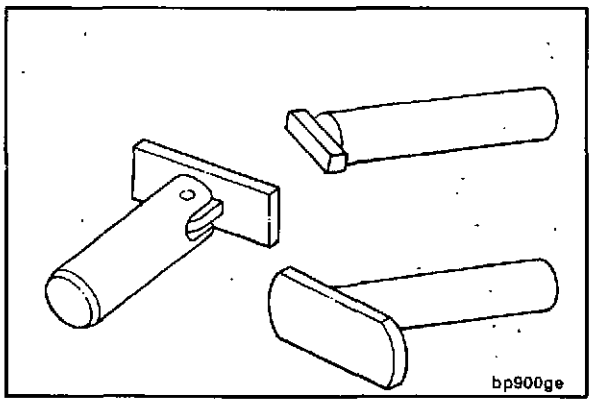
Use a blunt tool to remove the upper thrust bearing.

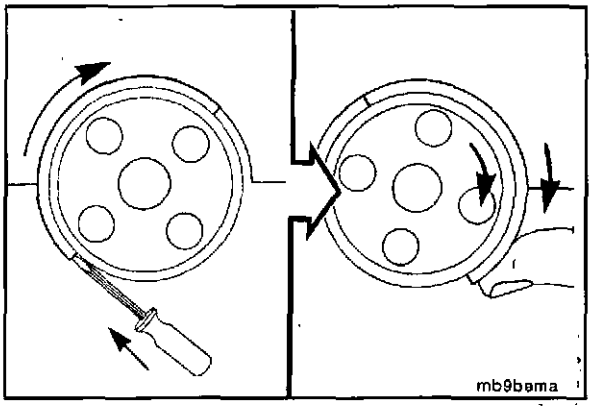


Part No. 3823818, Main Bearing Rollout Tool

Caution: Do not use a capscrew or any hard metal object as this can damage the crankshaft and cause serious engine failure.

To remove the upper main bearing shell, install a tool similar to the one shown, in the oil hole of the main bearing journal. Several varieties of small soft metal plugs are sold specifically for this purpose.

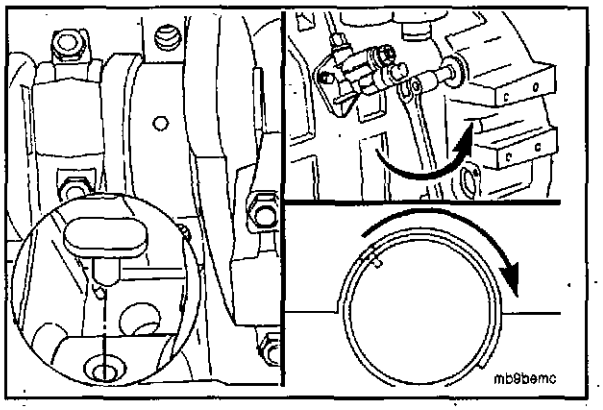




The No. 1 main does **not** have a hole in the journal so the bearing rollout tool **cannot** be used to replace the bearing.

Caution: Use care so the screwdriver does not damage the crankshaft or cylinder block.

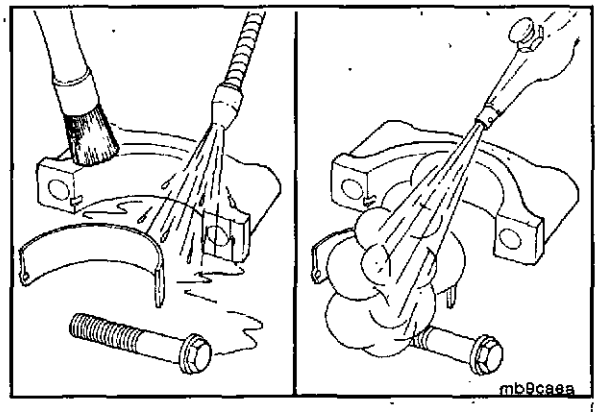
Use a flat blade screwdriver. Gently bump the end of the bearing to loosen it from the block. Then, use finger pressure against the bearing shell and rotate the crankshaft to roll the bearing out.



Part No. 3377371, Engine Barring Tool

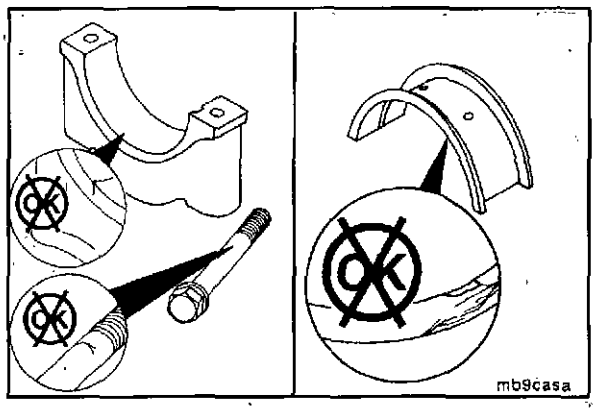
Rotate the crankshaft so the pin pushes against the end of the bearing opposite the tang. Remove the bearing.

Follow this procedure to remove the other bearings.



Cleaning and Inspection

Use solvent and a soft bristle brush to clean the cap, capscrews and bearings and dry with compressed air.

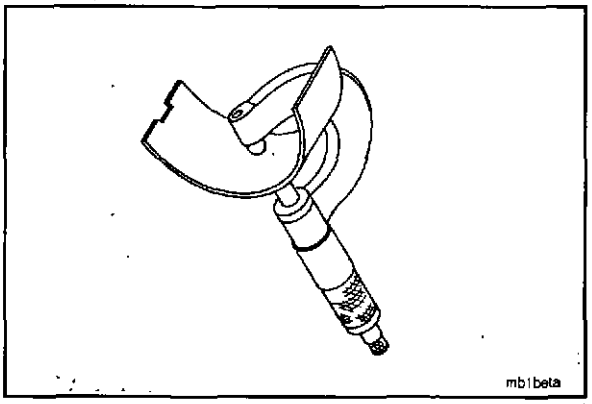


Visually inspect the main cap and capscrews for damage.

Visually inspect the bearing shells and the thrust bearings for nicks, scratches, or damage.

NOTE: If the main bearings are damaged, refer to the C Series Shop Manual to inspect the crankshaft main bearing journals. If the crankshaft is damaged, the engine **must** be removed for repair. Refer to Procedure 9-01.

Use an outside diameter ball tipped micrometer to measure the main bearing shell thickness.

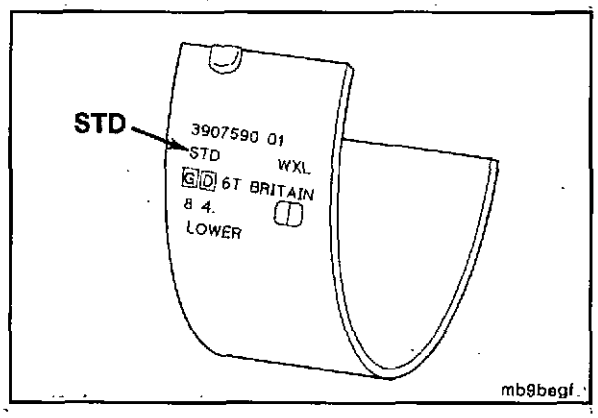


Standard Main Bearing Shell Thickness		
mm		in
3.446	MIN	0.1357
3.454	MAX	0.1360

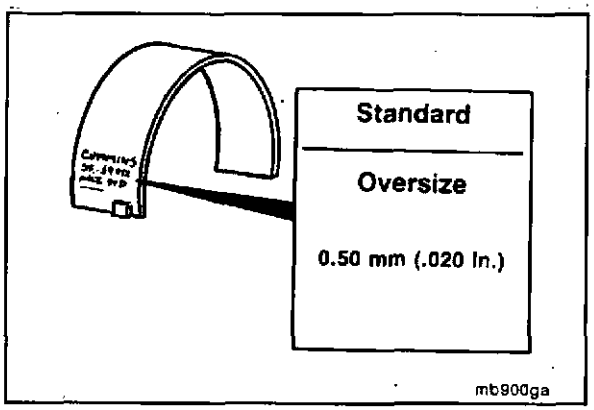
Discard any main bearing shell if it is thinner than the minimum specification.

NOTE: For more detailed information of bearing damage, refer to "Analysis and Prevention of Bearing Failures," Bulletin No. 3810387.

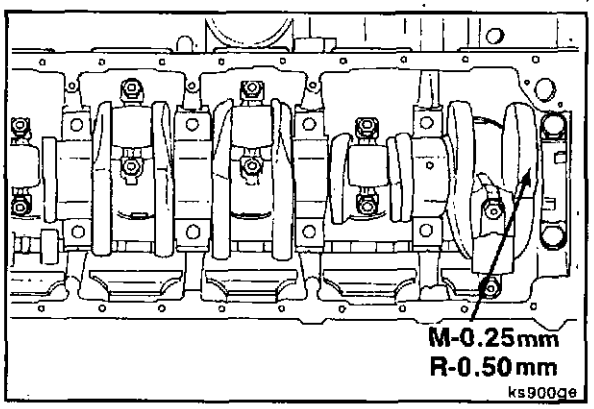
The upper bearings contain two oil holes. The lower bearings do **not**. Both bearings are marked on the back to indicate either standard (STD) or oversize (OS).

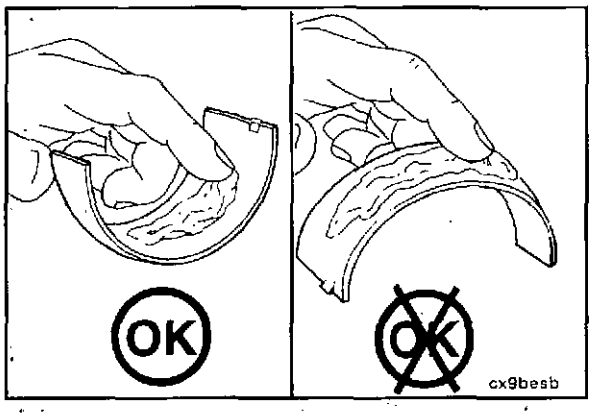


Determine the size of the bearing removed and obtain the same size for installation.



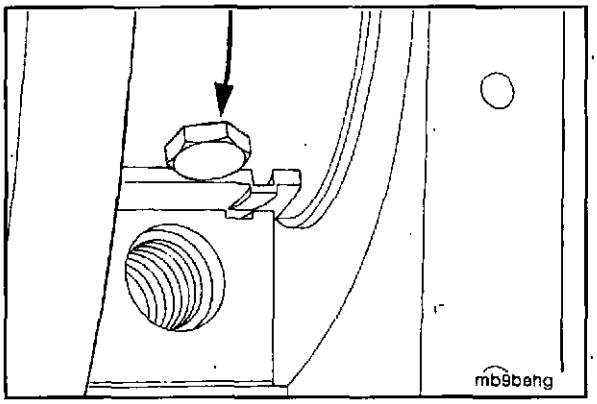
NOTE: Main bearing shells are available for crankshafts which are 0.50 mm [0.020-inch] undersize. Crankshafts which are machined undersize in the connecting rod and main bearing journals are marked on the front counter weight. If the crankshaft is marked, check the bearing shell part number to make sure the correct bearing size is used.





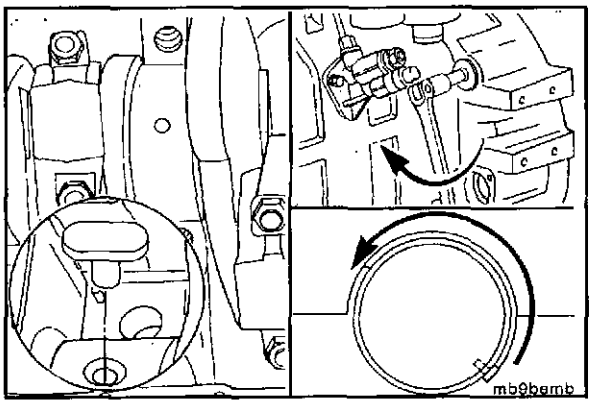
Caution: The cylinder block saddle and the cap mating surfaces must be clean and dry when the bearing shells are installed. Used bearings must be installed in their original location.

Use clean Lubriplate® 105 or its equivalent to lubricate the upper main bearing shell to crankshaft journal mating surface. Do **not** lubricate the side that is against the cylinder block.



Installation

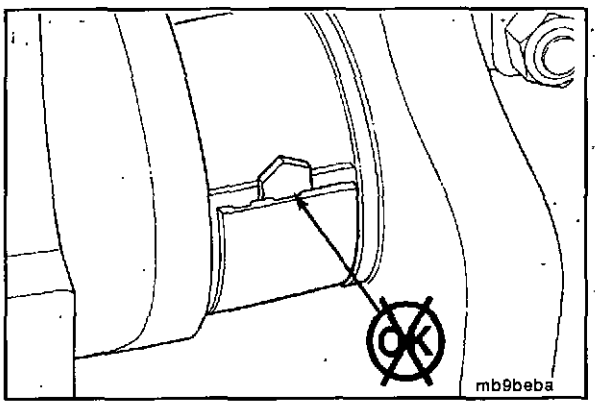
Position the new upper bearing on the crankshaft and install as far as possible by hand.



Part No. 3377371, Engine Barring Tool

Part No. 3823818, Main Bearing Rollout Tool

Use Part No. 3823818, main bearing rollout tool and Part No. 3377371, engine barring tool to finish pushing the bearing in slowly being sure it is aligned with the block. Make sure the tang on the bearing aligns with the notch.

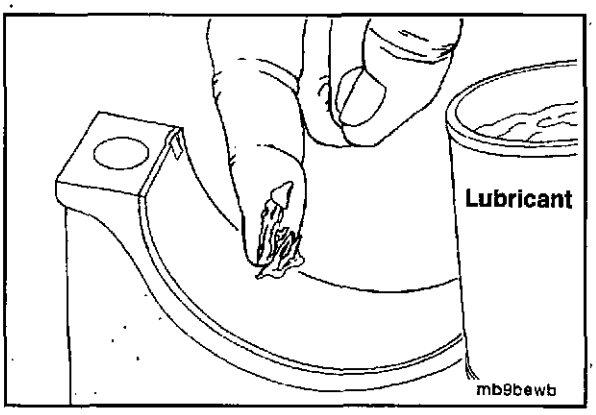


Caution: Make sure the pin does not slide under the bearing and damage the crankshaft.

Install the lower main bearings into the bearing caps.

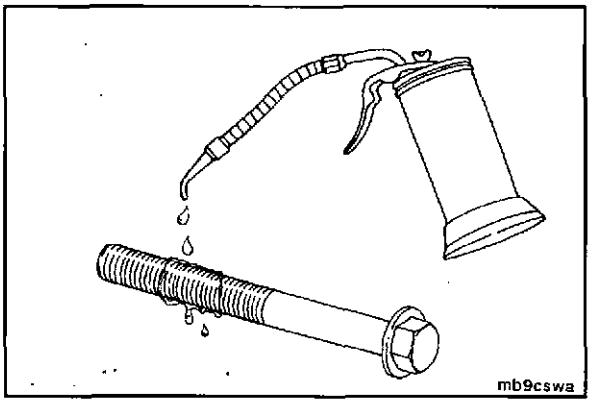
Make sure the tang of the bearing shell is in the slot of the cap.

Use clean Lubriplate® 105 or its equivalent to lubricate the bearing shells.



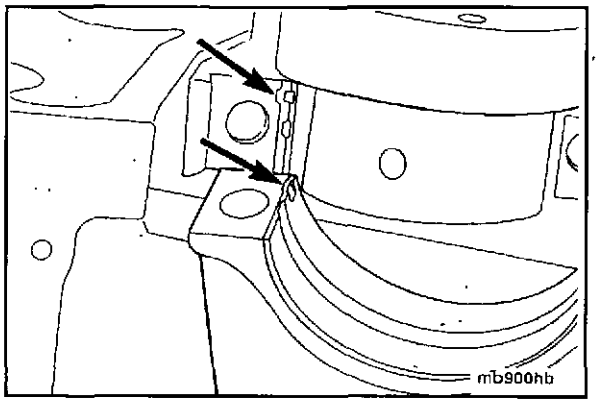
Use clean 15W-40 oil to lubricate the capscrew threads.

Drain the excess oil from the capscrews before installing them.



NOTE: The main bearing caps are numbered for location. No. 1 starts with the front of the block, and the numbers face the camshaft side of the engine.

When correctly installed, the tangs (slots) should both be on the same side.

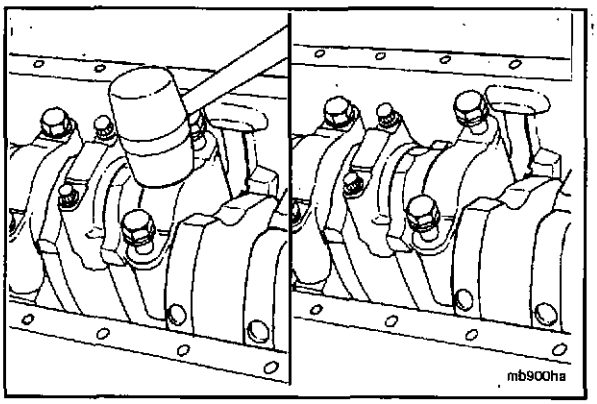


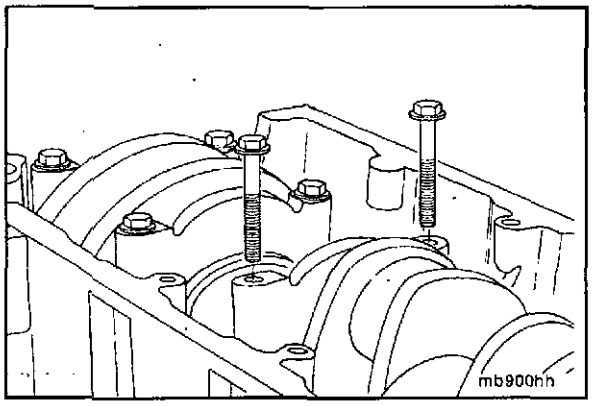
Small Plastic or Rubber Mallet

Tap the main cap gently into position.

NOTE: Make sure the bearing does **not** become dislodged from the cap.

When seated, the main bolts can be threaded in by hand.





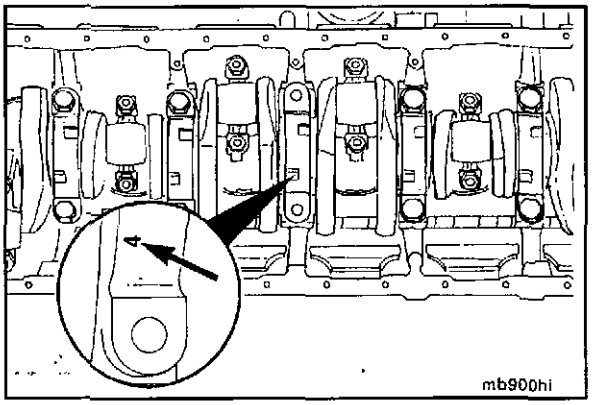
23 mm

Install a main bearing cap after each upper bearing is installed to keep the bearing in place while the other uppers are installed.

Tighten the capscrews to an initial torque.

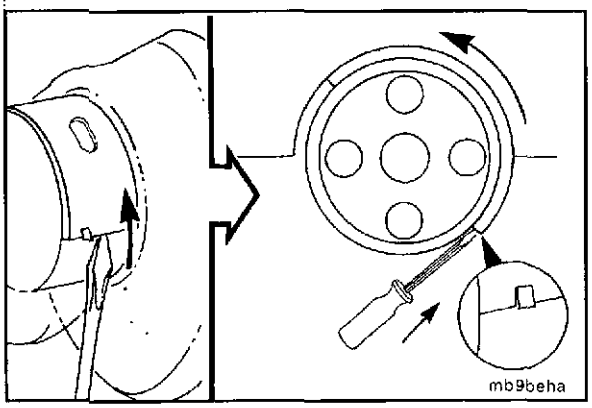
Initial Torque Value: 50 N•m [37 ft-lb]

NOTE: Do **not** tighten to the final torque value at this time.

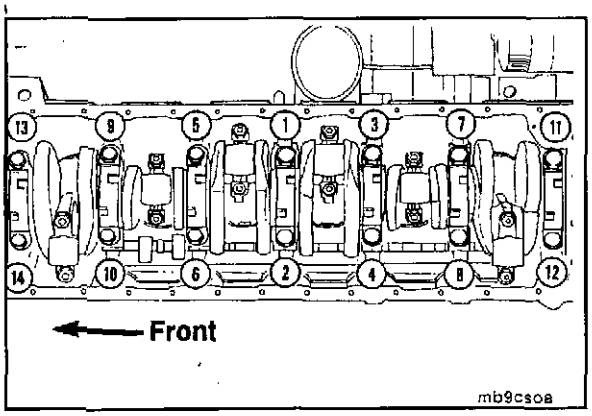


NOTE: The thrust journal does **not** have tangs or slots. Care should be taken to be sure the number stamped on the main cap is positioned to the camshaft side of the engine.

Push the crankshaft toward the center of its end thrust position to allow clearance for the bearing.



Since the bearing rollout tool **cannot** be used for the No. 1 bearing, use a blunt object or screwdriver to push the bearing into position as the crankshaft is rotated.



23 mm

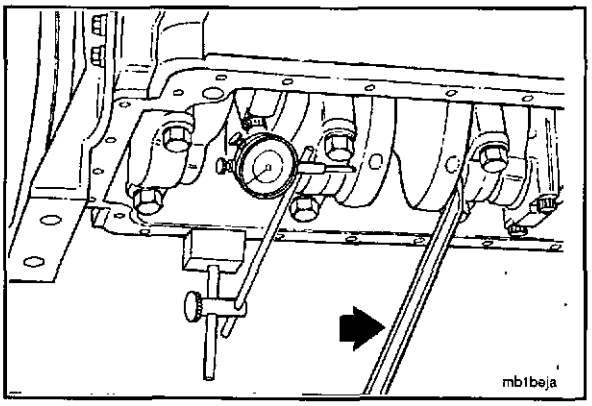
Tighten the capscrews evenly following the illustrated sequence.

Torque Value:

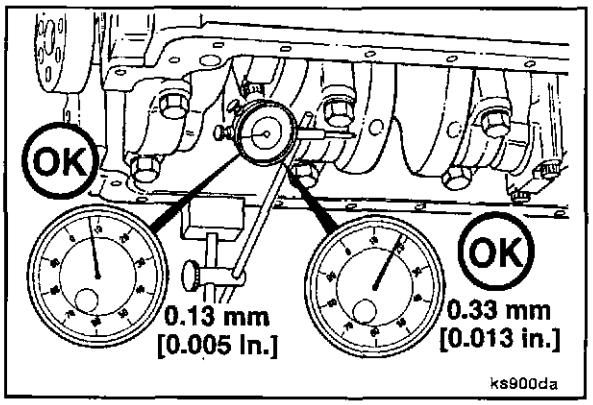
Step
1 - 50 N•m [37 ft-lb]
2 - 119 N•m [88 ft-lb]
3 - 176 N•m [129 ft-lb]

Measure the end clearance of the crankshaft as follows:

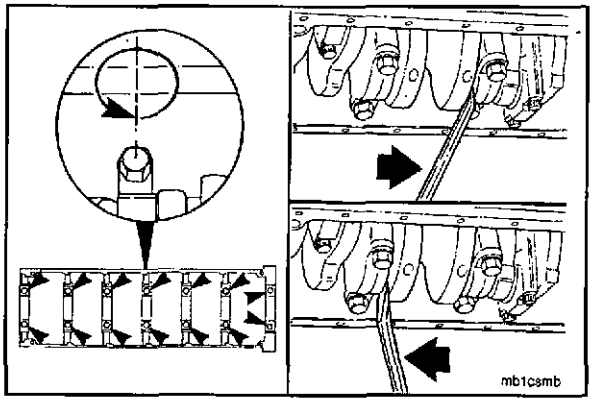
- Install a dial indicator onto the oil pan flange.
- Put the tip of the gauge against the crankshaft counterweight.
- Push the crankshaft toward the rear of the cylinder block.



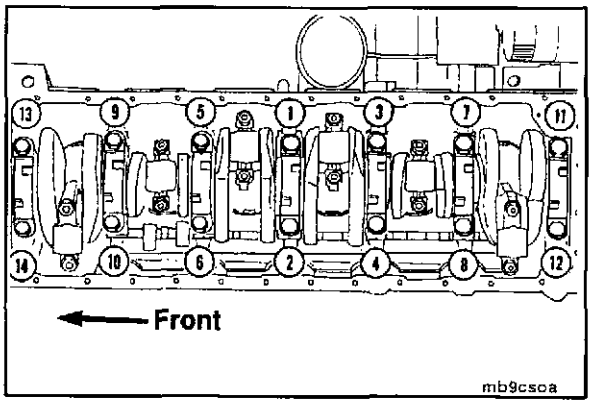
- Set the dial indicator at zero.
- Push the crankshaft toward the front of the cylinder block.
- If the end clearance is less than 0.127 mm [0.005-inch], do the following:

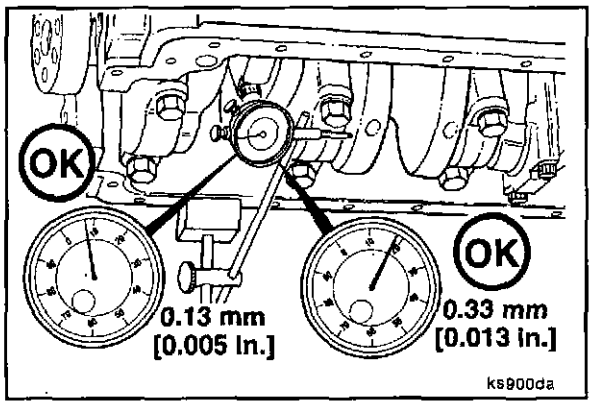


- Loosen the main bearing capscrews one turn.
- Push the crankshaft toward the front and then toward the rear of the cylinder block.

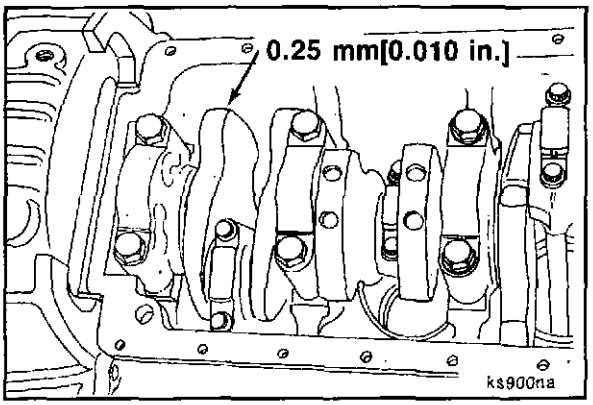


Tighten the main bearing capscrews in the sequence shown to the torque values listed in the installation procedure.



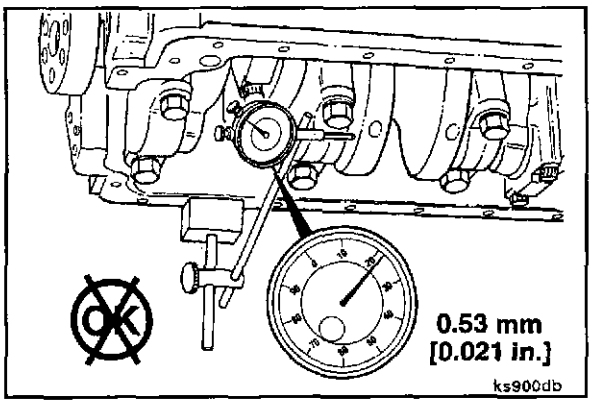


Measure the crankshaft end clearance. The end clearance specification for a new or reground crankshaft with new thrust bearings is 0.127 mm [0.005-inch] to 0.330 mm [0.013-inch].

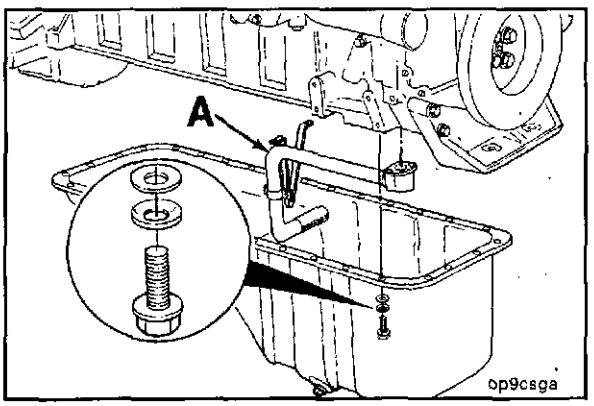


NOTE: Crankshafts that have been reground on the thrust bearing surfaces are marked for oversize thrust bearings on the rear crankshaft counterweight. If the crankshaft counter weight is marked, check the thrust bearing part number to make sure the correct bearing size is used.

Example: 0.010 = 0.25 mm [0.010-inch]

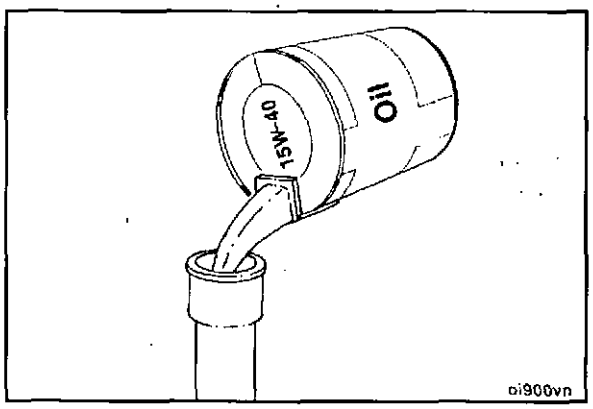


If the crankshaft end play is more than 0.330 mm [0.013-inch] new or 0.533 mm [0.021-inch] used, the crankshaft **must** be removed from the engine and repaired. Refer to the C Series Shop Manual.

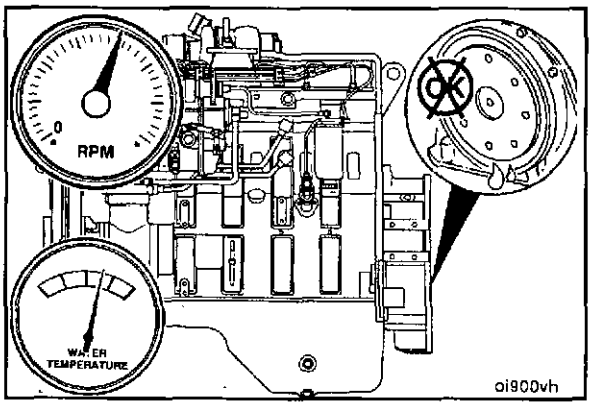


Install the oil pan and suction tube (A). Refer to Procedure 2-13.

Fill the engine with lubricating oil. Refer to Procedure 2-05.



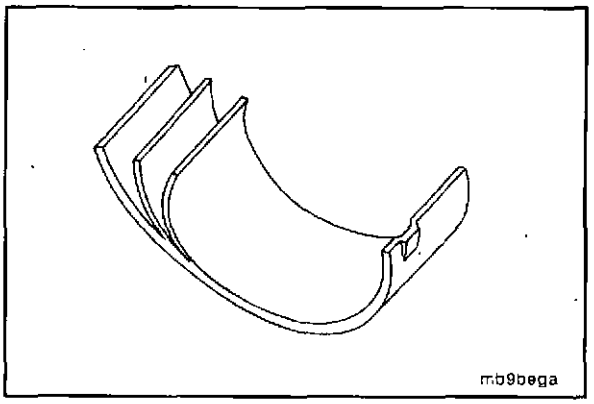
Operate the engine until the coolant temperature reaches 82°C [180°F], and check for lubricating oil leaks.



Connecting Rod Bearings - Replacement (7-12)

Diagnosing Malfunctions

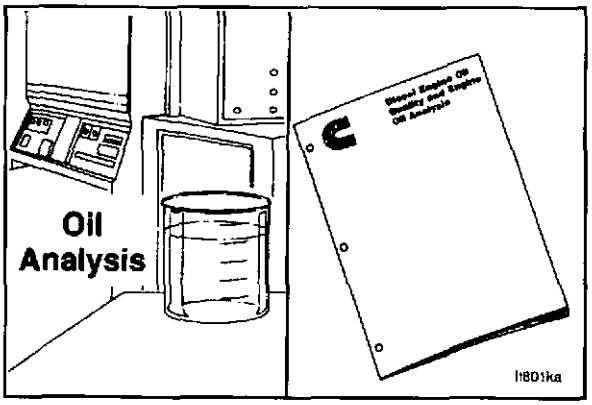
The connecting rod bearings are tri-metal with steel backing.

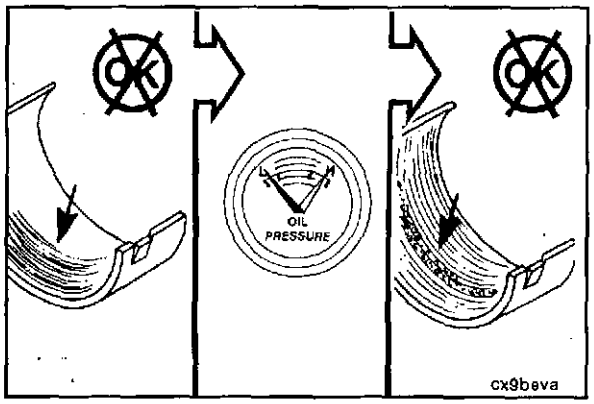


Improper maintenance of the lubrication system is the primary cause of reduced bearing life.

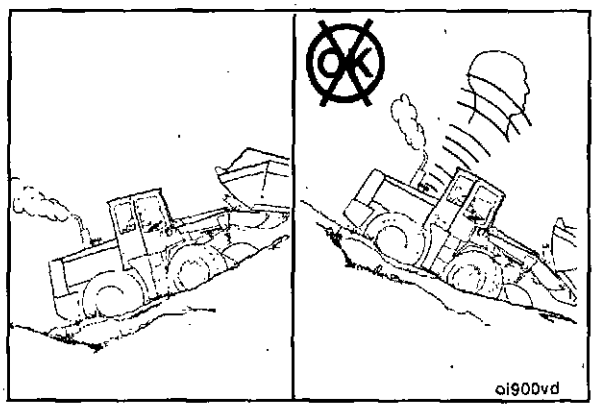
An oil analysis will aid in determining the extent of internal engine damage. Refer to Procedure 2-02.

For additional oil analysis, refer to Cummins Engine Oil Recommendations, Bulletin No. 3810340.

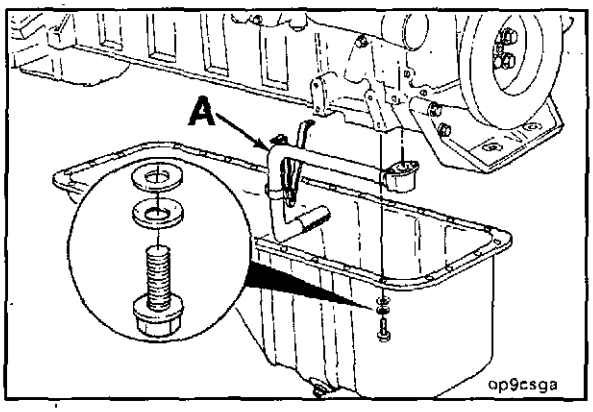




Normally, worn bearings can be detected by reduced oil pressure, but if this wear goes undetected, the excessive clearance will increase the impact between the bearing and the crankshaft causing a distinct knocking sound.



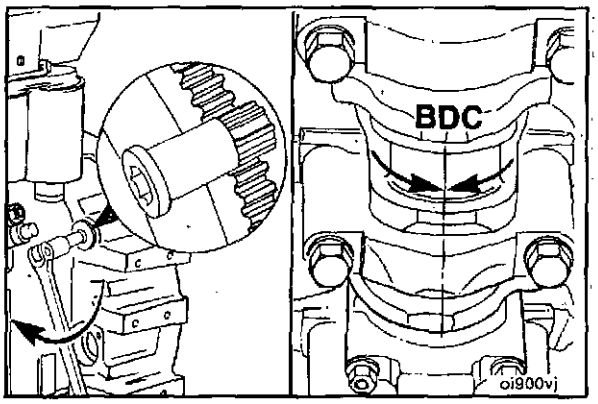
A connecting rod noise occurs when the engine is **not** loaded. Verify by first applying a load and then unloading and listening for the noise.



Removal

Drain the lubricating oil. Refer to Procedure 2-04.

Remove the lubricating oil pan and oil suction tube (A). Refer to Procedure 2-13.



Part No. 3377371, Engine Barring Gear

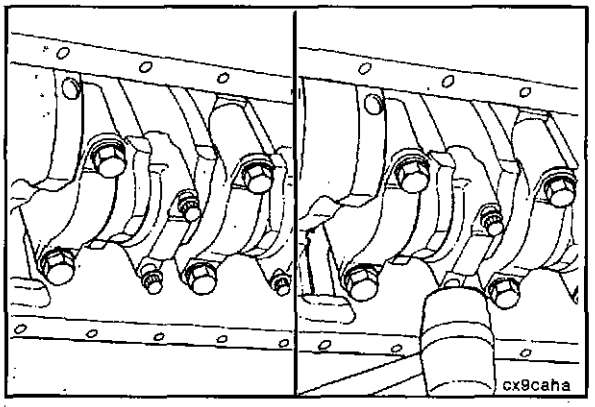
Rotate the crankshaft to position two of the connecting rods at bottom dead center (BDC).

19 mm, Plastic Hammer

Loosen the connecting rod capscrew nuts.

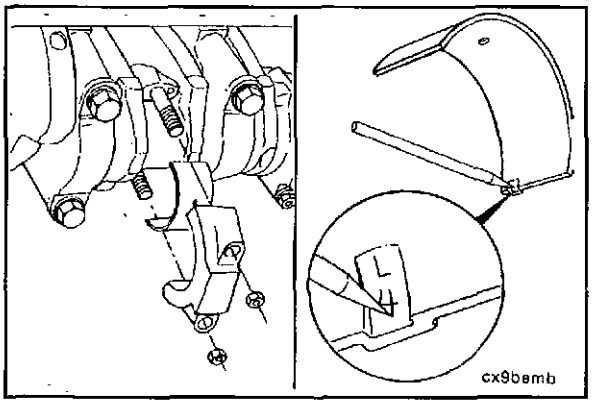
NOTE: Do **not** remove the capscrew nuts.

Hit the connecting rod capscrew nuts with a plastic hammer to loosen the rod caps.



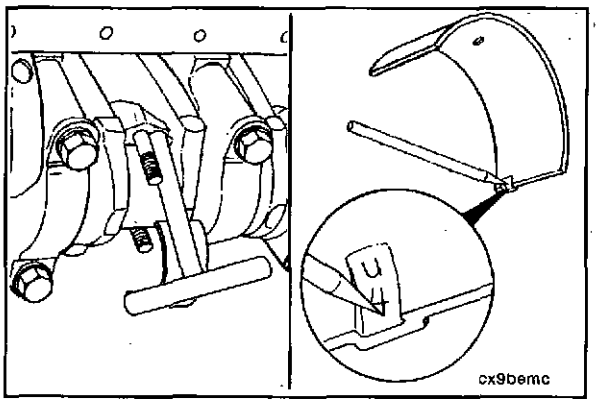
Remove the capscrew nuts and rod cap.

Remove the bearing shell from the rod cap, and mark it as the lower bearing shell from the connecting rod number from which it was removed.



Push the rod up far enough to allow the upper bearing shell to be removed.

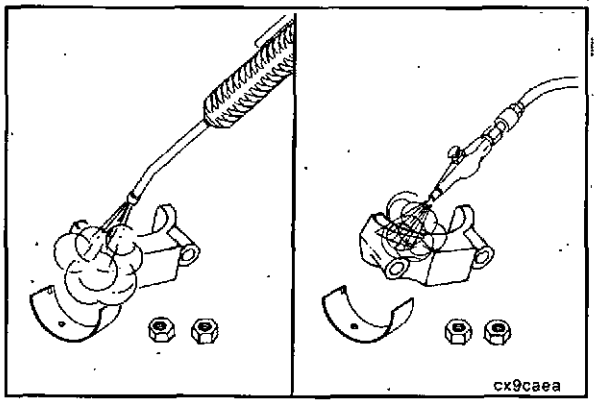
Remove the bearing shell, and mark it as the upper bearing shell from the connecting rod number from which it was removed.

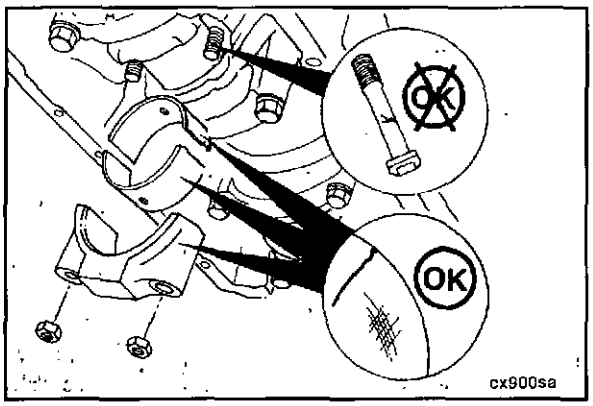


Cleaning and Inspection

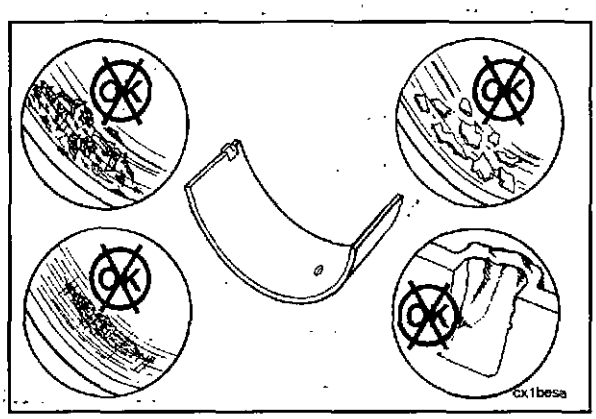
Warning: When using a steam cleaner, wear protective clothing and safety glasses or a face shield. Hot steam can cause serious personal injury.

NOTE: Refer to "Parts Reuse Guidlines", Bulletin No. 3810303, for information on bearing inspection.



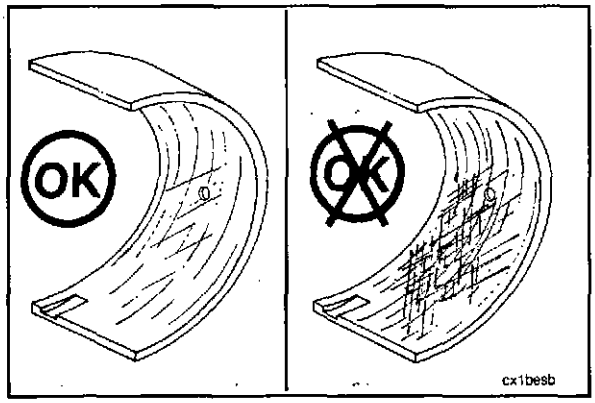


Visually inspect the rod caps, connecting rod bearing saddles, and capscrews for nicks, cracks, burrs, scratches, or fretting.

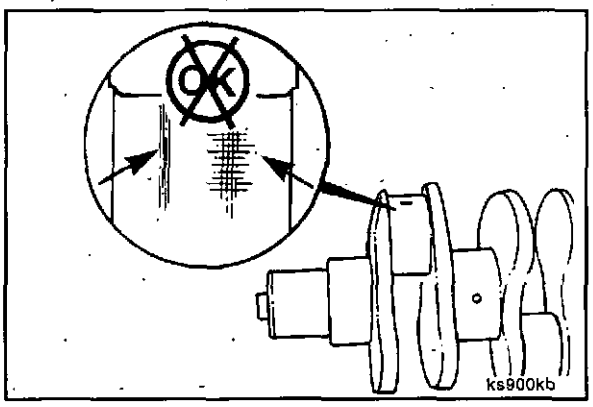


Visually inspect the bearings for damage.

NOTE: Replace any bearings with lock tang damage or scratches (deep enough to be felt with a fingernail). Also replace any bearings which show pitting, flaking, or corrosion into the lining.



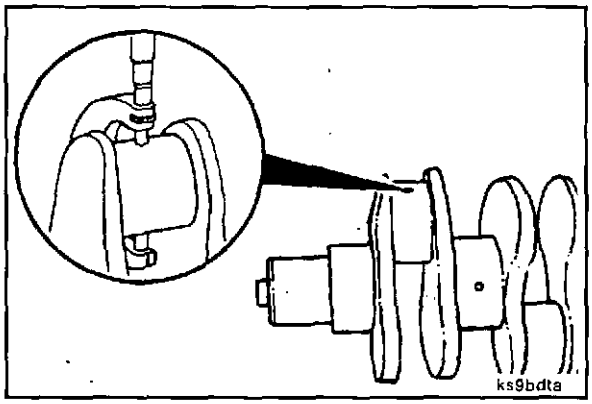
NOTE: Normal bearing wear produces a smooth finish which will wear into the lining. An exposed lining does **not** always indicate worn bearings. If large areas of the lining are visible in the bearings before the engine has accumulated 240,000 kilometers [150,000 miles] or 3,750 hours, inspect the engine for contamination from fine dirt particles and correct the problem.



Inspect the crankshaft rod journals for deep scoring or overheating.

Use a micrometer to measure the rod journal.

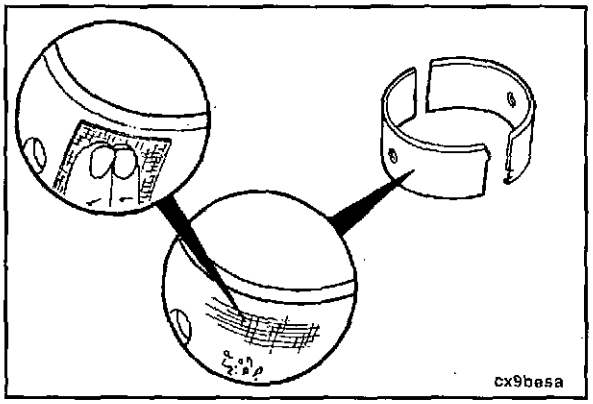
Connecting Rod Journal Dimensions (Minimum)		
mm		in
75.987	Standard	2.9916
75.737	Machined 0.25 mm	2.9818
75.487	Machined 0.50 mm	2.9719
75.237	Machined 0.75 mm	2.9621
74.987	Machined 1.00 mm	2.9522



Visually inspect the bearing shell seating surface for nicks or burrs.

If nicks or burrs cannot be removed with Scotch-Brite® 7448 or equivalent, the bearings must be replaced.

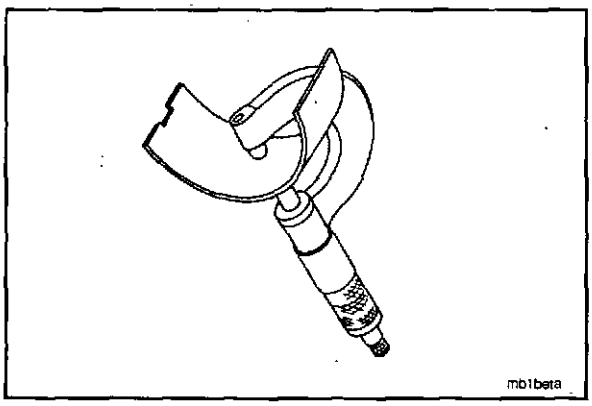
NOTE: For more detailed information of bearing damage, refer to "Analysis and Prevention of Bearing Failures," Bulletin No. 3810387.



Measure the rod bearing shell thickness with an outside micrometer that has a ball tip.

Standard Connecting Rod Bearing Thickness (Used)		
mm		in
2.43	MIN	0.0956
2.471	MAX	0.0973

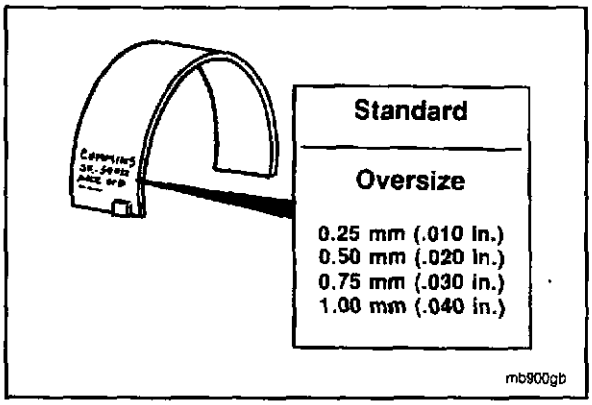
Discard a bearing shell if its thickness is below the minimum specification.

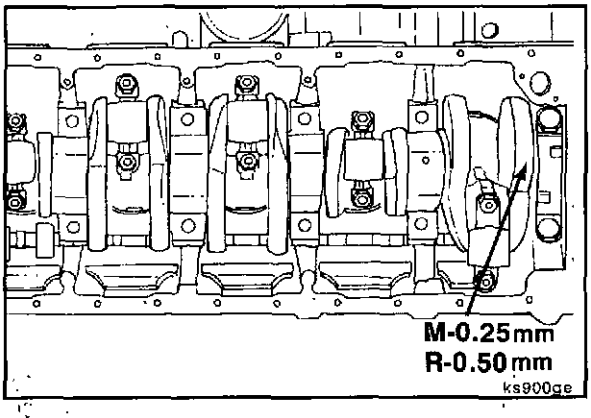


NOTE: Connecting rod bearings are identified with a part number and size stamped on the back side.

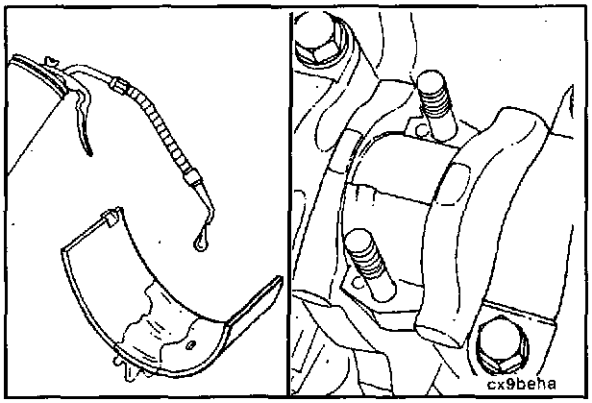
Determine the size of the removed rod bearing and obtain a set of the same size.

Oversize service rod bearings are available for use with crankshafts that have been machined undersize. Refer to the appropriate parts catalog.





Crankshafts which are machined undersize in the connecting rod or main bearing journals are marked on the front counterweight. If the crankshaft is marked, check the bearing shell part number to make sure the correct bearing size is used.

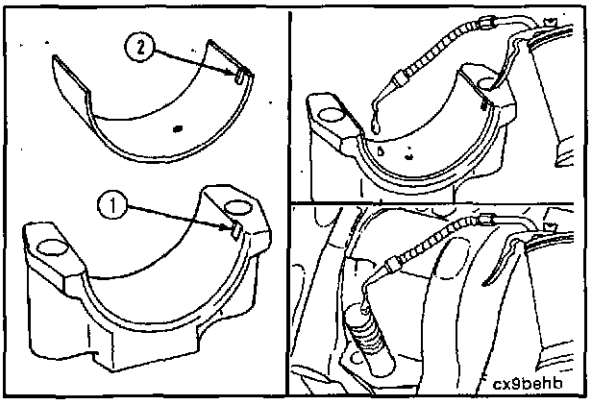


Installation

Caution: The connecting rod and bearing shell mating surfaces must be clean and dry when the bearing shells are installed. Used bearings must be installed in their original location.

Use clean Lubriplate® 105, or its equivalent, to lubricate the crankshaft journal mating surface of the upper bearing shell.

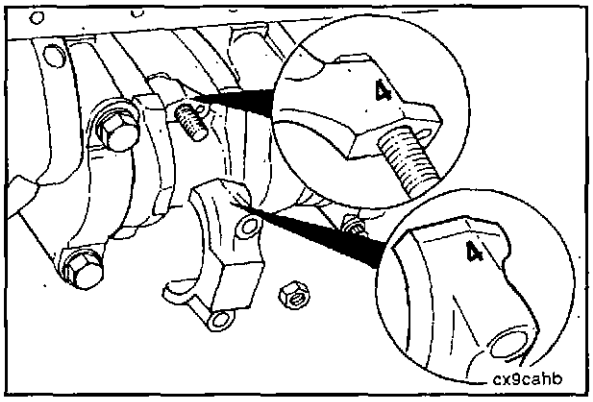
Install the upper bearing shell in the connecting rod with the tang of the bearing in the slot of the rod.



Install the bearing shell in the connecting rod cap with the tang (2) of the bearing in the slot (1) of the cap.

Use clean Lubriplate® 105, or its equivalent, to lubricate the bearing shell to crankshaft journal mating surface.

Use clean 15W-40 oil to lubricate the threads of the connecting rod capscrews.



Caution: The connecting rod cap number must match the number on the connecting rod and must be installed *with the numbers aligned to prevent damage to the connecting rods and the crankshaft.* The locking tang of the connecting rod cap must be toward the camshaft side of the cylinder block.

Lubricate under the connecting rod capscrew nuts with clean 15W-40 engine oil.

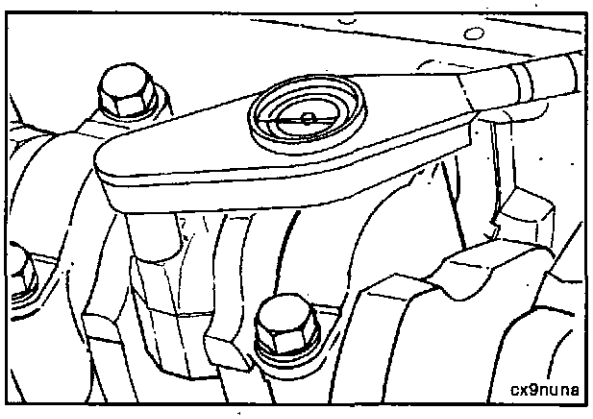
Install the connecting rod caps and rod capscrew nuts.

19 mm Socket, Torque Wrench

Tighten the connecting rod capscrew nuts in alternating sequence.

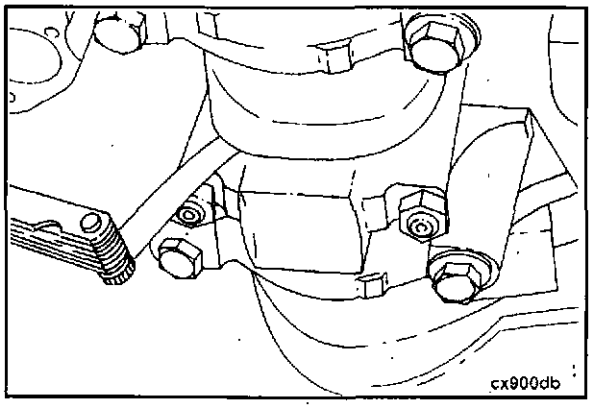
Torque Value:

Step 1 - 40 N•m [30 ft-lb]
Step 2 - 80 N•m [60 ft-lb]
Step 3 - 120 N•m [88 ft-lb]



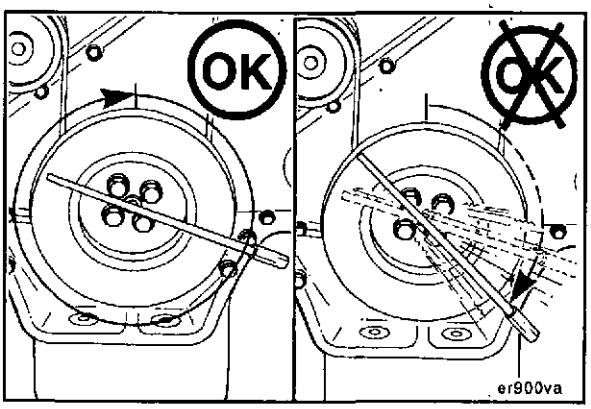
Measure the side clearance between the connecting rod and crankshaft.

Connecting Rod Side Clearance		
mm		in
0.10	MIN	0.004
0.33	MAX	0.013



NOTE: The crankshaft **must** rotate freely.

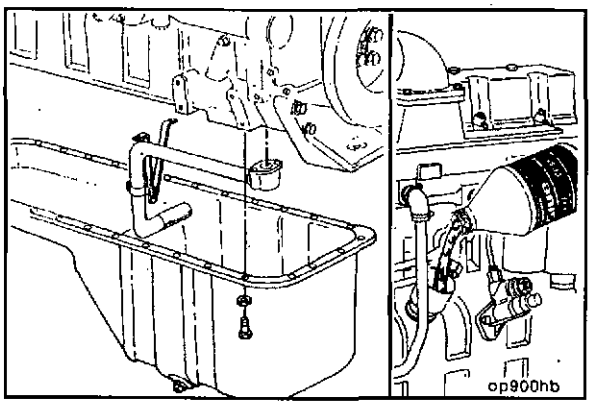
Check for freedom of rotation as the caps are installed. If the crankshaft does **not** rotate freely, check the installation of the rod bearings and the bearing size.

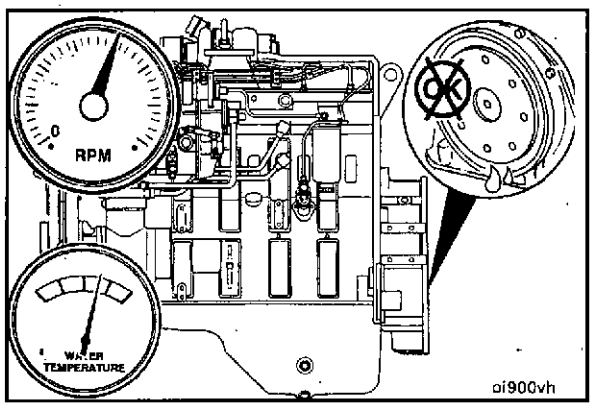


Install the oil suction tube. Refer to Procedure 2-13.

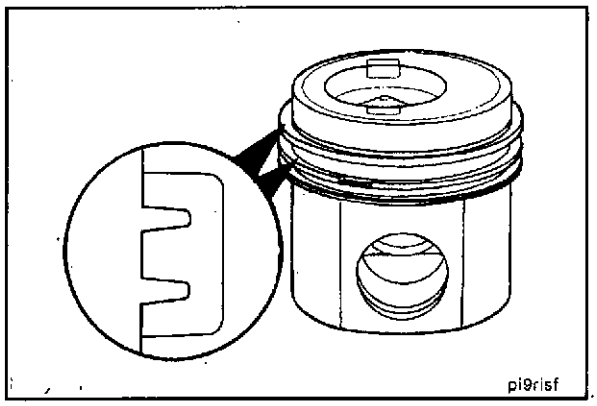
Install the lubricating oil pan. Refer to Procedure 2-13.

Fill the lubricating oil pan. Refer to Procedure 2-05.





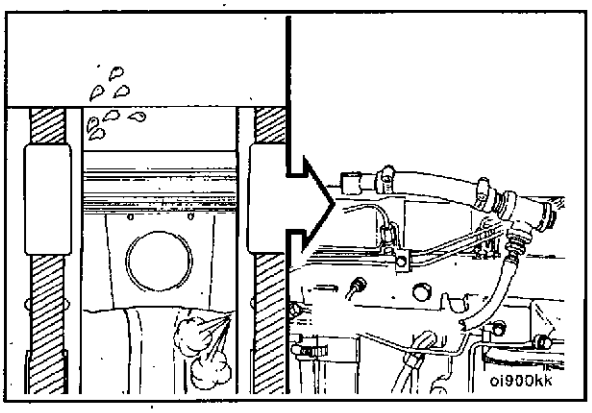
Operate the engine until the coolant temperature reaches 82°C [180°F] and check for leaks and proper operation.



Pistons and Rings - Replacement (7-13)

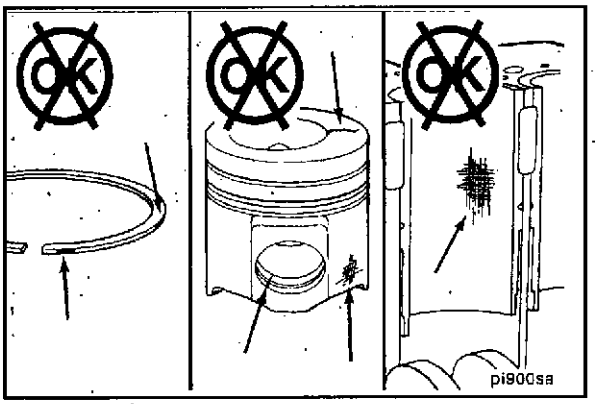
Piston - General Information

Design features include: Aluminum piston with dual Ni-resist ring insert: The top and intermediate ring grooves are of keystone design. The combustion bowl and piston top are hard anodized on certain higher rated horsepower engines. Always check the part number to be sure the correct configuration is used during piston replacement.



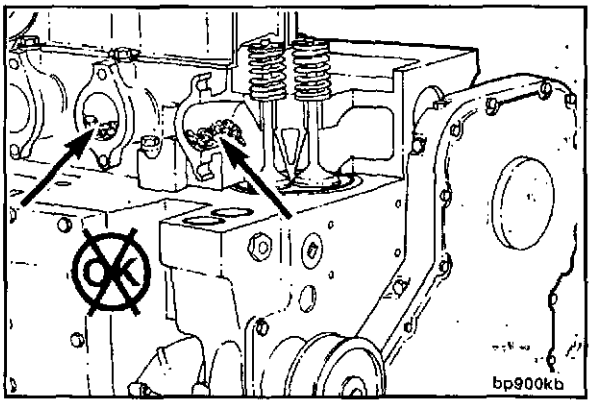
Piston and Rings - Diagnosing Malfunctions

There are a number of power related problems including excessive oil consumption, smoke, blowby and poor performance that can be caused by inadequate sealing between the piston rings and the cylinder liner walls. A blowby measurement can aid in detecting the problem, refer to Section 8.



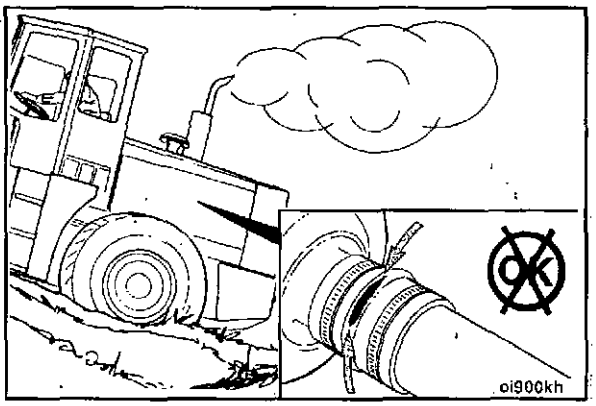
A loss of piston ring sealing may be detected during a compression check, refer to Procedure 7-01.

Visual inspection of the exhaust ports after removing the exhaust manifold can also confirm loss of sealing and excessive oil consumption.



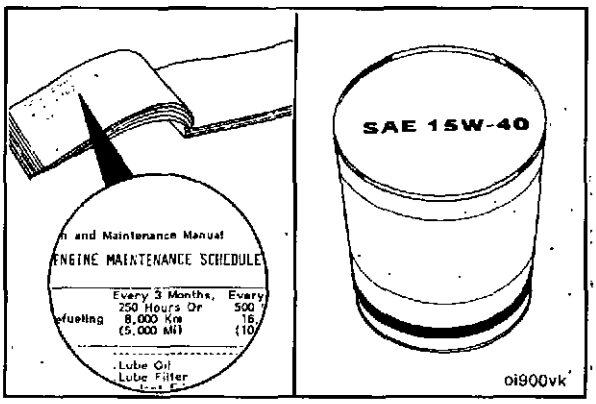
The cause of inadequate sealing between the cylinder wall and rings range from extreme abrasive wear "dust-out" in a short period of time because of poor maintenance of the air intake system to wear over a long period of service.

Refer to Section 3 for troubleshooting the combustion air system.



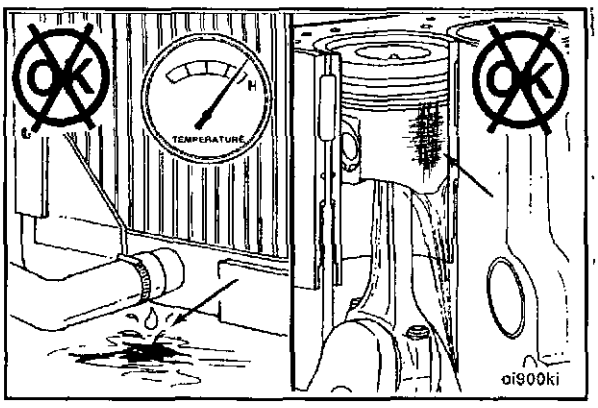
When troubleshooting for excessive oil consumption, remember oil viscosity can affect cylinder sealing.

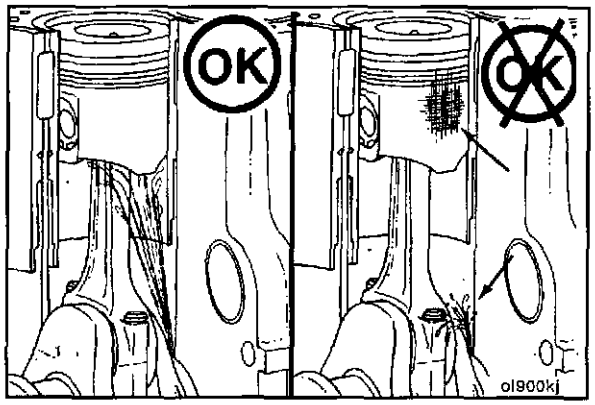
Make sure the correct oil change intervals are being followed and the specified grade of oil is being used, refer to the C Series Operation and Maintenance Manual.



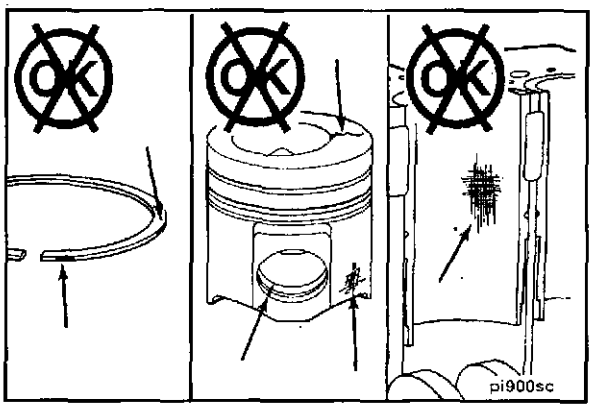
A sudden increase in oil consumption can indicate damage to the cylinder components.

Overheating of the engine from a loss of coolant will also cause the cylinder to overheat resulting in scuffing or seizure of the piston.



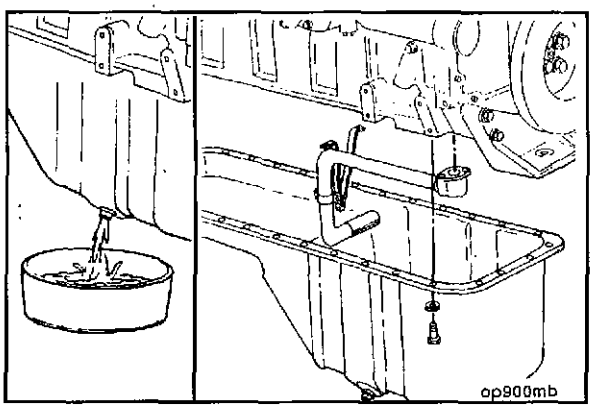


Loss of piston cooling can lead to piston scuffing or seizure.



Verification of the damaged or worn component requires visual and dimensional inspection of rings, pistons and cylinder liner bores.

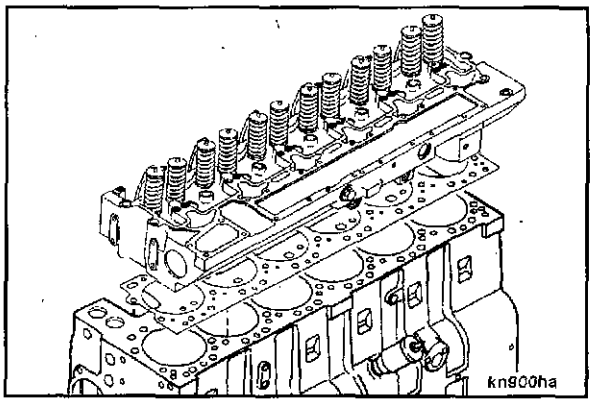
NOTE: If severe piston damage has occurred, check the turbocharger and other exhaust components for damage from debris.



Removal

Drain the lubricating oil. Refer to Procedure 2-04.

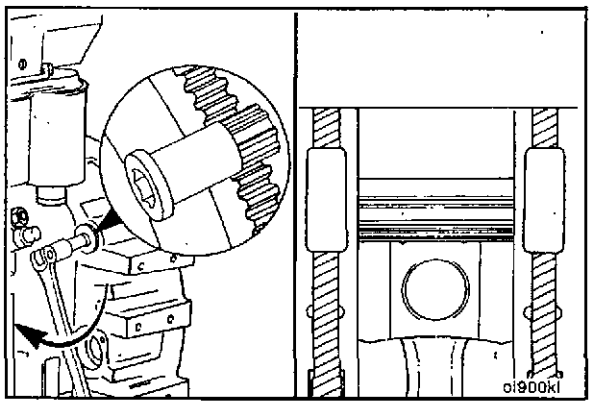
Remove the lubricating oil pan. Refer to Procedure 2-13.



Remove the cylinder head. Refer to Procedure 7-09.

Part No. 3377371, Engine Barring Gear

Rotate the crankshaft so the pistons are away from top dead center (TDC).

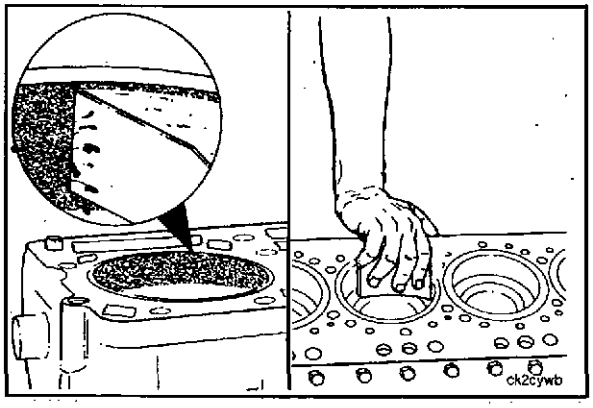


Caution: Do not use emery cloth or sandpaper to remove carbon from the cylinder liners. Aluminum oxide or silicon particles from emery cloth or sandpaper can cause serious engine damage. Do not use any abrasives in the ring travel area. The cylinder liner can be damaged.

Rotate the crankshaft and use a gasket scraper to remove the carbon ridge in each cylinder.

NOTE: Only scrape or sand above the piston travel area.

Use a fine fibrous abrasive pad such as Scotch-Brite® 7448, or equivalent, and solvent to remove the remaining carbon.



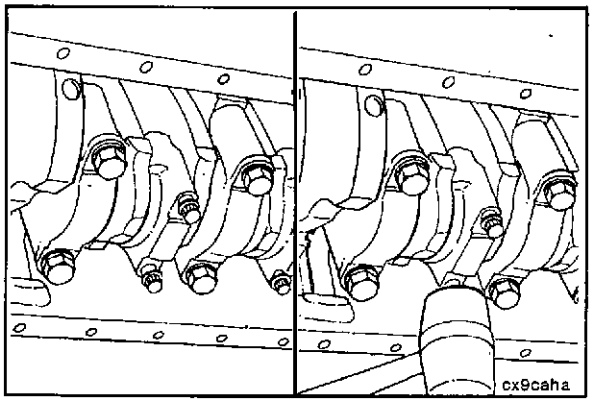
19 mm, Plastic Hammer

Rotate the crankshaft to position the rod caps at "BDC" for removal.

Loosen the connecting rod capscrew nuts.

NOTE: Do **not** remove the capscrews from the rods.

Use a plastic hammer to hit the connecting rod capscrews to loosen the caps.

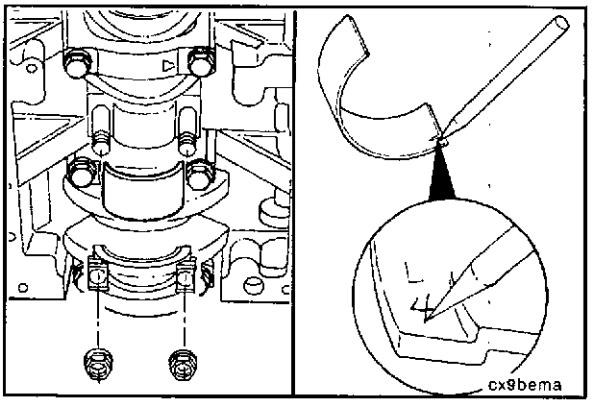


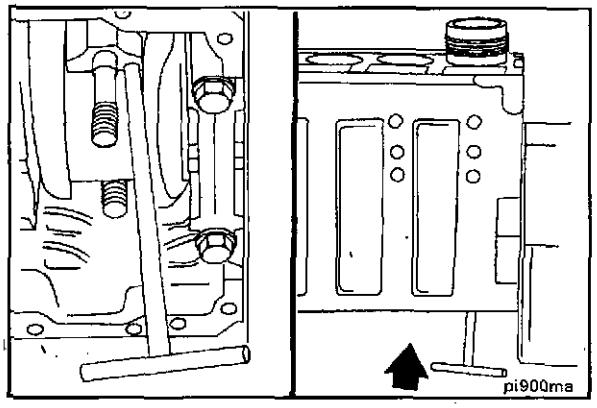
Remove the connecting rod capscrew nuts.

Remove the rod cap.

Remove the lower rod bearing.

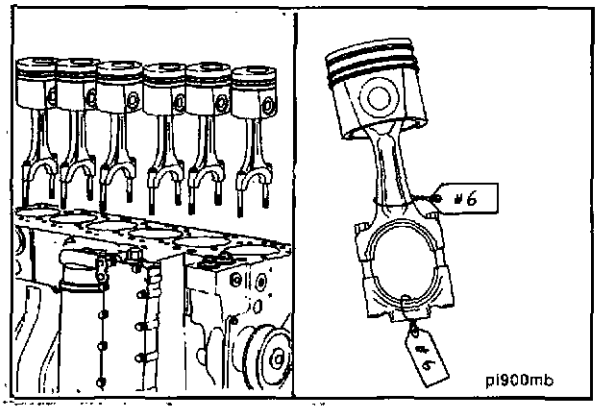
Mark the cylinder number and the letter "L" (lower) in the flat surface of the bearing tangs.





Use a "T-handle" piston pusher to push the rod away from the crankshaft.

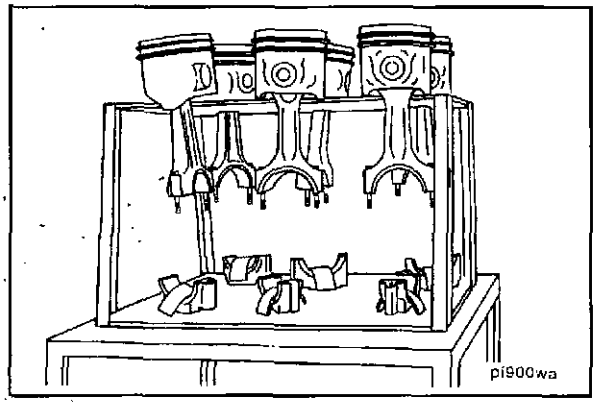
NOTE: Push the rod until the piston rings are outside of the top of the cylinder liner.



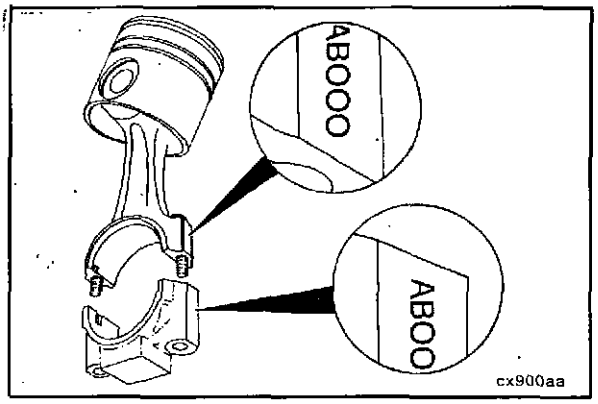
Use both hands to remove the piston and rod assembly.

NOTE: The piston and connecting rod assemblies **must** be installed in the same cylinder number they were removed from to be sure proper fit of worn mating surfaces if parts are used again.

Use a tag to mark the cylinder number each piston and rod assembly was removed from.



Place the rod and piston assemblies into a container to protect them from damage.

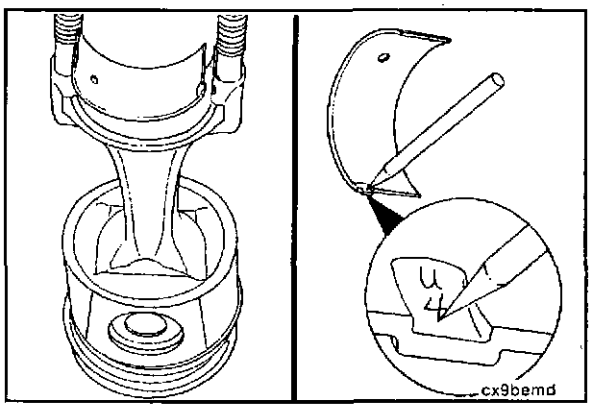


NOTE: *Unique serial numbers (not cylinder numbers) are* stamped on the connecting rod and matching cap.

When the rods and caps are installed in the engine, the numbers on the rods and caps **must** match and be in*stalled on the same side of the engine.*

Remove the upper rod bearing.

Mark the cylinder number and the letter "U" (upper) in the flat surface of the bearing tang.

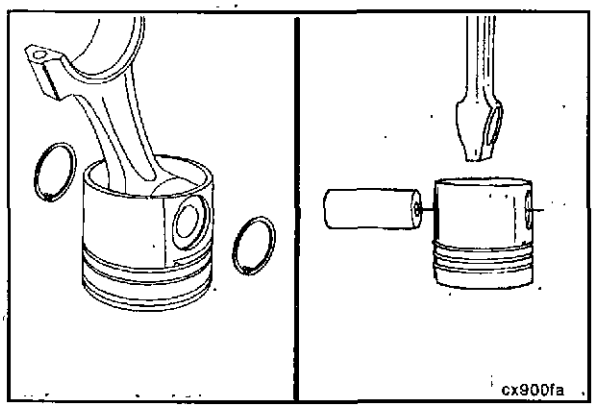


Piston and Rod Disassembly

Use internal snap ring pliers to remove the retaining rings from both sides of the piston.

Remove the piston pin.

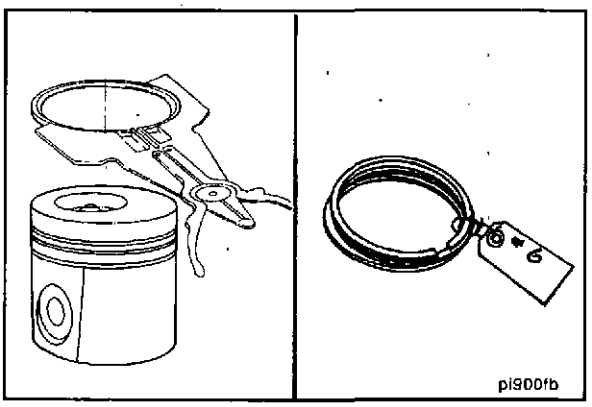
NOTE: Heating the piston is **not** required.



Part No. 3823137, Piston Ring Expander

Remove the piston rings.

Place a tag on the rings and record the cylinder number of the piston on the tag.

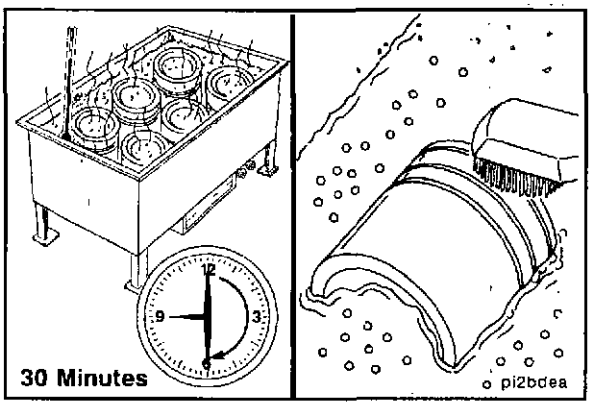


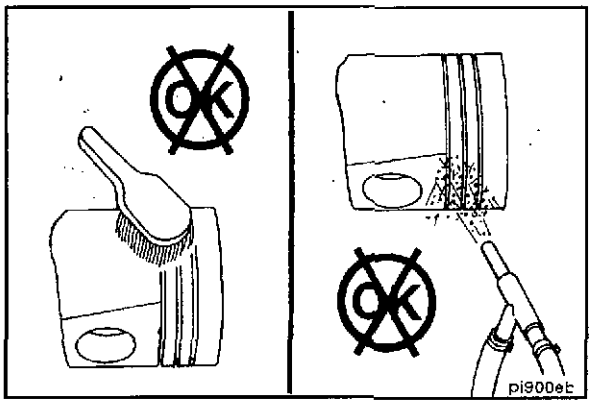
Cleaning and Inspection

Caution: Be sure the cleaning solvent is approved for aluminum. Damage to the pistons can result.

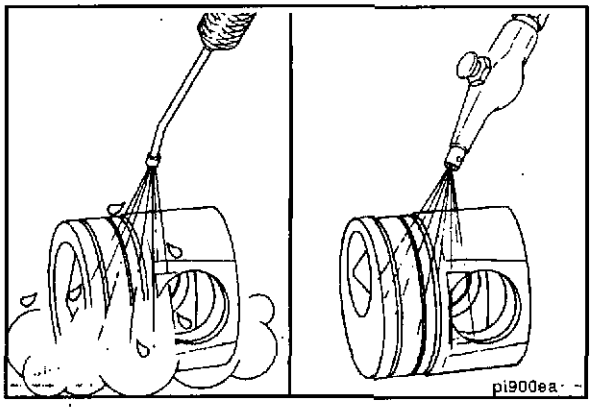
Allow the pistons to soak for a minimum of 30 minutes in a tank containing an approved cleaning solvent for aluminum.

Use a hot, soapy solution and a non-metallic brush to remove carbon deposits.





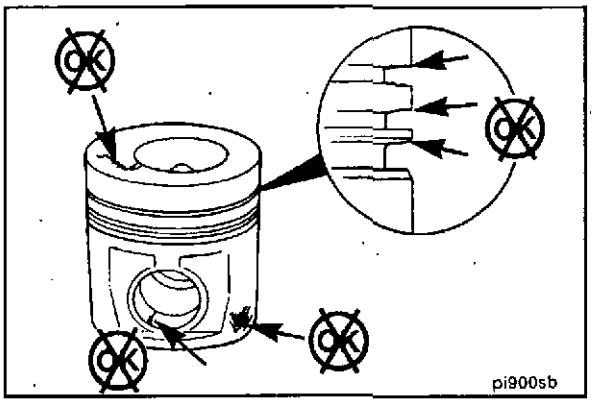
Caution: Do not use a metal brush. A metal brush will damage the piston ring grooves. Do not use glass beads, walnut shell or plastic bead blasting to clean the piston ring grooves or pin bores. This can cause the pin bore to crack or the rings to not seat.



Warning: When using a steam cleaner, wear protective clothing and safety glasses or a face shield. Hot steam can cause serious personal injury.

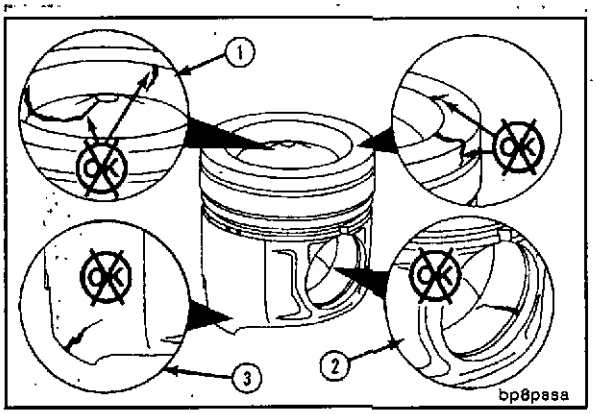
Use steam to clean the pistons.

Dry with compressed air.



Inspect the piston for damage and excessive wear. Check the top ring grooves, skirt and pin bore.

NOTE: Dimensional inspection of the piston is required only when the cause of the lack of sealing is not apparent.



Visually inspect the piston bowl (1), pin bore (2) and skirt (3) for cracks or damage.

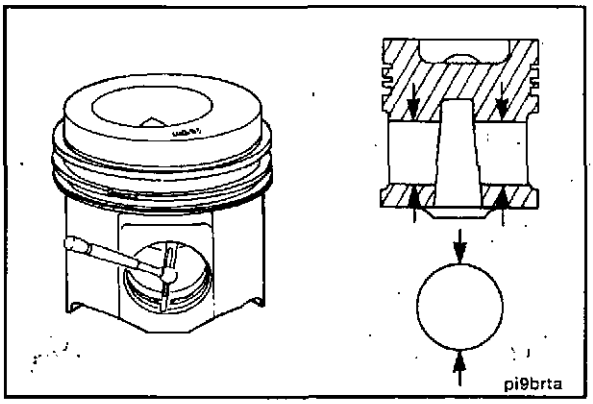
NOTE: Do **not** use pistons with cracks.

Measure the piston pin bore when the piston temperature is at 20°C [68°F].

Piston Pin Bore I.D.		
mm		in
45.006	MIN	1.7719
45.025	MAX	1.7726

NOTE: Add 0.013 mm [0.0005-inch] to the bore inside diameter per 5°C [10°F] temperature rise up to 32°C [90°F].

The pin bore should be checked closer to the O.D. of the piston since the pin bore is tapered.

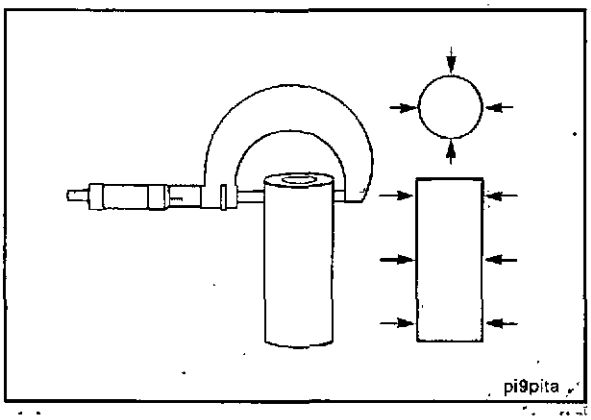


Visually inspect the piston pin for scratches, grooves, or other damage.

Measure the piston pin outside diameter.

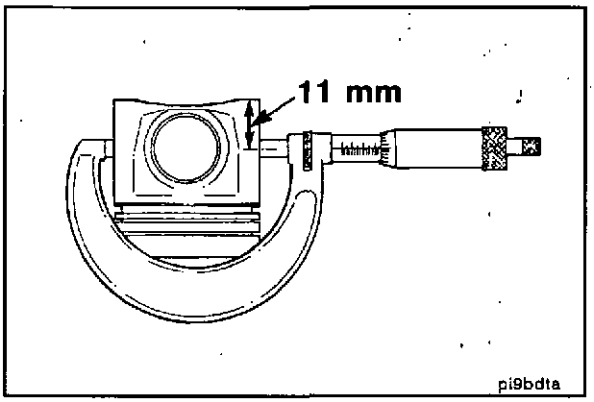
Piston Pin O.D.		
mm		in
44.993	MIN	1.7714
45.003	MAX	1.7718

NOTE: Discard the piston pin if it is more than 0.03 mm [0.001-inch] out of round.



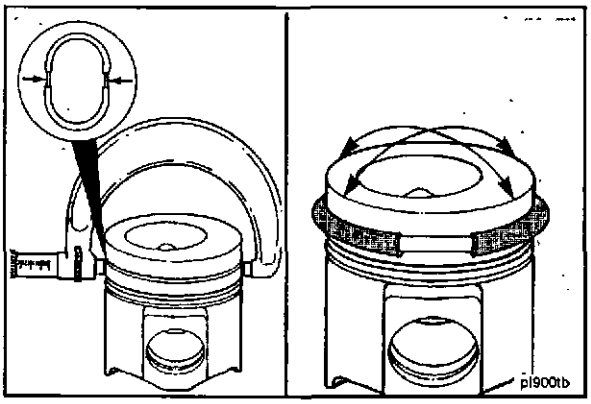
Measure the piston skirt diameter as illustrated.

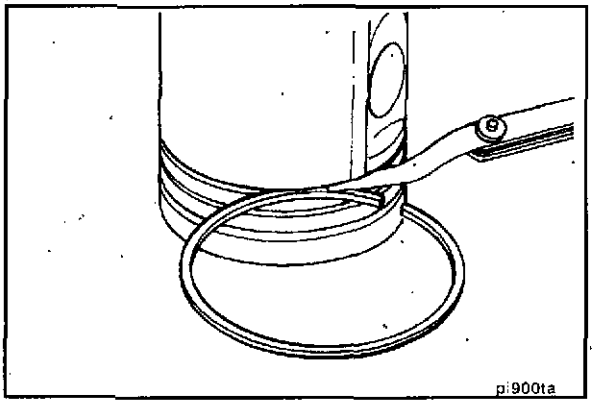
Piston Skirt O.D.		
mm		in
113.808	MIN	4.4806
113.879	MAX	4.4834



Use a micrometer and Part No. 3823966, piston ring groove gauge, to measure the wear of the top ring groove keystone angle. Use Part No. 3823965, piston ring groove gauge, to measure the wear of the intermediate ring groove keystone angle.

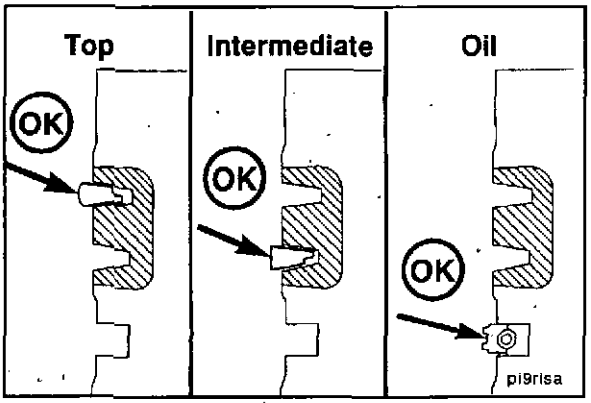
Piston Ring Groove (Keystone Angle)			
Ring	mm		in
Top:	113.938	MIN	4.4857
Intermediate:	114.323	MIN	4.5009





Use a new piston ring and feeler gauge to measure the side clearance of the rectangular intermediate and oil control ring grooves.

Piston Ring Clearance (Rectangular Groove)			
Ring	mm		in
Intermediate:	0.070	MIN	0.0028
	0.150	MAX	0.006
Oil Control:	0.020	MIN	0.0008
	0.130	MAX	0.0051



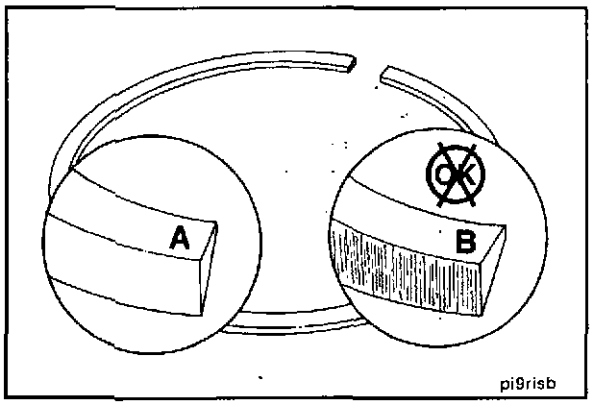
Piston Ring - Inspection

Check the cylinder liners for wear, for those cylinders with *no obvious damage, check the following conditions which* can cause loss of sealing:

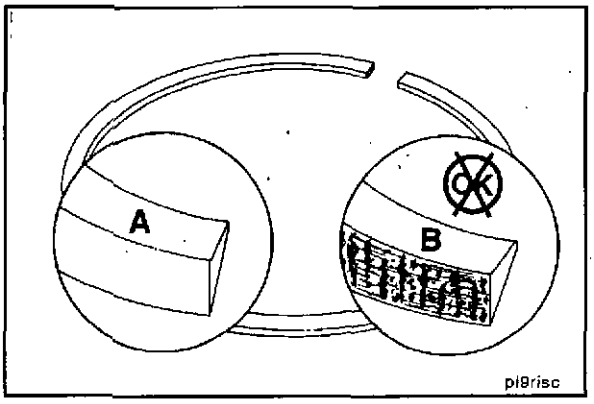
- Rings installed incorrectly

NOTE: There are two different design intermediate rings used (A) rectangular (B) "reverse twist."

Refer to piston ring installation in this section.



- Worn condition
- Abrasive wear is indicated by the concentrated vertical scratches. (B). The chromium plate is worn through and the face of the ring has a brighter finish compared to the dull satin finish of a new ring (A).
- This type of wear can be caused by ingested abrasive material. Inadequate cleaning during a previous repair or particles embedded in the liner can cause the condition.



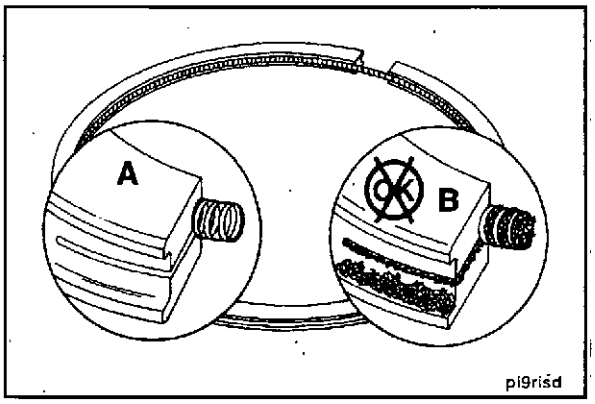
Scuffing and scoring is indicated by the heavy scratches, metal discoloration and voids (B).

This damage indicates a break down of the oil film on the liner wall causing transfer of material from the ring face to the liner. The condition can be caused by:

- Engine overheating
- Oil dilution or improper maintenance of the lubrication system
- Piston cooling nozzle malfunction

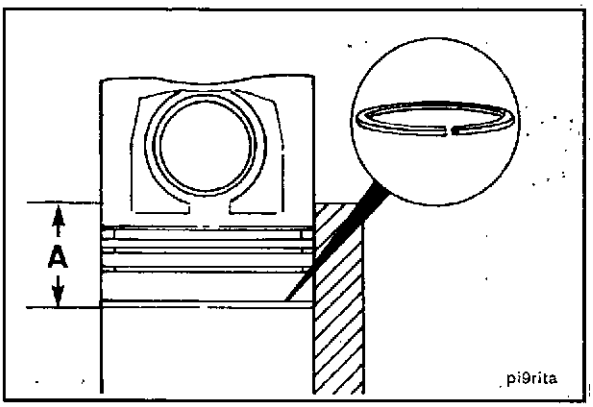
Oil ring plugging is indicated by the deposits in the oil ring grooves (B). Plugging of the ring drains restricts oil drain back which floods the ring belt area resulting in a loss of oil control. The conditon can be caused by:

- Low engine operating temperatures - long periods of idling or a cooling system malfunction
- Extended oil change intervals, the wrong grade of oil or poor quality oil



To check the piston ring gap, use the top end of a piston to align the piston rings in the wear area of the cylinder liner in which they will be used.

A = 89 mm [3.5 inches]

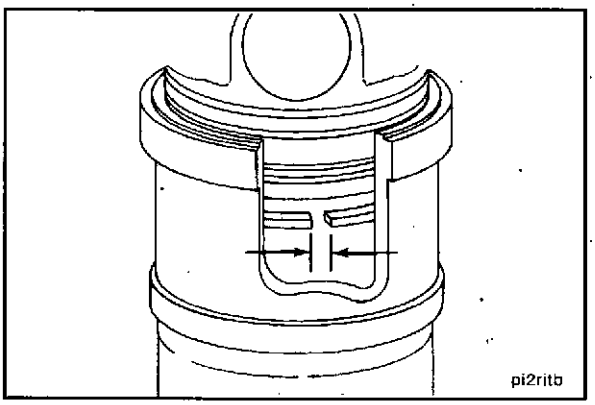


Use a feeler gauge to measure the piston ring end gap. Replace the ring if it does **not** meet the following specifications:

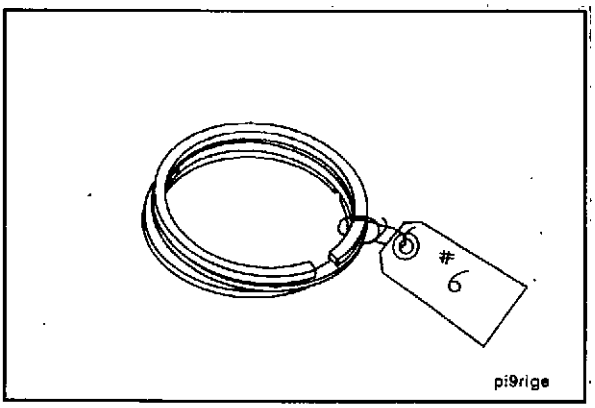
New Piston Ring End Gap

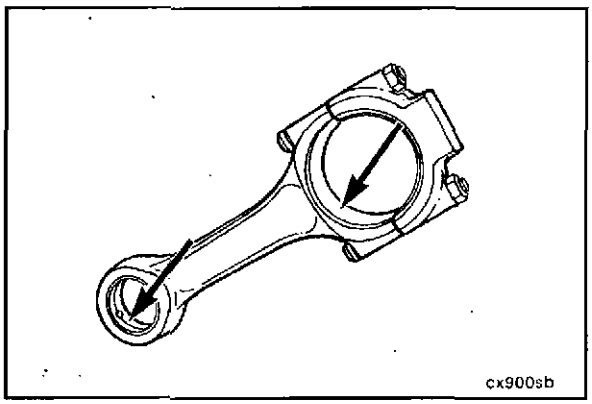
	mm		in
Top:	0.40	MIN	0.016
	0.70	MAX	0.028
Intermediate:	0.40	MIN	0.016
	0.70	MAX	0.028
Oil Control:	0.30	MIN	0.012
	0.60	MAX	0.024

NOTE: Add 0.09 mm [0.004 in] for every 0.03 mm [0.001 in] of bore wear up to the maximum worn limit.

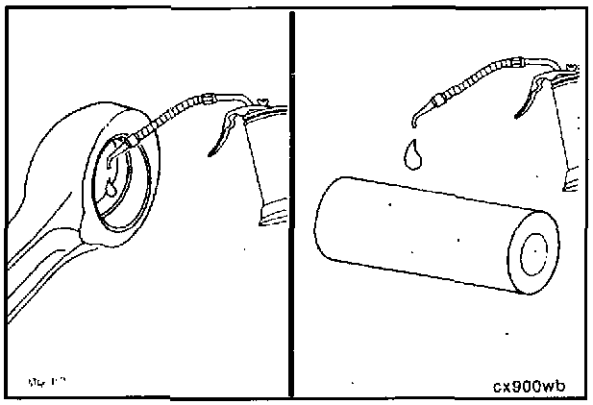


Identify the ring sets for installation in the cylinder in which the end gap was measured.





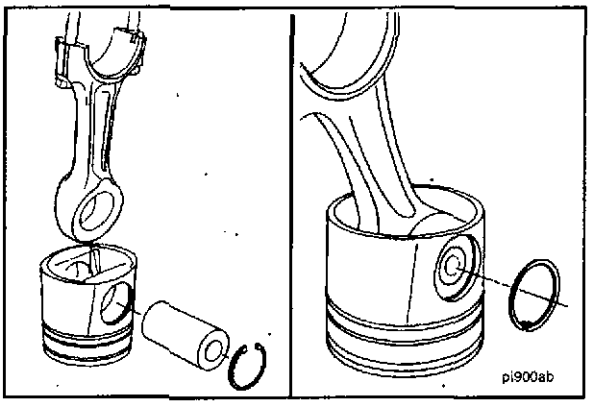
Inspect the connecting rod pin bushing bore and the crankshaft bore. Refer to Procedure 7-14.



Installation

Piston Pin Installation

Use clean 15W-40 oil to coat the connecting rod piston pin bore and the piston pin.

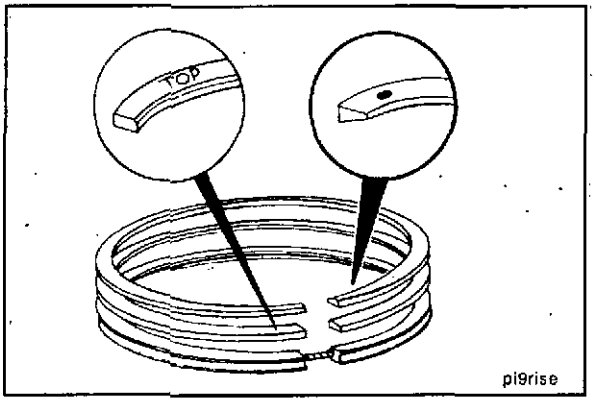


NOTE: The retaining ring must be seated completely in the piston groove to prevent engine damage during engine operation.

Install a new retaining ring into the piston pin bore.

Align the pin bore of the rod with the pin bore of the piston and install the piston pin.

NOTE: Be sure that the word "Front" marked on top of the piston and the numbers on the connecting rod and cap are properly oriented.

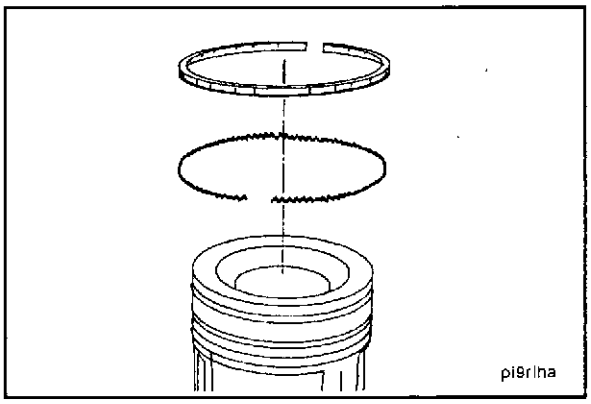


Piston Ring Installation

The top surface of the upper two rings are identified: Assemble with the word "TOP" or the supplier mark up.

The bottom or oil control ring can be installed with either side up.

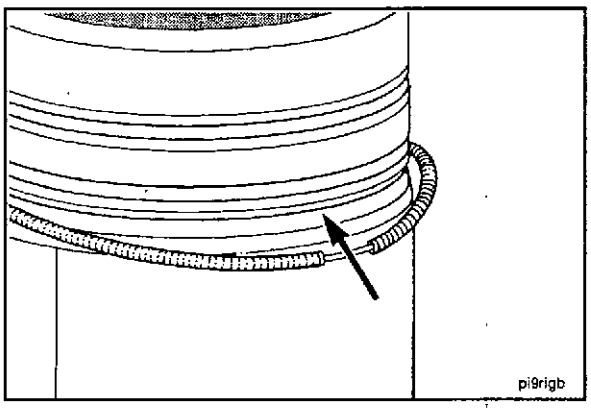
NOTE: The two-piece oil control ring **must** be installed with the expander ring gap 180 degrees from the gap of the oil ring. Do **not** overlap the ends of the expander ring.



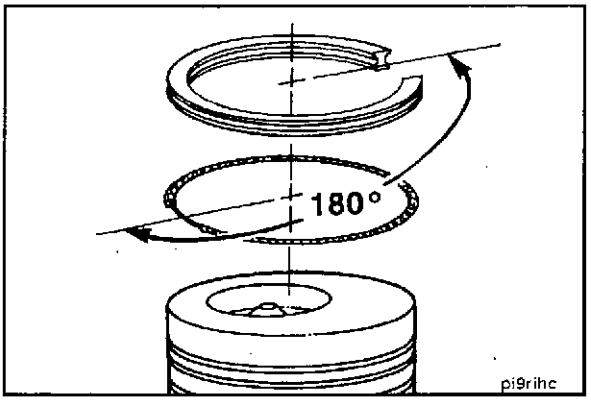
Part No. 3823137, Piston Ring Expander

Install the rings on the piston.

Position the oil ring expander in the oil control ring groove.

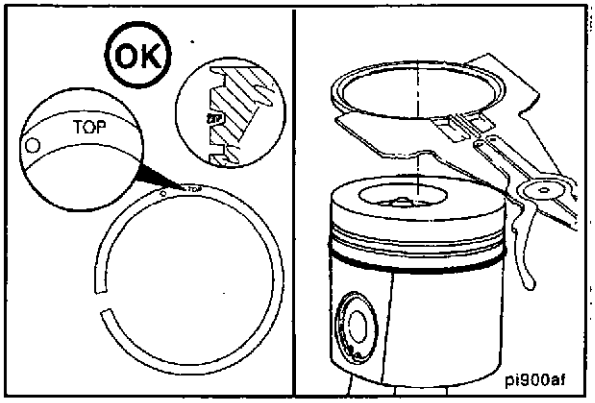


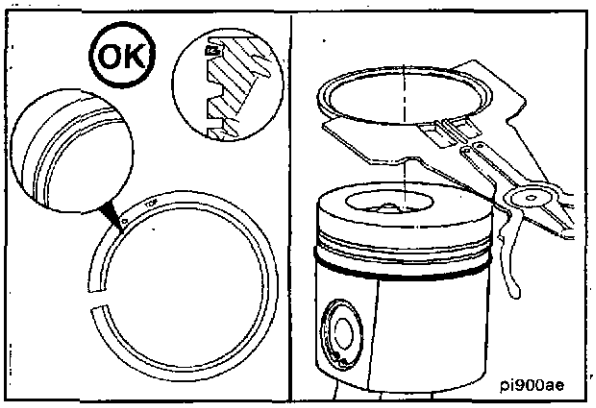
Install the oil control ring with the end gap opposite the ends on the expander.



Install the intermediate ring.

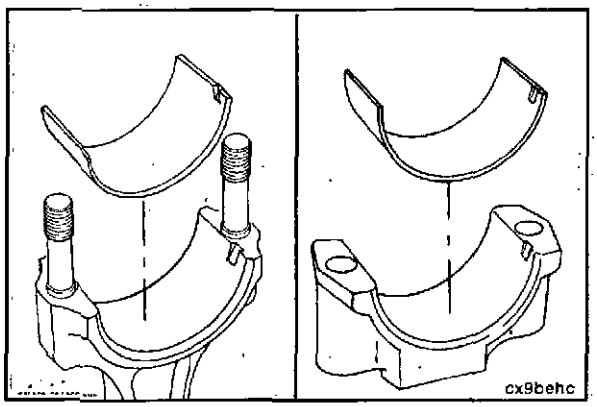
NOTE: The intermediate ring must be installed with the cutback notch to the bottom of the piston. The word "TOP" or the "0" stamp will be on the side opposite the cutback notch.





Install the top ring.

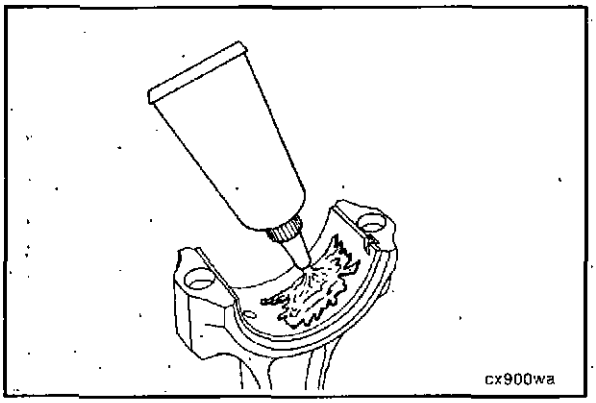
NOTE: The top ring must be installed with the cutback notch to the top of the piston. The word "TOP" or the "0" stamp will be on the same side of the ring as the cutback notch.



Install the bearing shells into both the rod and the cap. Make sure the tang on the bearing shell is in the slot of the cap and rod.

Bearings are marked on the back to indicate either *standard (std.) or oversize (OS).*

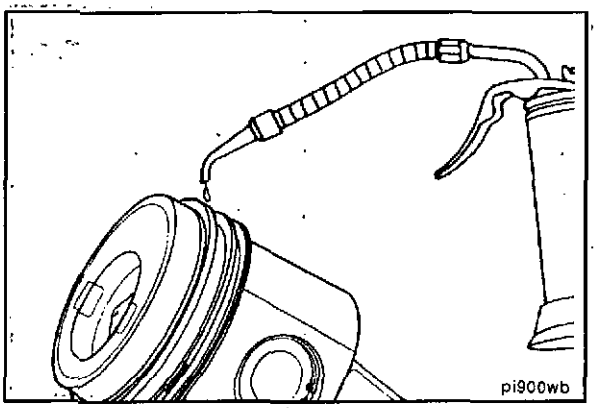
NOTE: If used bearing shells are to be installed, each bearing shell **must** be installed in its original location.



Caution: Prevent dirt from mixing with the lubricant. Dirty lubricant will accelerate bearing wear.

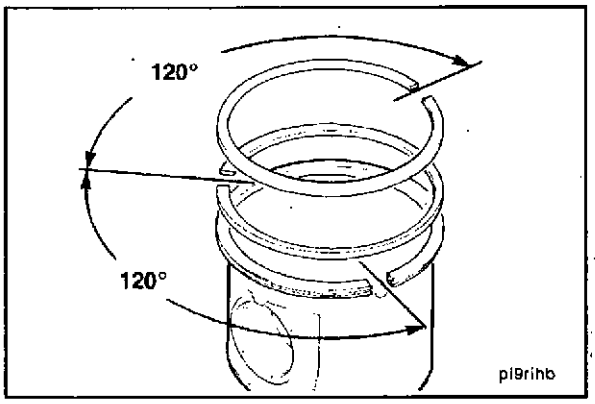
Lubricate the rod bearings with a light film of Lubriplate 105™.

NOTE: Do **not** lubricate the back of the bearing.



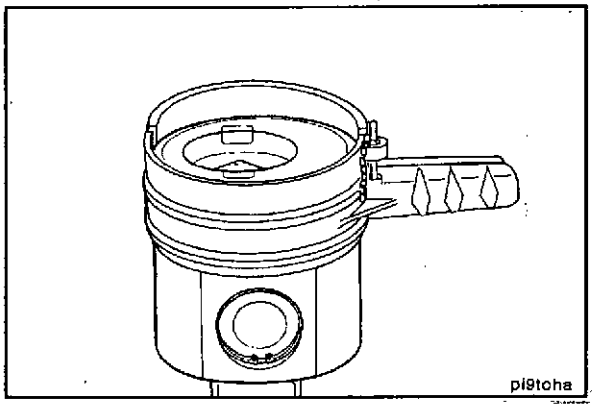
Lubricate the rings and piston skirts with clean engine oil.

Position the rings.

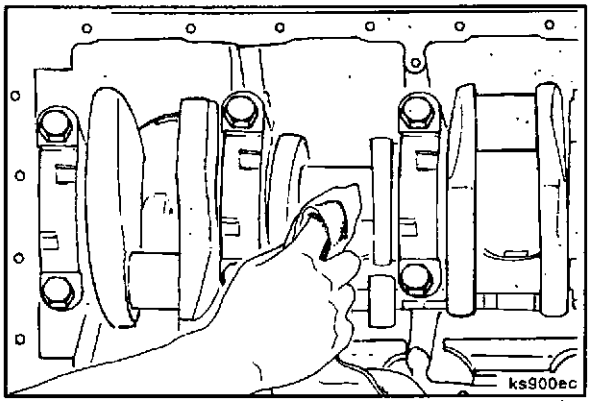


Part No. 3823290, Piston Ring Compressor

Compress the rings.

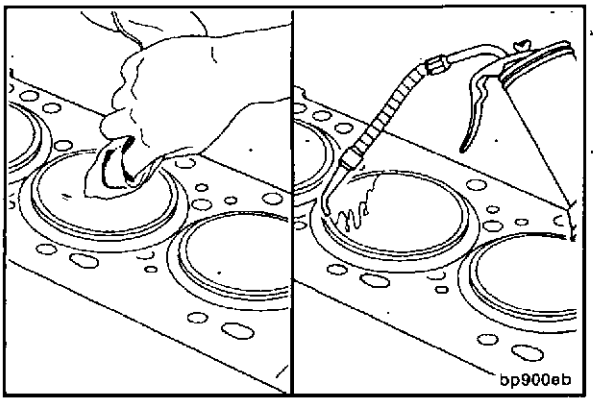


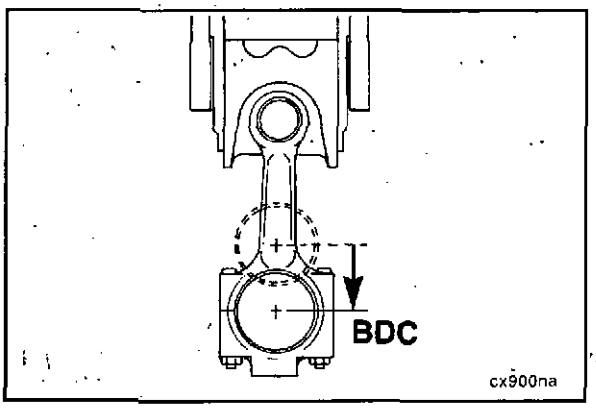
Use a clean lint-free cloth to clean the crankshaft bearing journals.



Use a clean lint-free cloth to wipe the cylinder bores.

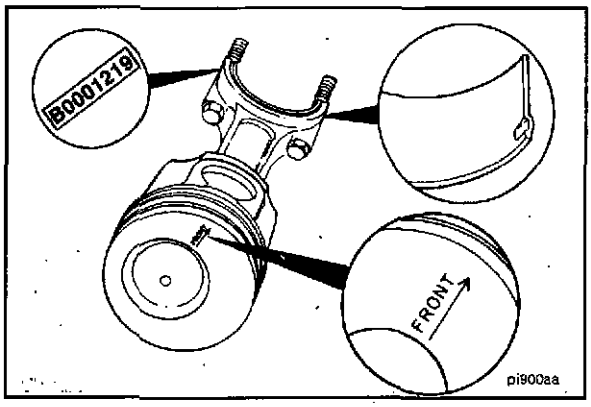
Lubricate the cylinder bore with clean engine oil.



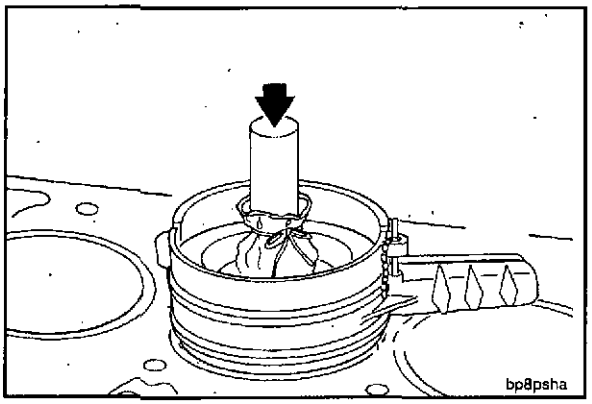


Part No. 3377371, Engine Barring Gear

Rotate the crankshaft to position the journal for the connecting rod at bottom dead center (BDC).



Caution: Be sure "Front" marking on the piston and the numbers on the rod and cap are oriented as illustrated.

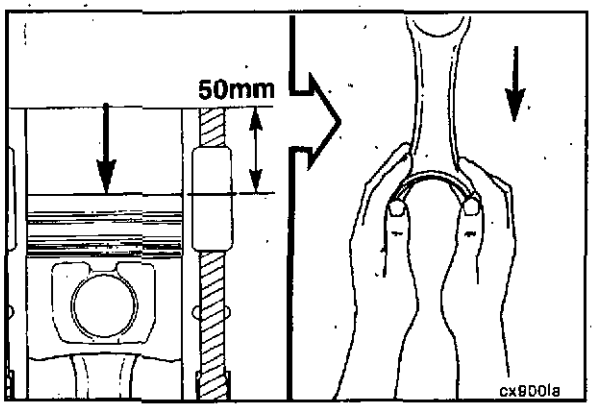


Caution: Use care when installing the piston and connecting rod so the cylinder bore is not damaged.

Position the piston and rod assembly into the cylinder bore with the word "front" on the piston toward the front of the cylinder block.

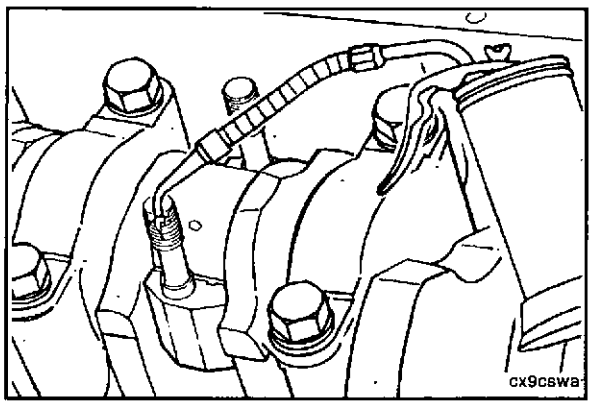
Hold the ring compressor against the cylinder liner. Push the piston through the ring compressor and into the cylinder liner.

NOTE: If the piston does **not** move freely, remove the piston and inspect for broken or damaged rings.



Push the piston into the bore until the top of the piston is approximately 50 mm [2 inches] below the top of the bore, pull the connecting rod onto the crankshaft journal.

Use clean engine oil to lubricate the threads of the connecting rod capscrews.

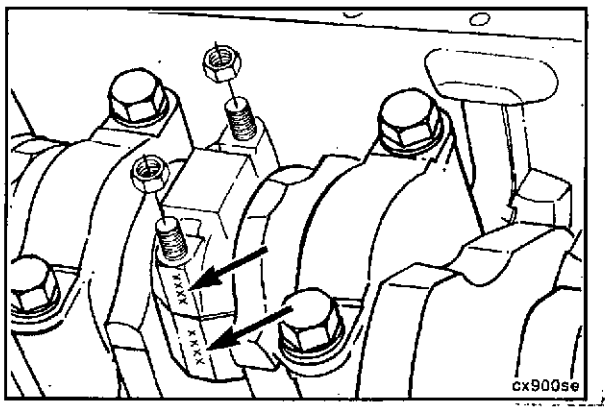


NOTE: The numbers marked on the connecting rod and the cap **must** be the same. The tang slot side of the cap **must** be on the same side as the tang slot in the connecting rod when the cap is installed.

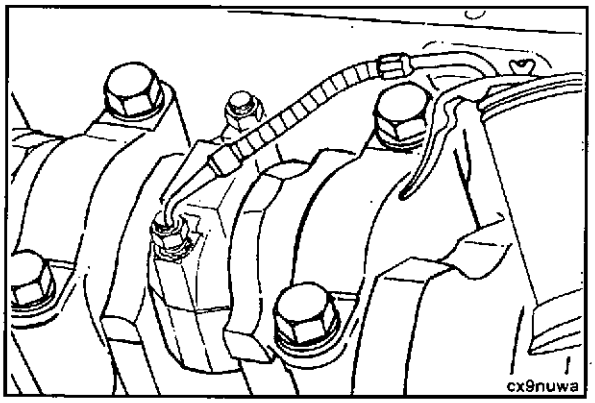
Install the bearing in the connecting rod cap.

Install the rod cap and start the connecting rod nuts.

Use Lubriplate® 105, or equivalent, to coat the inside diameter of the bearing shell.

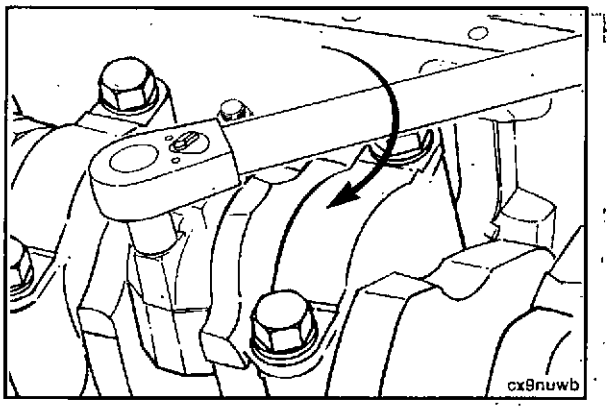


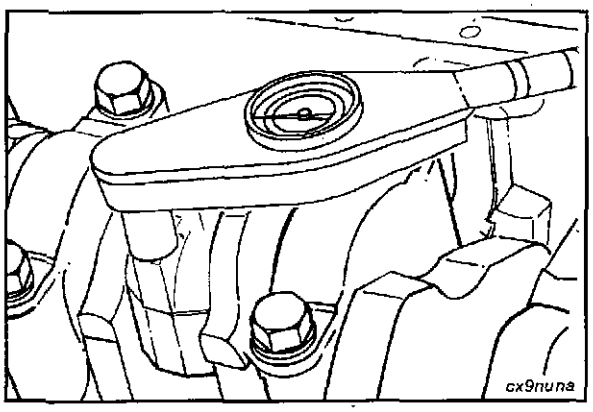
Use clean 15W-40 oil to lubricate the connecting rod nuts.



19 mm

Alternately tighten the rod nuts to pull the rod cap into position.



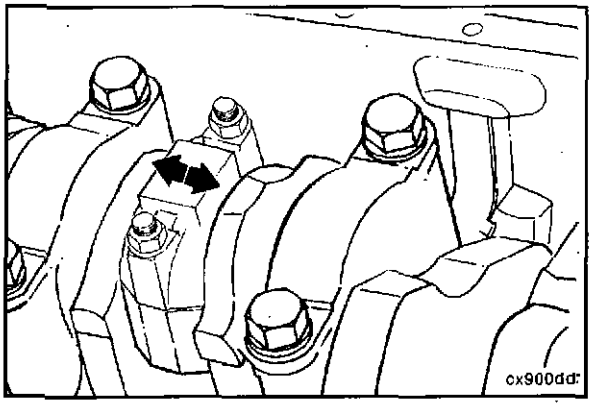


19 mm Socket, Torque Wrench

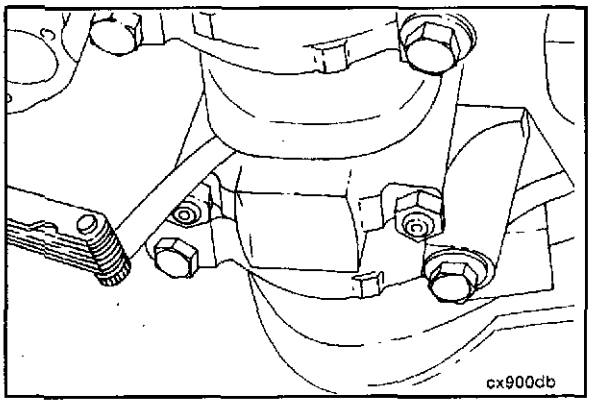
Tighten the connecting rod cap to the connecting rod evenly.

Torque Value:

Step 1 - 40 N•m [30 ft-lb]
Step 2 - 80 N•m [60 ft-lb]
Step 3 - 120 N•m [88 ft-lb]

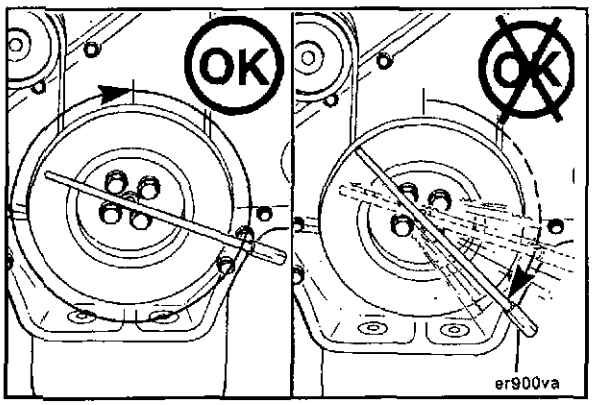


Shake the connecting rod after tightening to verify side clearance.



Measure the side clearance between the connecting rod and crankshaft.

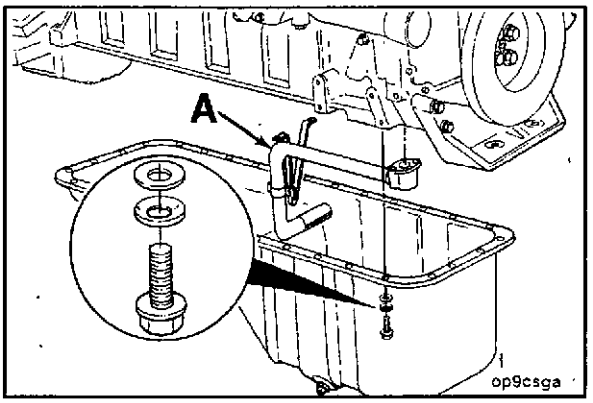
Connecting Rod Side Clearance		
mm		in
0.10	MIN	0.004
0.33	MAX	0.013



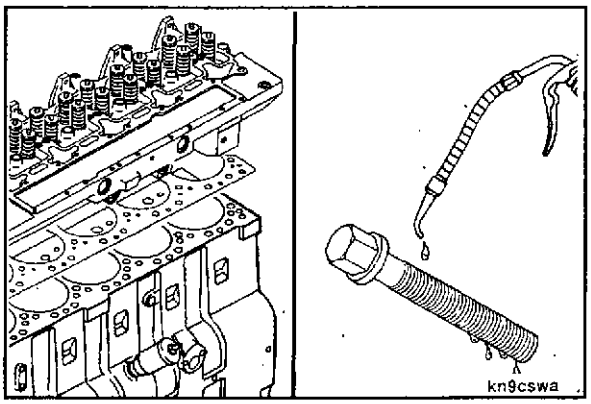
NOTE: The crankshaft **must** rotate freely.

Check for freedom of rotation as the caps are installed. If the crankshaft does **not** rotate freely, check the installation of the rod bearings and the bearing size.

Install the suction tube (A) and oil pan. Refer to Procedure 2-13.

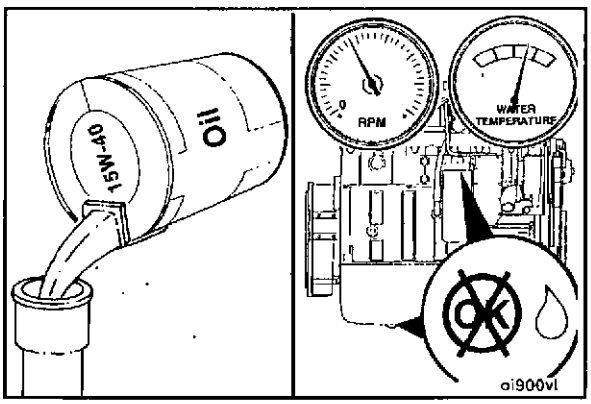


Install the cylinder head. Refer to Procedure 7-09.



Fill the lubricating oil pan. Refer to Procedure 2-05.

Operate the engine until the coolant temperature reaches 82°C [180°F] and check for leaks and proper operation.

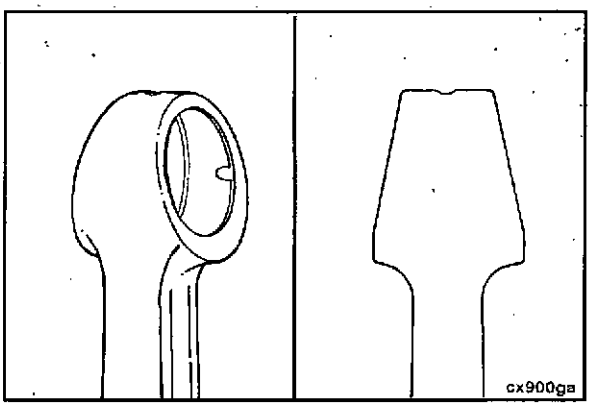


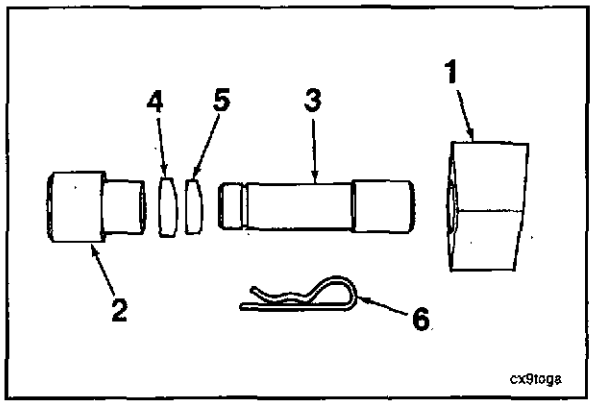
Connecting Rods - Replacement (7-14)

General Information

The piston pin end of the connecting rod is angle cut to provide additional bearing surface. The piston pin bore in the rod is fitted with a bronze bushing.

Service replacement rod bushings are available. Refer to the appropriate parts catalog for part numbers.

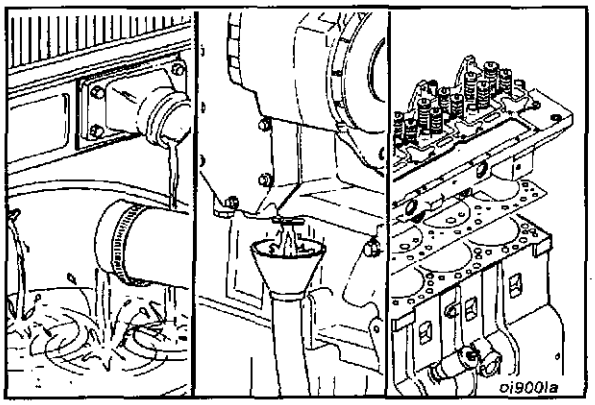




Part No. 3823690, Connecting Rod Pin Bore Bushing Removal/Installation Tool

This tool is used to remove and install the bushings to the correct position.

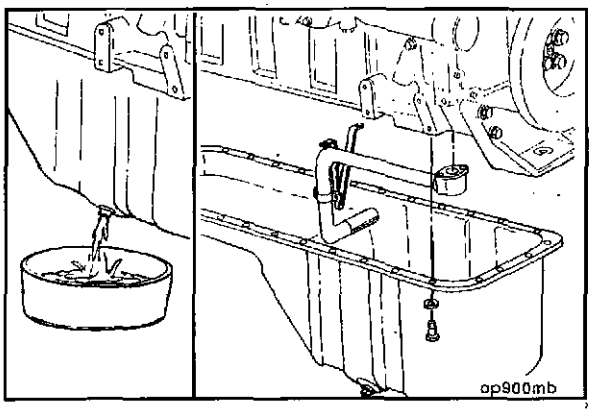
Ref. No.	Part No.	Description	Qty
1	3823691	Anvil	1
2	3823693	Cup	1
3	3823692	Mandrel	1
4	3823694	Driver Ring	1
5	3823695	Knock-out-ring	1
6		Hitch Pin	1



Removal

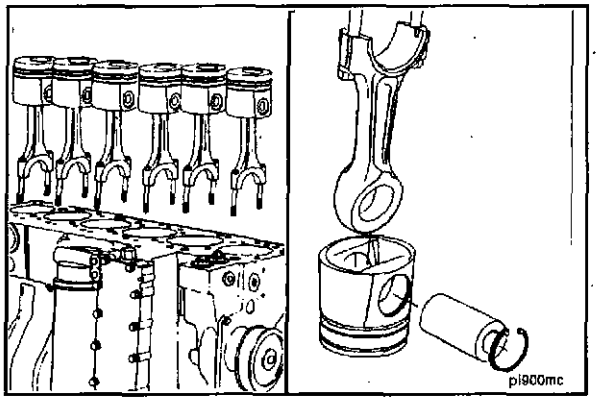
Drain the coolant. Refer to Procedure 1-01.

Remove the cylinder head. Refer to Procedure 7-09.



Drain the lubricating oil. Refer to Procedure 2-04.

Remove the lubricating oil pan and oil suction tube. Refer to Procedure 2-13.



Remove the piston and connecting rod assemblies from the engine. Refer to Procedure 7-13.

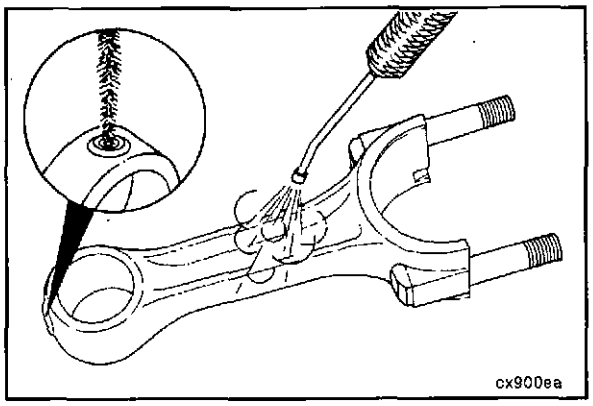
Remove the pistons from the connecting rods. Refer to Procedure 7-14.

Cleaning and Inspection

Use a nylon bristle brush to clean the oil drillings.

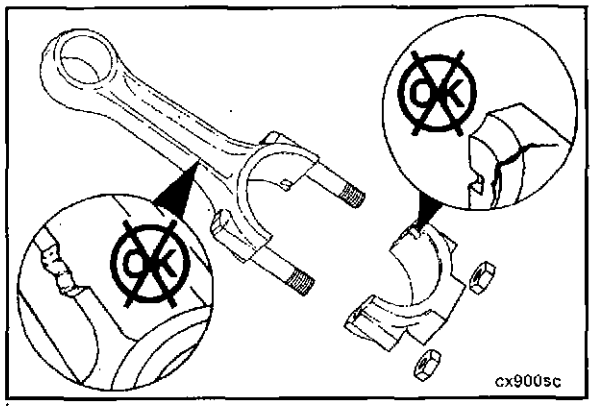
Warning: When using a steam cleaner, wear protective clothing and safety glasses or a face shield. Hot steam can cause serious personal injury.

Use steam or solvent to clean the connecting rods. Dry with compressed air.

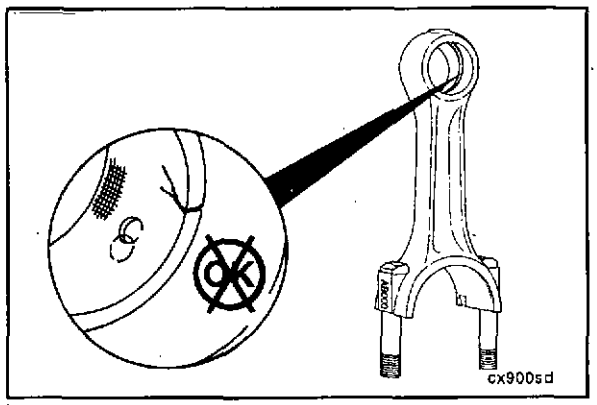


Inspect the connecting rods and caps for damage.

Replace the connecting rod if the "I-beam" is nicked or damaged.

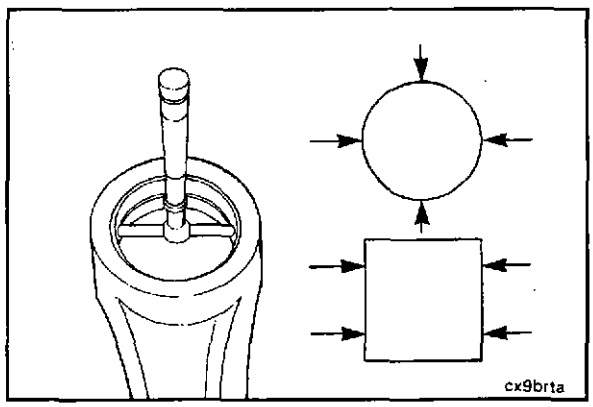


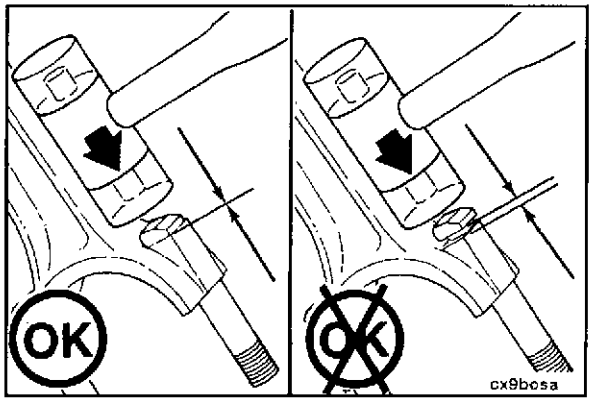
Visually inspect the connecting rod pin bore bushing for damage or misalignment of the oil passage and bushing.



Measure the connecting rod piston pin bushing inside diameter.

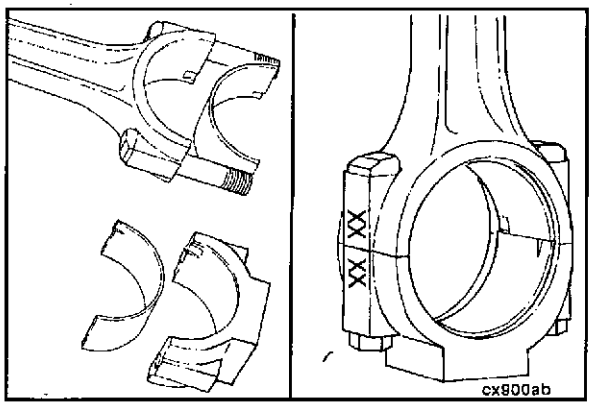
Connecting Rod Pin Bore Specifications		
mm		in
45.023	MIN	1.7726
45.060	MAX	1.7740





Plastic Hammer

Tap the connecting rod bolts in until the head is aligned and seated on the flat machined surface of the connecting rod.

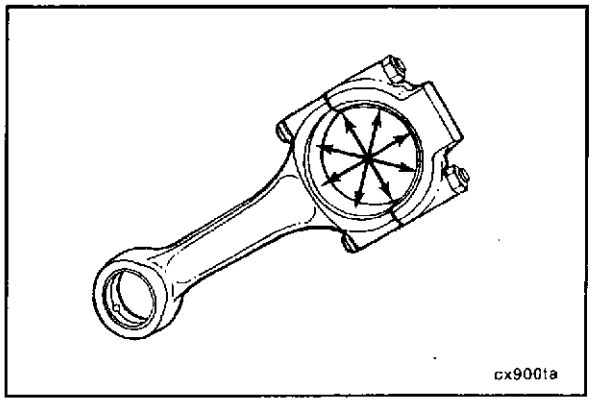


Install the bearing shells in the connecting rod and cap. Install the connecting rod caps and the connecting rod nuts.

NOTE: The connecting rod cap number **must** match the number on the connecting rod and be installed with the numbers aligned.

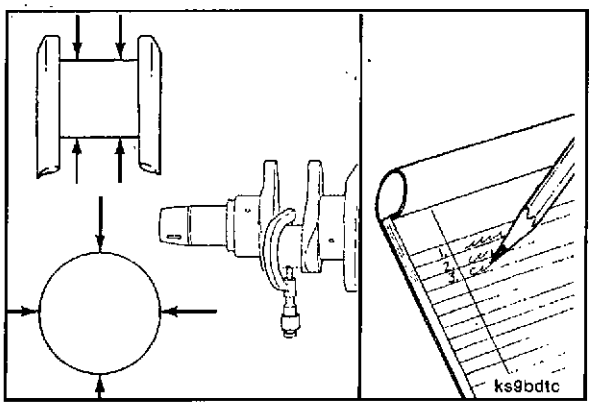
Tighten the connecting rod nuts in alternating sequence.

Torque Value: Step 1 - 40 N•m [30 ft-lb]
Step 2 - 80 N•m [60 ft-lb]
Step 3 - 120 N•m [88 ft-lb]



Measure the connecting rod crankshaft bore inside diameter with the bearing installed.

Connecting Rod Crankshaft Bore I.D.		
mm		in
76.046	MIN	2.9939
76.104	MAX	2.9962



Measure and record the mean diameter of the rod journals on the crankshaft.

Crankshaft Rod Journal Diameter		
mm		in
75.962	MIN	2.9906
76.013	MAX	2.9926

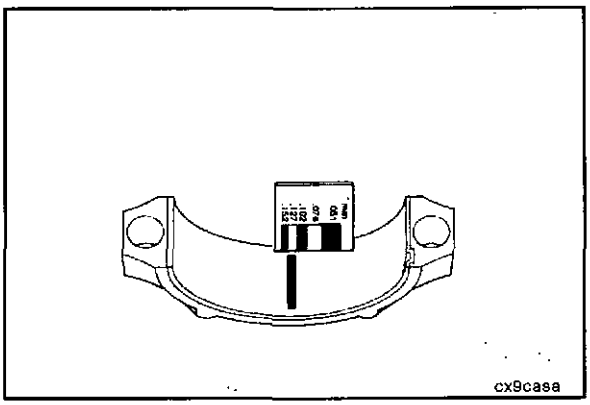
Out-of-Roundness: 0.050 mm [0.002 inch]

Taper: 0.013 mm [0.0005 inch]

Bearing Clearance: = Rod inside diameter minus crankshaft journal diameter.

NOTE: Bearing clearance can also be determined with Plastigauge.

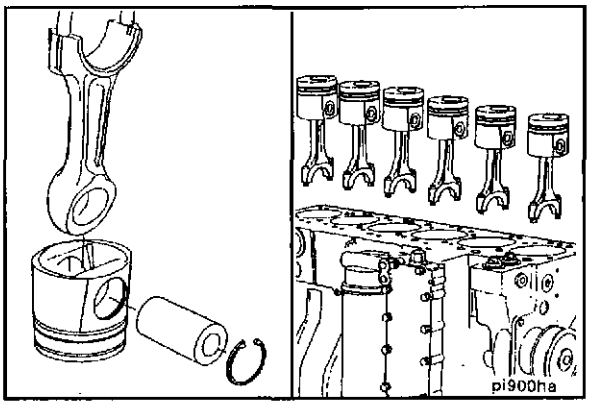
Connecting Rod Bearing Clearance		
mm		in
0.033	MIN	0.0013
0.117	MAX	0.0046



Installation

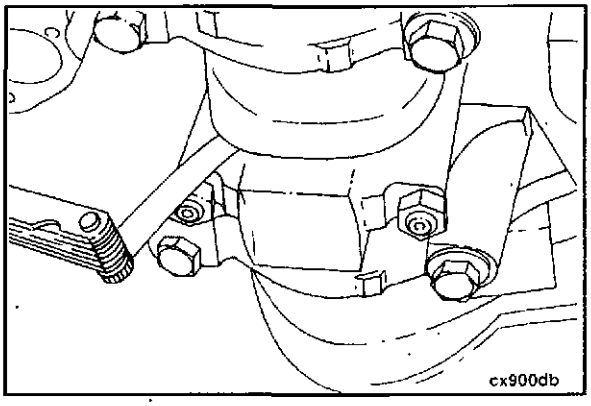
Install the pistons on the connecting rods. Refer to Procedure 7-14.

Install the piston and connecting rod assemblies. Refer to Procedure 7-13.



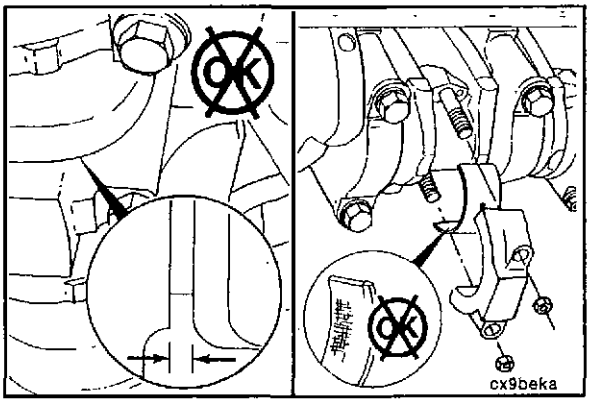
Measure the connecting rod side clearance.

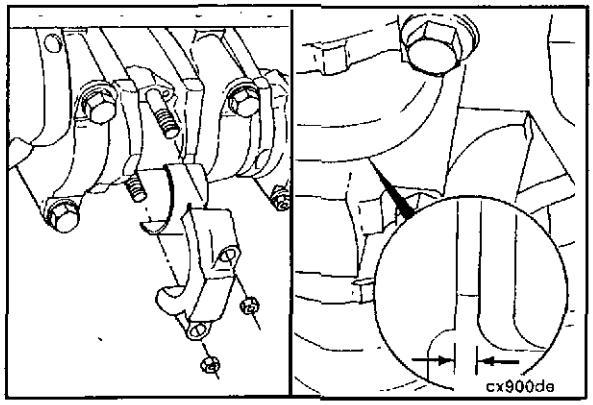
Connecting Rod Side Clearance		
mm		in
0.10	MIN	0.004
0.33	MAX	0.013



NOTE: If the side clearance is **not** within specifications:

- Remove the rod caps and inspect for dirt, damage, or correct bearings.





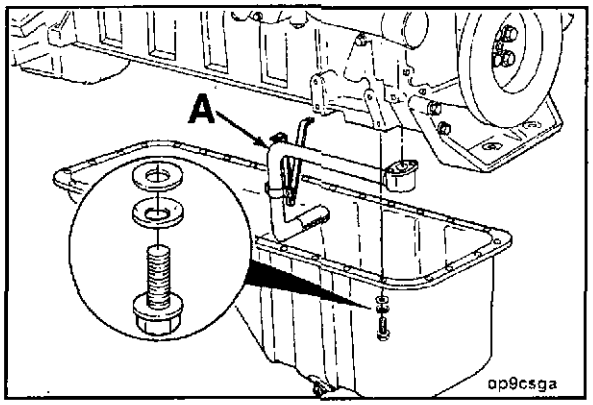
Install the connecting rod caps.

Torque Value:

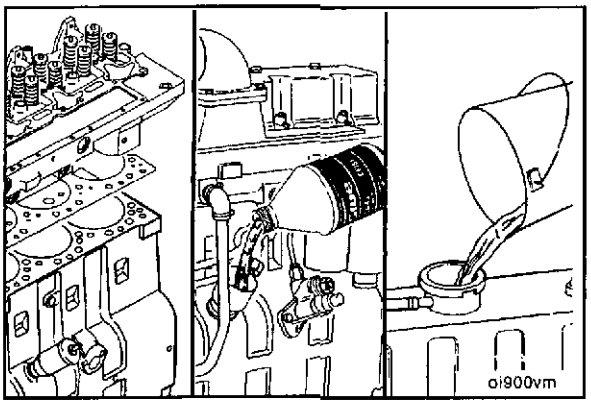
Step 1 - 40 N•m [30 ft-lb]
Step 2 - 80 N•m [60 ft-lb]
Step 3 - 120 N•m [88 ft-lb]

- Measure the side clearance again.

NOTE: If the side clearance is **not** within the specifications, the connecting rod **must** be replaced.



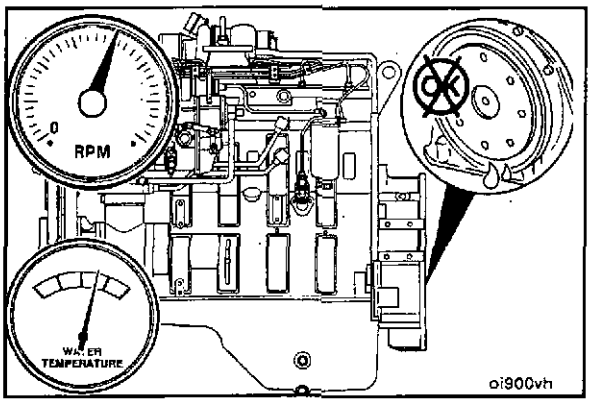
Install the oil suction tube (A) and oil pan. Refer to Procedure 2-13.



Install the cylinder head. Refer to Procedure 7-09.

Fill the lubricating oil pan. Refer to Procedure 2-05.

Fill the cooling system. Refer to Procedure 1-01.

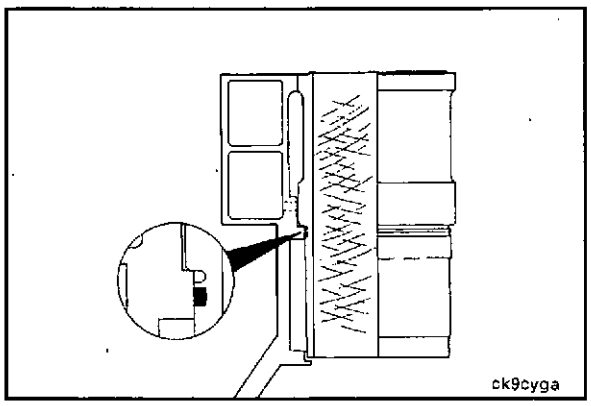


Operate the engine until the coolant temperature reaches 82°C [180°F] and check for leaks and proper operation.

Cylinder Liners - Replacement (7-15)

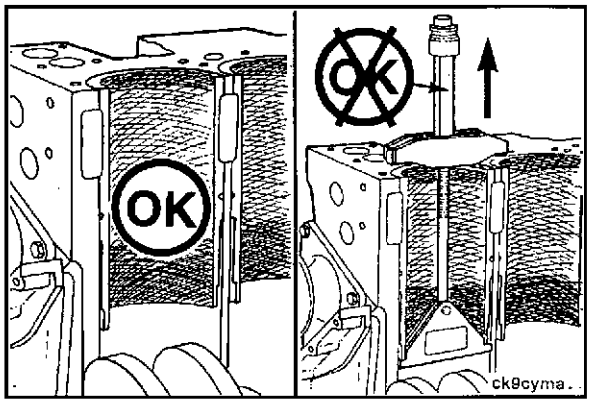
General Information

The cylinder block has a replaceable cylinder liner. A mid-stop design is used to locate the liner in the block. A press fit between the liner and the block provides coolant sealing at the top of the liner. A rectangular ring seal (liner seal) is used for sealing at the mid-stop portion of the liner.



NOTE: Cummins Engine Company, Inc. does **not** recommend removing the cylinder liners to repair an oil consumption problem if the inside diameters of the liners are within the inspection limits included in this procedure.

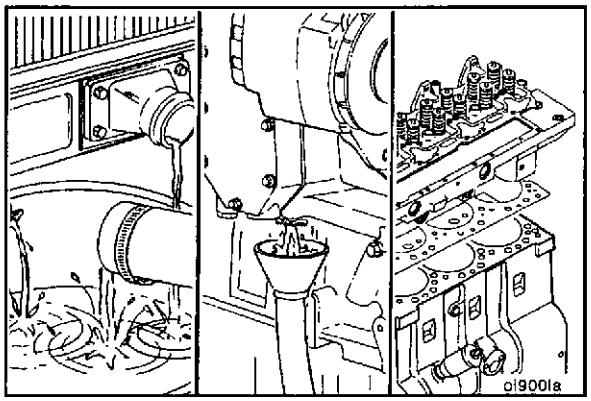
Careful analysis of the condition of the liner bores, piston rings and pistons can result in the restoration of cylinder sealing with a minimum replacement of parts.



Removal

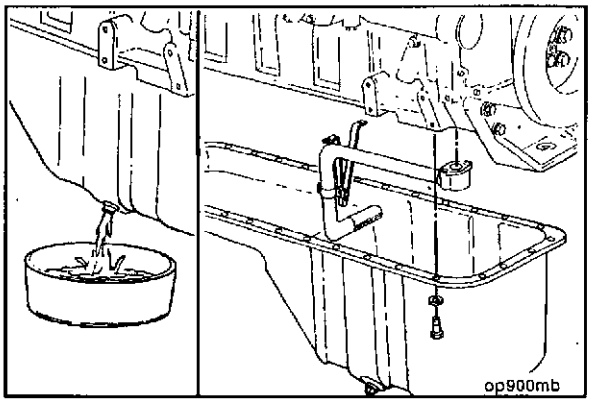
Drain the cooling system. Refer to Procedure 1-01.

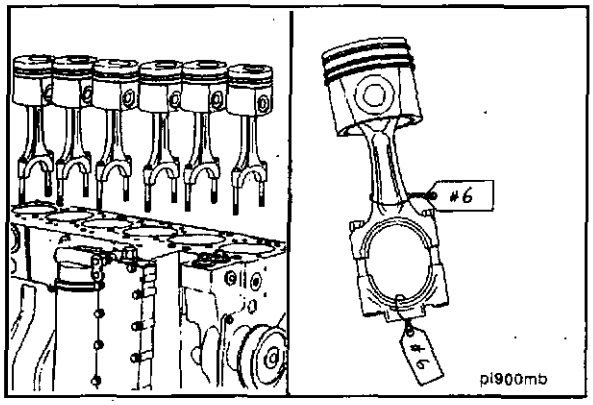
Remove the cylinder head. Refer to Procedure 7-09.



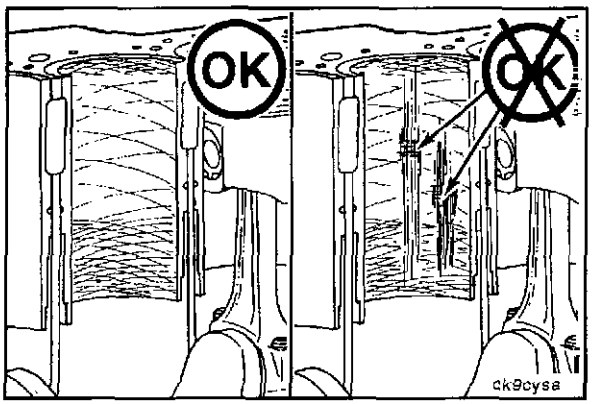
Drain the lubricating oil. Refer to Procedure 2-04.

Remove the lubricating oil pan and oil suction tube. Refer to Procedure 2-13.





Remove the pistons and the connecting rods. Refer to Procedure 7-13.



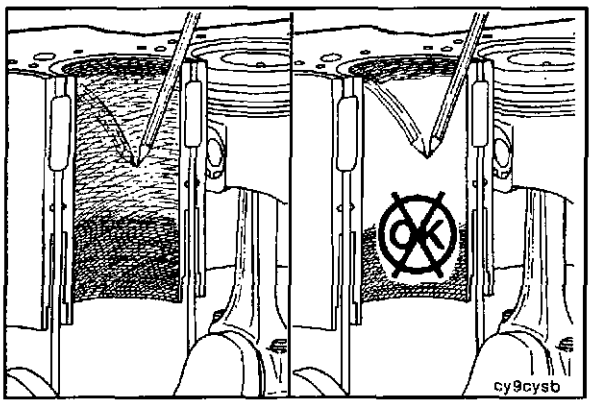
Preliminary Liner Inspection

NOTE: Before removing the cylinder liners, visually inspect the condition to determine reuse.

Visually inspect the inside diameters of the liner for cracks, scuffing or scoring.

Inspect the inside diameters for vertical scratches deep enough to be felt with a fingernail.

NOTE: If a fingernail catches in the scratch, the liner **must** be replaced.

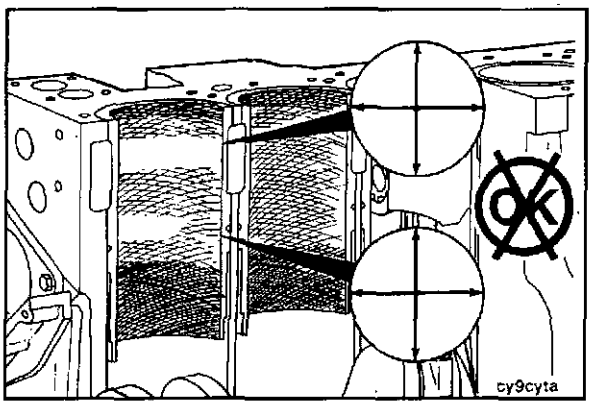


Visually inspect the inside diameter for liner bore polishing.

A moderate polish produces a bright mirror finish in the worn area with traces of the original hone marks or an *indication of an etch pattern.*

A heavy polish produces a bright mirror finish in the worn area with no traces of hone marks or an etch pattern.

Do not reuse liners exhibiting heavy polish or any indications of particle embedment from a failure. Severely worn liners will have a ridge near the top of the liner bore.



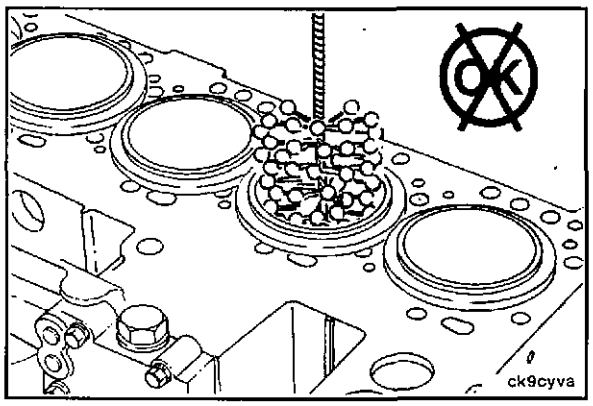
If the wear pattern indicates the liner bore is **not** straight or **not** round, use a dial bore gauge to measure the liner inside diameter in four places 90 degrees apart at the top and bottom of the piston travel area.

Cylinder Liner Dimensions

mm		in
0.04	Maximum Out Of Round	0.0016
0.04	Maximum Taper	0.0016
114.04	Maximum Bore Diameter	4.4897

NOTE: If a liner bore is **not** acceptable for reuse, it **must** be replaced. Damaged liners **cannot** be honed or deglazed. This would destory the cross-hatch pattern needed for oil control.

NOTE: Do **not** remove or disturb the liner seals for liners which pass the inspection criteria.

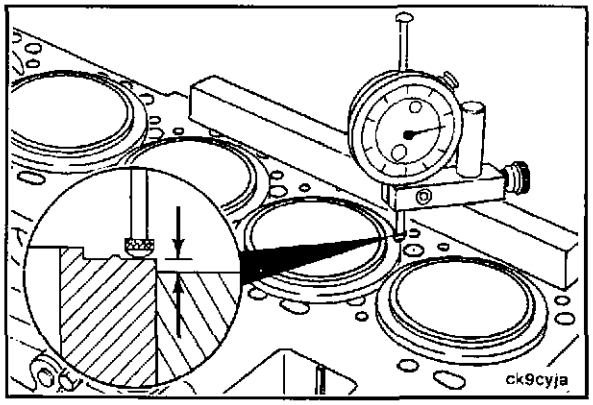


Liner Protrusion Gauge Part No. 3823495

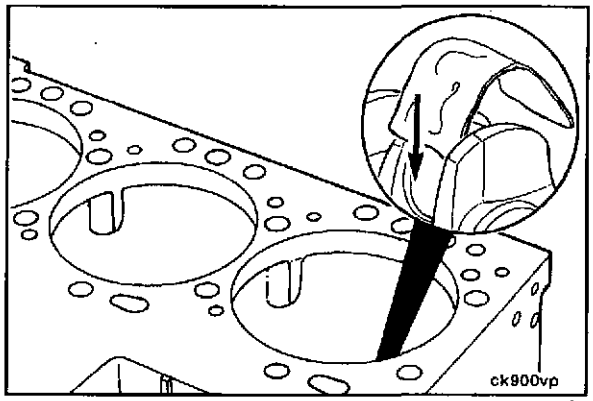
Liner protrusion is the distance the liner protrudes above the block face. Before removing the liners, check the protrusion in the "unclamped" state.

Cylinder Liner Protrusion		
mm		in
0.025	MIN	0.001
0.122	MAX	0.0048

If the liner was installed correctly and the liner protrusion is out of limits, it will be necessary to machine the counterbore and add shims to restore to the original specifications.



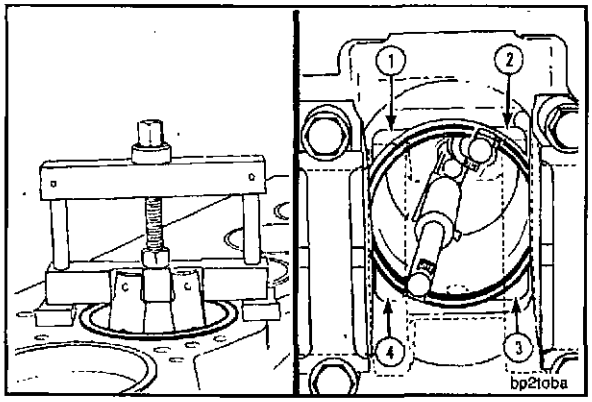
Use clean shop rags to cover the crankshaft to prevent debris from falling into the main journal area or into the connecting rod journal oil drilling.

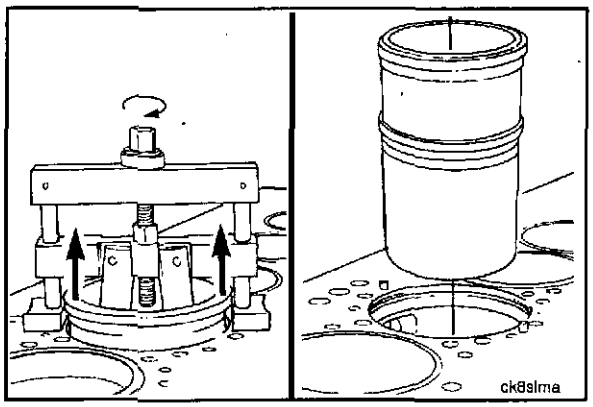


Part No. 3376015 Cylinder Liner Puller

Caution: The liner puller must be installed and used as described to avoid damage to the cylinder block. The puller must not contact the block casting at points (1), (2), (3) and (4).

Insert the liner puller into the top of the cylinder block.

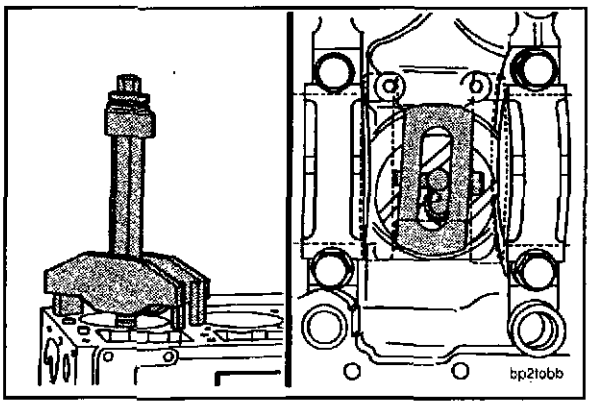




NOTE: The liner puller **must** be centered on the top of the cylinder block.

Turn the puller jackscrew **clockwise** to loosen the liner *from the cylinder block.*

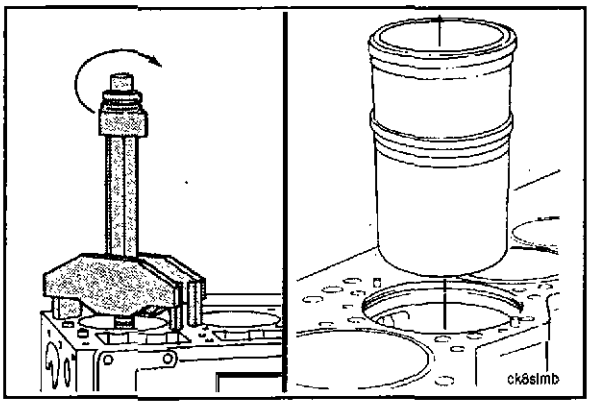
Use both hands to remove the liner.



Part No. 3375629 Universal Liner Puller

Caution: The liner puller must be installed and used as described to avoid damage to the cylinder block. The puller plate must be parallel to the main bearing saddles and must not overlap the liner outside diameter.

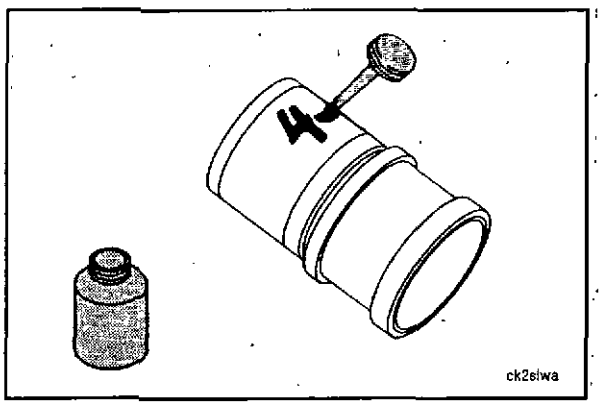
Insert the liner puller into the top of the cylinder block.



NOTE: The liner puller **must** be centered on the top of the cylinder block.

Turn the puller jackscrew **clockwise** to loosen the liner from the cylinder block.

Use both hands to remove the liner.

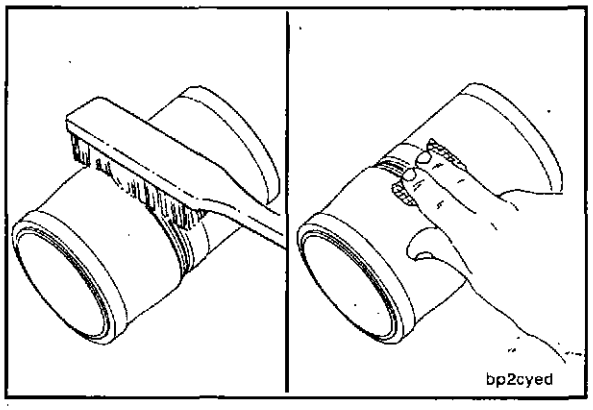


Use Dykem® or equivalent to mark the cylinder number on each liner.

Cleaning and Inspection

Caution: Do not use any abrasives in the ring travel area of the liner. The liner can be damaged.

Use a soft wire brush or a fine fibrous abrasive pad such as Scotch-Brite® 7448 or equivalent to clean the flange seating area.

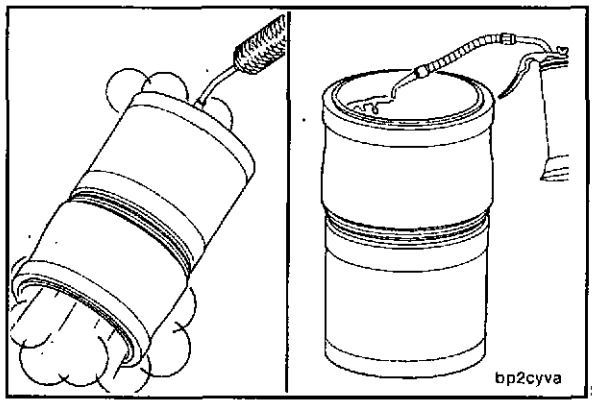


Warning: When using a steam cleaner, wear protective clothing and safety glasses or a face shield. Hot steam can cause serious personal injury.

Use solvent or steam clean the liners and dry with compressed air.

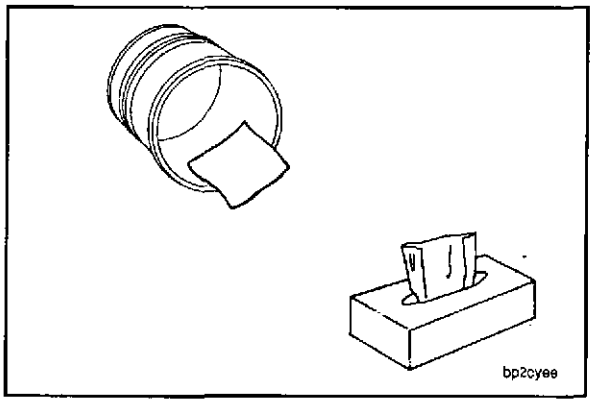
Use clean 15W-40 oil to lubricate the inside diameter of the liners.

Allow the oil to soak in the liner for 5 to 10 minutes.

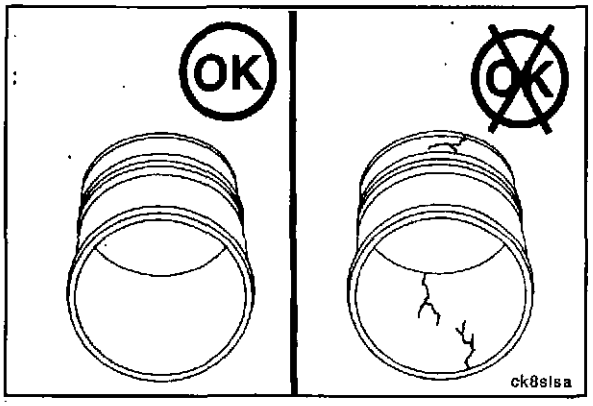


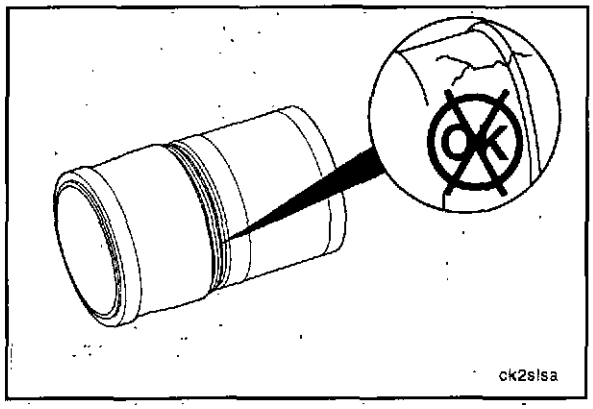
NOTE: Use "lint-free" paper towels to wipe the oil from the inside of the liners.

Continue to lubricate the inside of the liners and wipe clean until the paper towel shows no gray or back residue.

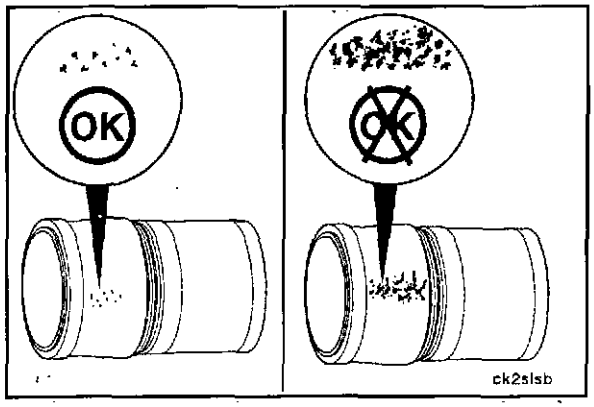


Visually inspect the liners for cracks on the inside and outside diameters.





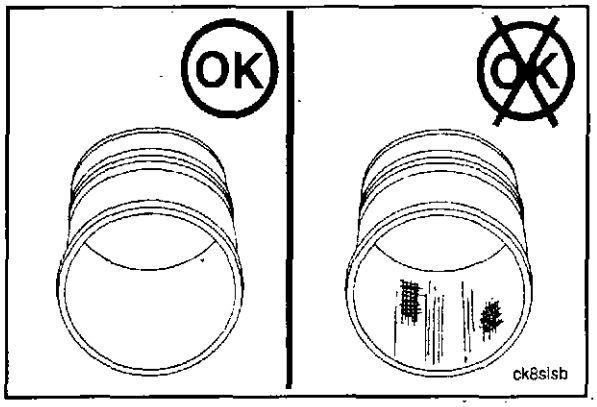
Inspect for cracks under the flange.



Visually inspect the outside diameter and seat area for excessive corrosion or pitting.

NOTE: Pits must **not** be more than 1.6 mm [0.06 inch] deep.

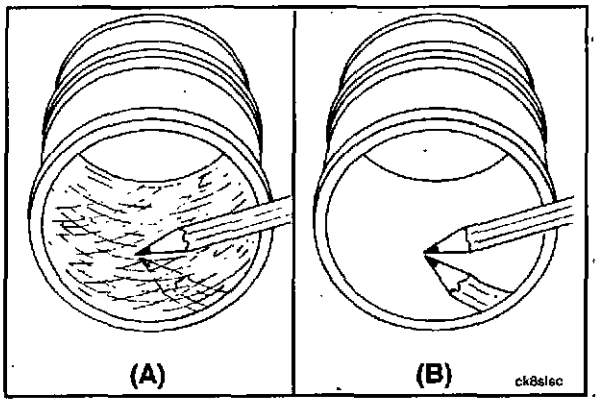
Replace the liner if the pits are too deep or if the corrosion **cannot** be removed with fine emery cloth.



Inspect the inside diameters for vertical scratches deep enough to be felt with a fingernail.

NOTE: If a fingernail catches in the scratch, the liner **must** be replaced.

Visually inspect the inside diameter for scuffing or scoring.



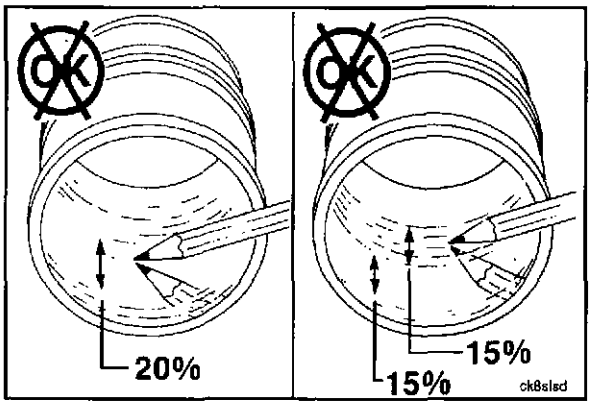
Visually inspect the inside diameter for liner bore polishing.

A **moderate polish** produces a bright mirror finish in the worn area with traces of the original hone marks or an *indication of an etch pattern.*

A **heavy polish** produces a bright mirror finish in the worn area with no traces of hone marks or an etch pattern.

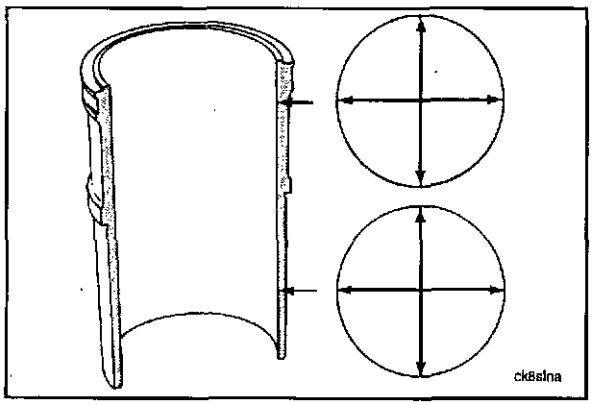
Replace the liner if:

- A heavy polish is present over 20 percent of the piston ring travel area.
- Both moderate and heavy polish over 30 percent of the piston ring travel area and one half (15 percent) is heavy polish.



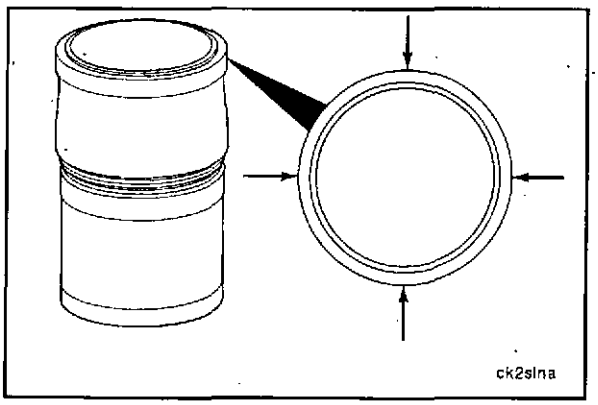
Part No. 3375072, Dial Bore Gauge

Measure the liner inside diameter in four places 90 degrees apart at the top and bottom of the piston travel area.



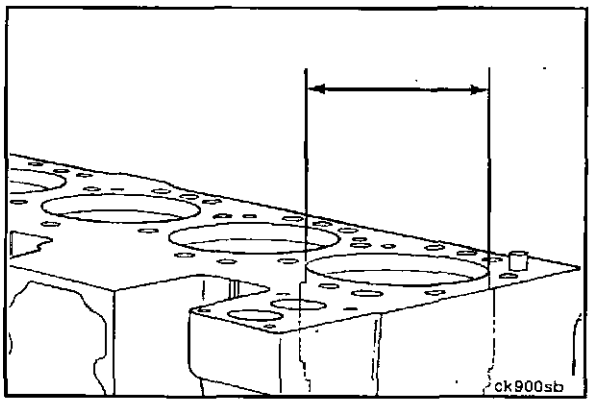
Cylinder Liner I.D.		
mm		in
114.000	MIN	4.4882
114.04	MAX	4.9897

Measure the outside diameter of the liner top press fit area.

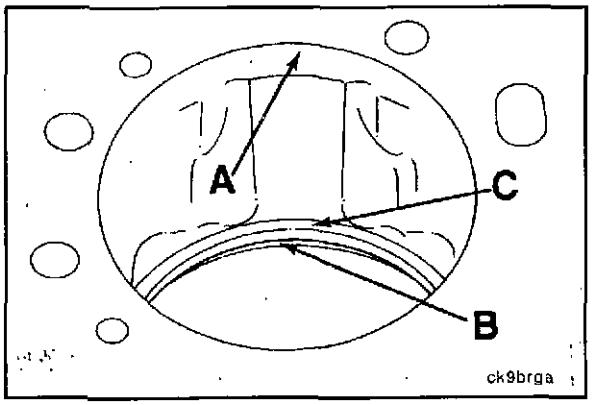


Cylinder Liner O.D. (Top Press Fit)		
mm		in
130.938	MIN	5.1550
130.958	MAX	5.1558

Measure the cylinder liner bore in the block.



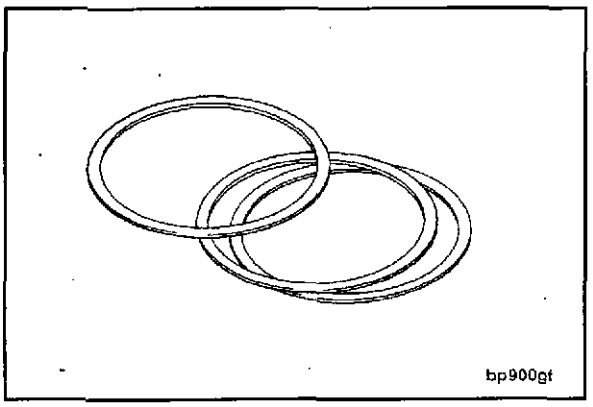
Cylinder Liner Bore in Block (Press Fit Bore)		
mm		in
130.900	MIN	5.1535
130.950	MAX	5.1570



Installation

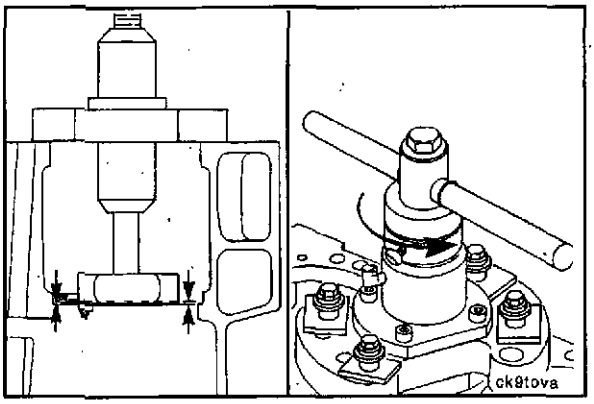
Caution: Clean all deposits and debris from sealing surfaces A, B and C. Use Scotch-Brite® 7448 or equivalent and cleaning solvent to polish the surfaces. Due to the critical machined tolerances, care should be taken not to remove any additional material.

If surface C has cracks or signs of extreme wear, the counterbore will require machining and the installation of shims for the correct liner protrusion.



Cylinder liner shims are available as follows:

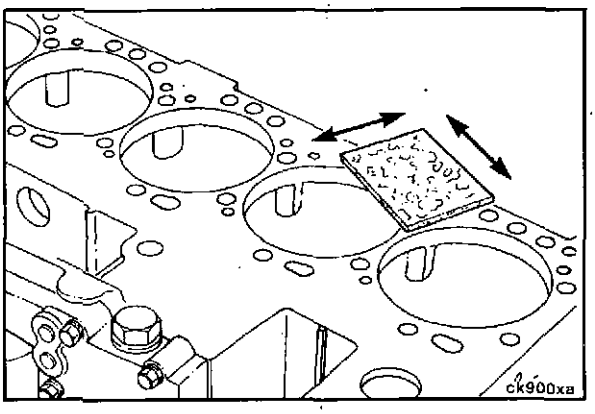
Cylinder Liner Shim Thickness		
mm	Part No.	in
0.25	3924445	0.010
0.38	3924446	0.015
0.51	3924447	0.020
0.76	3924448	0.030
1.00	3924449	0.040



Part No. 3823558, Counterbore Machining Tool

Machine the counterbore to the proper depth.

NOTE: Part No. 3823567, cutter plate, and Part No. 3823570, cutter bit, **must** be used with the counterbore machining tool.

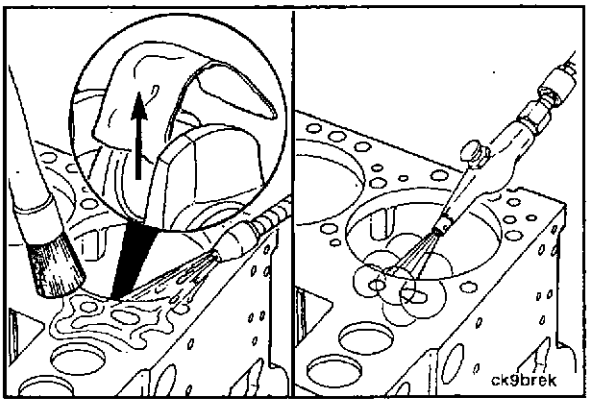


Clean the combustion deck with a gasket scraper or Scotch-Brite® 7448 cleaning pad or equivalent and diesel fuel or solvent.

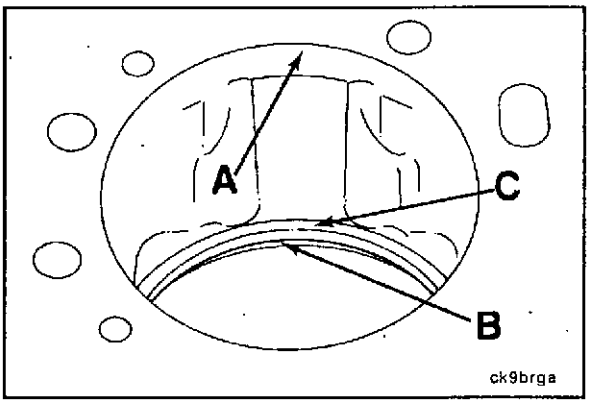
Thoroughly flush the block with mineral spirits or cleaning solvent.

Remove the shop rags and clean the crankshaft with a cleaning solvent.

Blow the cylinder bores and crankshaft dry and wipe them clean with a lint-free cloth.

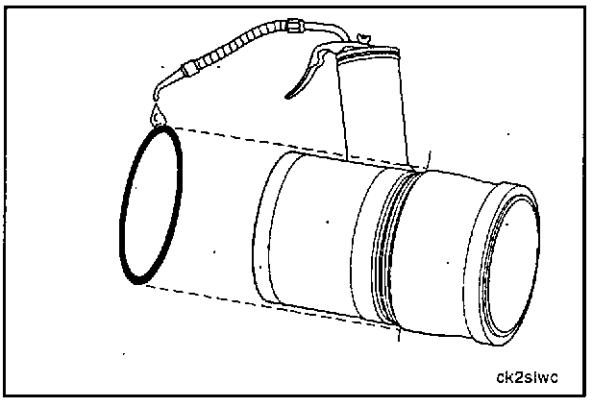


Lubricate surfaces A and B with clean 15W-40 engine oil.

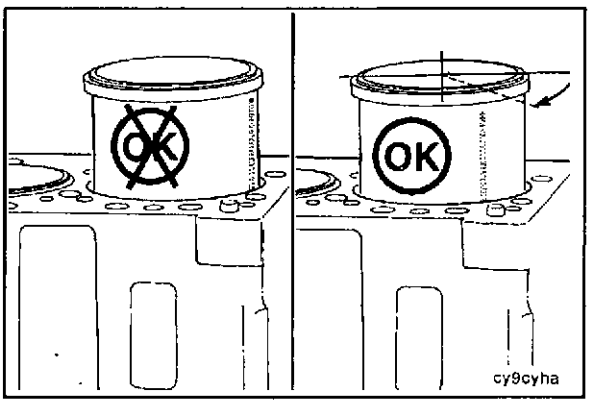


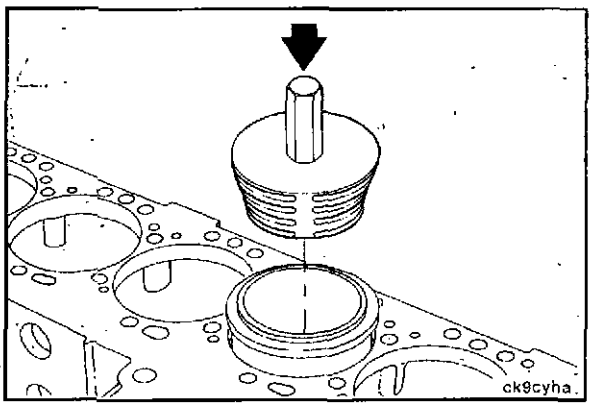
Use clean 15W-40 oil to coat the liner o-ring seals.

Install new o-ring seals on the liners.



When reusing liners, install them in the same cylinder from which they were removed and rotate them 45 degrees (1/8 turn) from their original position. When correctly installed, any liner pitting should be positioned as illustrated so the pitted surface is rotated away from the location where pitting occurs:

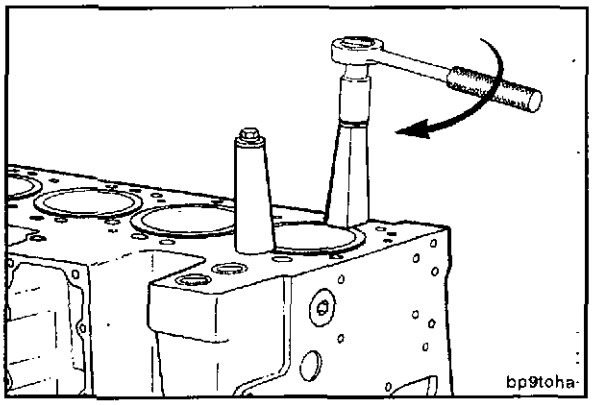




Part No. ST-1229, Cylinder Liner Driver, Leather Mallet

Install the liner in to the bore of the cylinder block.

NOTE: If the liner does not rest on the cylinder block counterbore seat, remove the liner. Inspect the counterbore seat and liner for nicks, burrs, or dirt. Install the liner again.



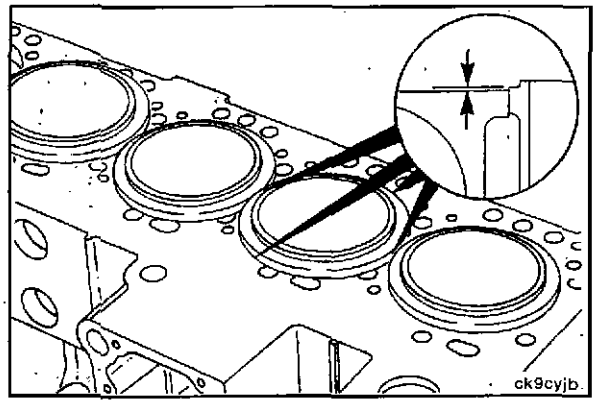
Liner Clamps, Part No. 3822503

Use two cylinder head capscrews and position the two liner clamps as illustrated.

Tighten the capscrews.

Torque Value: 68 N•m [50 ft-lb]

Remove the clamps and repeat this procedure until all liners have been clamped and released.

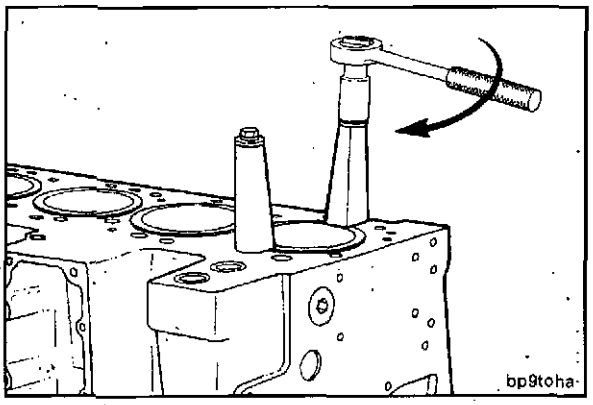


Liner Protrusion Gauge Part No. 3823495

Liner protrusion is the distance the liner protrudes above the block face.

Measure the liner protrusion at four points 90 degrees apart.

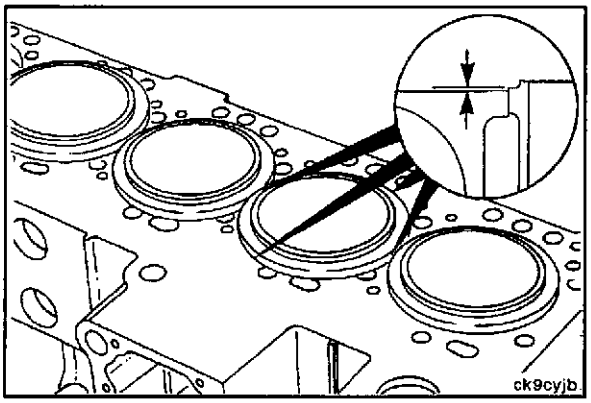
Cylinder Liner Protrusion		
mm		in
0.025	MIN	0.001
0.122	MAX	0.0048



NOTE: If the liner protrusion varies more than 0.025 mm [0.0010 inch] for 180 degrees:

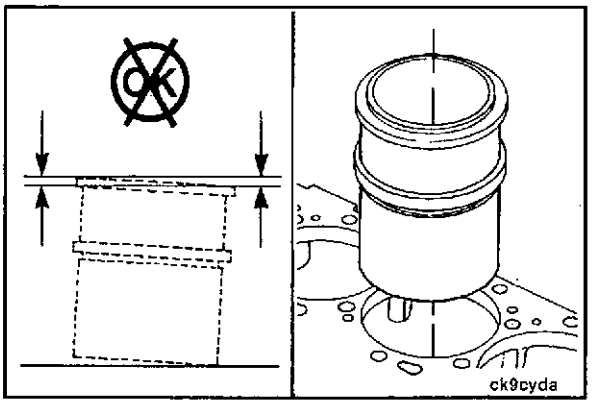
- Install and tighten the liner clamps again.

- Inspect the liner protrusion again.

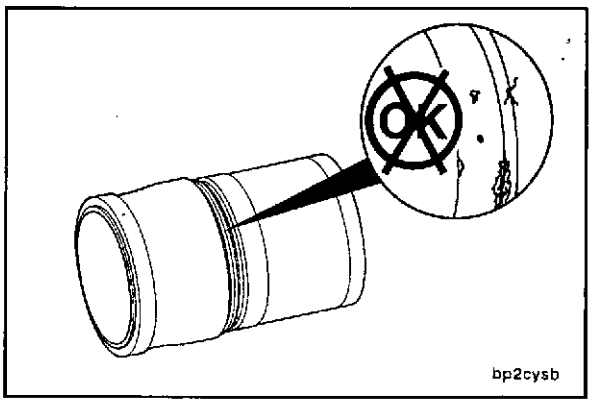


NOTE: If the protrusion still varies more than 0.025 mm [0.0010 inch]:

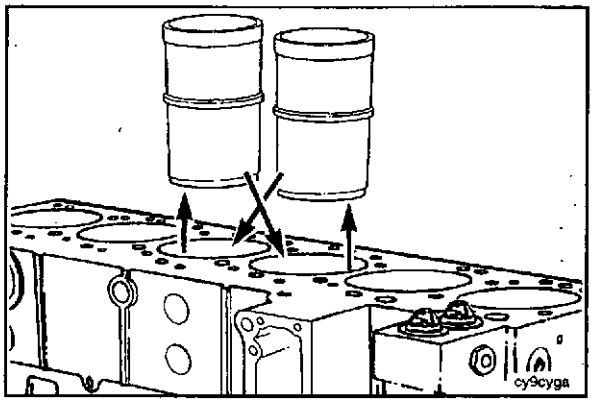
- Remove the liner.

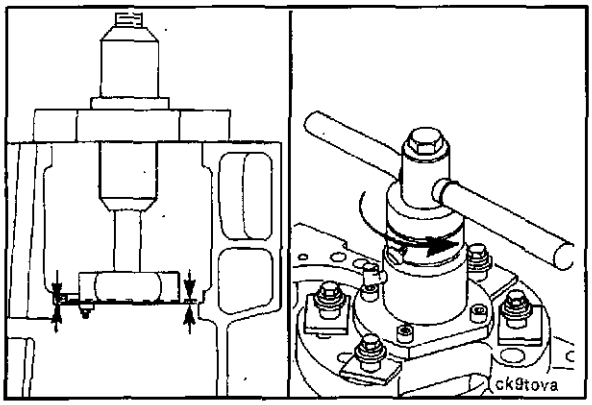


- Inspect the liner sealing edge for burrs, dirt or damage.
- Replace the liner if it is damaged.
- Install the liner again.
- Inspect the liner protrusion.

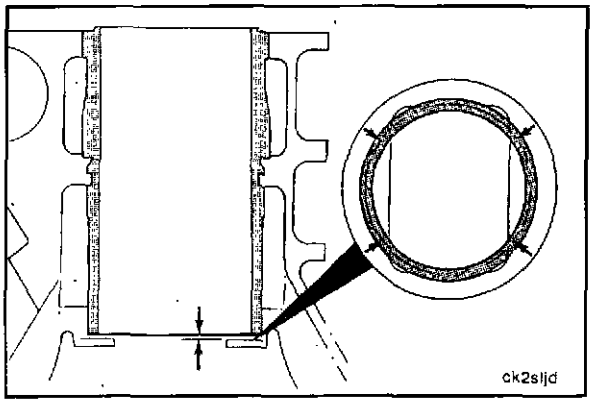


Service Tip: If the out-of-limit condition is minimal, tolerance stack-up may allow the protrusion limits to be obtained by installing other new liners in the out-of-limit bore.



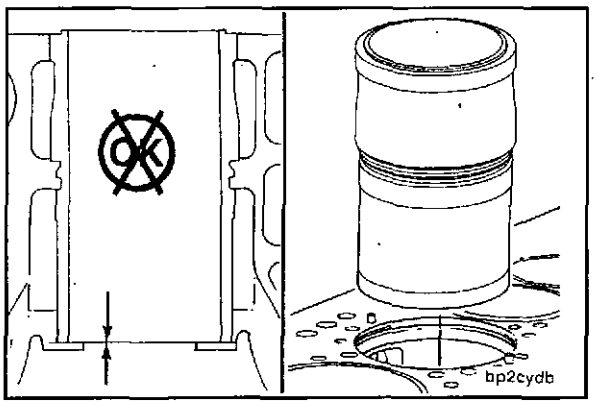


NOTE: If the liner protrusion still does **not** meet the specifications, machine the cylinder block liner bore for shims.



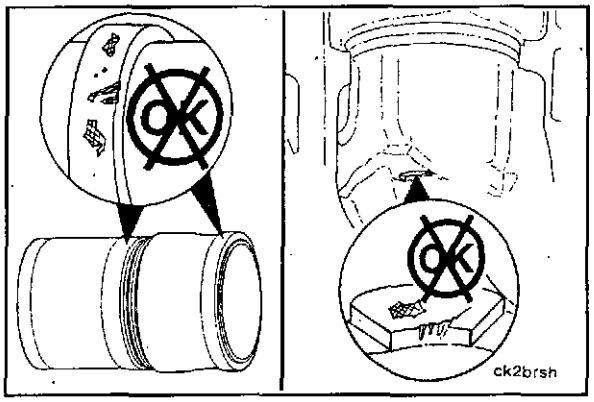
Use a feeler gauge to inspect the liner to block clearance at the four block casting points.

Cylinder Liner to Block Clearance		
mm		in
0.229	MIN	0.009



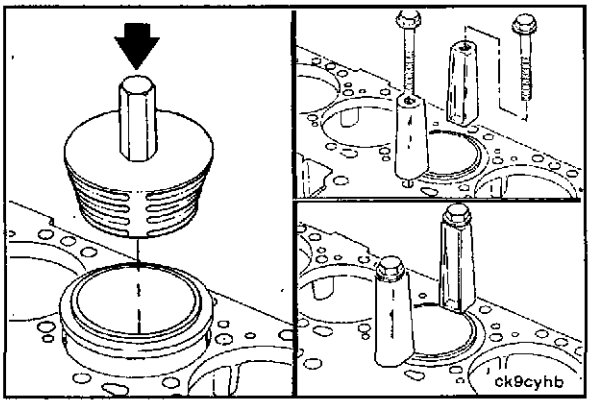
NOTE: If the clearance is **less** than 0.229 mm [0.009 inch]:

- Remove the liner.

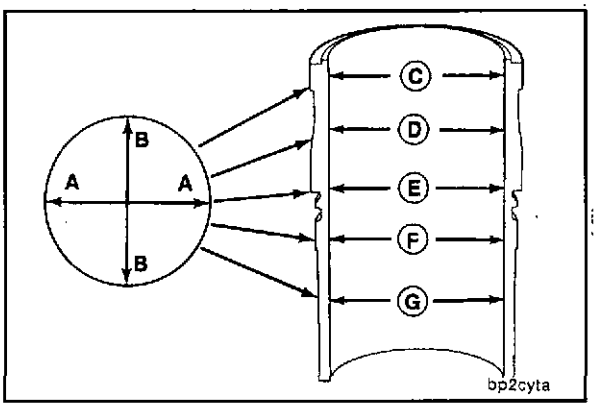


- Inspect the liner and cylinder block for dirt or damage.

- Replace the liner if it is damaged.
- Install the liner again.

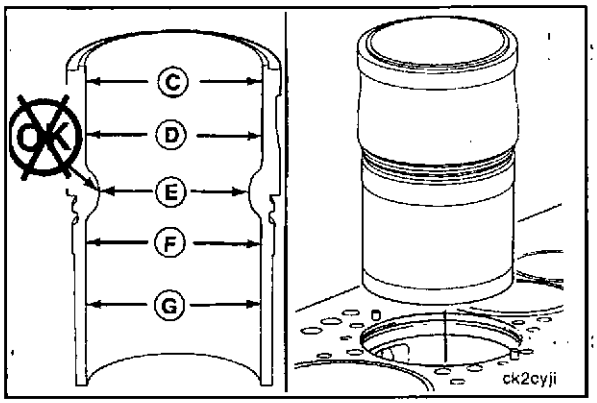


Measure the liner bore for out-of-roundness at points "C", "D", "E", "F" and "G". Measure each point in the direction "AA" and "BB". The bore **must not** be more than 0.08 mm [0.003 inch] out-of-round.



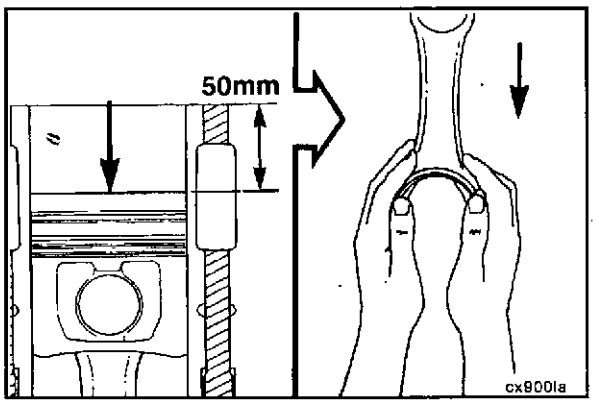
NOTE: If the liner bore is more than 0.08 mm [0.003 inch] out-of-round:

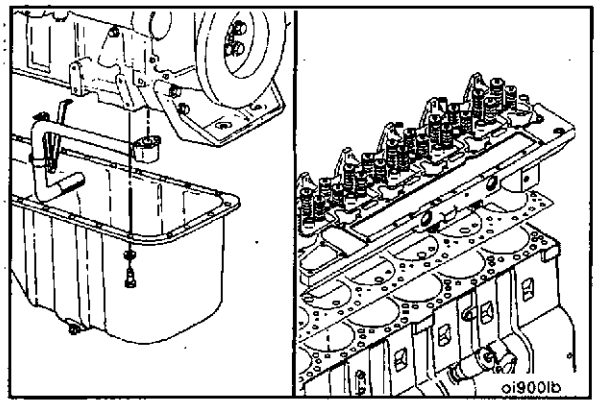
- Remove the liner so the cylinder block liner bore can be measured.



Install the pistons and connecting rods. Refer to Procedure 7-13.

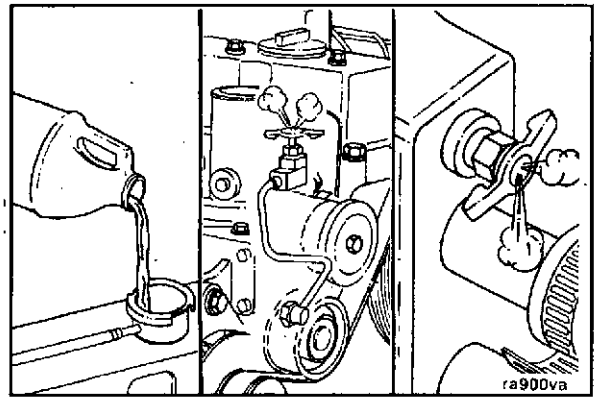
NOTE: Do not interchange pistons from the original cylinder location.



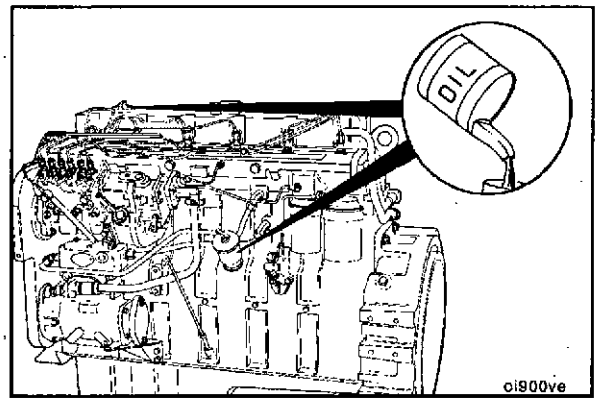


Install the lubricating oil pan and suction tube. Refer to Procedure 2-13.

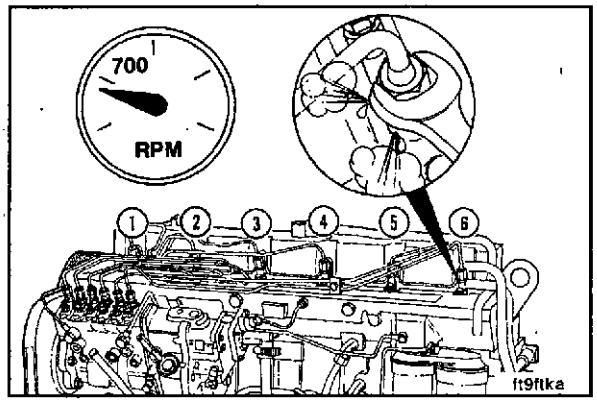
Install the cylinder head. Refer to Procedure 7-09.



Fill and vent the cooling system. Refer to Procedure 1-01.



Fill the lubricating system with oil. Refer to Procedure 2-05.



19 mm

Start the engine and operate at idle.

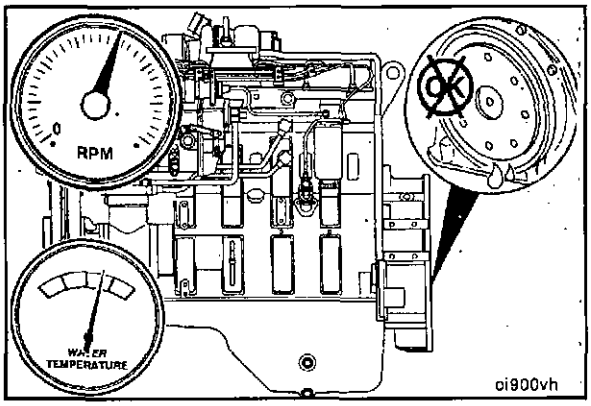
Bleed the high pressure fuel lines.

Loosen the high pressure fuel line to allow entrapped air to escape.

Tighten fuel lines.

Torque Value: 24 N•m [18 ft-lb]

Operate the engine until the coolant temperature reaches 82°C [180°F] and check for leaks and proper operation.

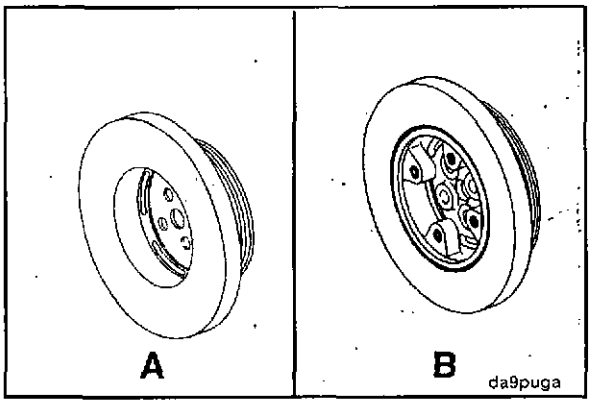


Vibration Damper - Replacement (7-16)

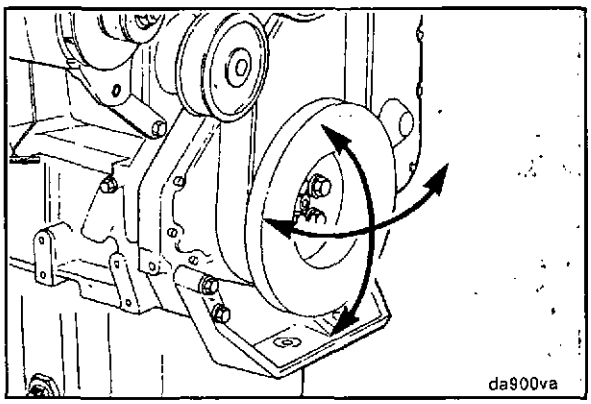
General Information

NOTE: *There are two different design vibration dampers* used:

- Viscous damper (A) for certain engines rated at speeds above 2500 RPM.
- Rubber element damper (B) for engines rated at speeds below 2500 RPM. The rubber damper is available either with or without the crankshaft adapter.



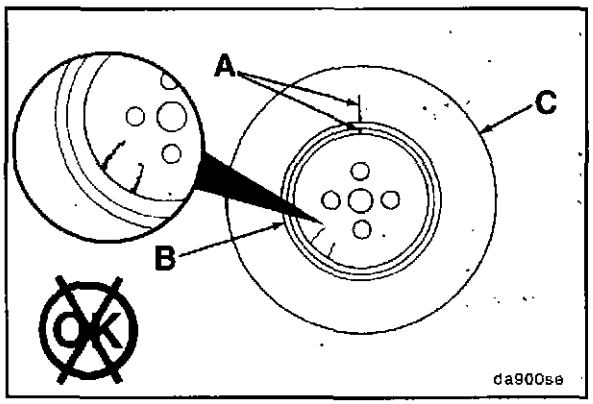
When diagnosing a vibration problem, check the damper for obvious wobble when it is rotating.

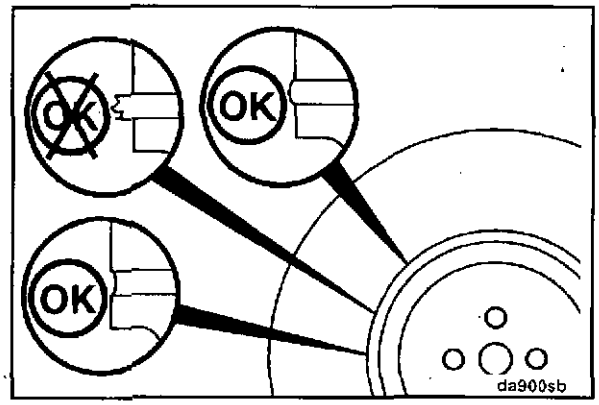


Rubber Element Vibration Damper - Inspection (In-Chassis)

Check the index lines (A) on the damper hub (B) and the inertia member (C). If the lines are more than 1.59 mm [1/16 inch] *out of alignment, replace the damper.*

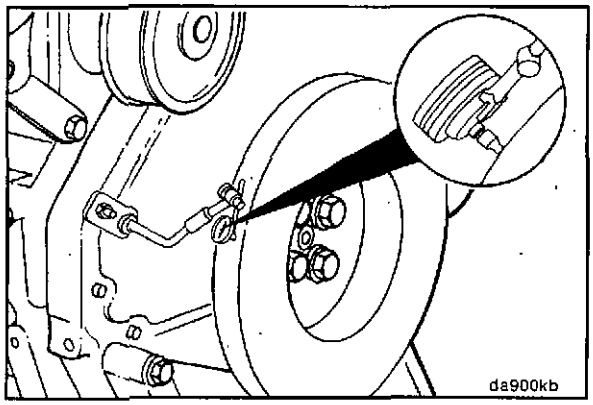
Inspect the vibration damper hub (B) for cracks. Replace the damper if the hub is cracked.



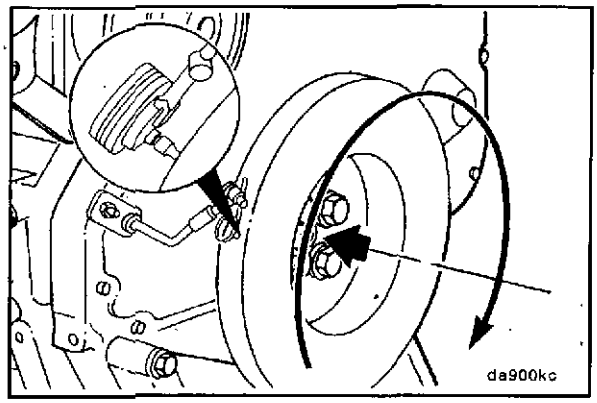


Inspect the rubber member for deterioration. If pieces of rubber are missing or if the elastic member is more than 3.18 mm [1/8 inch] below the metal surface, replace the damper.

NOTE: Also look for forward movement of the damper ring on the hub. Replace the damper if any movement is detected.

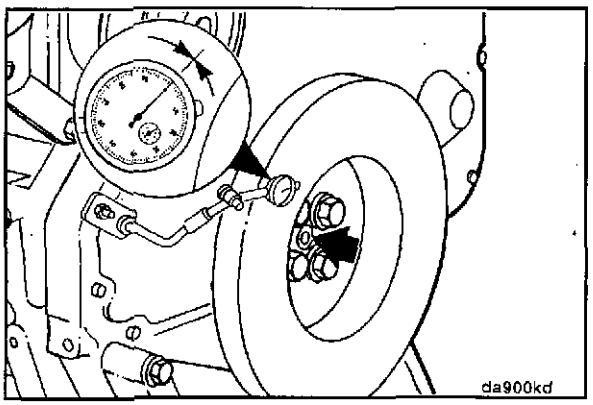


Measure the vibration damper eccentricity by installing the dial indicator on the gear cover as indicated.



Part No. 3377371, Engine Barring Gear

Rotate the crankshaft and record the indicator movement. Replace the vibration damper if the eccentricity exceeds 0.10 mm [0.004 inch] per 25.4 mm [1.0 inch] of damper diameter. Refer to replacement procedure in this section.



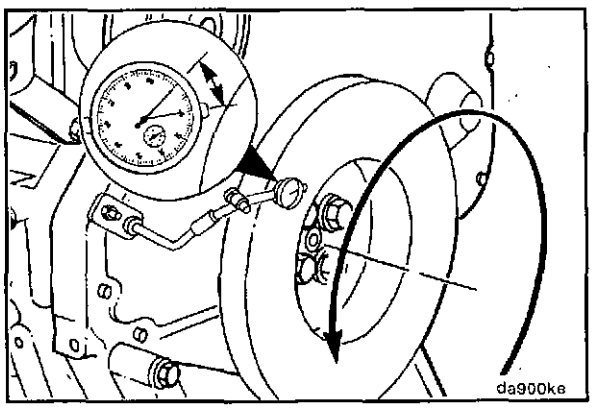
Install the dial indicator, as indicated, to measure wobble.

Push the crankshaft to the front or to the rear and zero the indicator.

Rotate the crankshaft 360 degrees, maintaining the position of the crankshaft (either toward the front or the rear) in relation to the cylinder block.

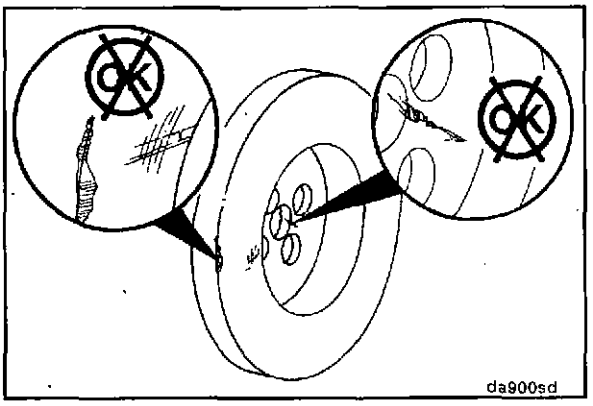
Record the total indicator motion.

Replace the damper if wobble exceeds 0.18 mm [0.007 inch] per 25.4 mm [1.0 inch] of radius. Refer to replacement procedure in this section.



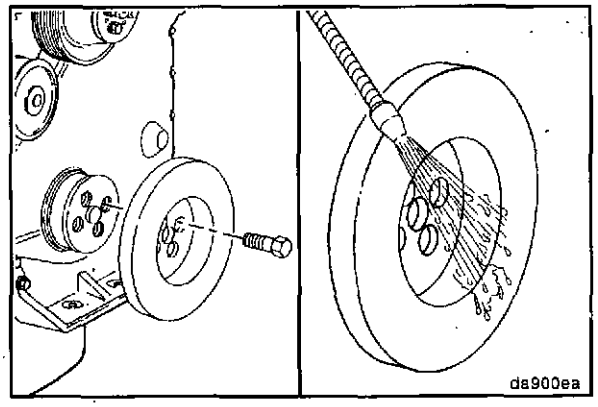
Viscous Vibration Damper - Inspection

Check the mounting web for cracks. Check the housing for dents or raised surfaces. Replace the damper if any of these defects are identified. Refer to replacement procedure in this section.

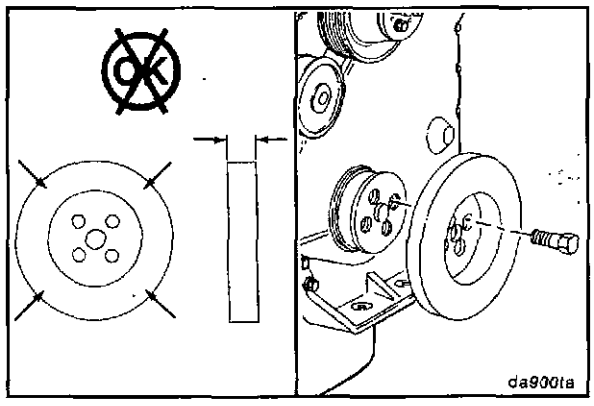


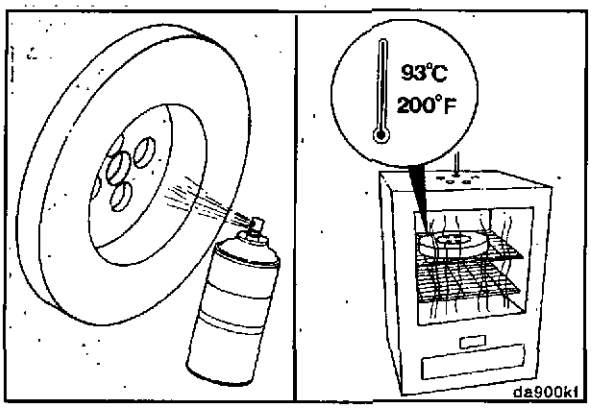
Remove the viscous vibration damper. Refer to replacement procedure in this section.

Clean the damper with a solvent cleaner.

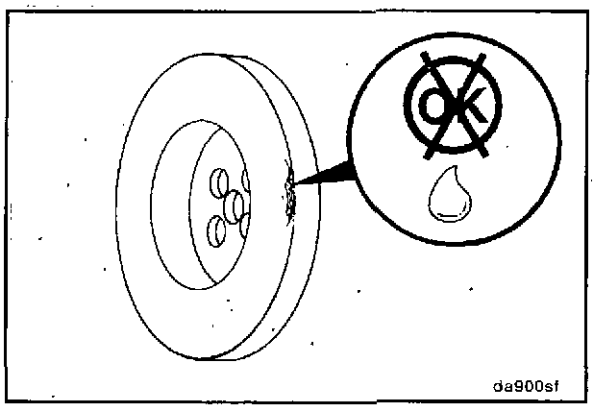


The viscous damper is filled with a silicone fluid. After many hours of use, the silicone fluid may become thicker and expand. To determine if the damper thickness is correct, remove the paint from the damper in four locations on either side of the damper. Measure and record the thickness of the damper in four places. Measure the thickness 3.175 mm [0.125 inch] from the outside of the damper. Replace the damper if its thickness varies by more than 0.25 mm [0.010 inch].





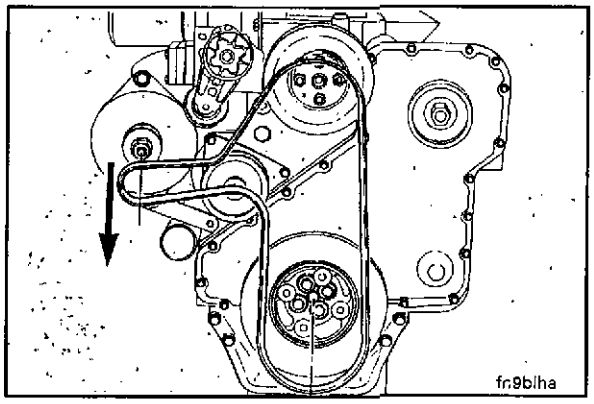
Spray the damper with spot check developer, Type SKD-NF or its equivalent. Heat the damper in an oven (rolled lip side down) at 93°C [200°F] for 2 hours.



Caution: Wear protective gloves to prevent personal injury when handling parts that have been heated.

Remove the damper from the oven and check for fluid leakage. If there is leakage, replace the damper.

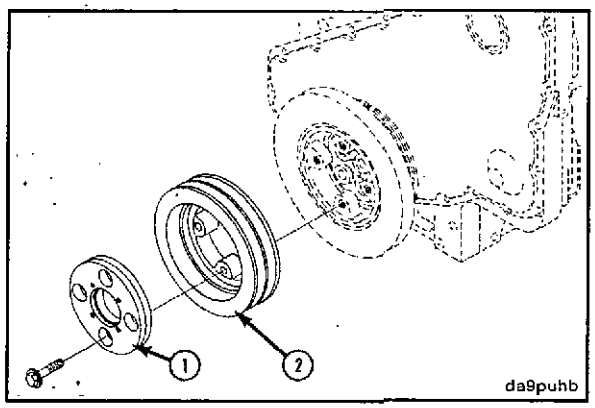
Refer to replacement procedure in this section.



Removal

3/8 or 1/2 inch Square Drive

Remove the fan drive belt.

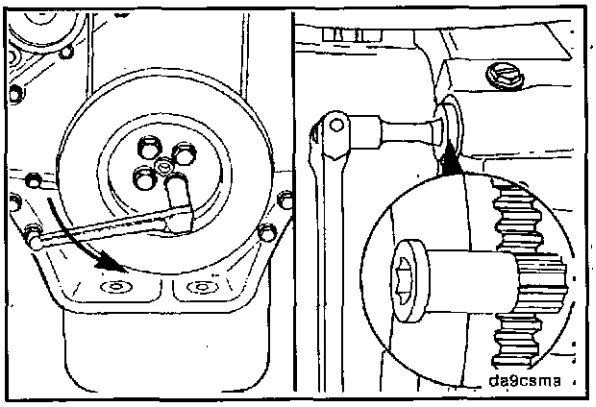


15 mm

Remove the crankshaft adapter (1) and pulley (2), if equipped.

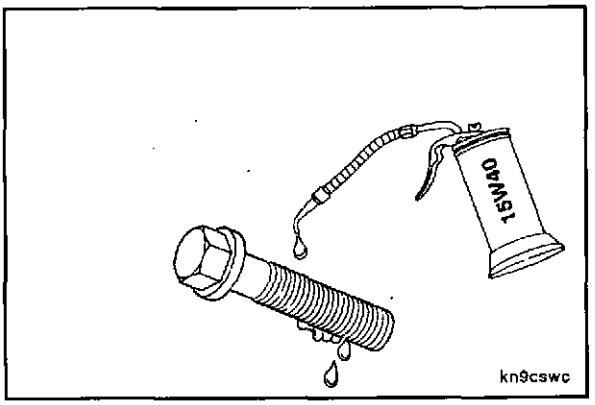
18 mm, Part No. 3377371, Engine Barring Gear

Remove the vibration damper. Use the barring gear to hold the crankshaft while removing the capscrews.



Installation

Lubricate the threads of the capscrews with a film of SAE 15W-40 engine oil.

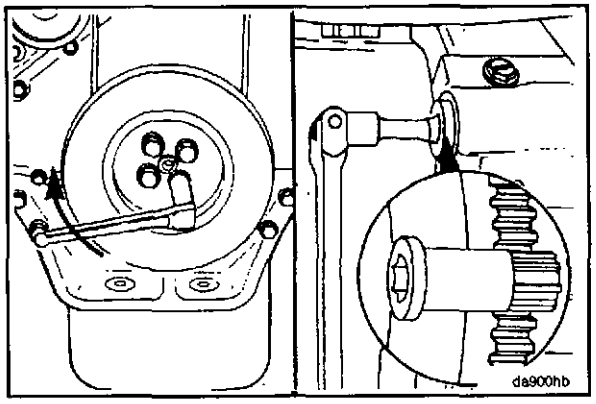


18 mm, Part No. 3377371, Engine Barring Tool

Install the vibration damper.

Use the barring gear to hold the engine when tightening the capscrews.

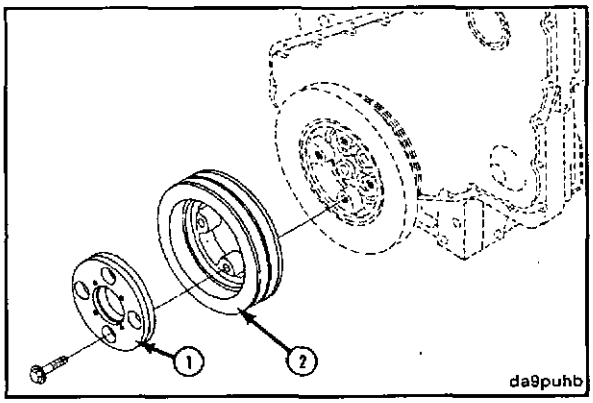
Torque Value: 200 N•m [148 ft-lb]

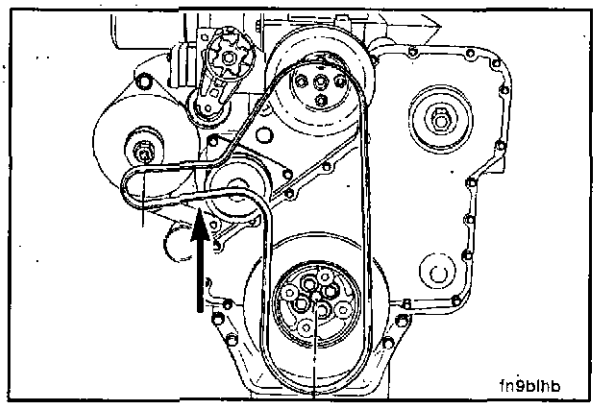


15 mm

Install the crankshaft adapter (1) and pulley (2), if equipped.

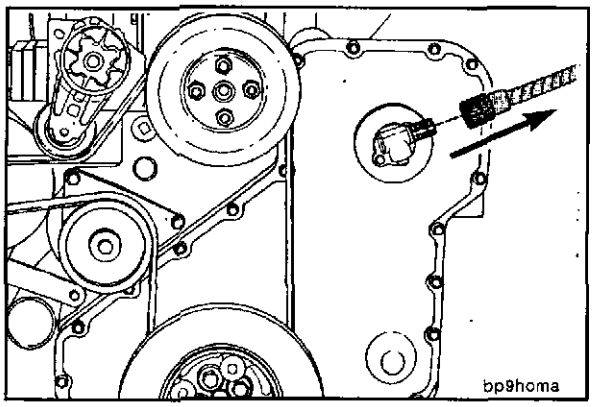
Torque Value: 77 N•m [57 ft-lb]





3/8 or 1/2 inch Square Drive

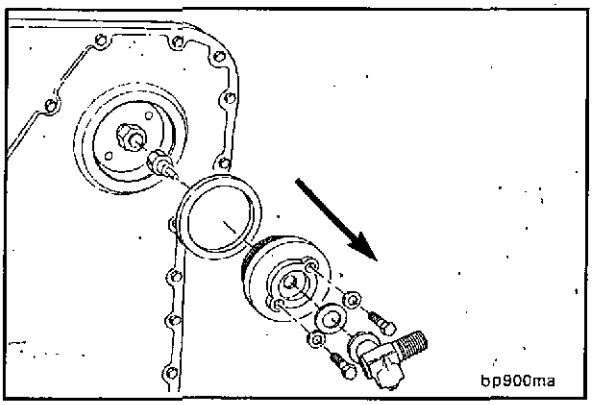
Install the fan drive belt and driven accessories.



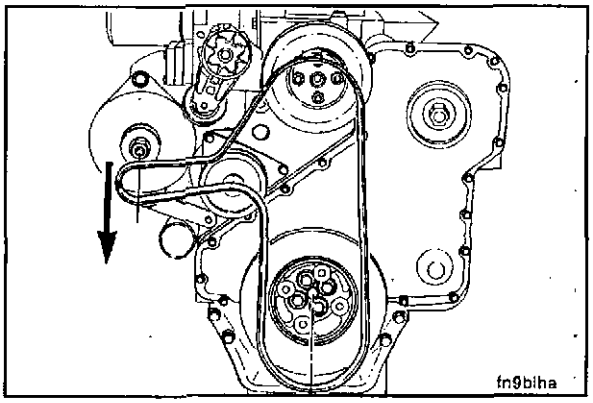
Gear Cover - Replacement (7-17)

Removal

Remove the tachometer drive cable.



Remove the tachometer drive.



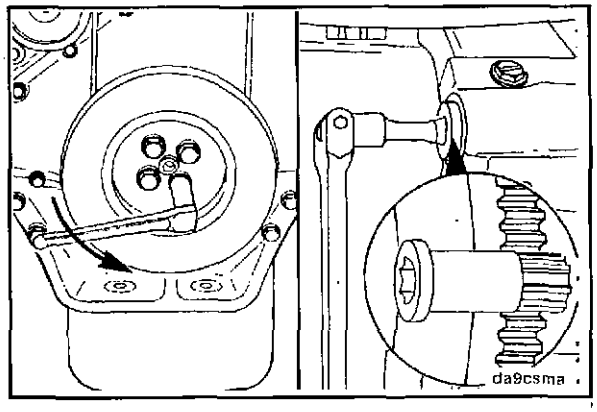
3/8 or 1/2 inch Square Drive

Remove the fan drive belt.

18 mm, Part No. 3377371, Engine Barring Gear

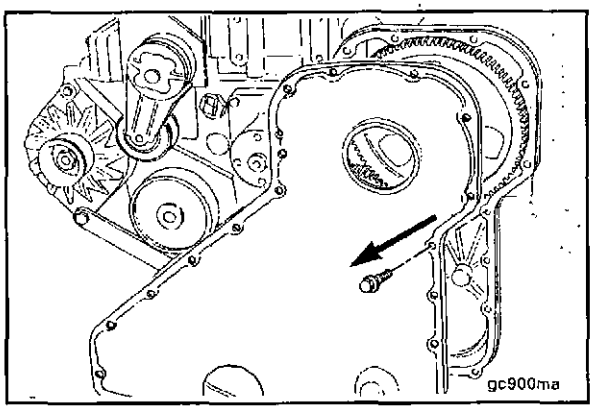
Remove the vibration damper and pulley. Hold the crankshaft while removing the capscrews.

Remove the crankshaft oil seal dust shield, if used.



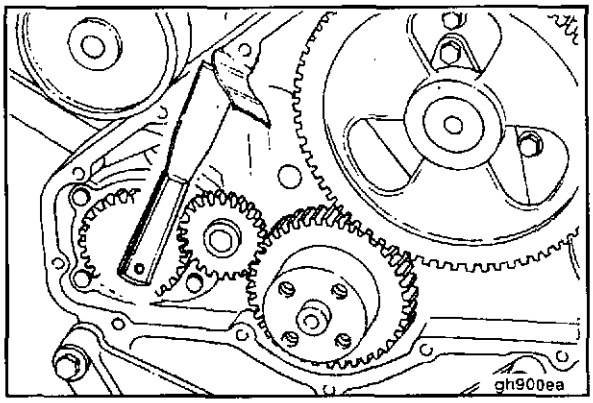
10 mm

Remove the gear cover.



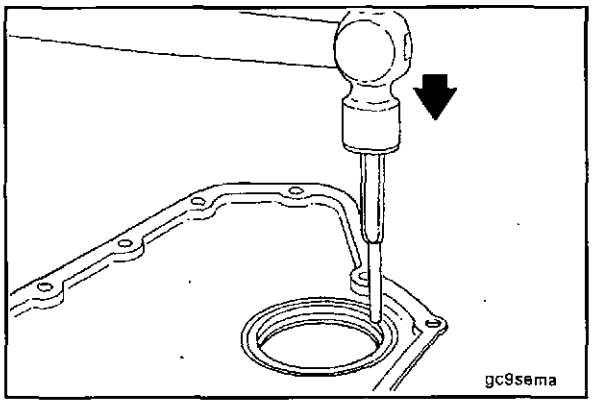
Cleaning and Inspection

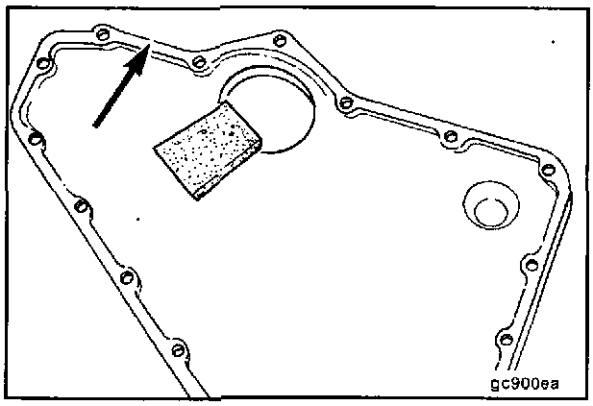
Clean the gasket sealing surface.



Hammer, Punch

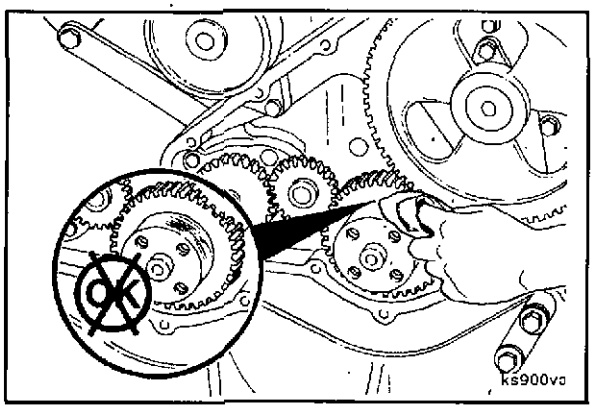
Drive or press the seal out of the front cover.





Clean the gasket sealing surfaces and the surface between the oil seal and gear cover.

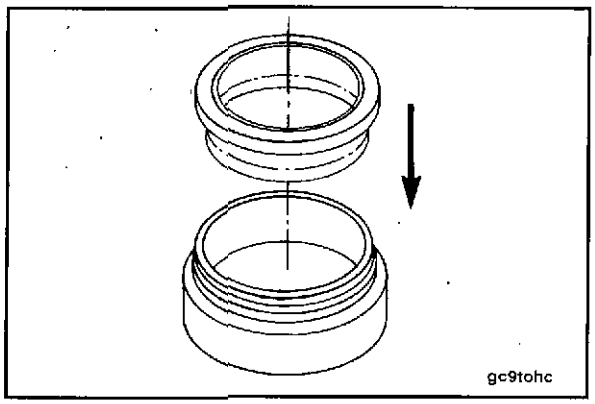
Inspect the gear cover for cracks, dents and other damage.



Caution: The seal lip and the sealing surface on the crankshaft must be clean and free from all oil residue to prevent seal leaks.

Thoroughly clean the seal contact area of the crankshaft.

Visually inspect the sealing surface of the crankshaft for wear. If the crankshaft has a groove worn due to the oil seal, a wear sleeve **must** be used to prevent seal leakage. Refer to Procedure 7-19.

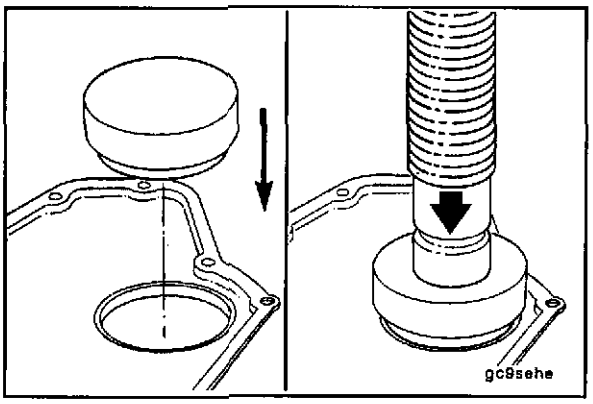


Installation

3824499 Installation Tool

Leave the plastic pilot installation tool in the lubricating oil seal.

Position the seal on the service tool, Part No. 3824499, with the lubricating oil seal dust lip facing outward.



NOTE: Properly support the front cover lubricating oil seal flange to prevent damage to the lubricating oil seal and front cover.

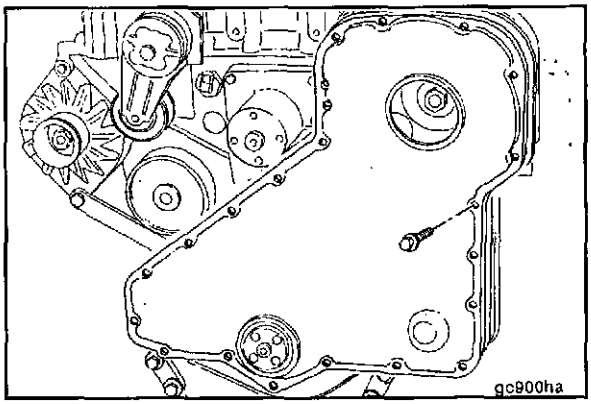
Press the lubricating oil seal into the front cover from the back side of the cover toward the front side of the cover.

Press the lubricating oil seal until the service tool bottoms against the front cover.

Apply a thin (2 mm) bead of sealant, Part No. 3823494, to both sides of the front cover gasket.

NOTE: Do not remove the plastic seal pilot tool from the lubricating oils seal at this time. Use the plastic seal pilot tool to guide the seal on the crankshaft.

Install the gasket and front cover on the engine.

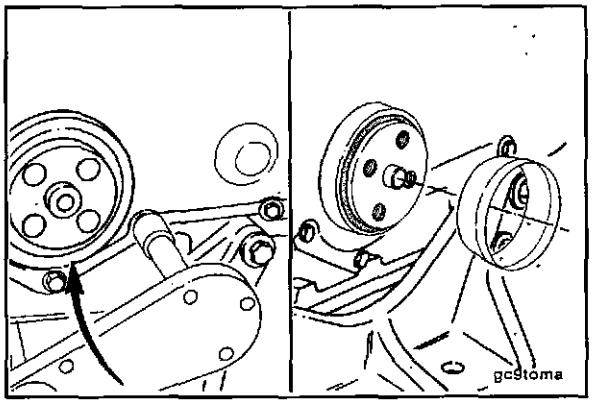


Tighten the gear cover capscrews.

NOTE: The capscrews must be torqued within 15 minutes after applying the sealant to the gasket.

Torque Value: 24 N•m [18 ft-lb]

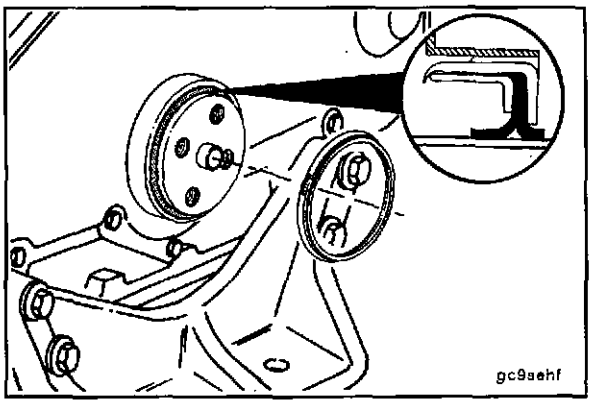
Remove the plastic seal pilot tool from the crankshaft.



Install the crankshaft oil seal dust shield, if used, as follows:

- Push the dust shield onto the crankshaft with the part number facing out away from the engine.
- The dust shield must contact the oil seal.

NOTE: No lubrication is required for installation.



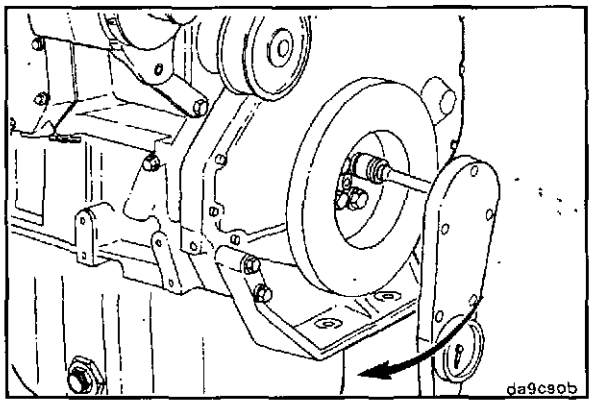
18 mm, Part No. 3377371, Engine Barring Gear

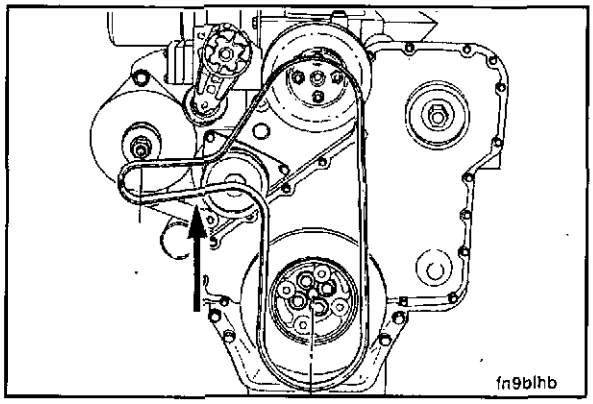
Install the vibration damper and pulley.

Use the barring gear to hold the crankshaft while tightening the capscrews.

Torque Value:

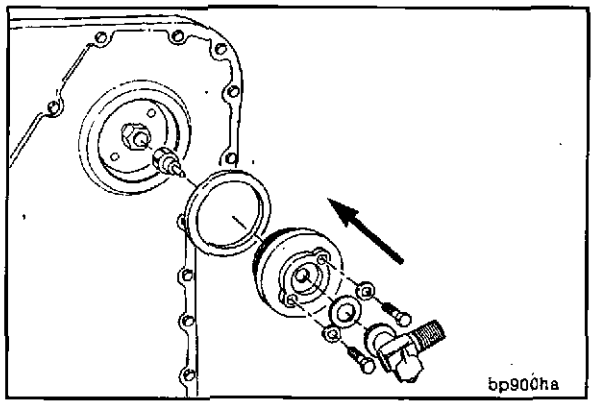
Vibration Damper: 200 N•m [148 ft-lb]
Pulley to Vibration Damper: 77 N•m [57 ft-lb]





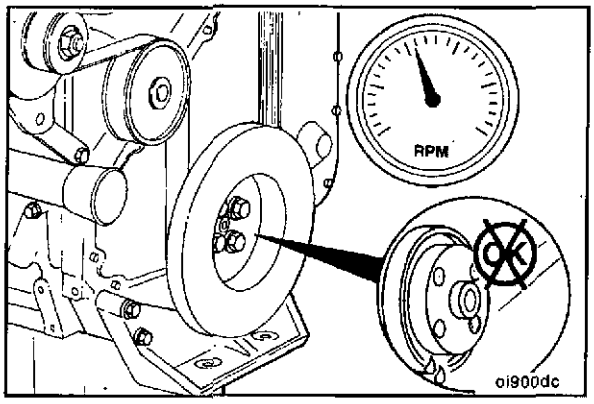
3/8 or 1/2 inch Square Drive

Install the fan drive belt.

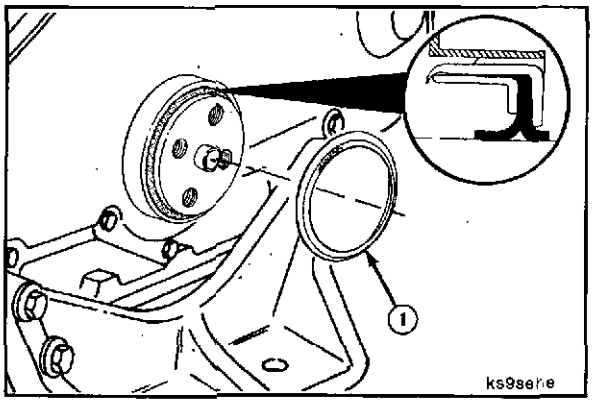


Install the tachometer drive and cable.

Install the driven accessories in the reverse order of removal.



Operate the engine 5 to 10 minutes to check for leaks and proper operation.



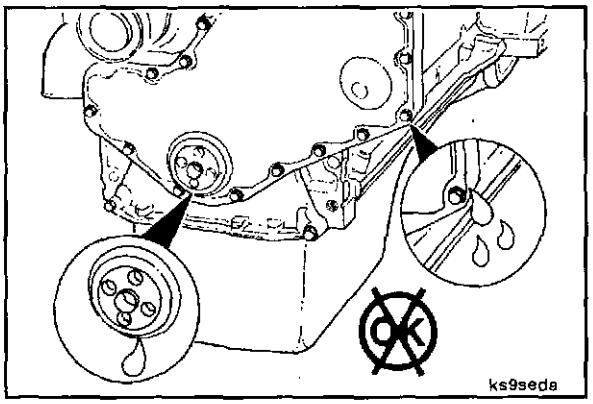
Seal, Front Crankshaft - Replacement (7-18)

General Information

The front crankshaft seal is mounted in the front gear cover. A double lipped Teflon seal is used. The sealing surface on the crankshaft **must be** clean and dry during assembly.

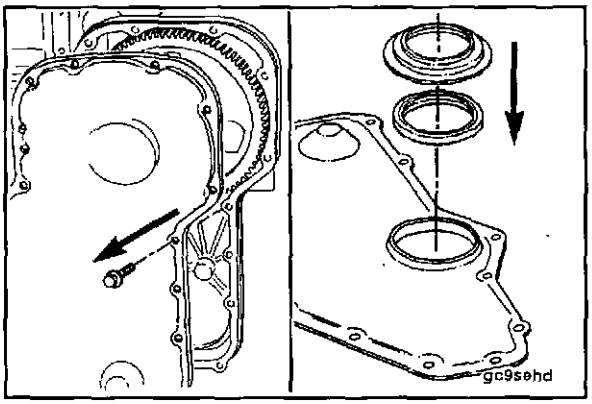
NOTE: For engines operating in extremely dusty environments, a dust shield (1) is used to keep debris from entering the seal and causing premature wear to the oil seal and crankshaft.

Before removing the gear cover or oil seal, clean the front area of the engine and visually inspect for leaks from the gear cover gasket and seal area. If the seal is leaking, it will be necessary to remove the gear cover for seal replacement.



Removal and Installation

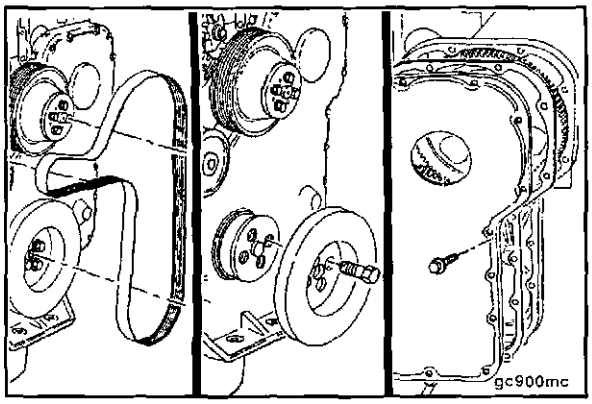
NOTE: Since the gear cover has to be removed to replace the crankshaft seal, the instructions are included in Procedure 7-17, Gear Cover Replacement.



Wear Sleeve, Front Crankshaft - Replacement (7-19)

Removal

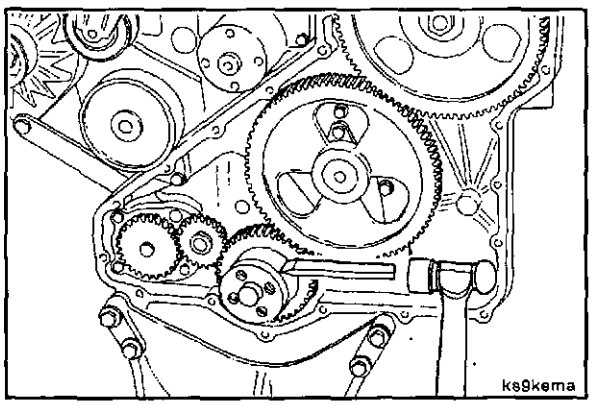
Remove the fan drive belt, vibration damper, gear cover and seal. Refer to Procedure 7-17.

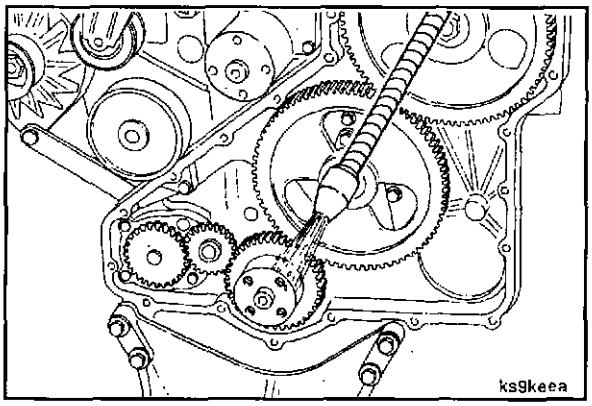


Hammer and Chisel

Caution: Do not nick or gouge the crankshaft with the chisel. If the crankshaft is damaged, it must be replaced.

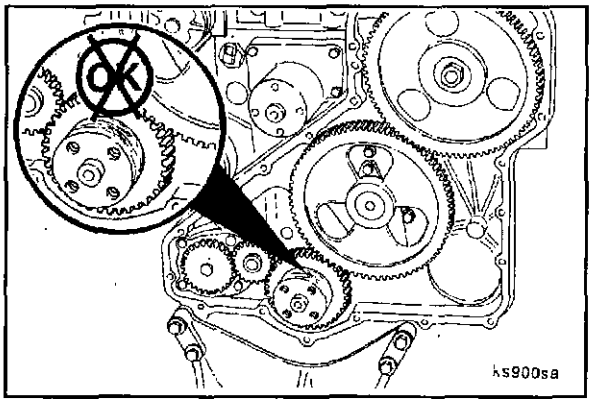
Use a hammer and a chisel that is only as wide as the wear sleeve. Make one or two chisel marks across the wear sleeve. This will expand the wear sleeve allowing the sleeve to be removed.



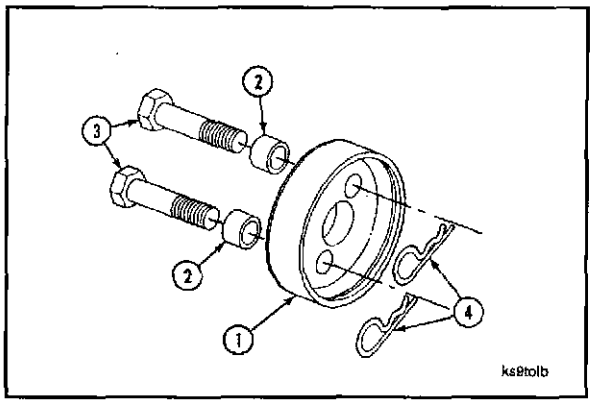


Cleaning and Inspection

Clean the crankshaft seal area.



Inspect the crankshaft at the oil seal area for dirt, nicks, chisel marks, scratches, rust or corrosion, or other damage that would prevent a proper wear sleeve installation.

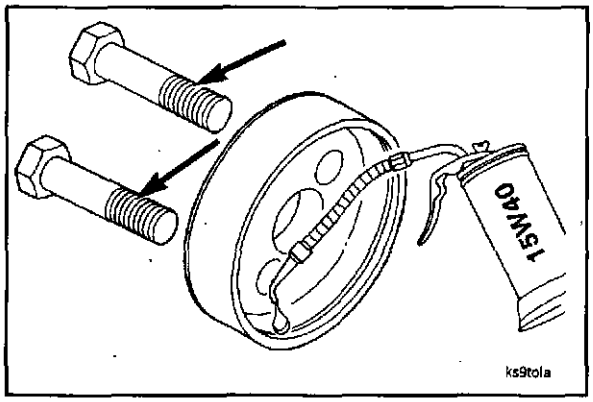


Installation

Part No. 3823908, Crankshaft Front Wear Sleeve Installation Tool

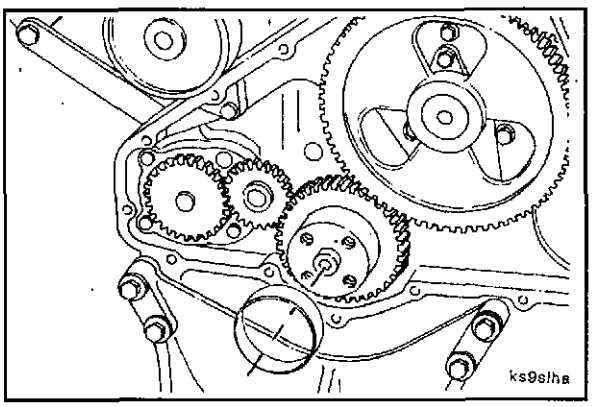
Use the driver to install the wear sleeve to the correct position on the crankshaft. The kit consists of the following:

Ref. No.	Description	Qty.
1	Driver	1
2	Spacer	2
3	Capscrew M14X1.5X60mm	2
4	Hair Pin Cotter	2

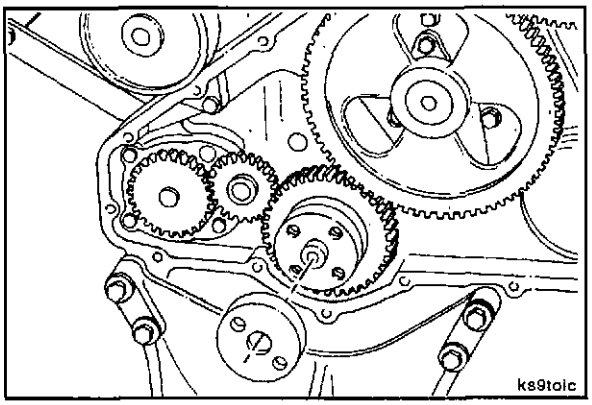


Apply a thin coat of 15W-40 engine oil to the driver inside diameter and capscrew threads.

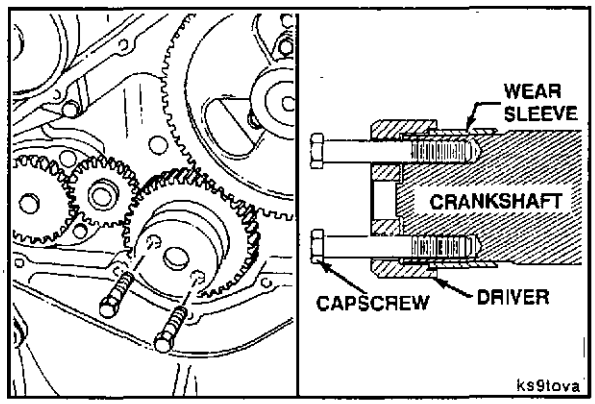
Position the chamfered end of the wear sleeve onto the end of the crankshaft.



Position the counterbore end of the driver onto the wear sleeve.



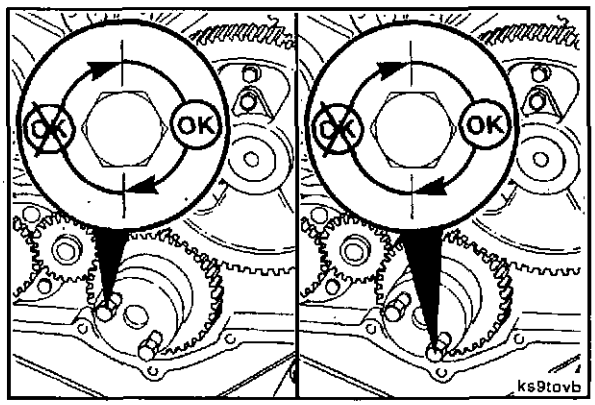
Install two capscrews (without spacers or hair pin cotters) through the driver and into the crankshaft capscrew holes. Align the wear sleeve and driver perpendicular with the crankshaft. Tighten the capscrews "finger tight".

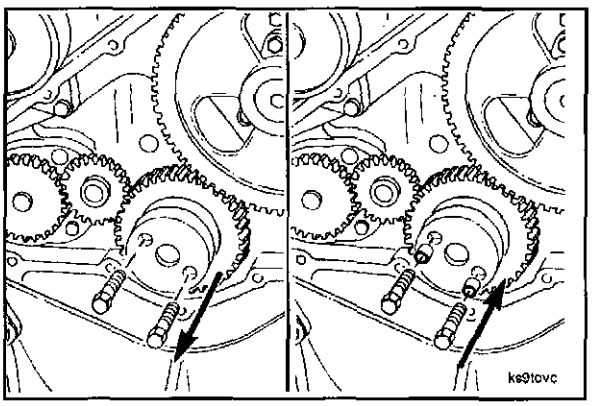


Alternately tighten the capscrews until the sleeve is installed to a depth of approximately 16 mm [0.625 inch].

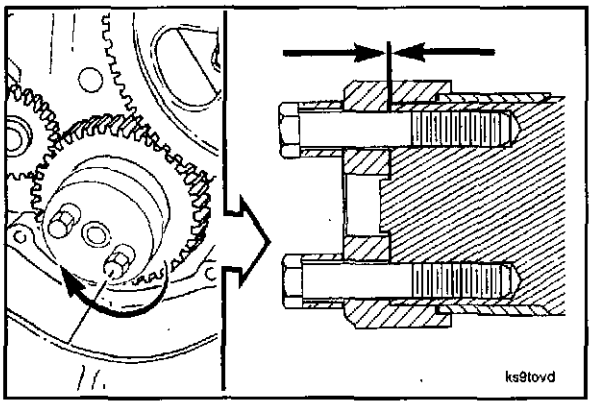
NOTE: To prevent damage to the wear sleeve, do not exceed 1/2 revolution of each capscrew.

Approximate torque value: 20 N•m [15 ft-lb]

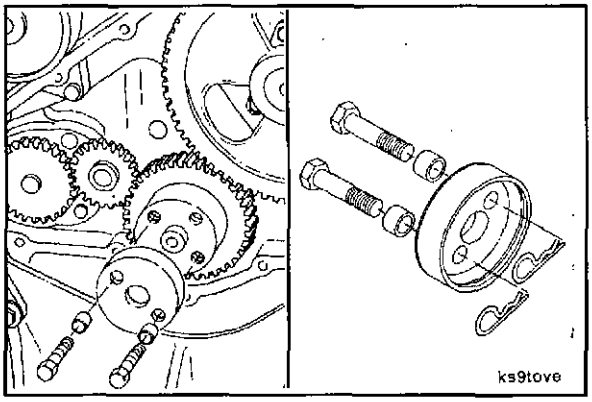




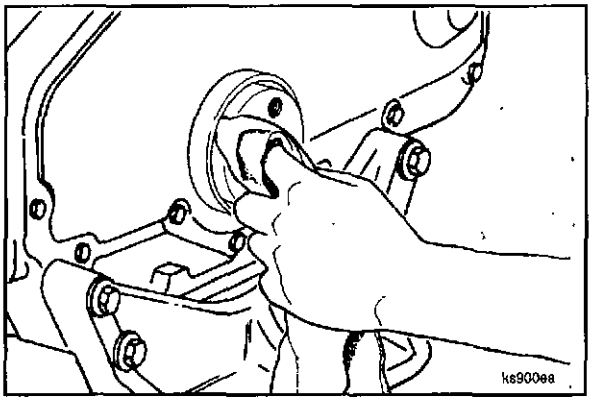
Remove the capscrews and install a spacer on each capscrew. Install the two capscrews again.



Continue to alternately tighten the capscrews until the bottom of the driver contacts the end of the crankshaft.



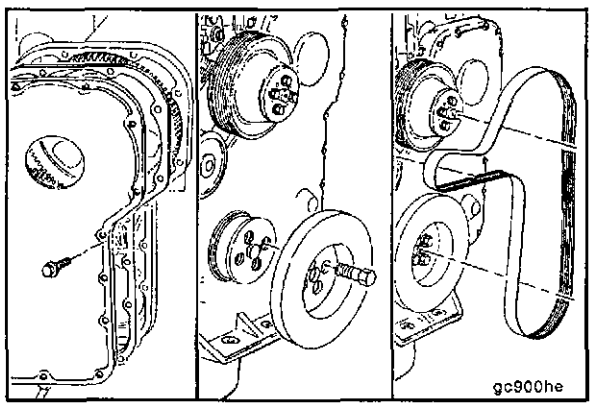
Remove the driver. Use the hair pin cotters to secure the capscrews and spacers to the tool during storage.



Clean the wear sleeve and crankshaft of any excess lubricate.

NOTE: The wear sleeve and oil seal mating surface **must** be clean and dry to be sure of proper oil sealing.

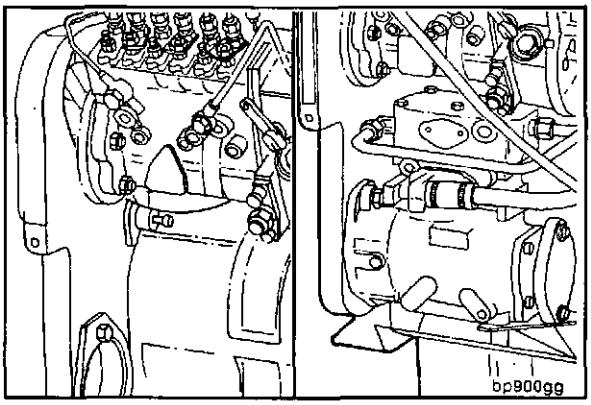
Install the gear cover, vibration damper and fan drive belt. Refer to Procedure 7-17.



Gear Housing - Replacement (7-20)

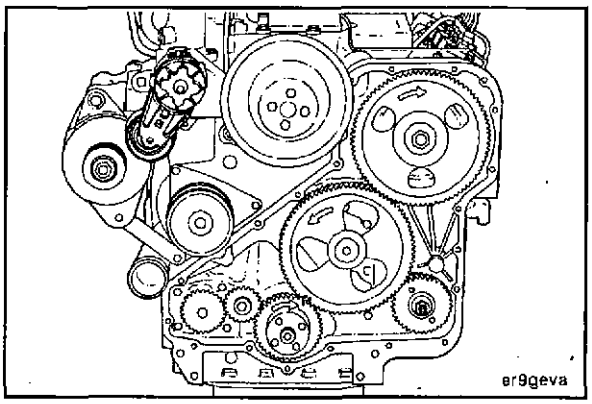
General Information

The gear housing provides a support for the injection pump, timing pin, and the accessory drive gear, if used.

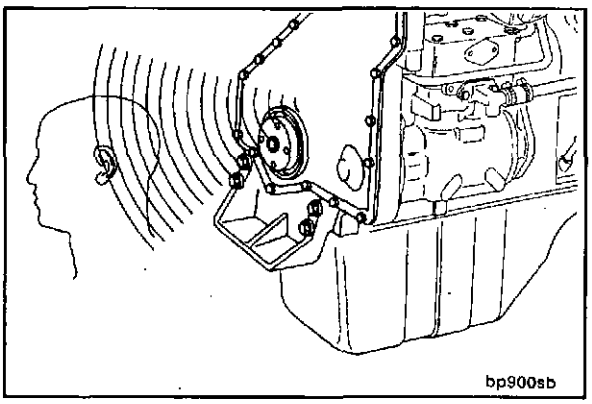


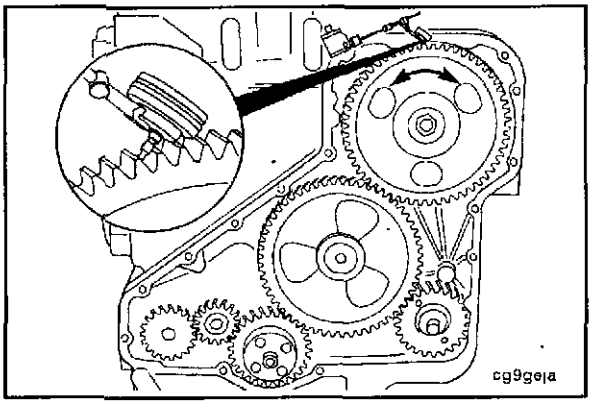
Gear Train

The gear train consists of the crankshaft gear, lubricating oil pump drive and idler gear, camshaft gear, fuel pump drive gear and accessory drive gear, if used.



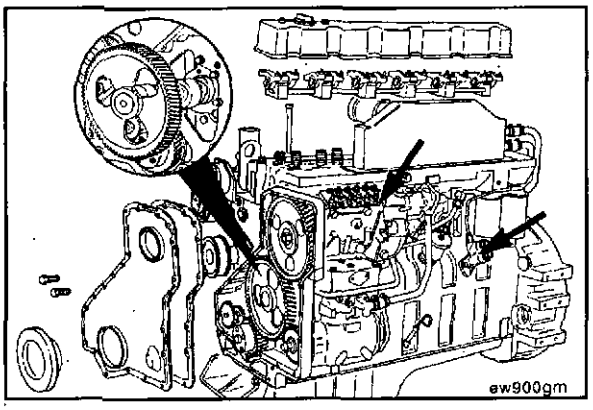
Noise emitted from the gear housing can indicate worn or damaged gear teeth or excessive gear back lash.





Excessive gear backlash can affect engine timing and engine performance.

Refer to the applicable sections in this manual to measure the gear backlash and check gear tooth wear.



Removal

Remove the valve cover. Refer to Procedure 7-02.

Remove the rocker assemblies and push rods. Refer to Procedure 7-08.

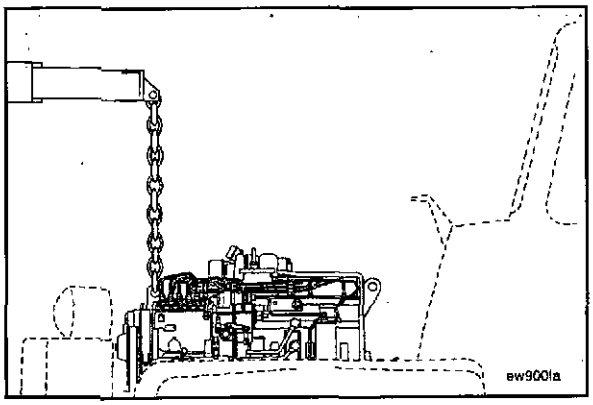
Remove the fan drive belt, vibration damper and gear cover. Refer to Procedure 7-17.

Remove the fuel transfer pump. Refer to Procedure 5-04.

Remove the fuel injection pump. Refer to Procedure 5-10.

Remove the camshaft and tappets. Refer to Procedure 7-24.

Remove the accessory drive or air compressor, if equipped. Refer to Procedure 4-05.



15 mm

Support the front of the engine and remove the front engine mount.

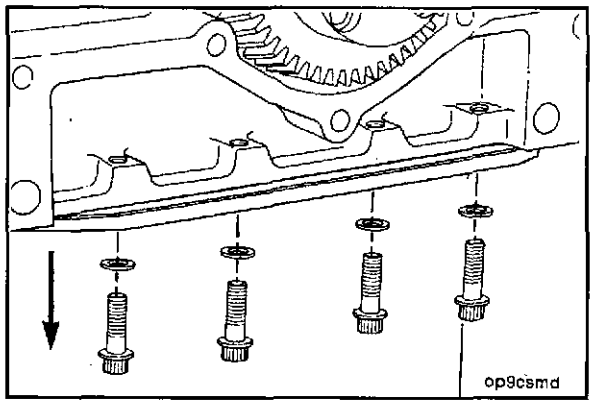
10 mm

Loosen all the oil pan mounting capscrews four to five turns.

Remove the four front oil pan capscrews which secure the oil pan to the gear housing.

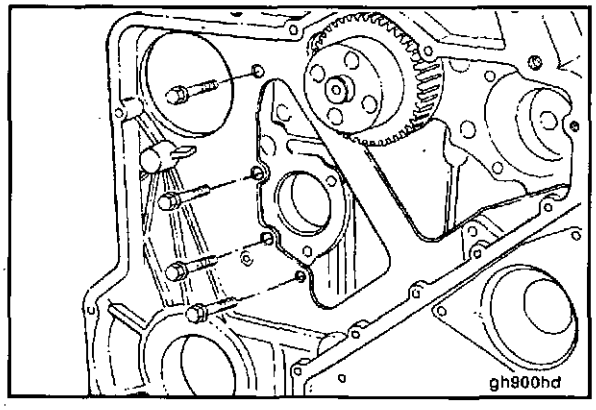
Caution: Use extreme care when releasing the oil pan gasket from the gear housing to prevent damage to the gasket. If the gasket is damaged, it may be necessary to remove the oil pan and replace the gasket. Refer to Procedure 2-13.

Insert a feeler gauge or a shim stock between the gear housing and the oil pan gasket. Move the feeler gauge or shim stock back and forth to release the gasket from the gear housing.



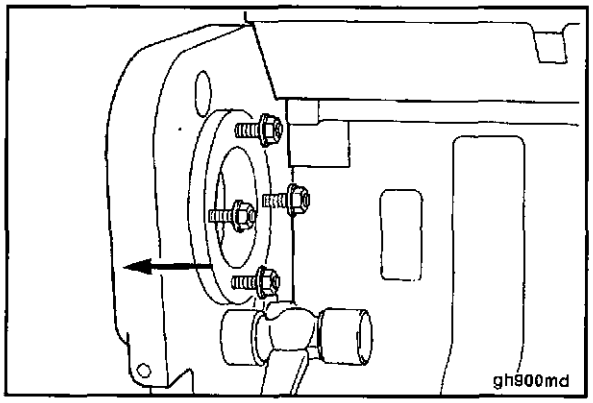
10 mm

Remove the gear housing capscrews.



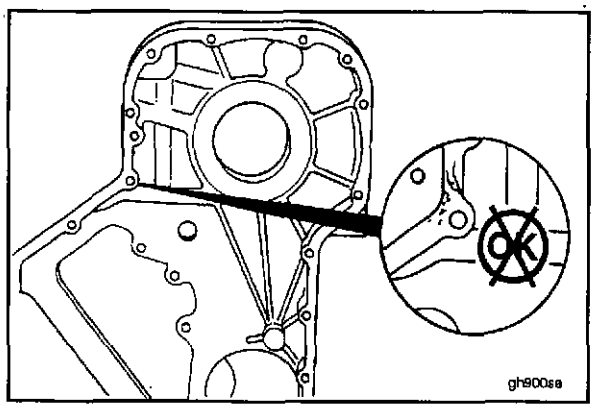
Plastic Hammer

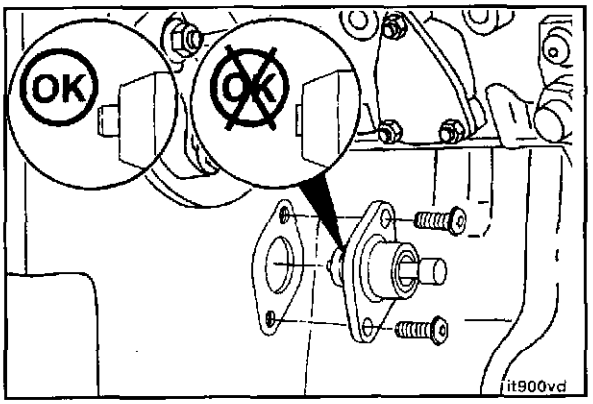
Remove the gear housing.



Cleaning and Inspection

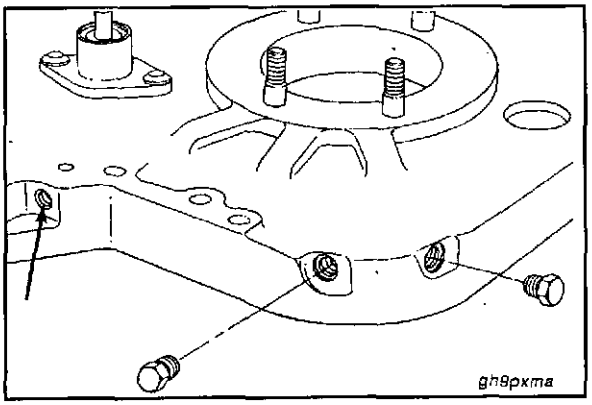
Visually inspect the gear housing for cracks or damaged sealing surfaces.





Inspect the timing pin housing and pin for damage.

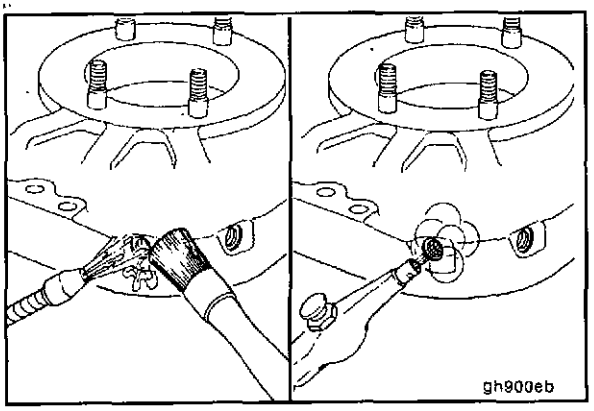
NOTE: Do **not** remove the timing pin assembly unless it is *damaged or leaking, or the gear housing is being replaced.* Refer to Procedure 7-07.



7/16 inch

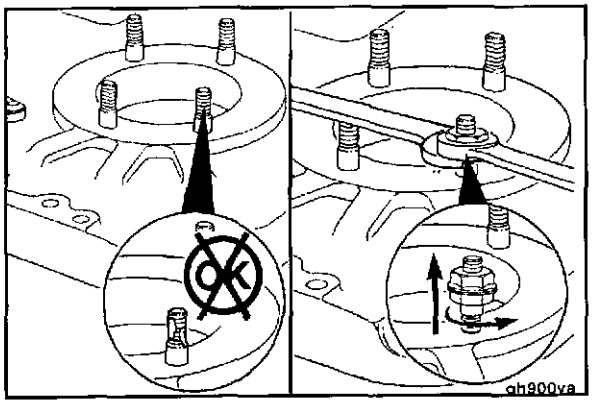
NOTE: If the gear housing is being used again:

Remove the pipe plugs from the oil drillings.



Nylon Brush

Use solvent and a nylon bristle brush to clean the oil drillings. Dry with compressed air.

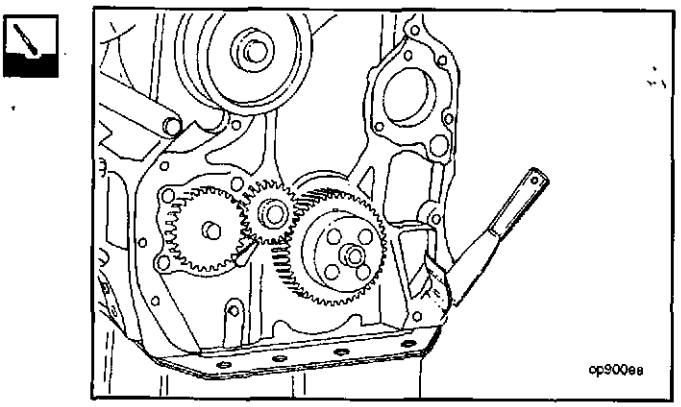


15 mm

Visually inspect the fuel pump mounting studs for damage.

To install or remove the fuel pump studs, use two nuts locked together on the stud.

Clean the gasket surface of the cylinder block.



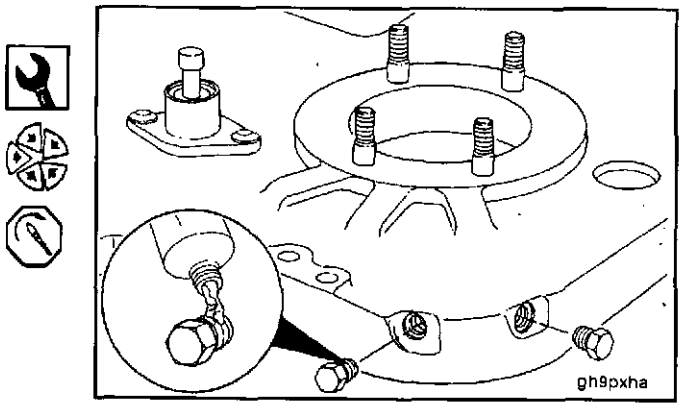
Installation

7/16 inch

Coat the pipe plugs with pipe sealant and install.

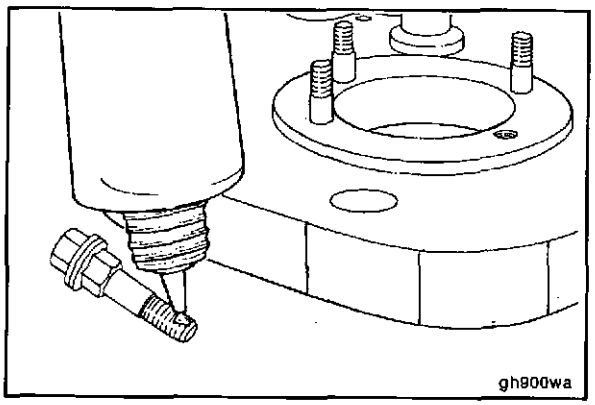
Torque Value: 7 N•m [60 in-lb]

Do **not** overtighten.



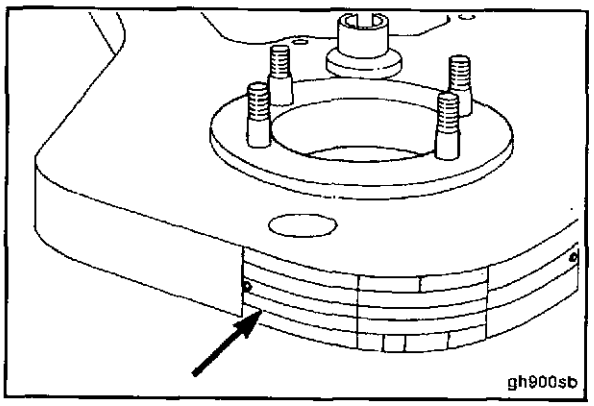
15 mm

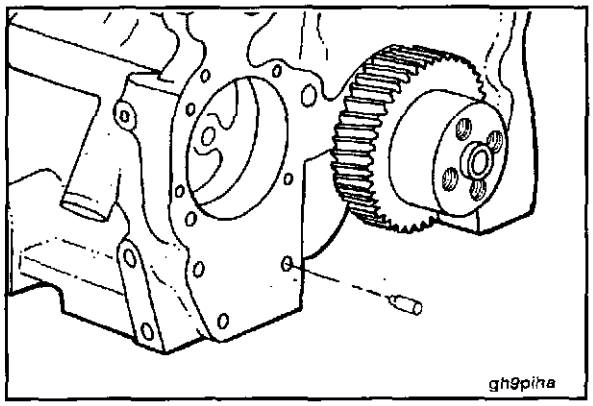
If the fuel pump studs are damaged or being installed in a new housing, coat the threads with Loctite™ 242 and use two nuts locked together to remove and install.



Small Chisel and Hammer

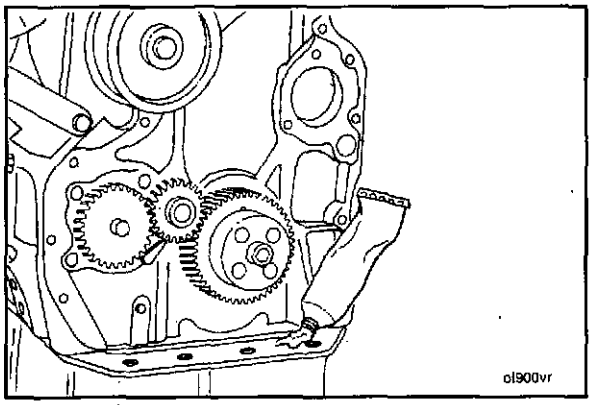
If the gear housing is being replaced, remove the engine dataplate and install on the new housing. Refer to Procedure 7-21.





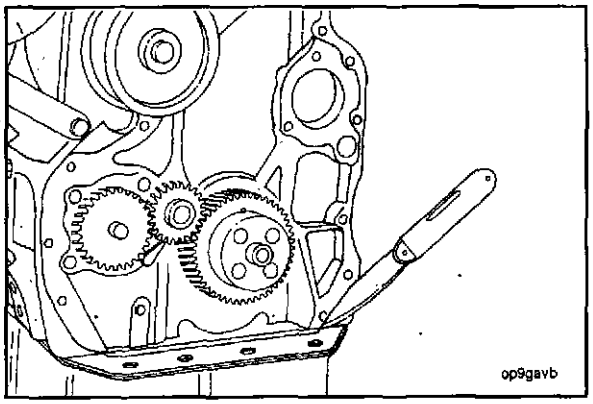
If removed, install the two gear housing dowel pins.

The tapered end of the dowel fits into the cylinder block; drive the pin to the bottom of the hole.

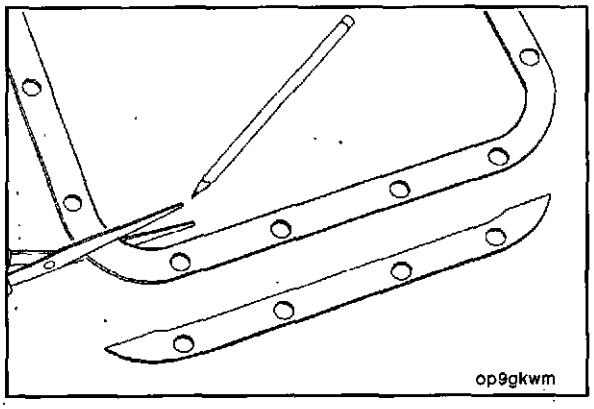


Inspect the oil pan gasket. If it is **not** torn, apply Part No. 3823494, Three Bond RTV sealant around the capscrew *holes and at the joint of the gear housing.*

NOTE: The gear housing and lubricating oil pan capscrews must be torqued within 15 minutes after applying the sealant.



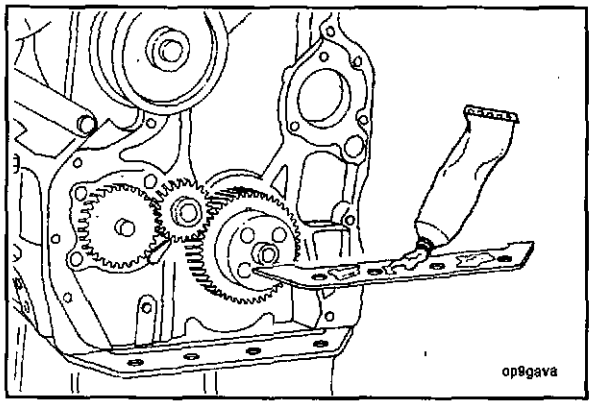
If the gasket is torn, it may be repaired. Cut the torn gasket off even with the front of the engine block.



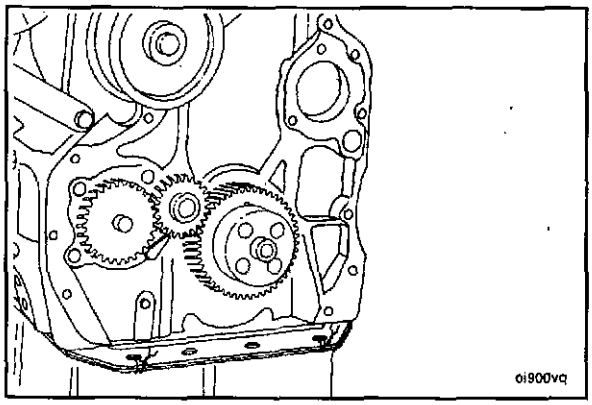
Use the old gasket as a pattern and cut the front section of a new gasket to the same size.

Clean the sealing surfaces and coat the new gasket on both sides with Part No. 3823494, Three Bond RTV sealant.

NOTE: The gear housing and lubricating oil pan capscrews must be torqued within 15 minutes after applying the sealant.

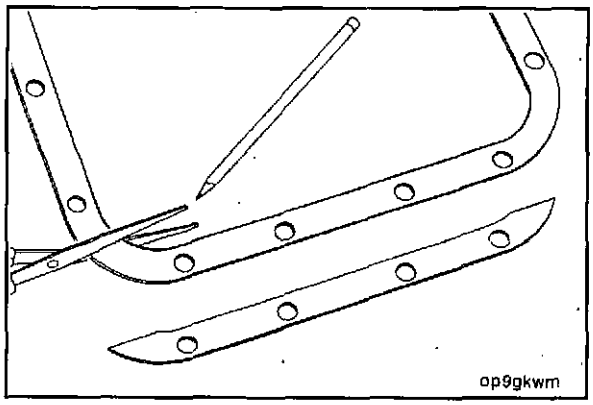


Use common thread or a very fine wire to hold the new gasket splice in position as illustrated.

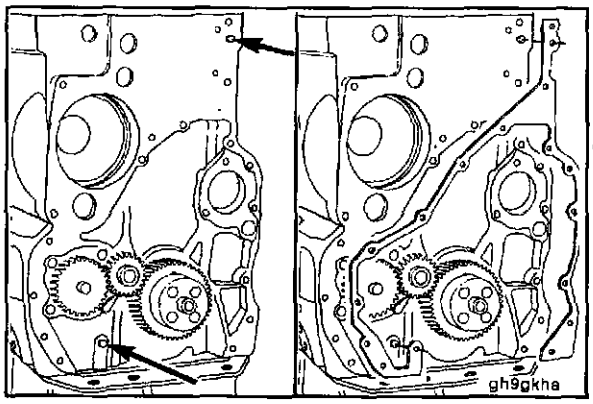


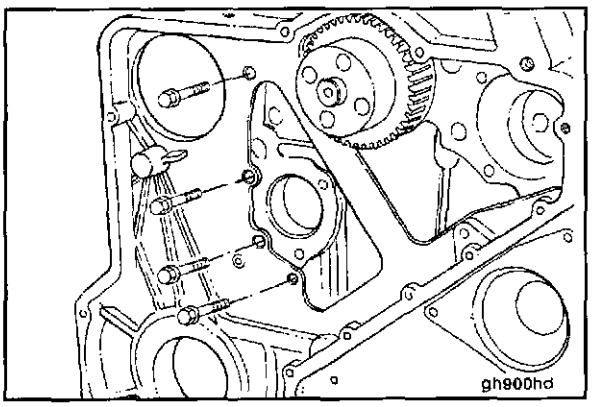
Mark and trim the new gear housing gasket, as illustrated.

1.59 mm [1/16 inch]



Position the gasket on the alignment dowels.





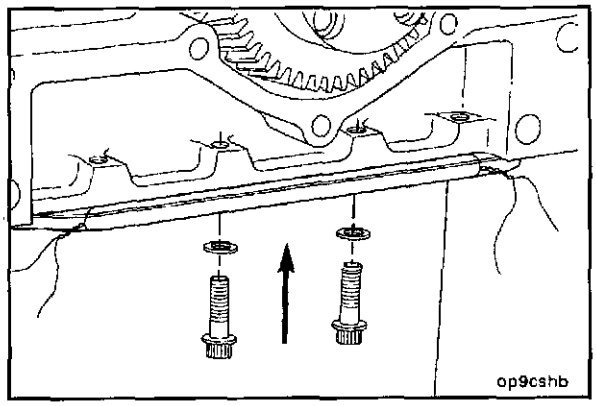
10 mm

Carefully install the gear housing and capscrews. Make sure both gaskets are in place.

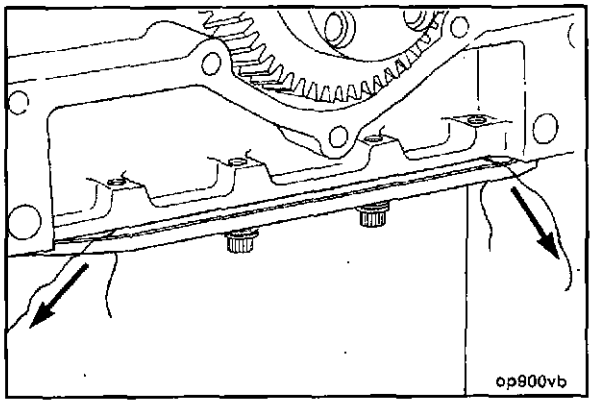
Torque Value:

M8 capscrews 24 N•m [18 ft-lb]
M12 capscrews 60 N•m [44 ft-lb]

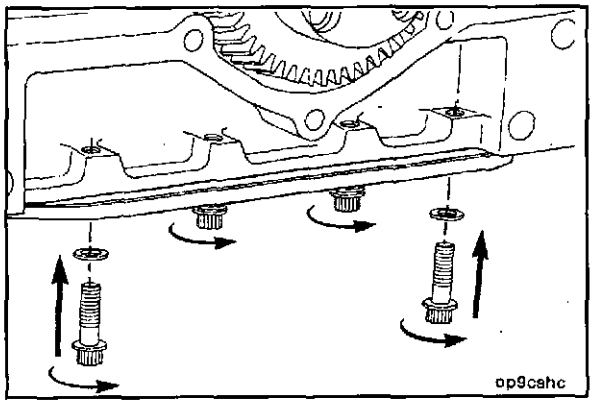
Caution: If a new housing or other than the original housing is installed, the timing pin assembly must be accurately located. Refer to Procedure 7-07.



Start two oil pan capscrews in the holes **not** being used to tie the gasket in place.



Remove the thread or wire holding the gasket in place.

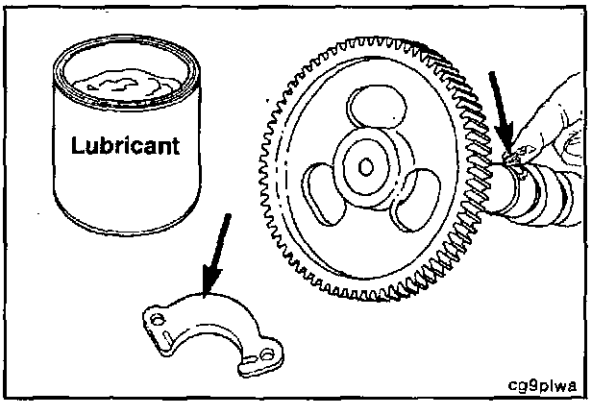


10 mm

Install the remaining two capscrews and tighten all oil pan mounting capscrews.

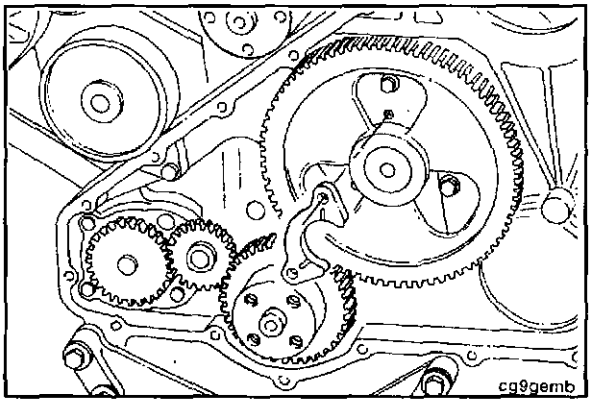
Torque Value: 24 N•m [18 ft-lb]

Lubricate the camshaft and thrust plate with Lubriplate™ 105.



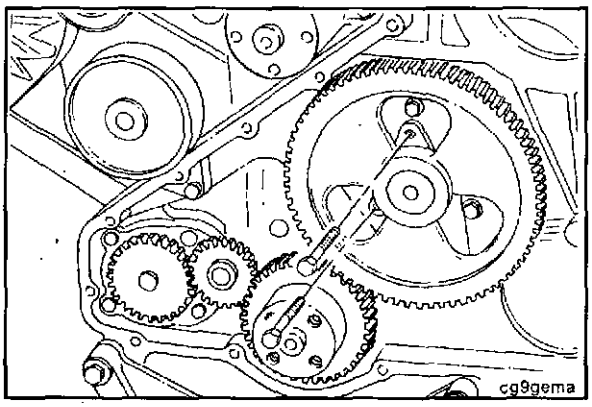
Install the camshaft/thrust plate.

Make sure the timing marks on the camshaft and camshaft gears are aligned.



Install the thrust plate capscrews.

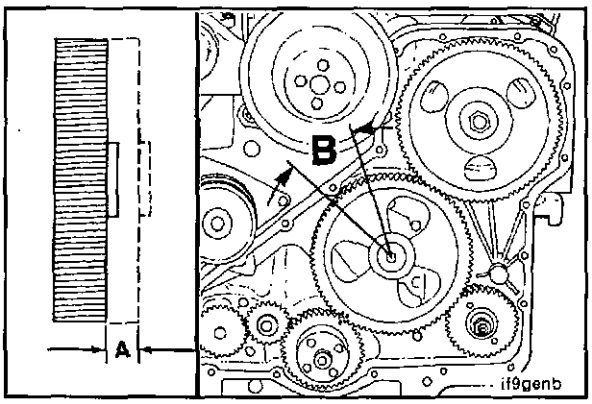
Torque Value: 24 N•m [18 ft-lb]

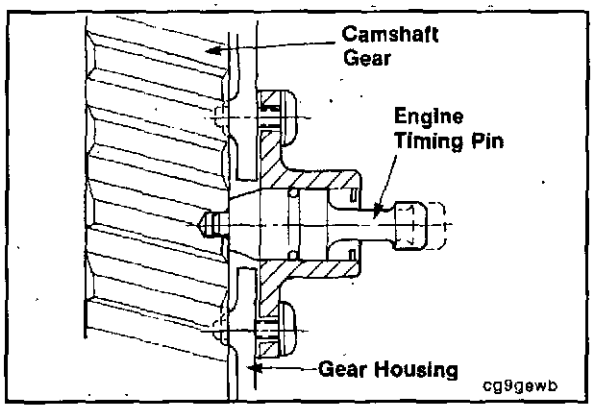


Verify the camshaft has proper backlash and end play. End play is controlled by the thickness of the thrust plate and the groove in the camshaft.

Camshaft End Clearance (A)		
mm		in
0.12	MIN	0.0047
0.46	MAX	0.018

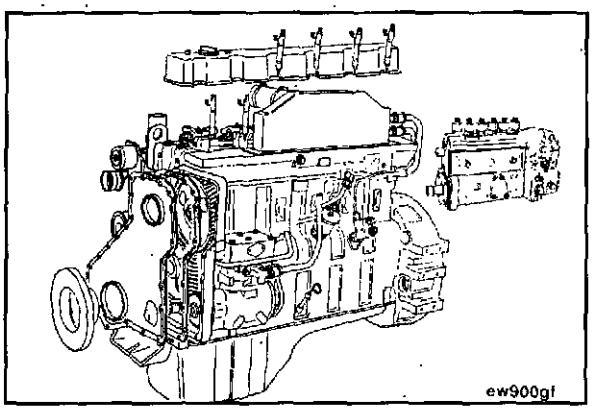
Camshaft Gear Backlash Limits (B)		
mm		in
0.08	MIN	0.003
0.33	MAX	0.013





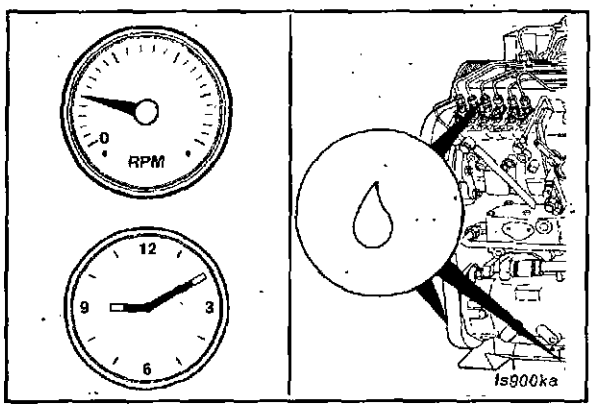
Timing Pin Relocating

NOTE: The location of the timing pin assembly on the gear housing is critical for correct engine adjustments. If the original gear housing is being installed, it is unnecessary to relocate the timing pin. If a new housing is being installed, *refer to Procedure 7-07 for timing pin installation and* adjustment.

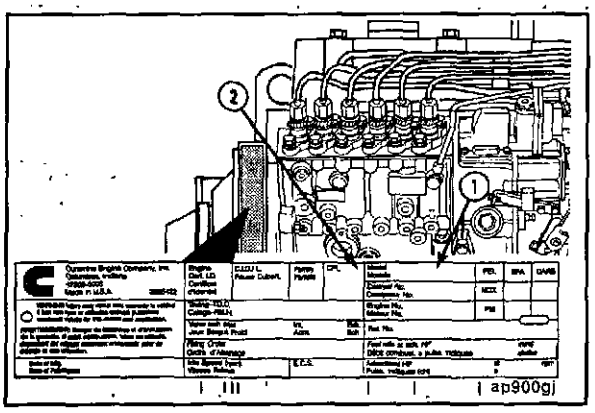


Complete the installation of the removed components:

- Accessory drive or air compressor, Procedure 4-05.
- Fuel injection pump, Procedure 5-10.
- Fuel transfer pump, Procedure 5-04.
- Valve tappets, Procedure 7-24.
- Fan drive belt, vibration damper and gear cover, Procedure 1-03.
- Rocker assemblies and push rods, Procedure 7-05.
- Valve cover, Procedure 7-02.



Operate the engine at idle for 5 to 10 minutes to check for leaks and proper operation.



Engine Dataplate - Replacement (7-21)

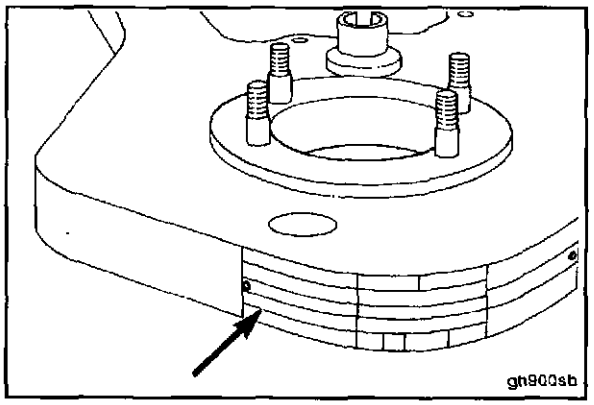
The engine dataplate shows specific information about the engine. The engine serial number (1) and Control Parts List (CPL) (2) provide information for ordering parts and service needs.

The dataplate must remain with the engine. If the gear housing is replaced, remove the dataplate and install it on the new housing.

Removal

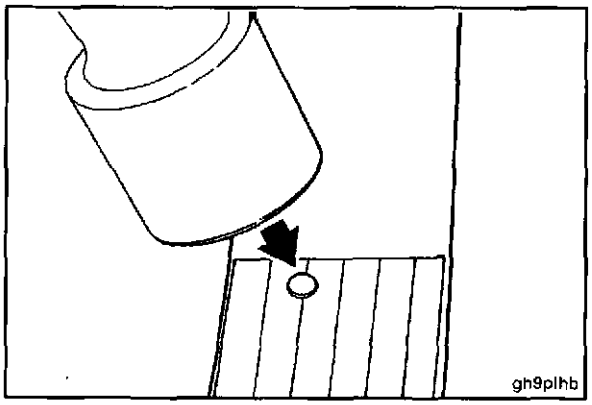
Small Chisel and Hammer

Remove the rivets that secure the dataplate to the gear housing.

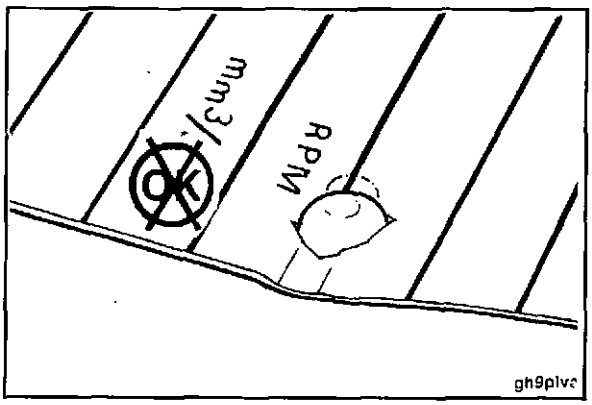


Installation

Drive the rivets in until they contact the dataplate.

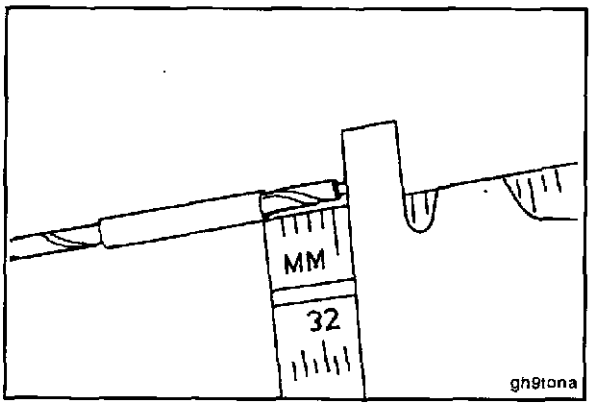


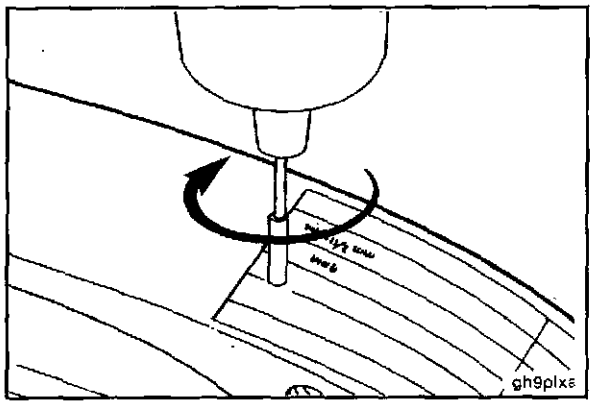
Caution: If the rivets are driven in too far, they will cut through the dataplate.



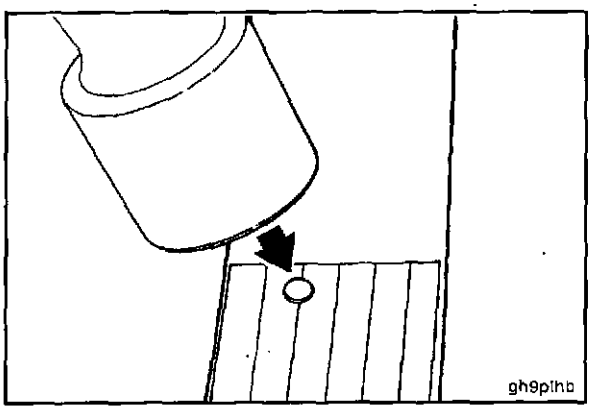
2.0 mm Drill Bit

If the dataplate is loose or has been damaged, drill new holes and attach with new rivets. Mark the drill bit at 6.0 mm [0.236 inch] to avoid drilling too deep into the gear housing.

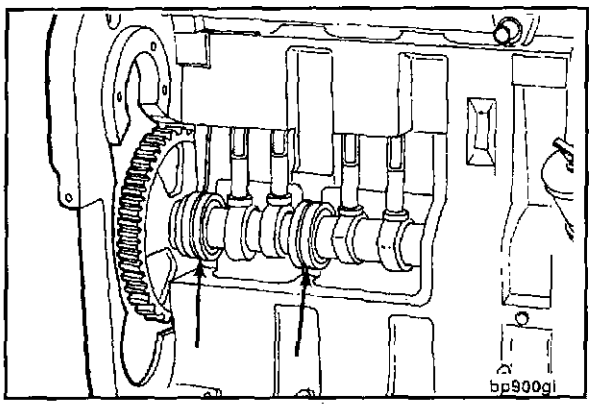




Drill the dataplate, taking care not to destroy any information printed on the dataplate.



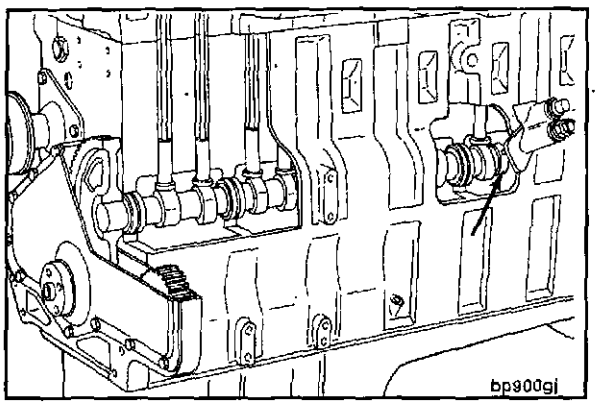
Drive the rivets in until they contact the dataplate.



Camshaft - Replacement (7-22)

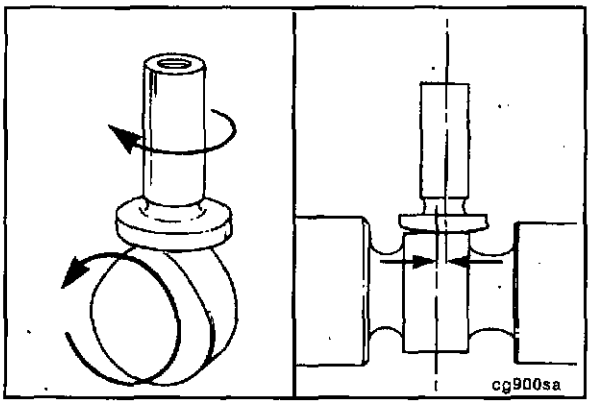
General Information

The camshaft is gear driven from the crankshaft. A replaceable bushing is used for each of the camshaft journals.



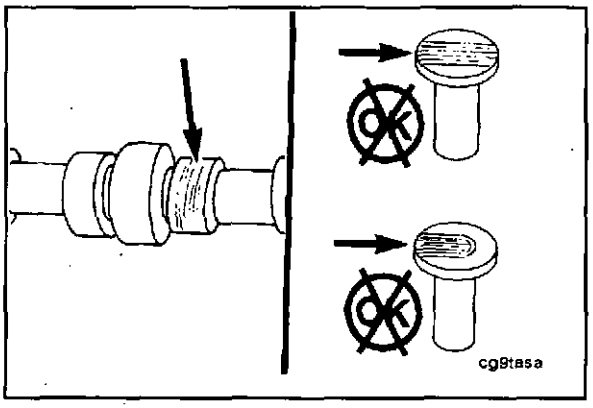
The camshaft has lobes to operate the intake and exhaust valves and a special lobe to drive the fuel transfer pump. The valve lobes contact the valve tappets which operate the valves. The plunger of the fuel transfer pump rides directly against the special lobe of the camshaft. The profile of the cam lobes is the same for all C Series engines.

The tappets are mushroom shaped. The offset position of the tappet against the camshaft lobe causes the tappet to rotate as it lifts the push rod.



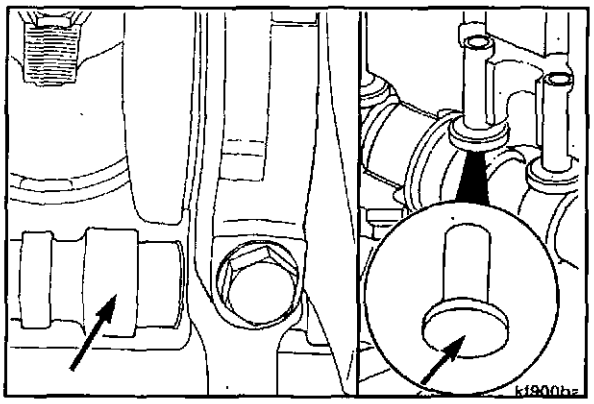
Diagnosing Malfunctions

Loose rocker levers and the need to reset the valve clearance frequently can indicate camshaft lobe or tappet wear. If an inspection of the levers, valve stems and push rods does **not** show wear, then tappet and/or camshaft lobe wear can be suspected.

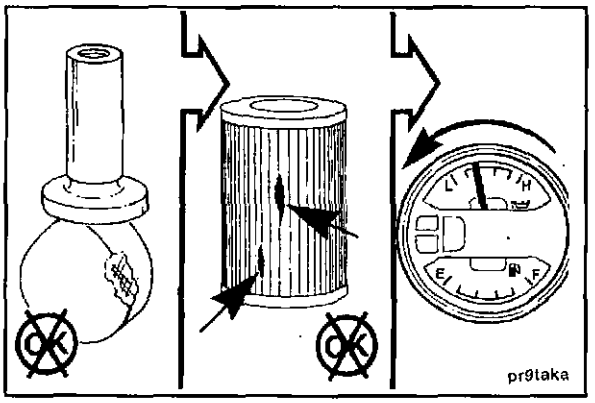


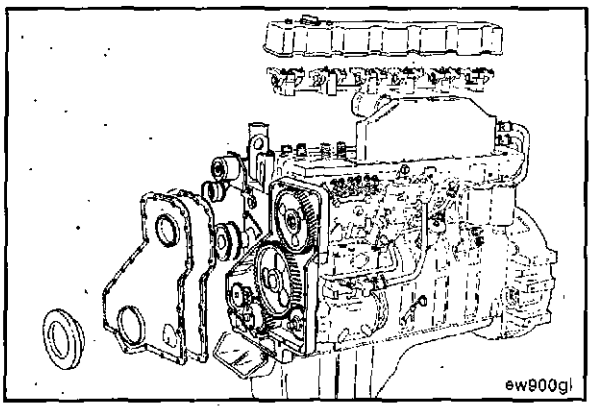
Caution: Anytime a new camshaft is installed, new tappets must also be installed.

The camshaft lobes can be visually inspected after removing the oil pan. Similarly, the face of the tappet can be inspected after removing the push rods and lifting the tappet.



A severely damaged camshaft journal(s) can generate small metal particles which will be found in the oil pan and filter and will be indicated as "iron" in an oil analysis. As the clearance in the journal(s) increases, a small decrease in oil pressure may be detected.

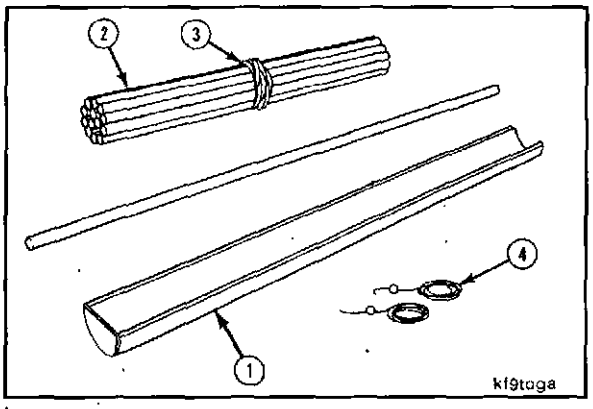




Removal

Remove the following components:

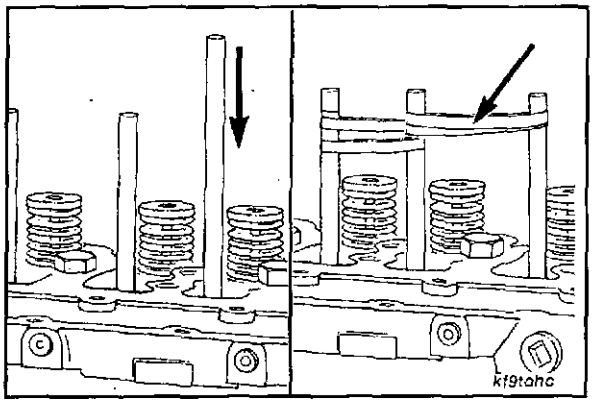
- Valve cover, Procedure 7-02.
- Rocker assemblies, Procedure 7-05.
- Push rods, Procedure 7-08.
- Vibration damper, Procedure 7-16.
- Gear cover, Procedure 7-17.
- Fuel pump drive gear, Procedure 5-10.
- Fuel transfer pump, Procedure 5-04.



Part No. 3822513, Tappet Removal Tool Kit

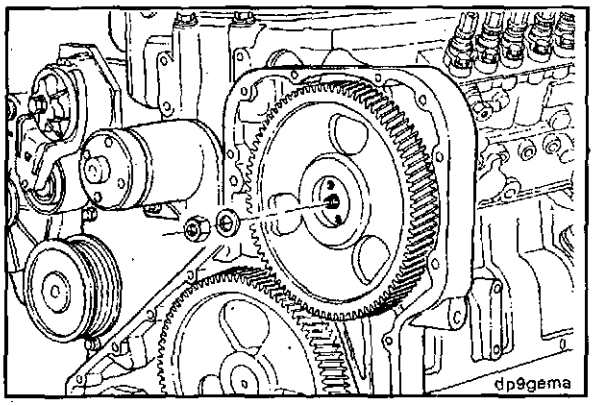
Lift the tappets so the camshaft can be removed.

Ref. No.	Description	Qty.
1	Valve Tappet Tray	1
2	Dowel Rods	12
3	Rubber Bands	12
4	Nylon String	1



Push a wooden dowel rod into each tappet. It may be necessary to push the dowel into the tappet with a soft face hammer.

Pull each valve tappet up until it makes contact with the cylinder block. Put a rubber band around two dowels to hold the tappets off the camshaft. Refer to Procedure 7-24.

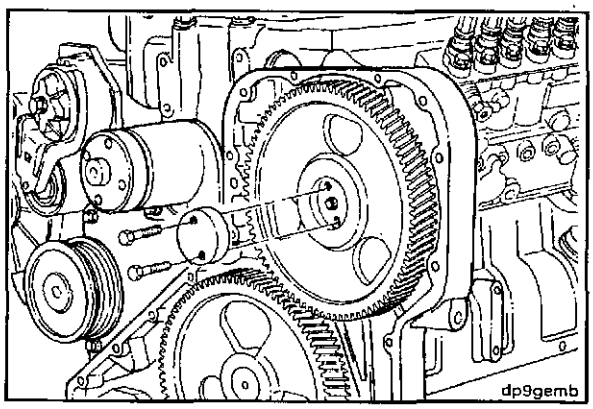


22 mm (PES.A Pump), 27 mm (PES.MW Pump), 30 mm (PES.6P)

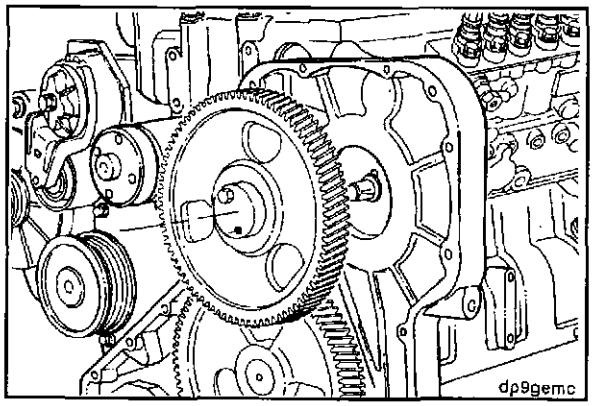
Remove the nut and washer from the fuel pump drive gear.

Part No. 3824469, Fuel Pump Gear Puller

Install the puller on the drive gear. Tighten the capscrews until the gear is loose on the fuel pump drive shaft.



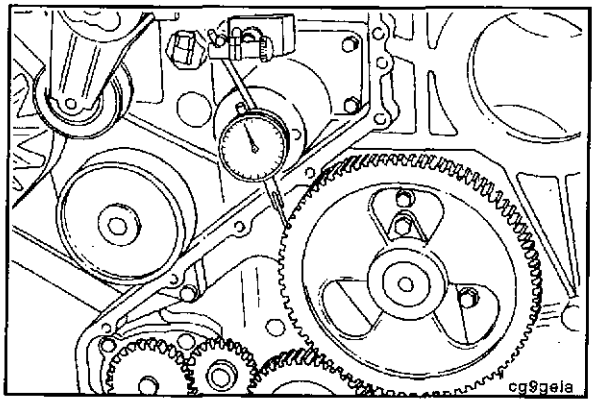
Remove the fuel pump drive gear.



NOTE: If the camshaft or gear are being replaced due to gear train noise, check the gear backlash.

NOTE: Excessive gear backlash can be caused by worn camshaft bushings.

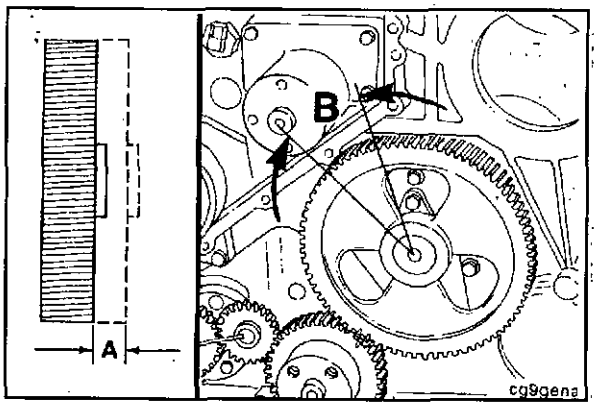
Position an indicator on a tooth of the camshaft gear.

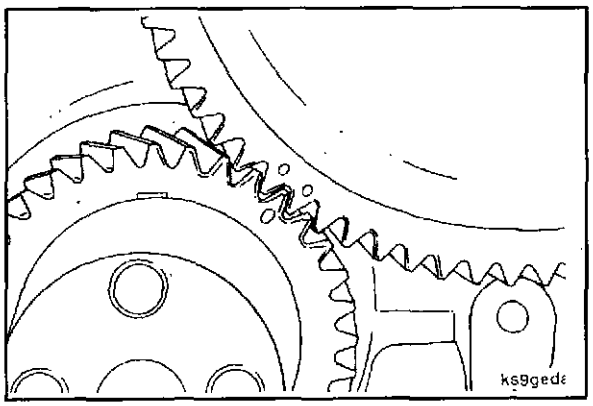


Note the camshaft gear backlash and end clearance. Mark the camshaft gear and crankshaft gear for further analysis if backlash or end clearance exceeds limits.

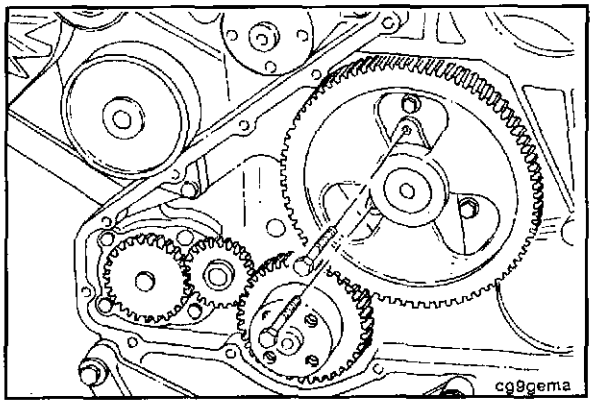
Camshaft End Clearance (A)		
mm		in
0.12	MIN	0.0047
0.46	MAX	0.018

Camshaft Gear Backlash Limits (B)		
mm		in
0.08	MIN	0.003
0.33	MAX	0.013



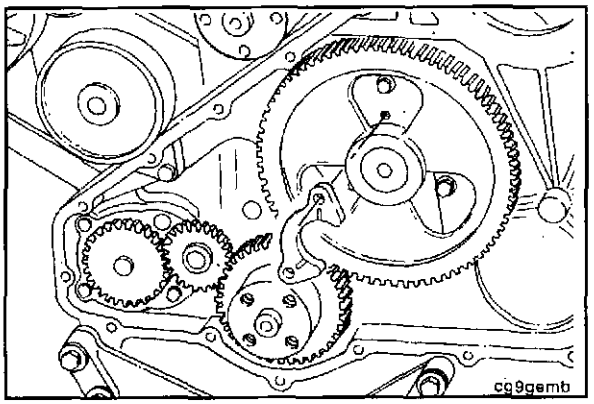


Rotate the crankshaft to align the timing marks before trying to remove the camshaft.

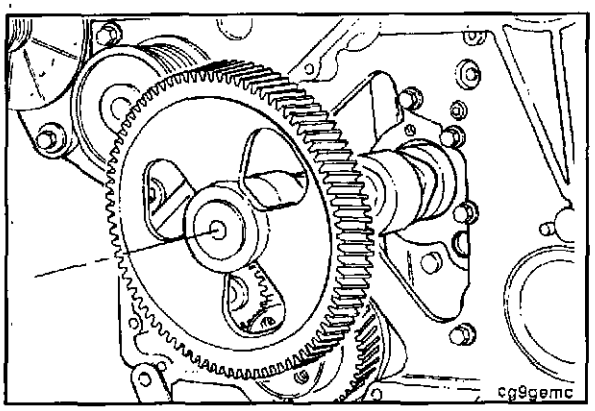


13 mm

Remove the camshaft thrust plate capscrews.



Remove the camshaft thrust plate.



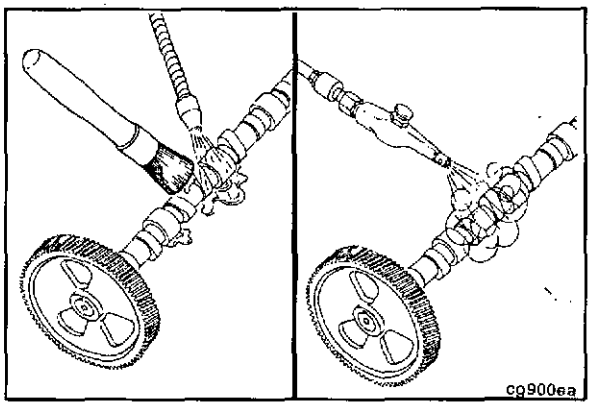
Remove the camshaft from the cylinder block.

NOTE: Rotate the camshaft as it is being removed. Use extreme care to be sure the camshaft bushings are **not** damaged during the camshaft removal process.

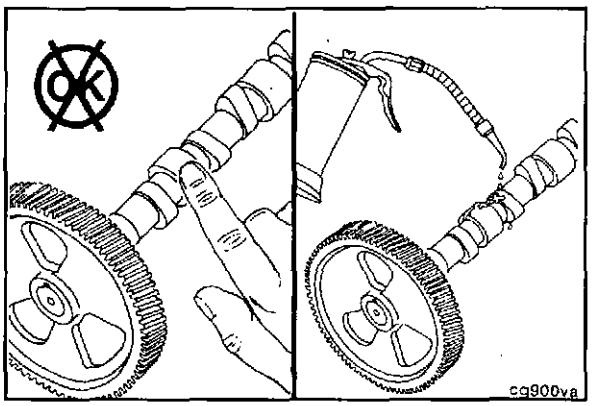
Cleaning and Inspection

Warning: When using a steam cleaner, wear protective clothing and safety glasses or a face shield. Hot steam can cause serious personal injury.

Clean the camshaft with steam or solvent. Dry with compressed air.

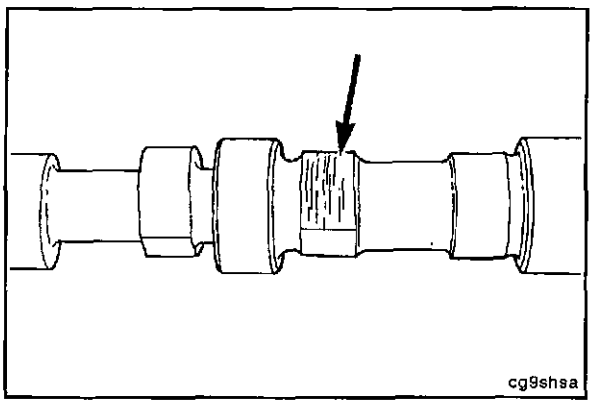


Caution: After the camshaft has been steam cleaned, do not touch the machined surfaces with bare hands, this will cause rust to form. Lubricate the camshaft with clean 15W-40 engine oil before handling.



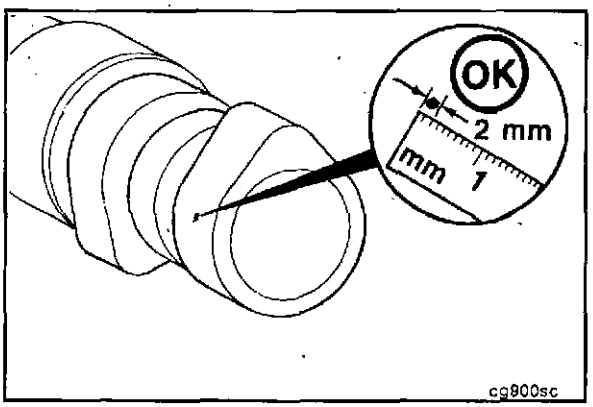
Visually inspect the fuel transfer pump lobe, valve lobes and bearing journals for wear, cracking, pitting, scratches and other damage.

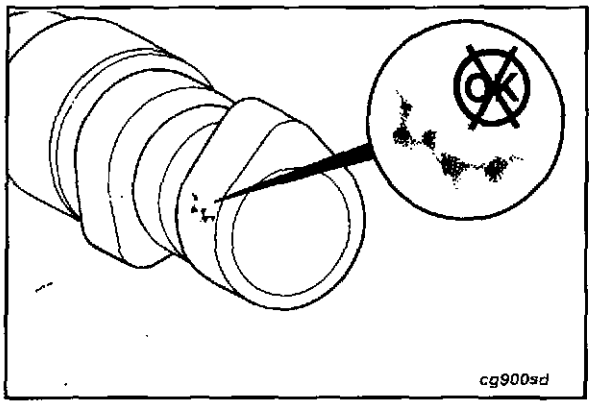
The following criteria defines the size of the pits, allowable wear and edge deterioration of the chilled iron camshaft lobes:



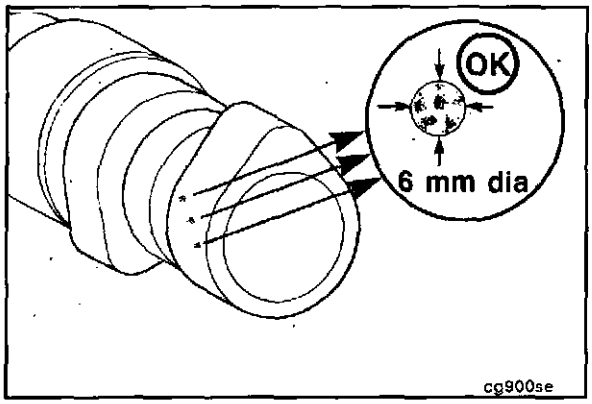
Pitting:

A single pit should **not** be greater than the area of a 2 mm [0.079 inch] diameter circle.

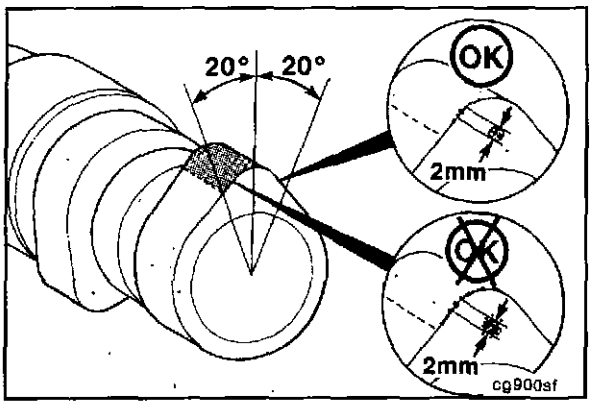




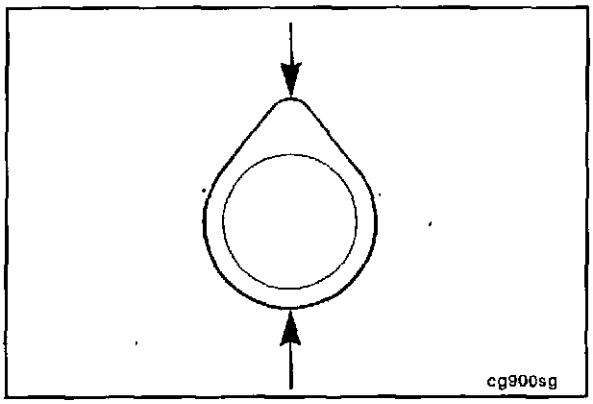
Interconnection of pits is **not** allowable and is treated as one pit.



The total pits, when added together, should **not** exceed a circle of 6 mm [0.236 inch].



Only one pit is allowed within + or - 20 degrees of the nose of the camshaft lobe.



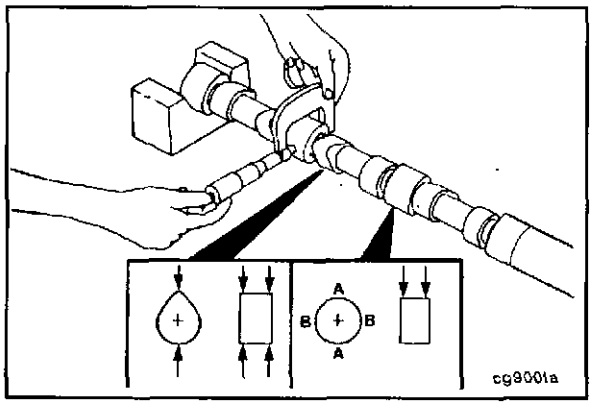
Measure across the peak of the lobes.

Camshaft Lobe Wear Limits (Minimum)

mm		in
51.774	Intake Valve	2.038
51.596	Exhaust Valve	2.031
41.31	Fuel Transfer Pump	1.626

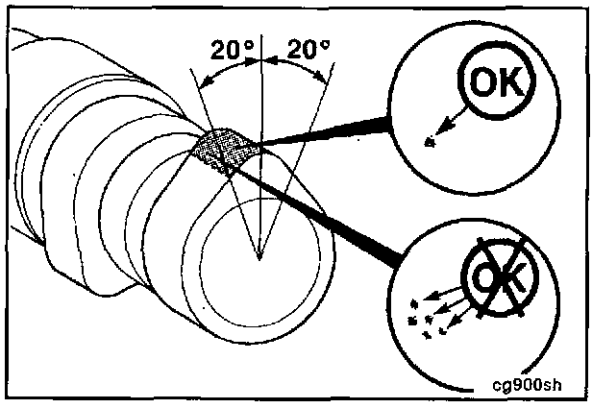
Camshaft Journal Diameter		
mm		in
59.962	MIN	2.3607
60.013	MAX	2.3627

NOTE: Replace the camshaft if the outside diameter of any bearing surface is less than 59.962 mm [2.3607 inch].

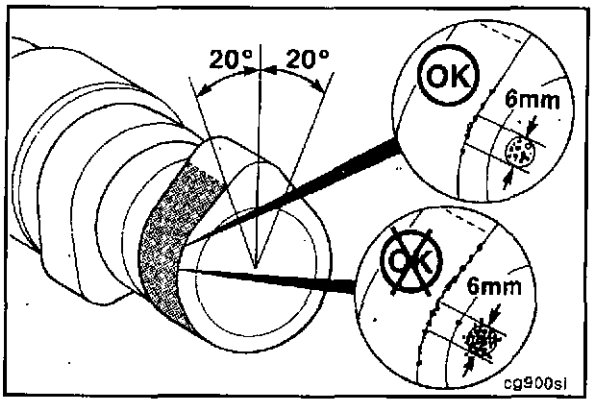


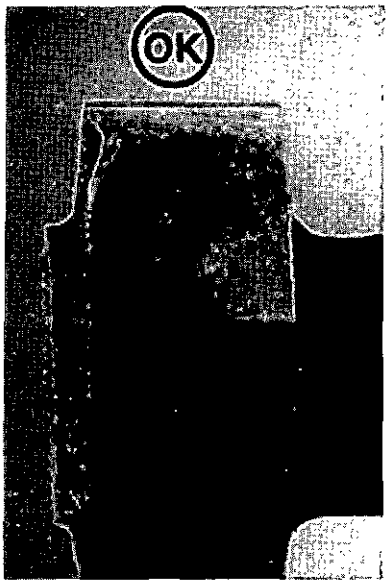
Edge Deterioration (Breakdown)

The area of edge deterioration should **not** be greater than the equivalent area of a 2 mm [0.079 inch] circle within + or - 20 degrees of the nose of the camshaft lobe.



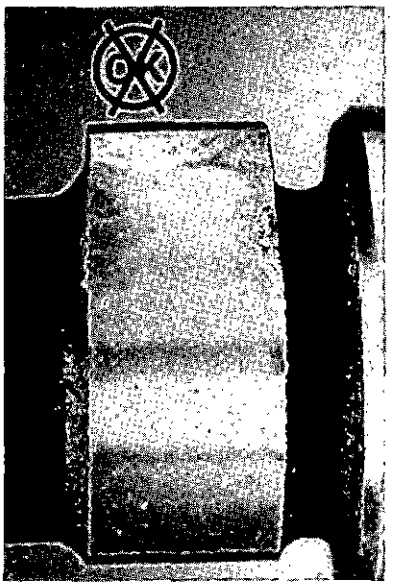
Outside of the + or - 20 degrees of the nose of the camshaft lobe, the areas of edge deterioriation should not be greater than the equivalent area of a 6 mm [0.236 inch] circle.

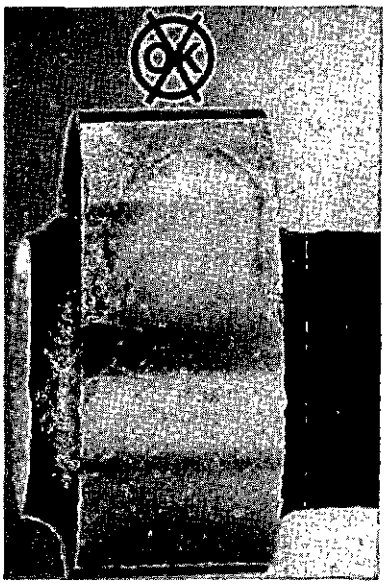


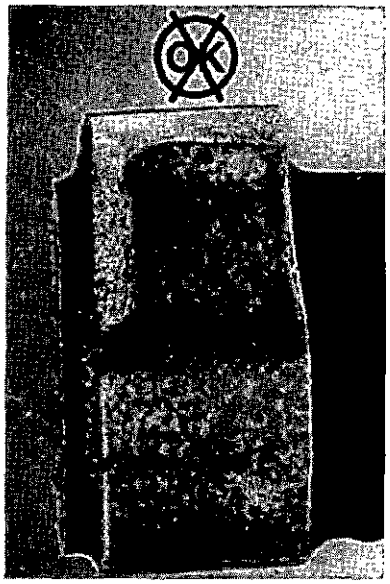


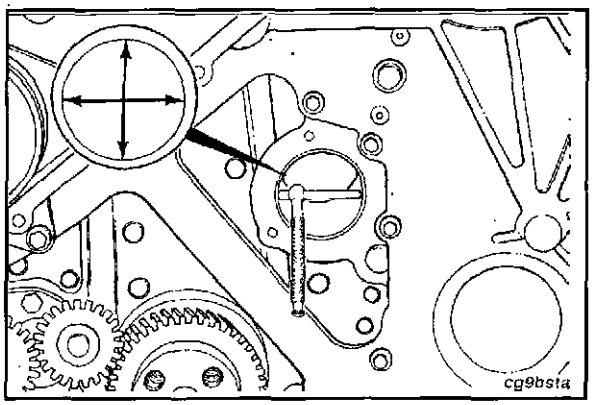
This illustration shows normal grain pattern and a casting flaw within the nose area. Both of these conditions are acceptable for reuse.

The following three illustrations show wear patterns that are not acceptable for reuse:









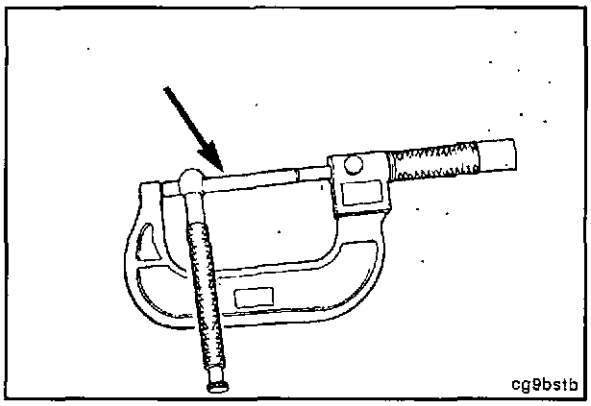
Measure the camshaft bores. Use a bore gauge. The bores **must** be measured in two positions. Take a second *measurement 90 degrees from the first measurement.*

Camshaft Bore Diameter (Maximum)		
mm		**in**
64.01	(Without Bushing)	2.520
60.12	(With Bushing)	2.367

If the bushing diameter is more than 60.12 mm [2.367 inch], the camshaft bushings **must** be replaced.

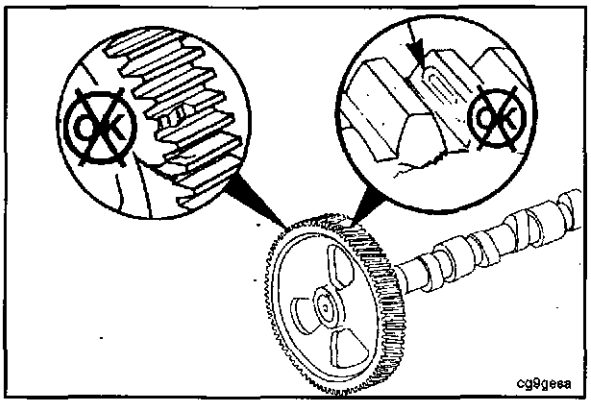
NOTE: The engine **must** be removed for bushing replacement, refer to Procedure 9-01.

Refer to the C Series Shop Manual for camshaft bushing replacement.



Camshaft Gear Inspection

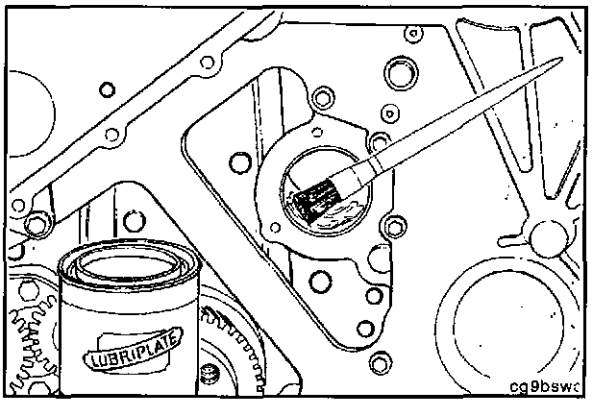
Visually inspect the gear teeth for wear and damage. Look for cracks at the root of the teeth. If the gear is damaged, it **must** be replaced. Refer to Procedure 7-23.



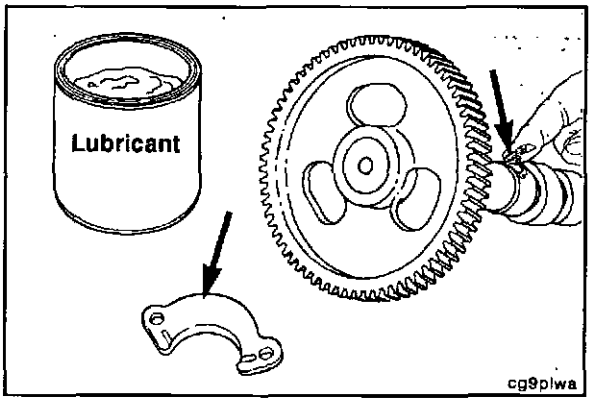
Installation

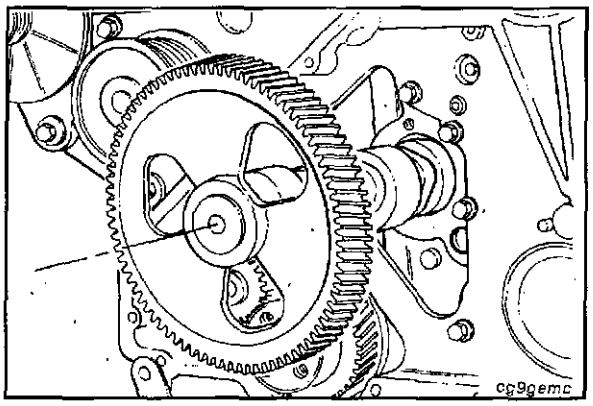
Lubricate the camshaft bores with Lubriplate™ 105.

Service Tip: The crankshaft should be positioned so the No. 1 cylinder is at approximately TDC, so the camshaft does **not** hit the crankshaft counterweight during installation.

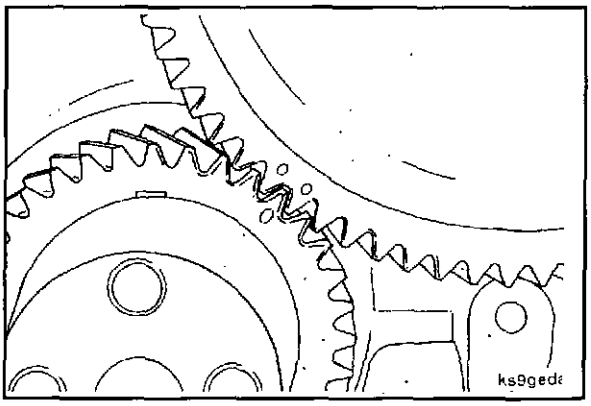


Lubricate the camshaft journals and lobes, and the thrust plate with Lubriplate™ 105.

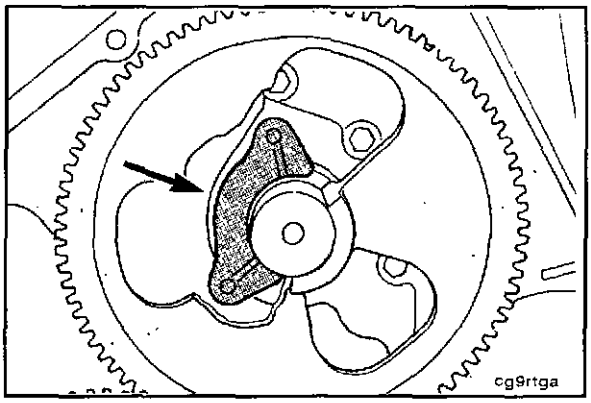




Position the camshaft/cam gear assembly into the cylinder block up to the last journal.

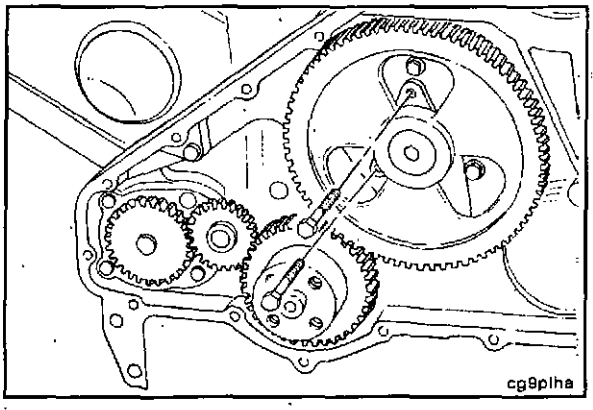


Align the timing marks on the camshaft with the timing mark on the crankshaft.



Caution: Make sure the camshaft assembly does not drop on your fingers when installing the thrust plate.

Install the camshaft thrust plate.

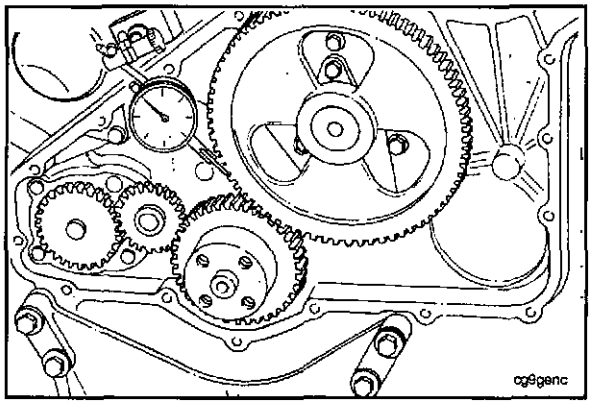


13 mm

Install the camshaft thrust plate capscrews.

Torque Value: 24 N•m [18 ft-lb]

Put a dial indicator on the camshaft gear and check the gear backlash between the camshaft gear and the crankshaft gear.



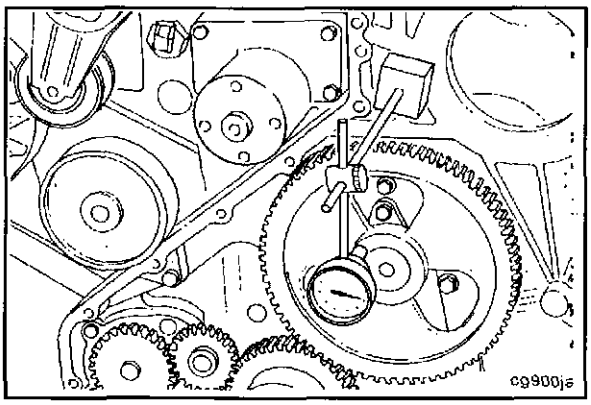
Camshaft Gear Backlash Limits		
mm		in
0.08	MIN	0.003
0.33	MAX	0.013

NOTE: The gears **must** be replaced if the backlash is greater than the above limit.

NOTE: Excessive gear backlash can be caused by worn camshaft bushings.

Measure camshaft end clearance with a dial indicator.

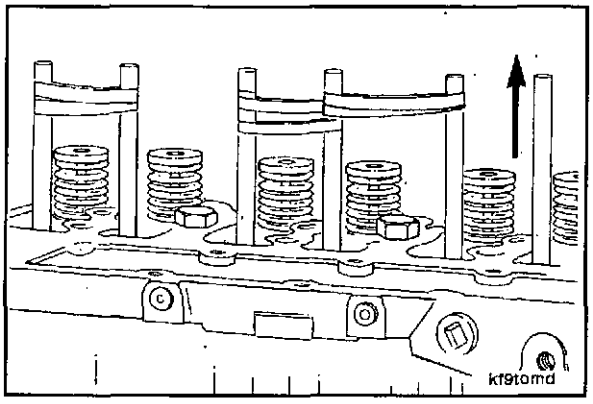
End clearance is controlled by the thickness of the thrust plate and the groove in the camshaft.



Camshaft End Clearance		
mm		in
0.12	MIN	0.0047
0.46	MAX	0.0181

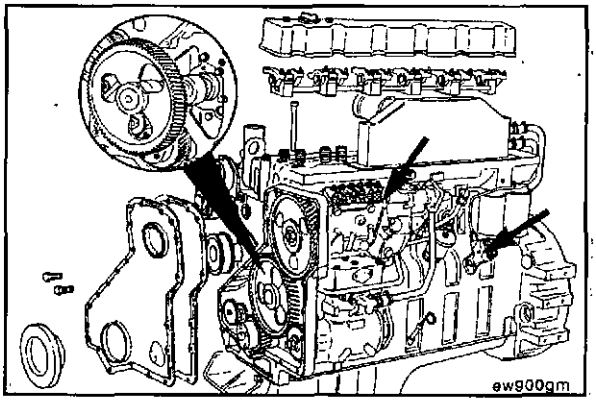
NOTE: If the camshaft end clearance is greater than the above limit, the thrust plate **must** be replaced.

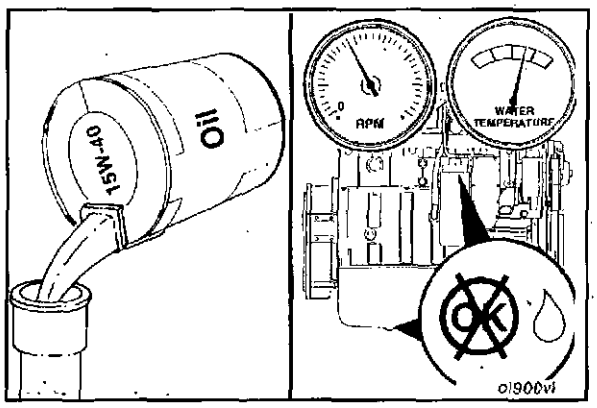
Remove the wooden dowel rods from the valve tappets.



Install all parts that were removed:

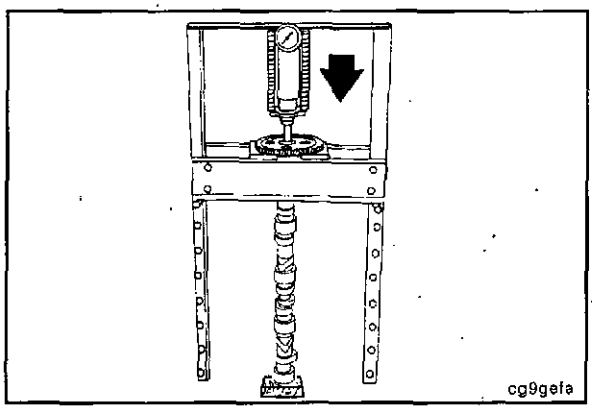
- Fuel transfer pump, Procedure 5-04.
- Fuel pump drive gear, Procedure 5-10.
- Gear cover, Procedure 7-17.
- Vibration damper, Procedure 7-16.
- Push rods, Procedure 7-08.
- Rocker assemblies, Procedure 7-05.
- Valve cover, Procedure 7-02.





Fill the engine with oil and coolant.

Operate the engine until the coolant temperature reaches 82°C [180°F] and check for leaks and proper operation.



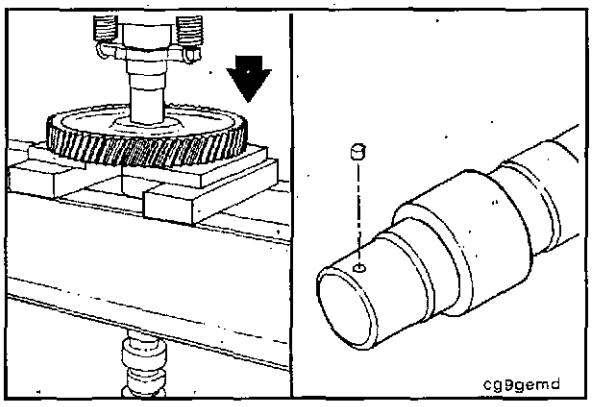
Camshaft Gear - Replacement (7-23)

Removal

A camshaft gear removal/installation tool, Part No. 3823589, is available for replacing the camshaft gear in restricted areas where the camshaft cannot be removed from the engine. Follow the directions included with the tool.

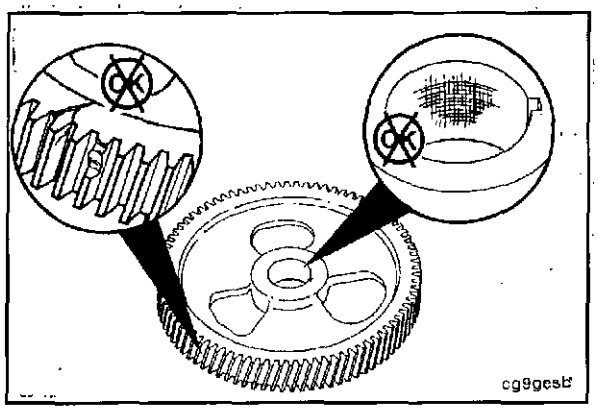
Caution: Place a wooden block under the camshaft to avoid damages as the camshaft drops free from the cam gear.

Place the camshaft and gear assembly in a hydraulic press. Press the gear off the camshaft.



Push the camshaft from the gear.

Remove the camshaft dowel pin.



Cleaning and Inspection

Visually inspect the camshaft gear for cracks, chipped, or broken teeth.

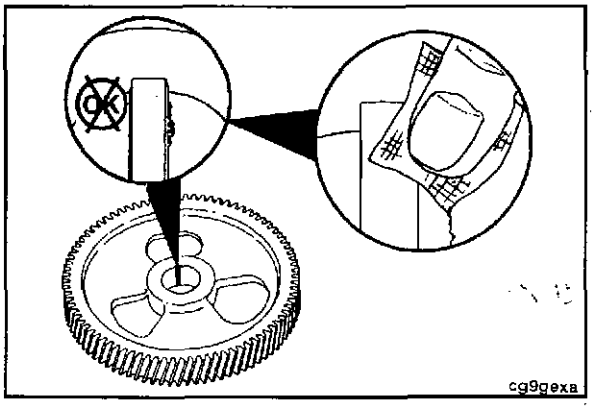
Inspect the bore of the gear for fretting or burrs.

NOTE: If the fretting, burrs, or raised material **cannot** be removed with Scotch-Brite® 7448 or equivalent, replace the gear.

Inspect the gear keyway for burrs.

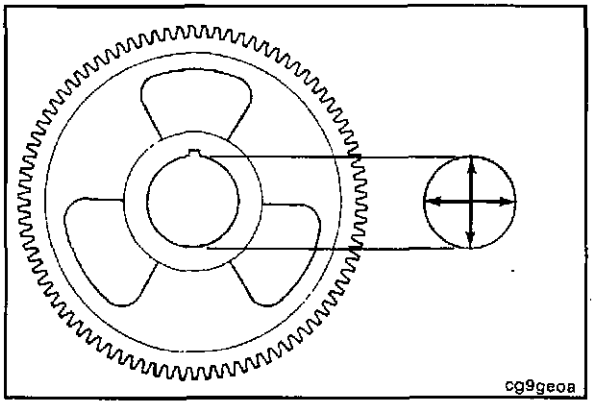
Remove burrs with Scotch-Brite 7448, or equivalent.

NOTE: If the keyway is damaged or the burrs **cannot** be removed, the gear **must** be replaced.



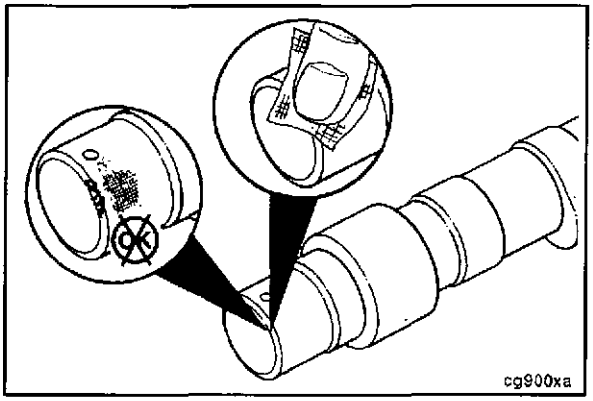
Measure the camshaft gear bore inside diameter.

Camshaft Gear Bore I.D.		
mm		in
41.480	MIN	1.633
41.505	MAX	1.634



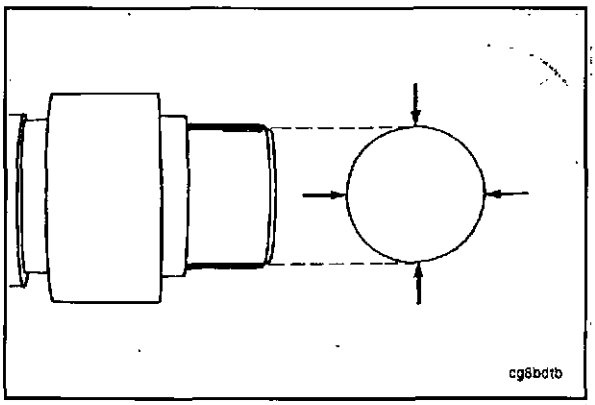
Visually inspect the camshaft nose for fretting or burrs.

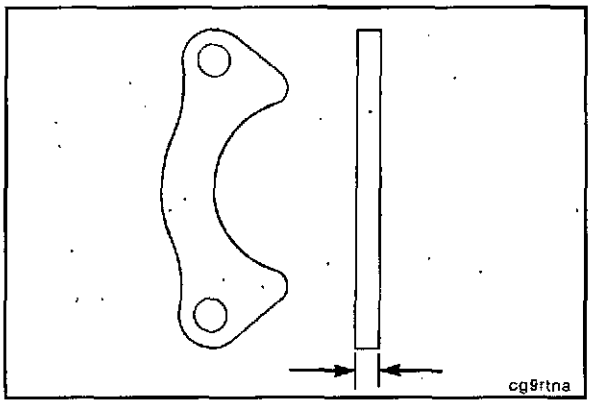
NOTE: If fretting or burrs **cannot** be removed with Scotch-Brite® 7448, or equivalent, replace the camshaft.



Measure the camshaft gear journal outside diameter.

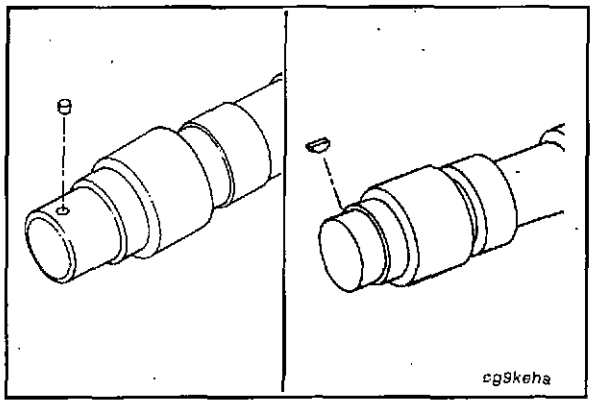
Camshaft Gear Journal O.D.		
mm		in
41.56	MIN	1.636
41.58	MAX	1.637





Measure the camshaft thrust plate thickness.

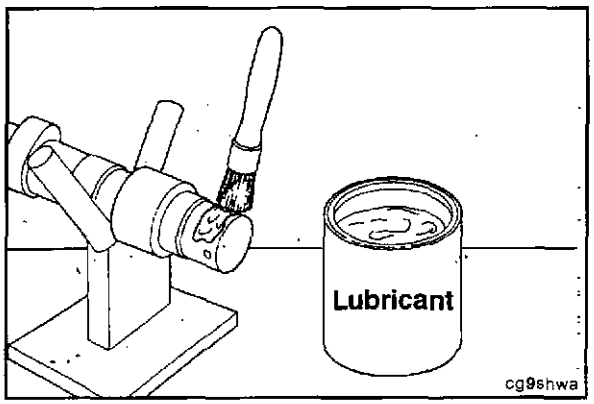
Camshaft Thrust Plate Thickness		
mm		in
9.34	MIN	0.368
9.58	MAX	0.377



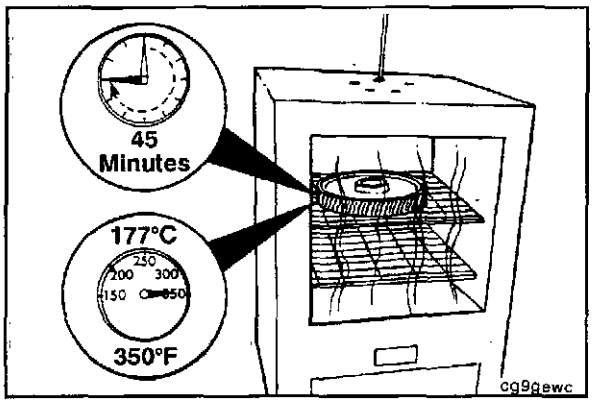
Installation

Use a leather hammer to install the camshaft gear dowel pin.

NOTE: The steel camshaft, Part No. 3923388, uses a dowel pin. The cast iron camshaft, Part No. 3924471, uses a woodruff key.



Lubricate the camshaft gear journals with Lubriplate™ 105.



Steel Camshaft Gear

Warning: Use insulated gloves, Part No. 3823730, when *handling heated parts. Hot parts can cause serious* personal injury.

Heat the gear in an oven for a minimum of 45 minutes, but **not** longer than 6 hours.

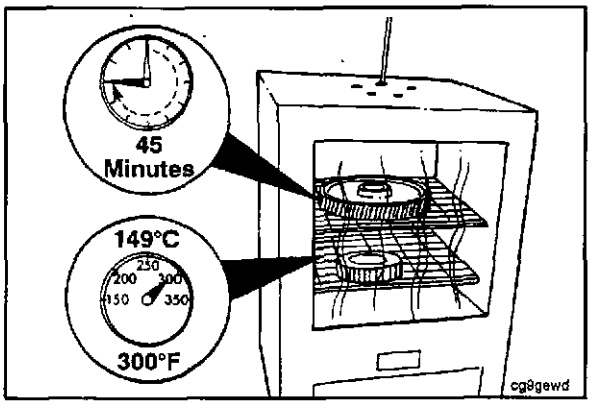
Temperature: 177°C [350°F]

Austempered Camshaft Gear

Heat the gear in an oven for 45 minutes.

Caution: The gear will be permanently distorted if overheated. The oven temperature should never exceed the specification.

Temperature: 149°C [300°F]

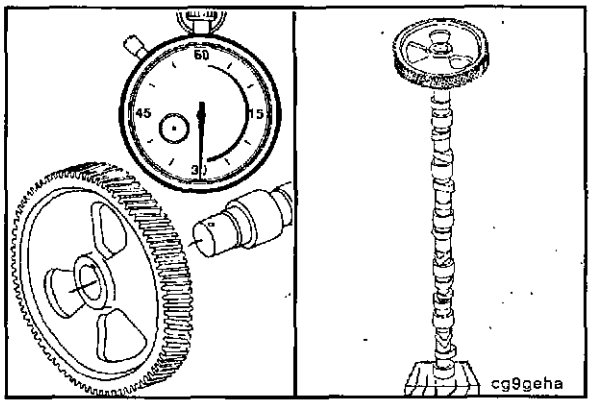


Caution: To prevent engine damage, the timing marks and gear part number must be facing away from the camshaft when the gear is installed.

Caution: Keep the camshaft in a vertical position with the gear up until the gear has cooled. Do not use water to reduce the cooling time. Using water will crack the gear.

NOTE: The gear **must** be installed within 30 seconds after it is removed from the oven.

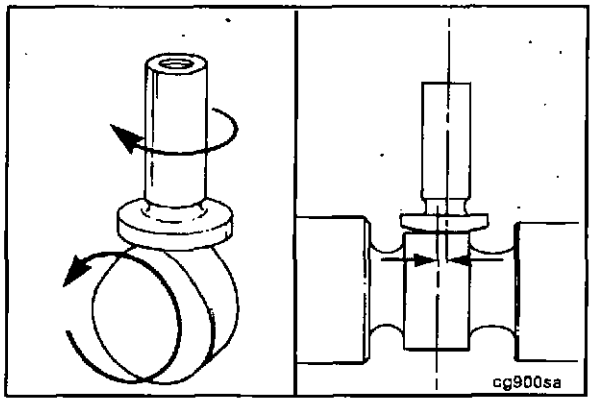
Remove the gear from the oven. Align the keyway in the gear with the dowel pin in the camshaft and install the gear on the camshaft. Be sure the gear is seated against the camshaft shoulder.



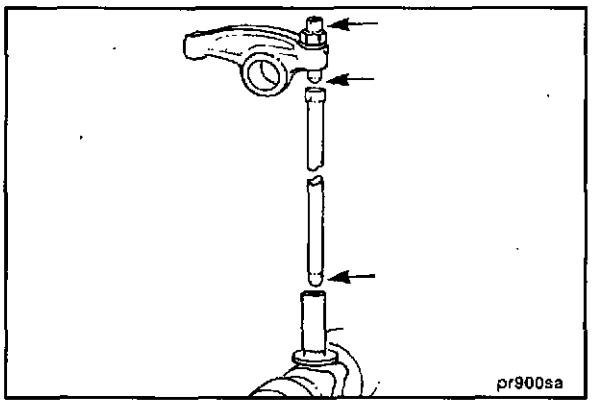
Valve Tappet - Replacement (7-24)

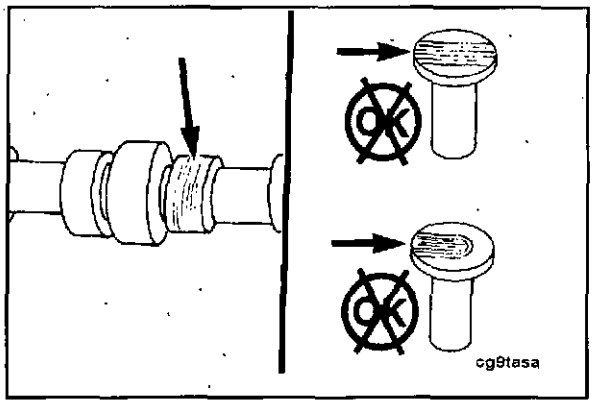
General Information

The valve tappets are mushroom shaped. The offset position of the tappet against the camshaft lobe causes the tappet to rotate as it lifts the push rod.

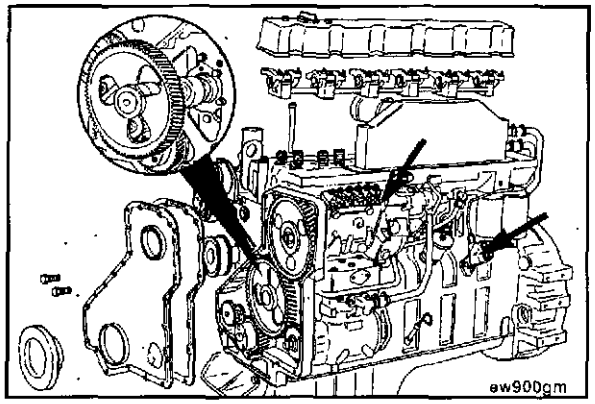


The ball end of the push rod fits into the ball socket in the tappet. The other end of the push rod has a ball socket in which the ball end of the rocker lever adjusting screw operates.





Loose rocker levers and the need to reset the valve clearance frequently can indicate camshaft lobe or tappet wear. If an inspection of the levers, valve stems and push rods does **not** show wear, then tappet and/or camshaft lobe wear can be suspected.

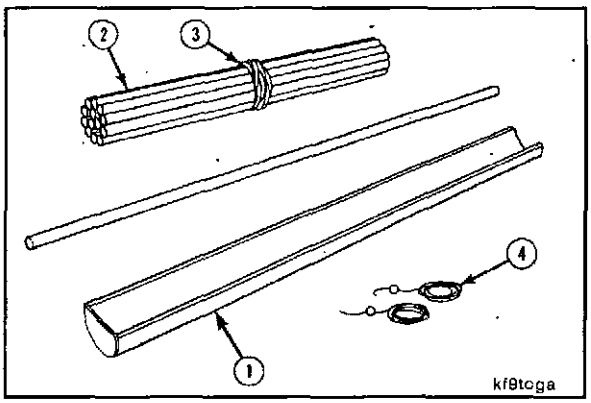


Removal

Replacement (With Oil Pan Installed)

Remove the following components:

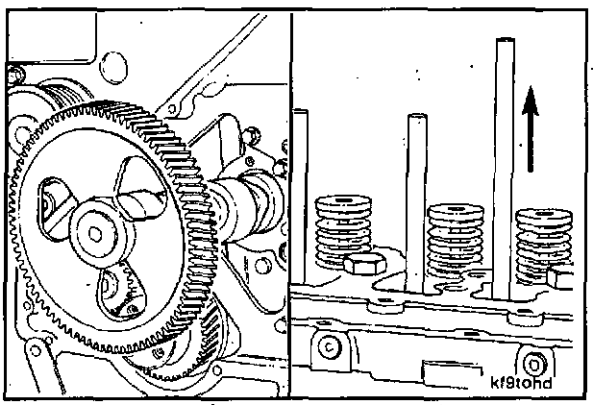
- Valve cover, Procedure 7-02.
- Rocker assemblies, Procedure 7-05.
- Push rods, Procedure 7-08.
- Vibration damper, Procedure 7-16.
- Gear cover, Procedure 7-17.
- Fuel pump drive gear, Procedure 5-10.
- Fuel transfer pump, Procedure 5-04.
- Camshaft, Procedure 7-22.



Part No. 3822513, Tappet Removal Tool Kit

The valve tappets can be removed with the oil pan installed by using Part No. 3822513, tappet removal tool kit. The kit consists of:

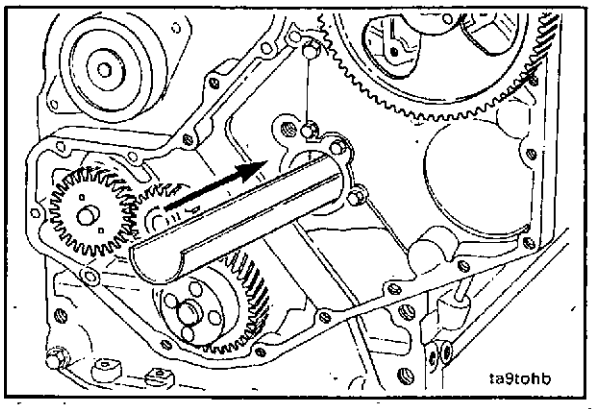
Ref. No.	Description	Qty.
1	Valve Tappet Tray	1
2	Dowel Rods	12
3	Rubber Bands	12
4	Nylon String	1



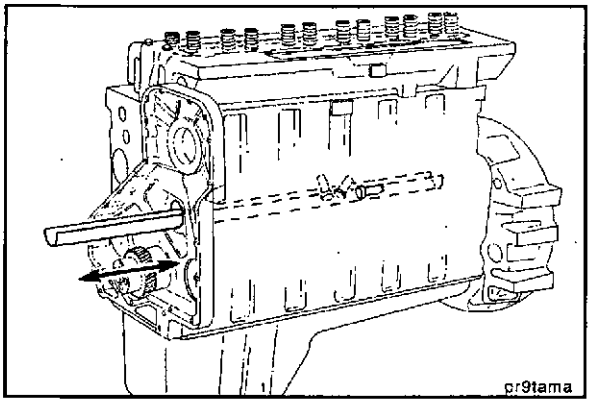
NOTE: It is necessary to remove the camshaft to replace the valve tappets; therefore, the tappets will be raised and secured with the dowel rods. Refer to Procedure 7-22 for camshaft replacement.

NOTE: Number each tappet with the cylinder number position as it is removed. The tappets **must** be installed in the same position as removed.

Insert the tray (1) to the full length of the camshaft bore.

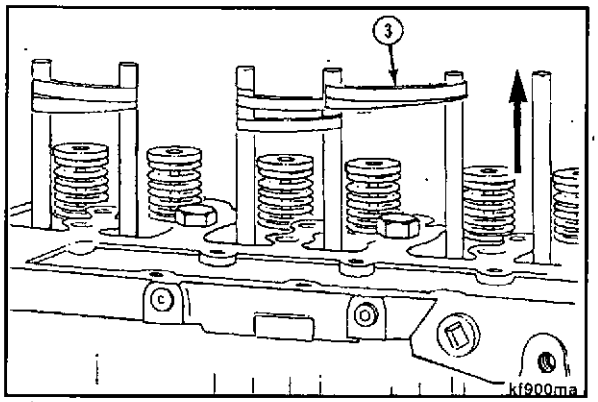


Make sure the tray is positioned so it will catch the tappet when the wooden dowel is removed.

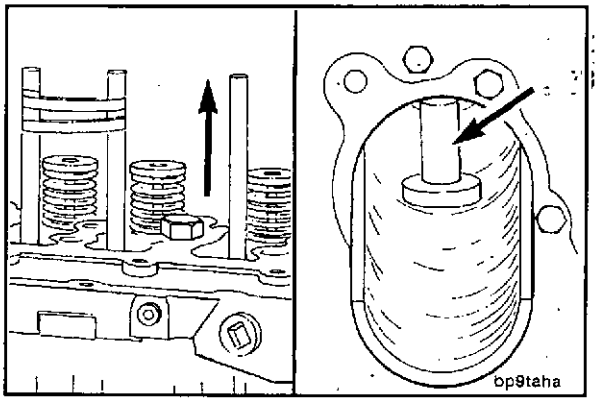


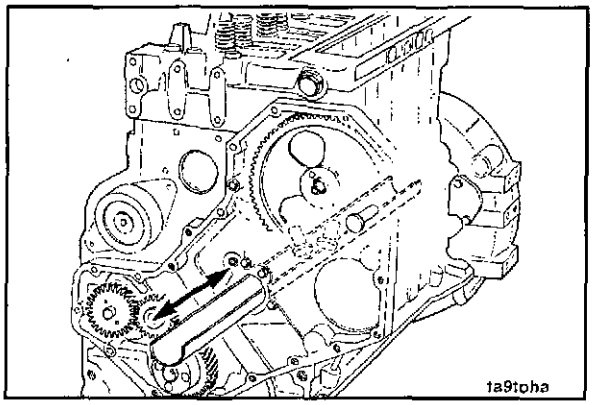
NOTE: Only remove one tappet at a time.

Remove the rubber band (3) from the two companion tappets, securing the tappet **not** to be removed with the rubber band.

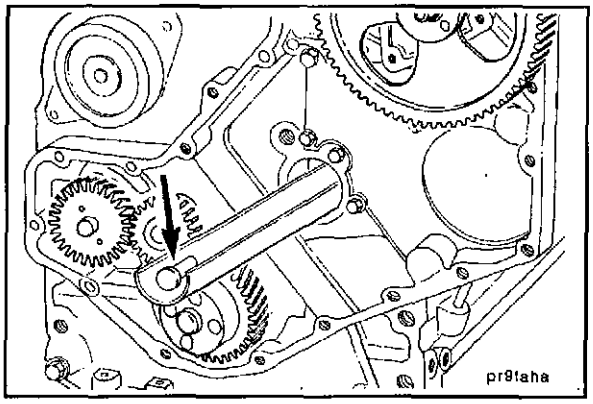


Pull the wooden dowel (2) from the tappet bore allowing the tappet to fall into the plastic tray.

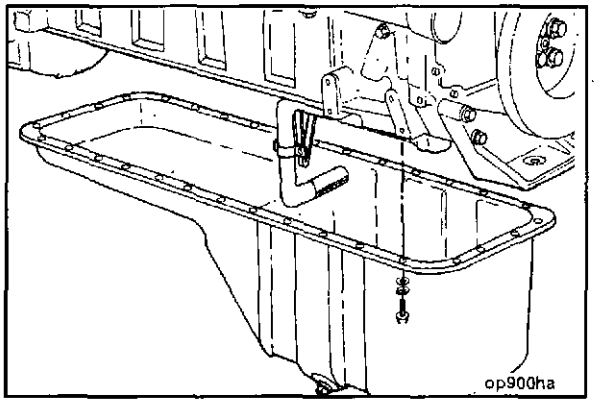




NOTE: The tappet **must** be in the horizontal position to remove it from the camshaft bore. When the tappet is dropped into the tray, it should fall into the horizontal position. If it does **not**, gently shake the tray to allow the tappet to fall over.



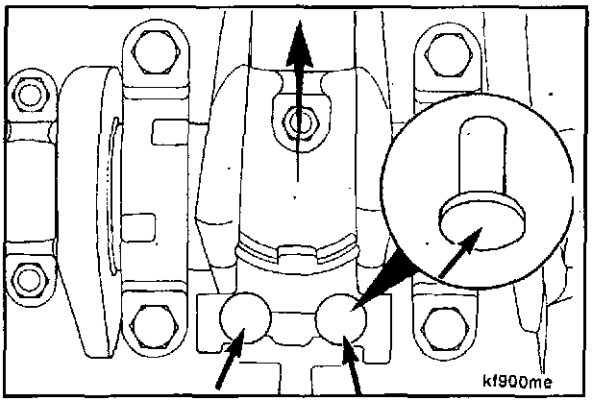
Carefully pull the tray and tappet from the camshaft bore and remove the tappet. Repeat the process until all tappets are removed.



Valve Tappet Removal (With Oil Pan Removed)

10 mm

Remove the oil pan. Refer to Procedure 2-14.



Part No. 3377371, Engine Barring Gear

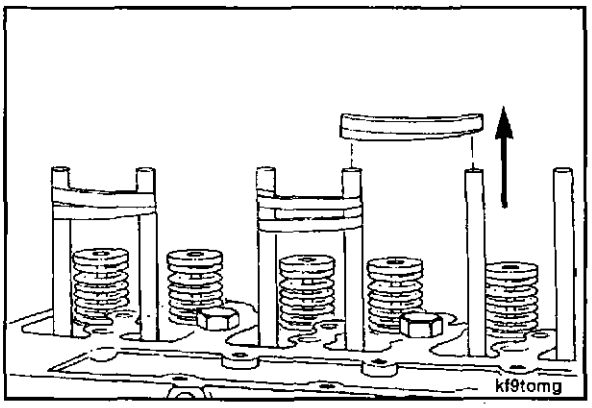
Rotate the crankshaft to access the tappets.

NOTE: Only four tappets are accessible at one time.

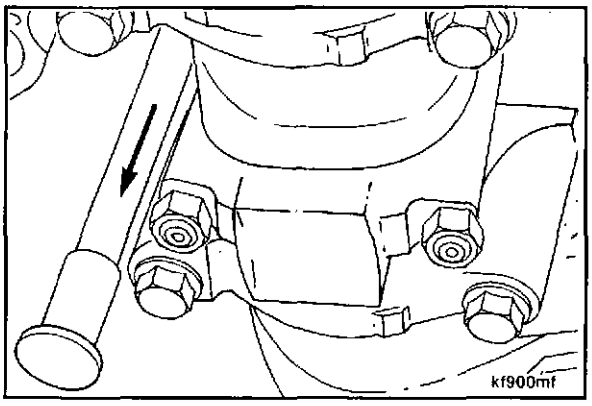
The crankshaft **must** be rotated three times to access all of the tappets.

Remove the rubber bands from the wooden dowels that are used to hold the tappets up during camshaft removal/ installation.

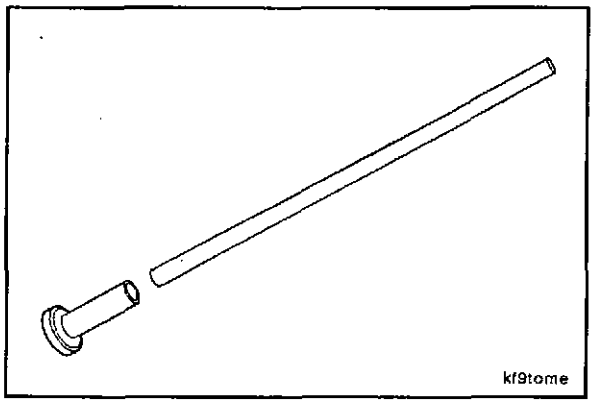
NOTE: Only remove the rubber bands from the accessible tappets.



Remove the accessible tappets/dowels.



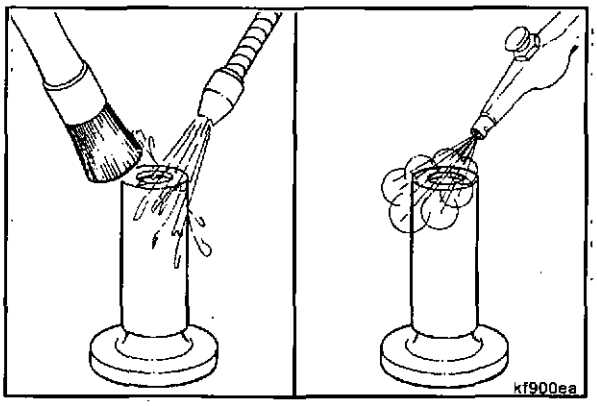
Remove the tappets from the wooden dowels.

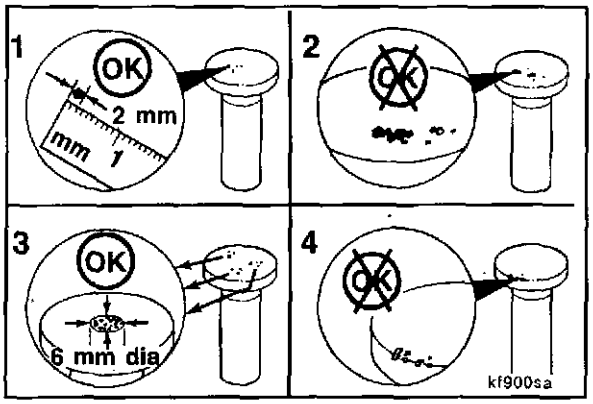


Cleaning and Inspection

Clean the tappets with solvent and dry with compressed air.

Caution: Any time a new camshaft is installed, new tappets must also be installed.

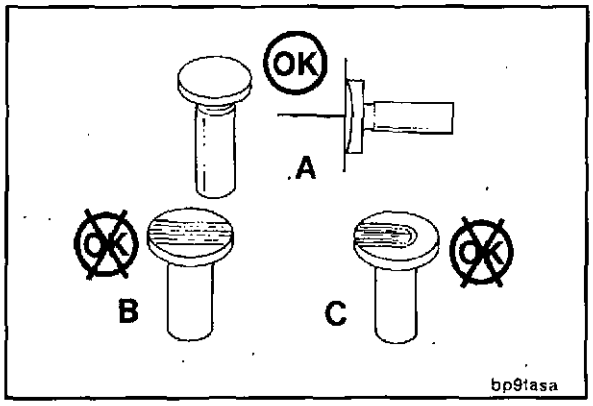




Pit marks on the tappet face are acceptable.

The following criteria defines the size of the pits allowed:

1. A single pit **cannot** be greater than 2 mm [0.078 inch].
2. Interconnection of pits is **not** allowed.
3. Total pits when added together should not exceed 6 mm [0.236 inch] diameter or a total of 4 percent of the tappet face.
4. **No** pitting is allowable on the edges of the wear face of the tappet.

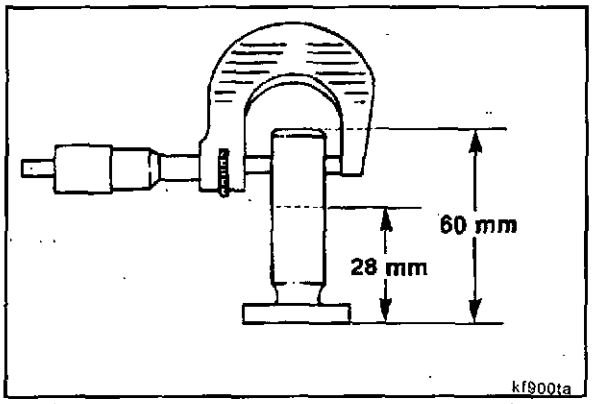


Inspect the socket, stem and face for excessive wear, cracks, concavity and other damage.

Reuse Guidelines:

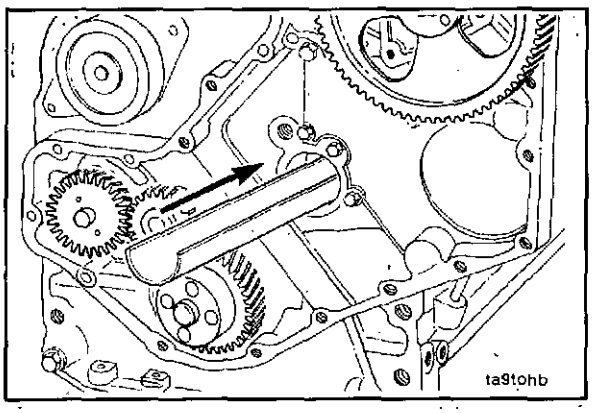
(A) - Normal wear
(B) and (C) - Abnormal wear - Do **not** reuse

Tappet Face Concavity (Maximum)		
mm		in
0.025	MAX	0.001



Measure the valve tappet stem.

Tappet Stem Diameter		
mm		in
15.93	MIN	0.627
15.98	MAX	0.629

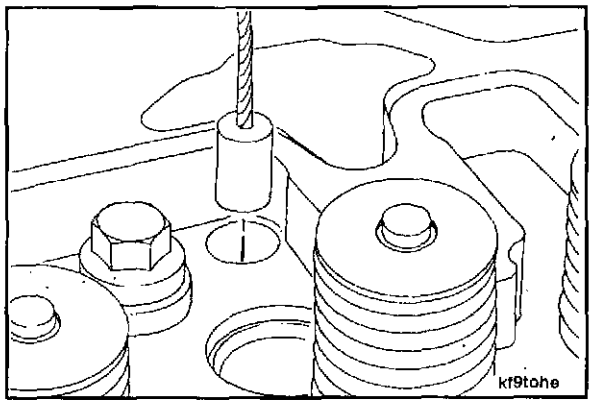


Installation

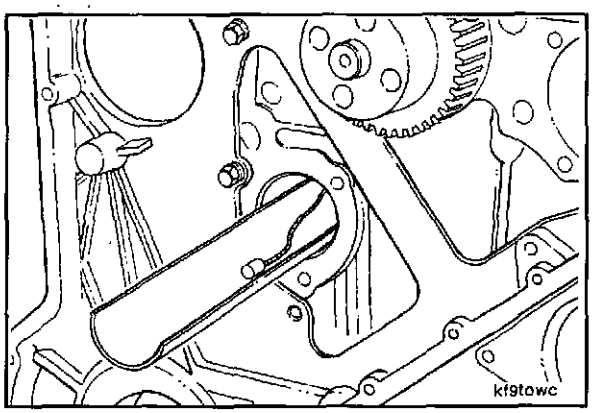
Valve Tappet Installation (With Oil Pan Installed)

Insert the plastic tray the full length of the camshaft bore.

Insert the installation tool down through the tappet bore and into the plastic tray.

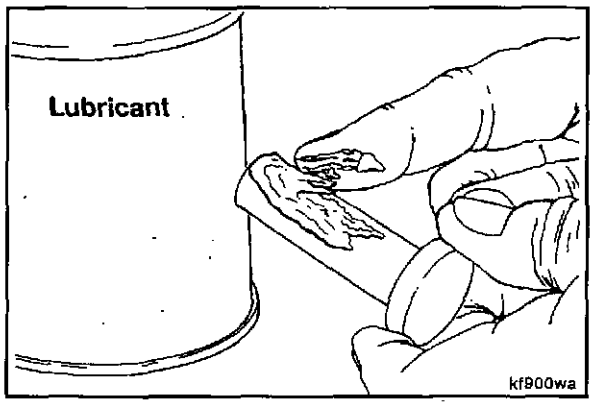


Carefully pull the plastic tray/installation tool out through the front of the camshaft bore.



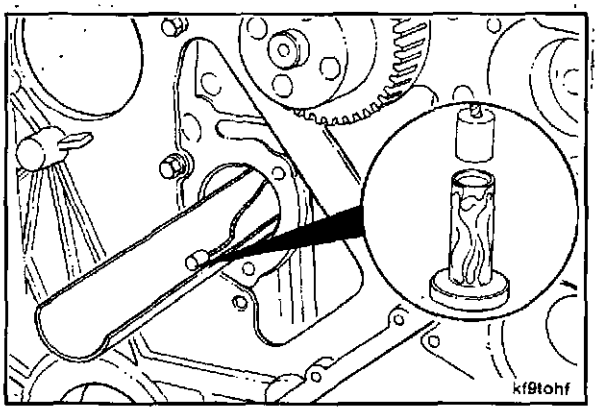
Lubricate the tappets with Lubriplate™ 105.

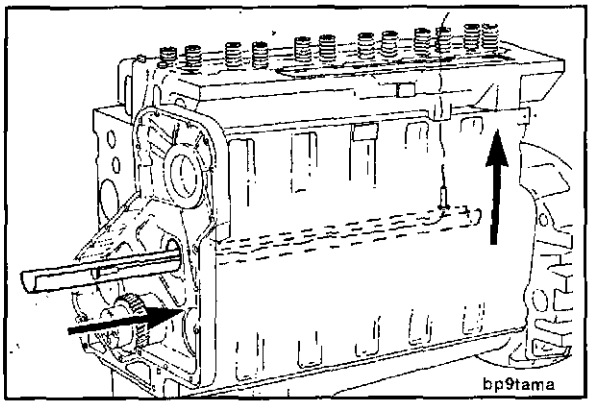
NOTE: If the tappets to be installed have been previously used, each tappet **must** be installed in the same position as it was removed from the engine.



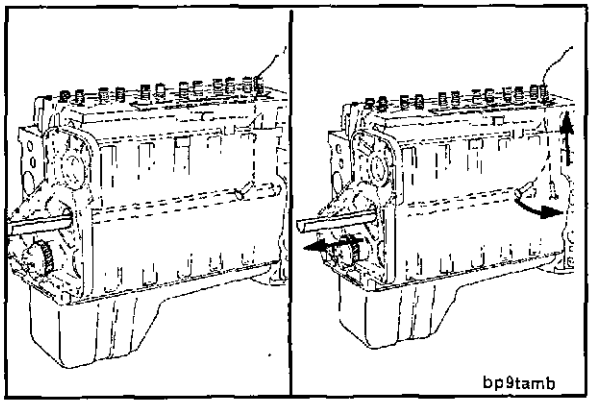
Insert the installation tool into the tappet bore.

NOTE: To aid in removing the installation tool after the tappet is installed, move the tool in and out of the tappet bore several times before installing the tappets.

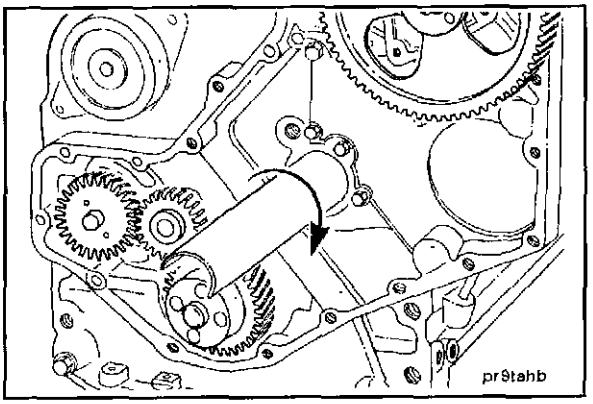




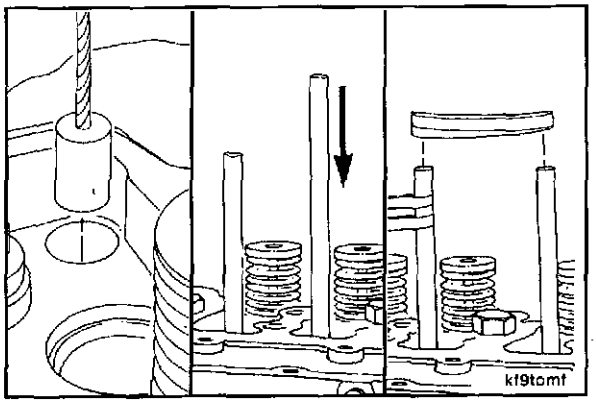
Pull the installation tool and tappet through the camshaft bore and up into the tappet bore.



If difficulty is experienced in getting the tappet to make the bend from the tray up to the tappet bore (due to the webbing of the block), pull the tray out enough to allow the tappet to drop down and align itself, then pull the tappet up into the bore.



After the tappet has been pulled up into position, turn the tray over in the camshaft bore so that the bottom surface of the tray is against the bottom face of the tappet. This will hold the tappet in place.



Remove the installation tool from the tappet.

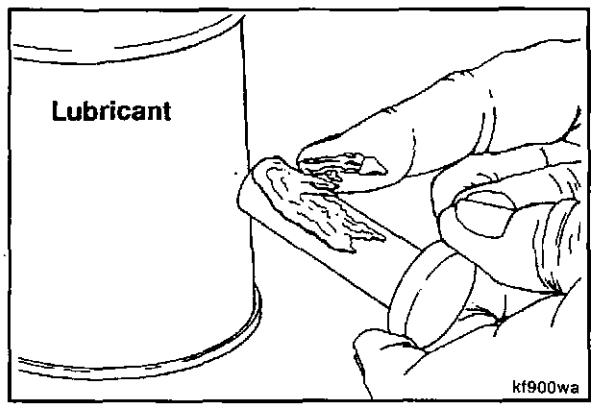
Insert a wooden dowel rod into the top of the tappet. Wrap rubber bands around the wooden dowels to secure the tappets.

Repeat this process until all tappets have been installed.

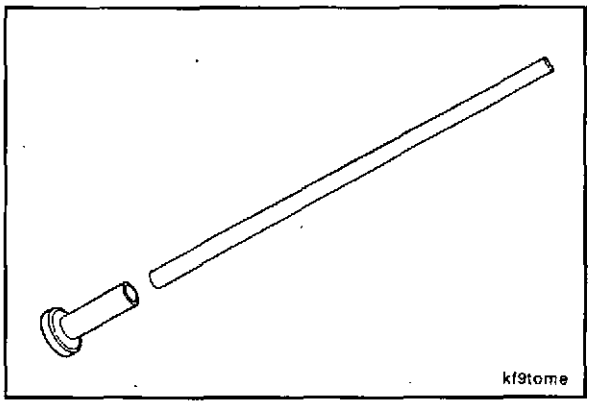
Remove the dowel rods and release the tappets in the tappet bores.

Valve Tappet Installation (With Oil Pan Removed)

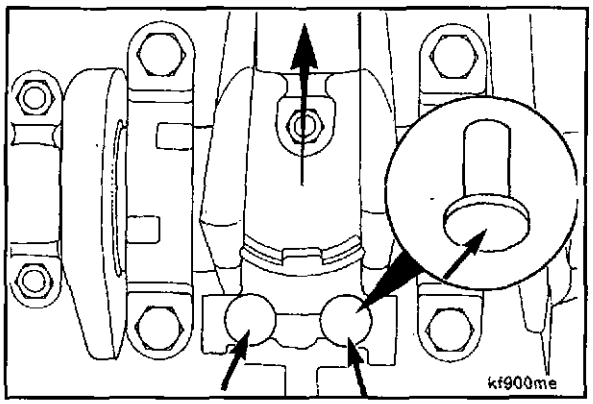
Lubricate the tappets with Lubriplate™ 105.



Insert the wooden dowel rods used for holding the tappets up during camshaft removal/installation into the tappets.

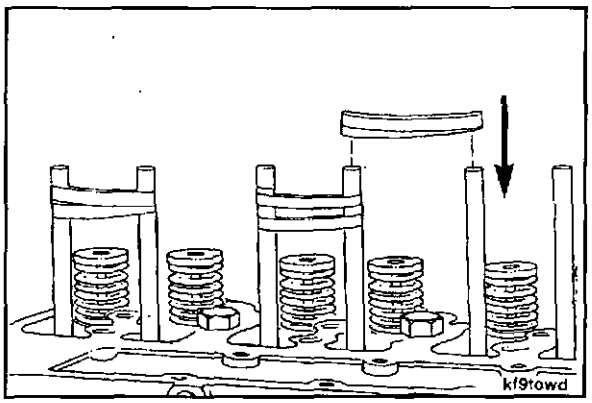


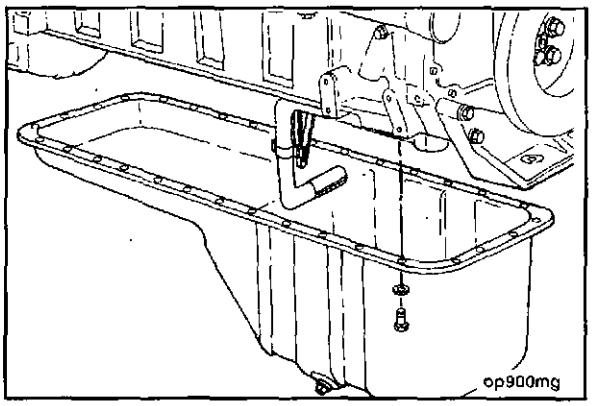
NOTE: Only four tappets are accessible at a time which will require rotation of the engine to install the remaining tappets.



Wrap rubber bands around the wooden dowels to secure the tappets.

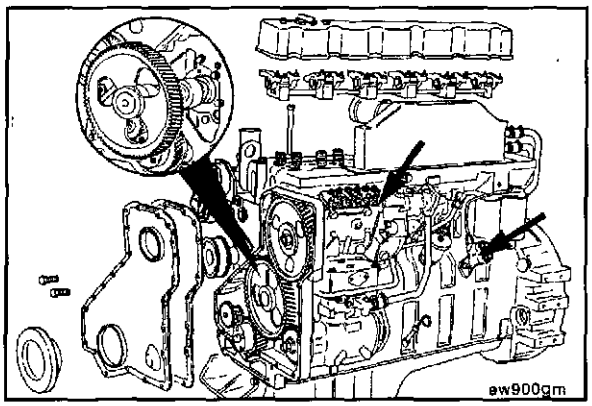
Repeat this process until all tappets have been installed. Remove the dowel rods and release the tappets in the tappet bores.





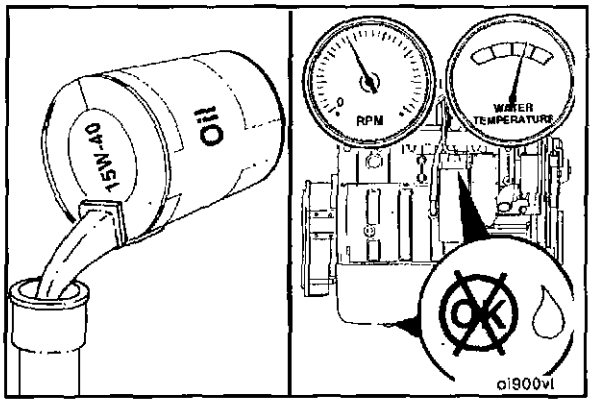
10 mm

Install the oil pan. Refer to Procedure 2-13.



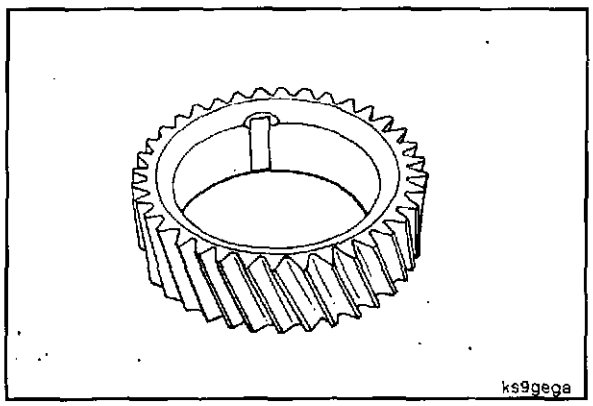
Install all components that were removed:

- Camshaft, Procedure 7-22.
- Fuel transfer pump, Procedure 5-04.
- *Fuel pump drive gear, Procedure* 5-10.
- Gear cover, Procedure 7-17.
- Vibration damper, Procedure 7-16.
- Push rods, Procedure 7-08.
- Rocker assemblies, Procedure 7-05.
- Valve cover, Procedure 7-02.



Fill the engine with oil and coolant.

Operate the engine until the coolant temperature reaches 82°C [180°F] and check for leaks and proper operation.



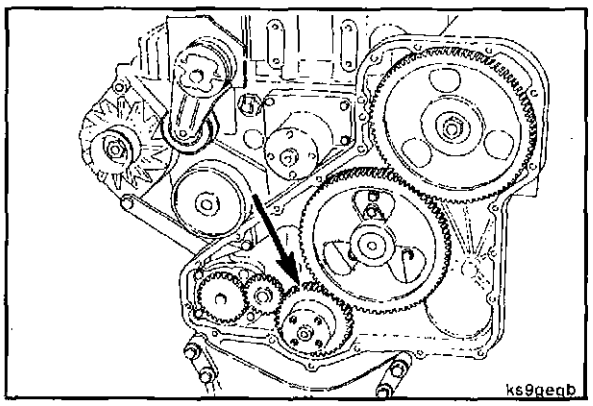
Crankshaft Gear - Replacement (7-25)

General Information

There are two different crankshaft gears used:

- Steel gear for engines with P7100 Bosch fuel pumps.
- Austempered gear for engines without P7100 Bosch fuel pumps.

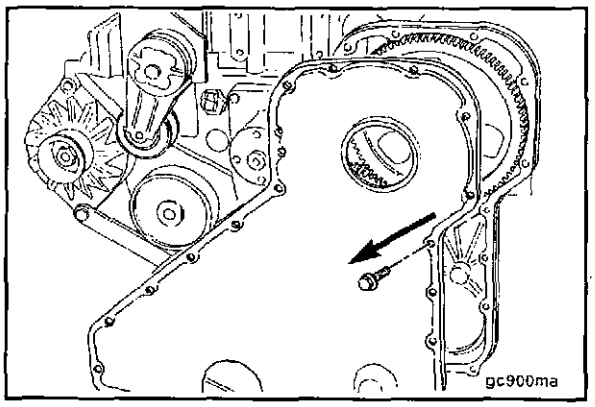
NOTE: The austempered gear can be replaced with the engine in-chassis. The steel gear **cannot** be replaced in-chassis. It will be necessary to remove the engine. Refer to Procedure 9-01.



Removal

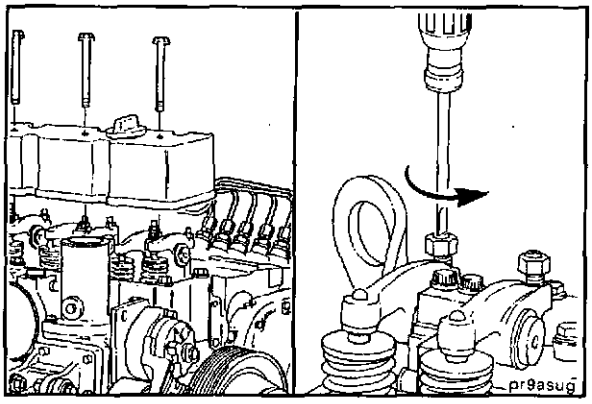
(Austempered Gear)

Remove the gear cover. Refer to Procedure 7-17.



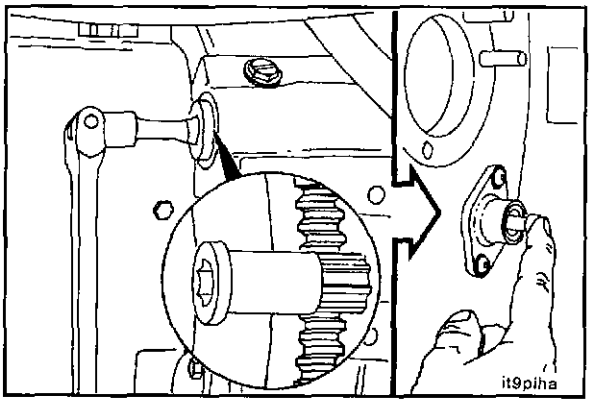
Remove the valve cover and loosen all rocker lever adjusting screws to remove the load on the camshaft.

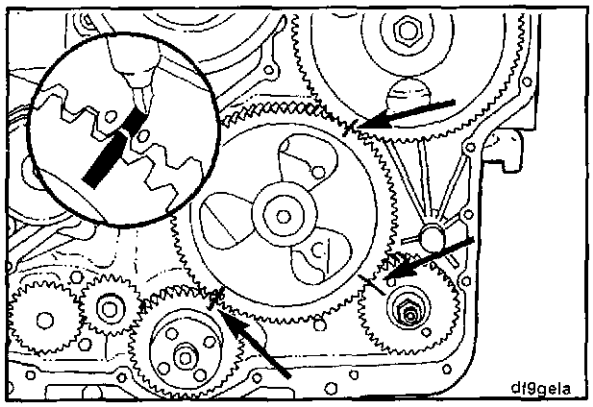
Refer to Procedure 7-02.



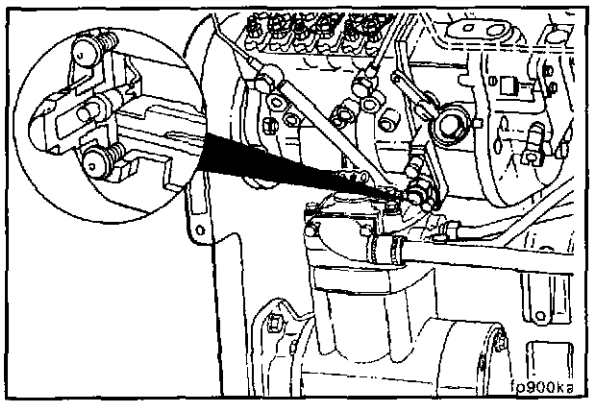
Part No. 3377371, Engine Barring Gear

Rotate the crankshaft and align the timing marks of the camshaft and crankshaft gears.

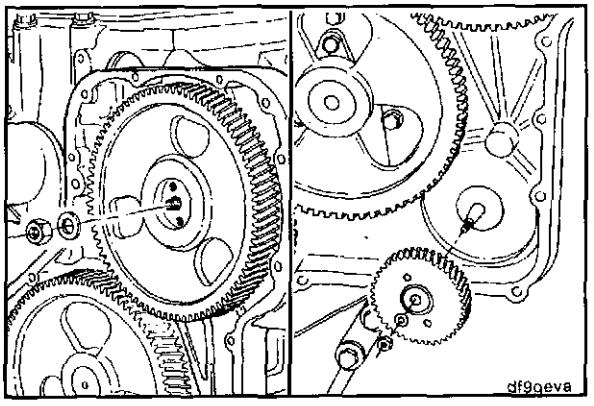




Use a felt tip marker to highlight the timing marks on the gear train. Use the marker to make alignment marks on the accessory drive gear and shaft.

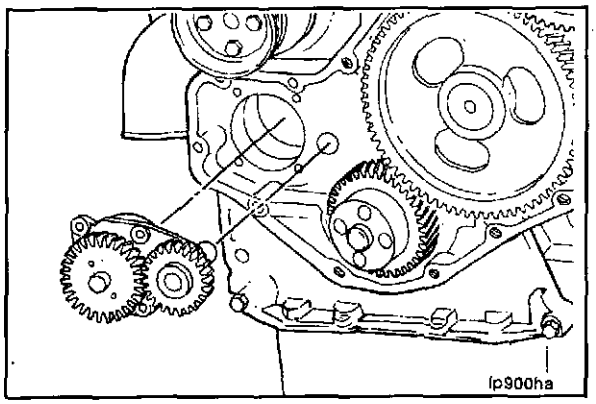


Lock the fuel injection pump. Refer to Procedure 5-10.



Part No. 3823259, Fuel Pump Gear Puller

Remove the fuel pump drive gear and the accessory drive gear. Refer to Procedure 5-10.



Remove the lubricating oil pump assembly. Refer to Procedure 2-14.

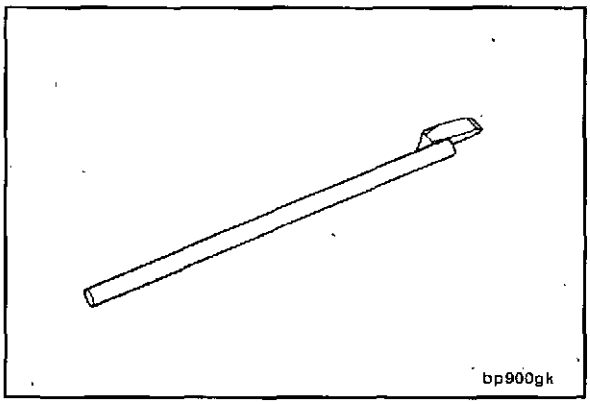
Part No. 3823585, Crankshaft Gear Splitter

Caution: Safety glasses are required when using this tool.

NOTE: Trying to accomplish this task with a cold chisel will result in damage to the engine gear housing gasket surface.

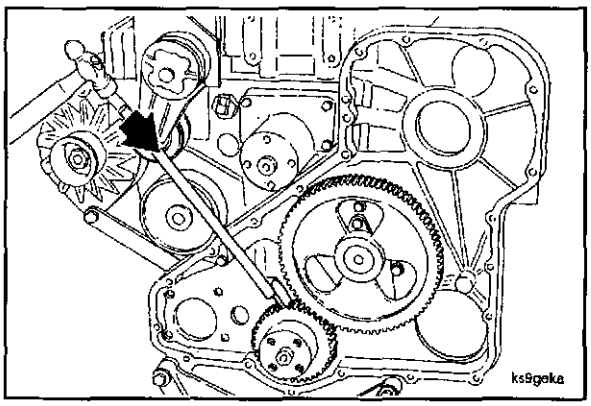
Caution: Use care to avoid damage to the polished surfaces of the crankshaft by driving the point of the tool into the crankshaft.

NOTE: Do not use gear splitter on steel gears.



Place the point of the chisel between two gear teeth. Strike the splitter with a two or three pound steel hammer.

Repeat this step if necessary.



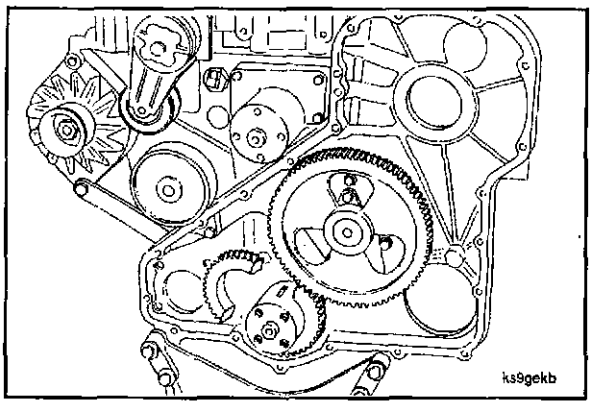
Remove the crankshaft gear.

NOTE: The camshaft gear will rotate slightly as the teeth follow the gear helix.

Caution: Use great care to not distrub the position of the camshaft gear after the crankshaft gear has been removed.

Caution: Do not damage the crankshaft when removing the key.

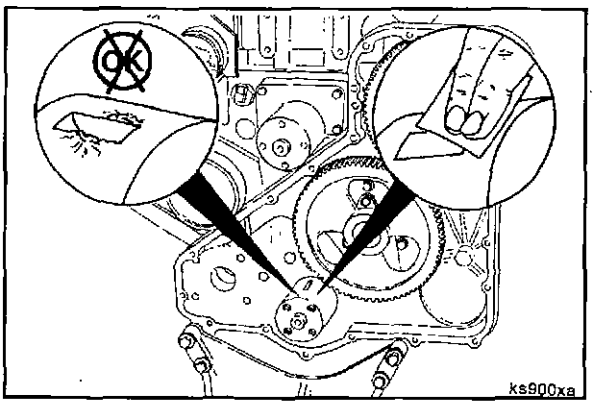
Use a flat chisel and a hammer to remove the crankshaft gear key.

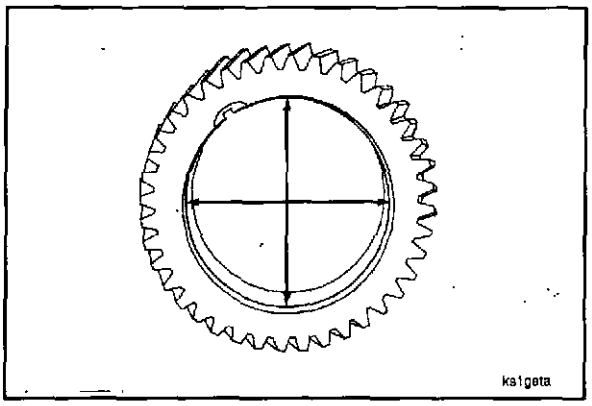


Cleaning and Inspection

Visually inspect the crankshaft gear journal for burrs or damage.

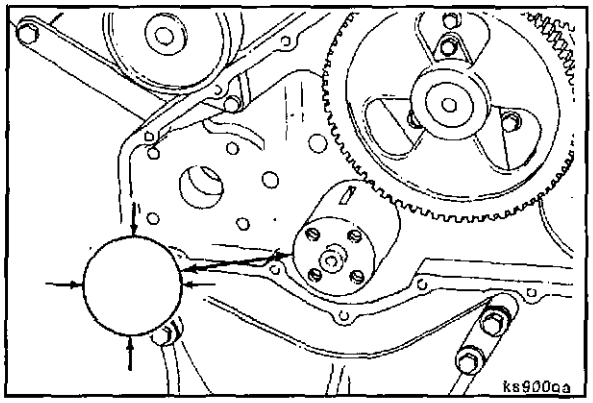
Remove any burrs with Scotch-Brite® 7448, Part No. 3823258, or equivalent.





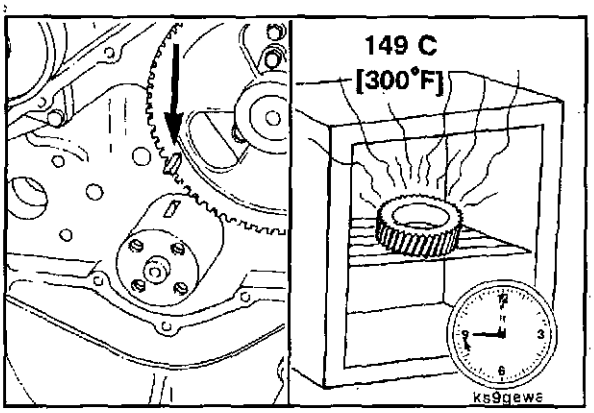
Measure the crankshaft gear bore inside diameter.

Crankshaft Gear Bore I.D.		
mm		in
75.898	MIN	2.9881
75.923	MAX	2.9891



Measure the crankshaft gear fit area outside diameter.

Crankshaft Gear Fit Area O.D.		
mm		in
75.987	MIN	2.991
76.006	MAX	2.992



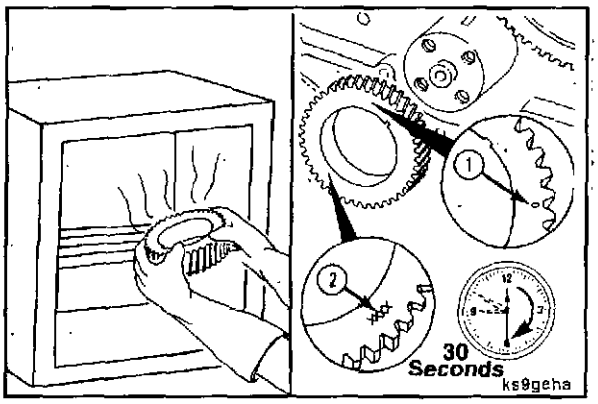
Installation

Use a leather hammer to install a new key in the crankshaft keyway.

Caution: Do not exceed the specified time or temperature when heating the crankshaft gear. The gear and teeth can be damaged.

Heat the gear in an oven for a minimum of 45 minutes but not more than 6 hours.

Temperature: 149°C [300°F]



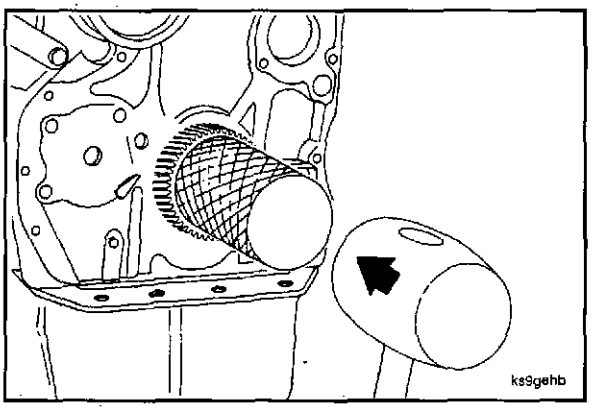
Caution: Use insulated gloves, Part No. 3823730, when handling heated parts. Hot parts can cause serious personal injury.

Caution: The timing mark (1) and part number (2) on the gear must be facing away from the crankshaft after the gear is installed. Engine damage can result if the gear is installed backwards.

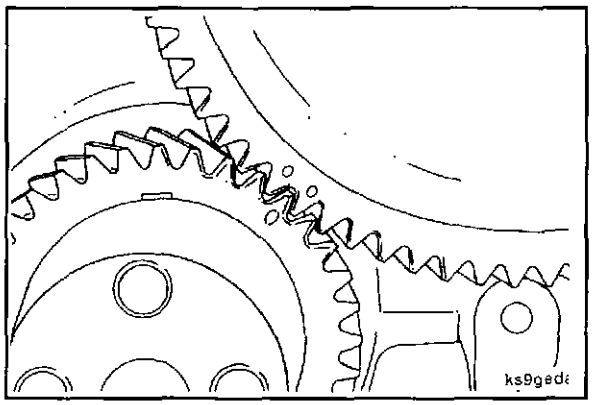
Use Lubriplate™ 105, or equivalent, to lubricate the outside diameter of the crankshaft gear journal.

Remove the gear from the oven. Align the keyway of the gear with the key in the crankshaft and install the gear within 30 seconds.

NOTE: If the gear cools and stops on the crankshaft before it is fully installed, use a driver to complete the installation.



NOTE: If any gears were rotated, it will be necessary to align the timing marks of the crankshaft and the camshaft gears. Refer to Procedure 7-22.



Install the fuel pump drive gear.

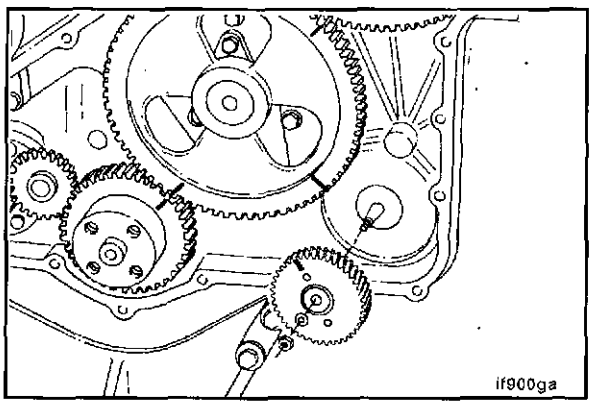
Tighten the capscrews.

Refer to procedure 5-10.

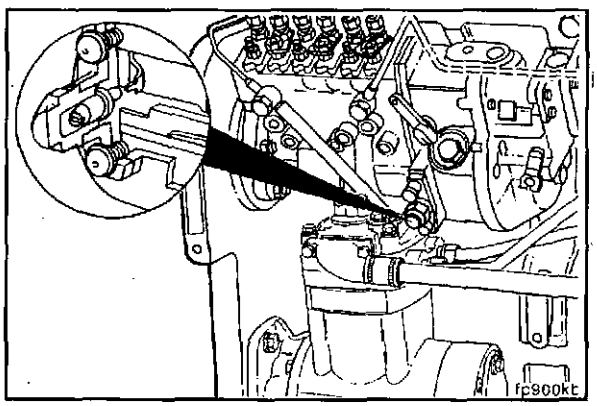
Install the accessory drive gear. Make sure to align the marks that were made during removal.

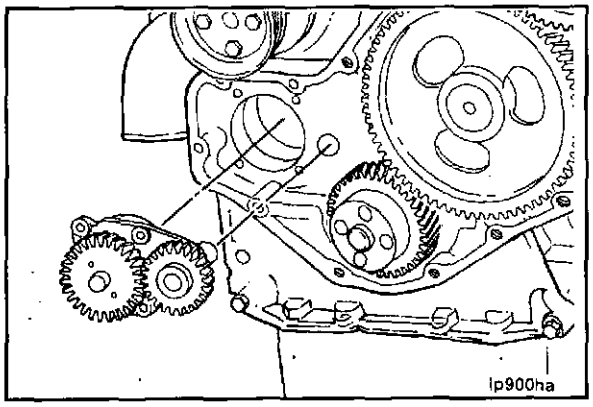
Tighten the capscrews.

Torque Value: 126 N•m [93 ft-lb]

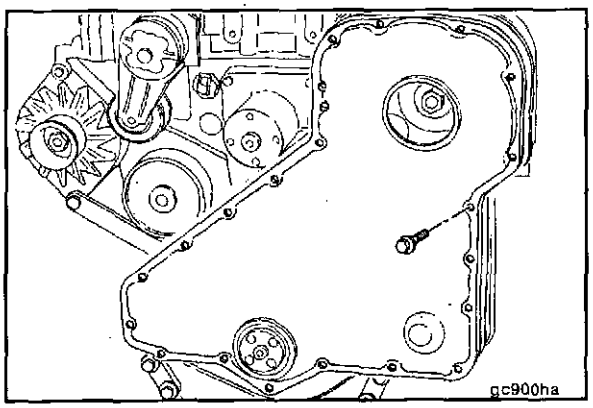


Unlock the fuel injection pump.

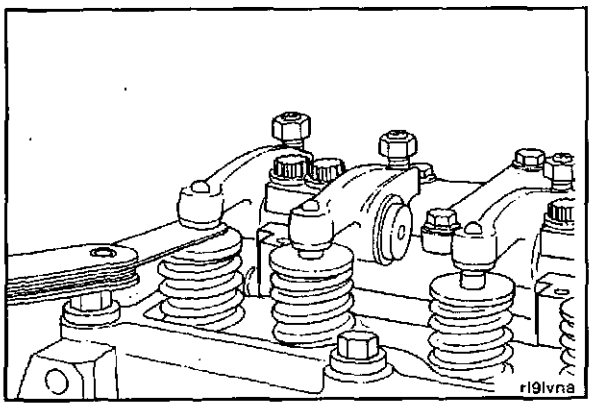




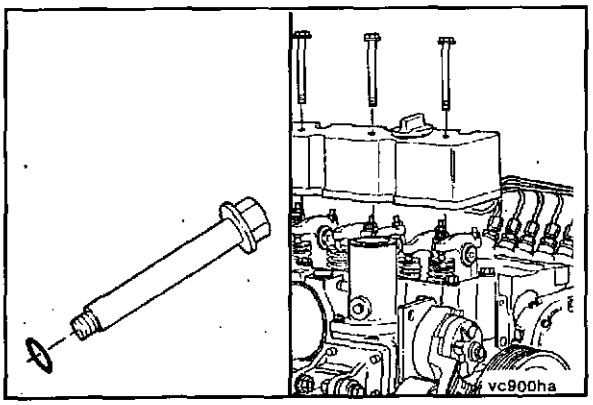
Install the lubricating oil pump. Refer to Procedure 2-14.



Install the gear cover. Refer to Procedure 7-17.

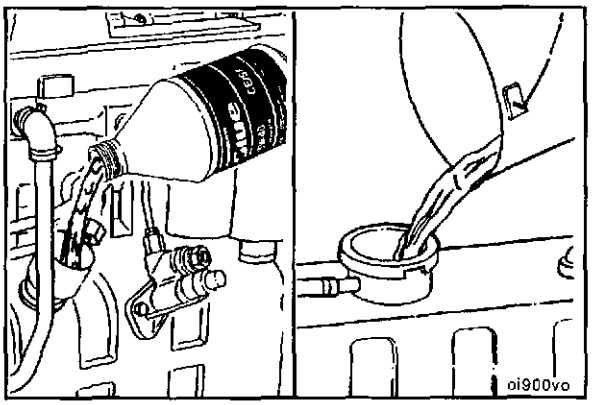


Adjust the valve clearance. Refer to Procedure 7-06.

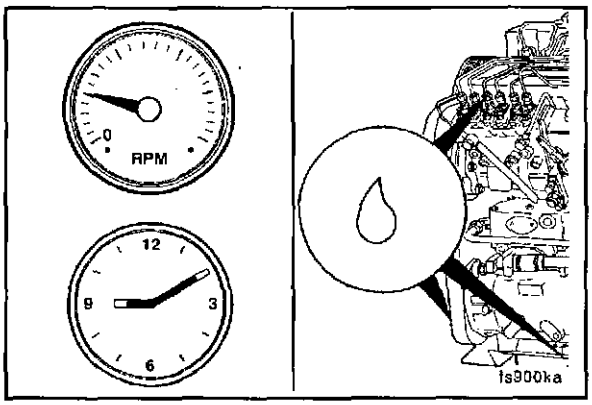


Install the valve cover. Refer to Procedure 7-02.

Fill the engine with oil and coolant. Refer to Procedures 2-05 and 1-01.



Operate the engine at idle for 5 to 10 minutes to check for leaks and proper operation.



Flywheel - Replacement (7-26)

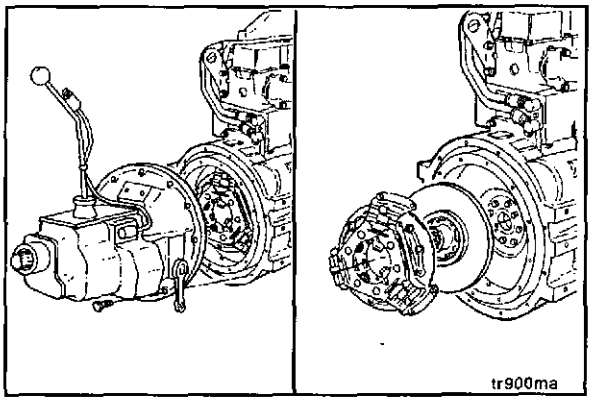
Removal

Part No. 3377371, Engine Barring Gear

Remove the vehicle drive line and transmission. Refer to the manufacturer's instructions.

Remove the clutch discs and the pressure plate.

NOTE: Use the barring gear, Part No. 3377371, to hold the flywheel to prevent rotation.

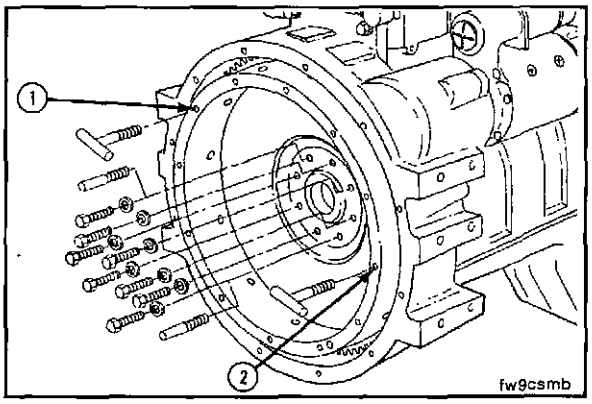


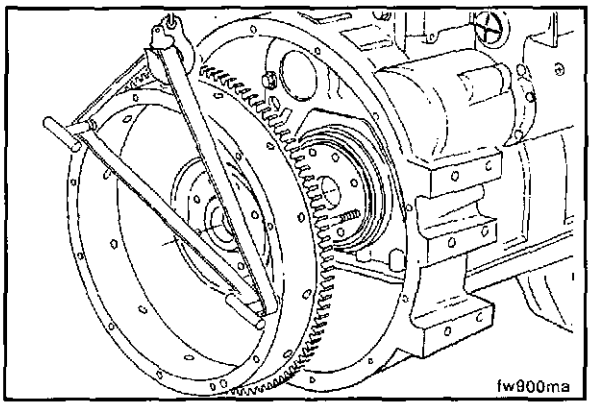
Remove two capscrews 180 degrees apart. Install two M12X1.25X90 mm guide pins.

NOTE: If a clutch is used in the equipment, the threads in the clutch pressure plate mounting capscrew holes can be metric or standard. Be **sure** to use the correct capscrews.

Determine the capscrew thread design and size and install two "T-handles" in the flywheel at points (1) and (2).

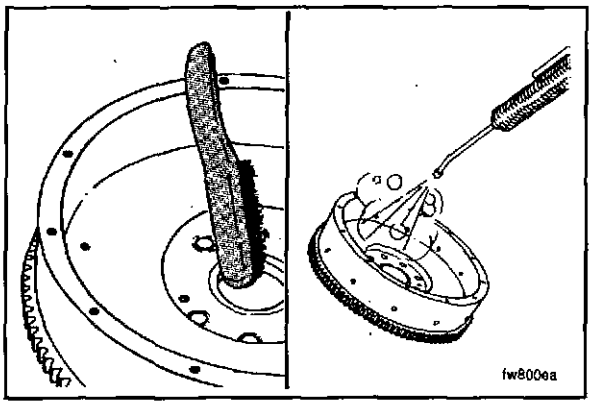
Remove the remaining six flywheel mounting capscrews.





The component weighs 23 kg [50 lb] or more. To avoid personal injury, use a hoist or get assistance to lift the component.

Remove the flywheel from the guide pins.

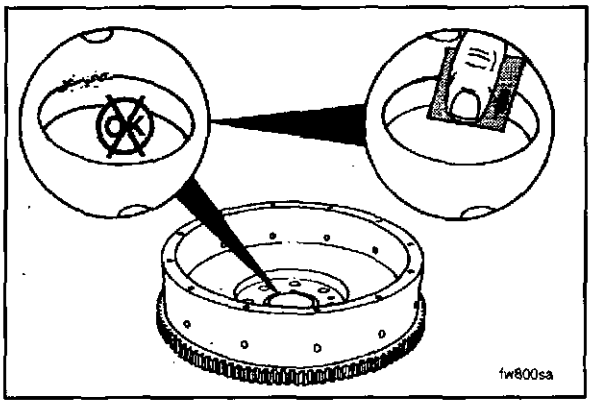


Cleaning and Inspection

Use a wire brush to clean the crankshaft pilot bore.

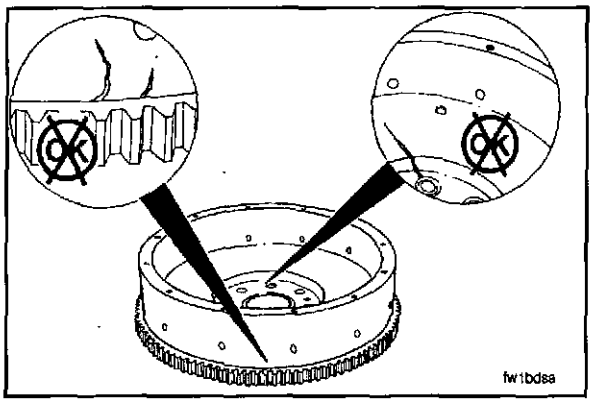
Warning: When using a steam cleaner, wear protective clothing and safety glasses or a face shield. Hot steam can cause serious personal injury.

Use steam or solvent to clean the flywheel. Dry with *compressed air.*



Visually inspect for nicks or burrs.

Use Scotch-Brite® *7448*, or equivalent, to remove small nicks and burrs.

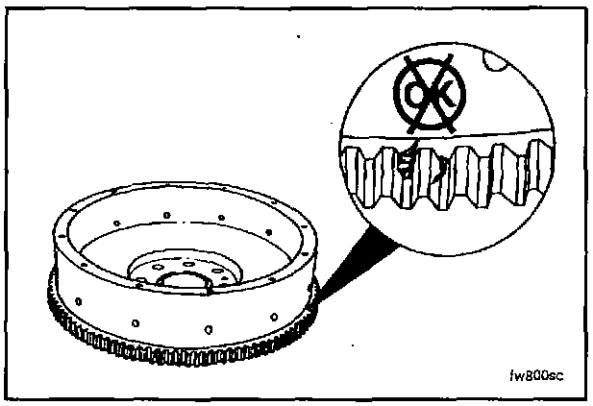


***Warning: Do not use a cracked or resurfaced flywheel.* These can break, causing serious personal injury or property damage.**

Use the crack detection kit, Part No. 3375432, to check for cracks in the flywheel. Follow the instructions provided with the kit.

Inspect the flywheel ring gear teeth for cracks and chips.

NOTE: If the ring gear teeth are cracked or broken, the ring gear **must** be replaced. Refer to Procedure 7-27.

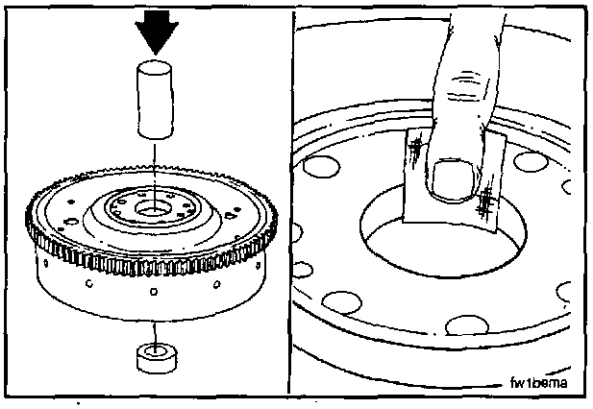


Installation

NOTE: Use a new pilot bearing when installing a new or rebuilt clutch.

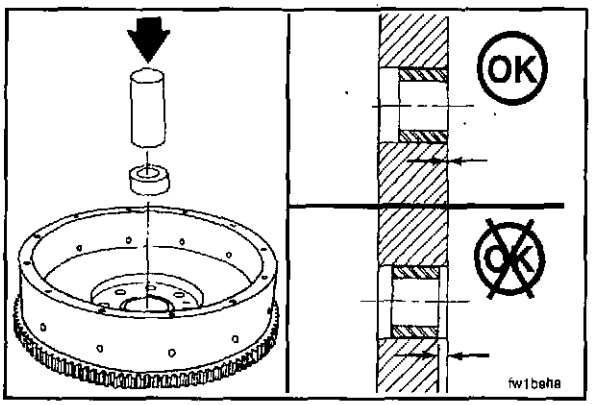
Use a mandrel and a hammer to remove the pilot bearing.

Use a Scotch-Brite® 7448, or equivalent, to clean the pilot bore.



Use a mandrel and hammer to install the pilot bearing.

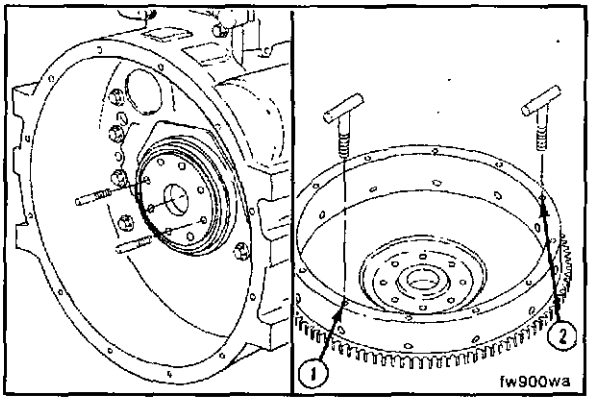
NOTE: The pilot bearing **must** be installed even with the pilot bore surface.

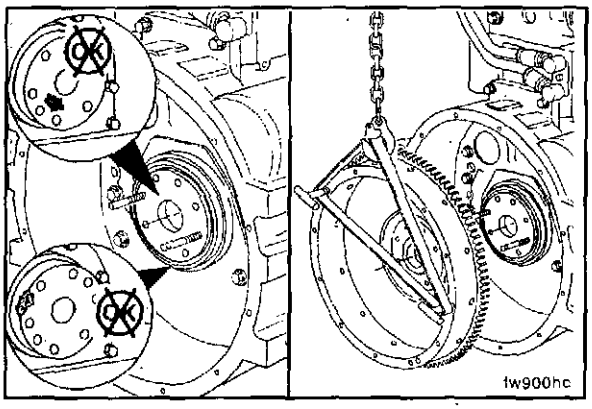


Install two M12X1.25X90 mm guide pins into the crankshaft flange 180 degrees apart.

NOTE: If a clutch is used in the equipment, the threads in the clutch pressure plate mounting capscrew holes can be metric or standard. Be **sure** to use the correct capscrews.

Determine the capscrew thread design and size and install two "T-handles" into the flywheel at points (1) and (2).

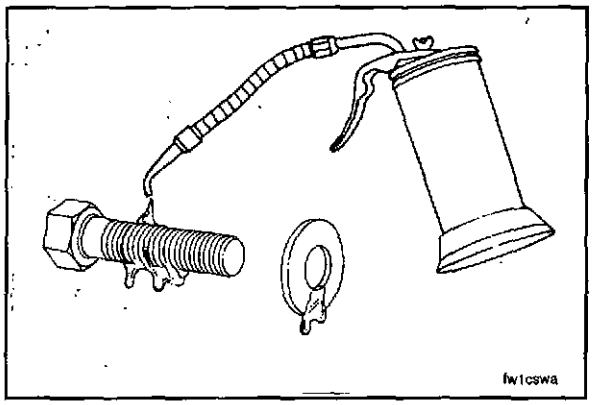




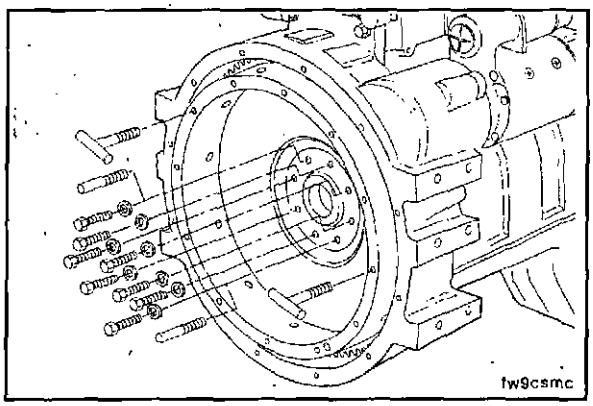
Visually inspect rear face of crankshaft and flywheel mounting flange for cleanliness and raised nicks or burrs.

The component weighs 23 kg [50 lbs] or more. To avoid personal injury, use a hoist or get assistance to lift the component.

Install the flywheel on the guide pins.



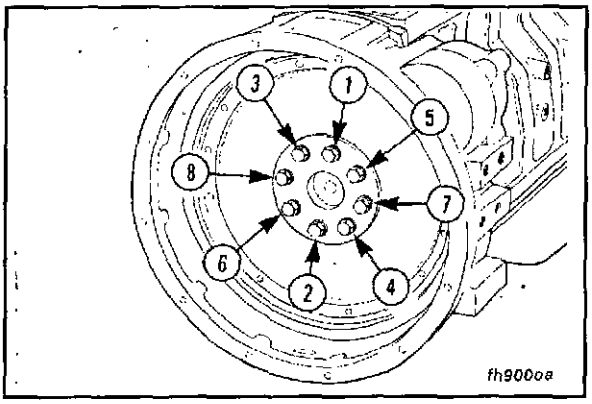
Lubricate the threads of the capscrews and the surface of the washers with 15W-40 lubricating oil.



Install the six capscrews.

Remove the "T-handles" and guide pins.

Install the remaining capscrews into the holes from which the guide pins were removed.



19 mm Socket, Torque Wrench, Part No. 3377371, Engine Barring Gear

Hold the crankshaft when tightening the flywheel capscrews.

Tighten the capscrews in a star pattern.

Torque Value: 137 N•m [101 ft-lb]

Refer to the equipment manufacturer's procedures to install the transmission.

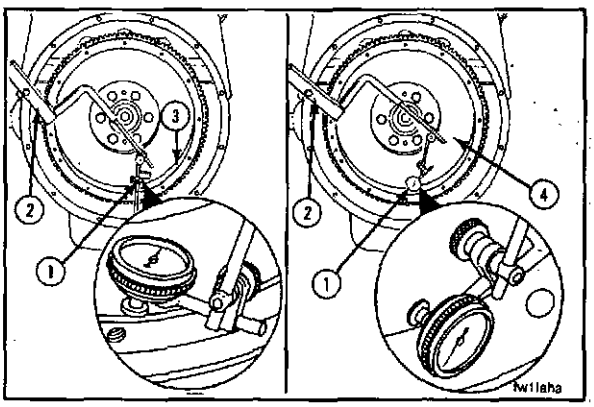
Flywheel Bore Runout Measurement

Use the dial indicator gauge (1), Part No. 3376050, or its equivalent and dial gauge attachment (2), Part No. ST-1325, to inspect the flywheel bore (3) and the surface (4) runout.

Install the attachment to the flywheel housing.

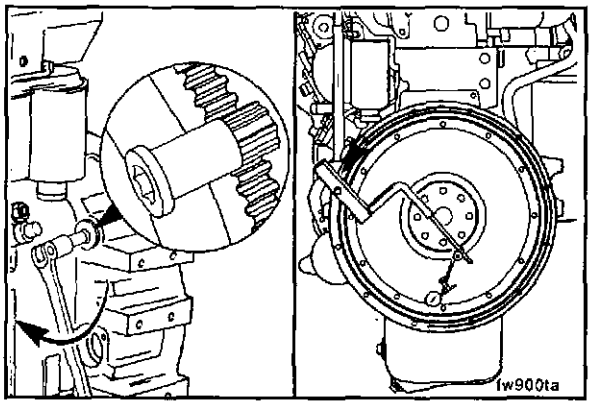
Install the gauge on the attachment.

Install the contact tip of the indicator against the inside diameter of the flywheel bore, and set the dial indicator at "0" (zero).



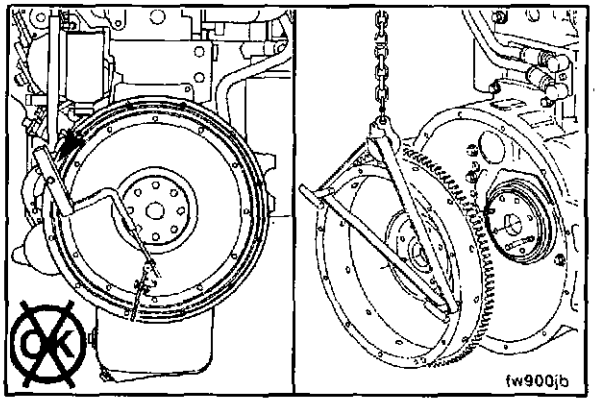
Use the barring gear, Part No. 3377371, to rotate the crankshaft one complete revolution (360 degrees).

NOTE: The total indicator reading (TIR) **must not** exceed 0.127 mm [0.0050-inch].

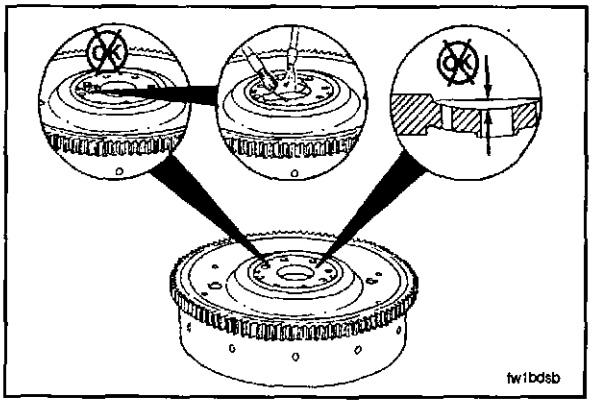


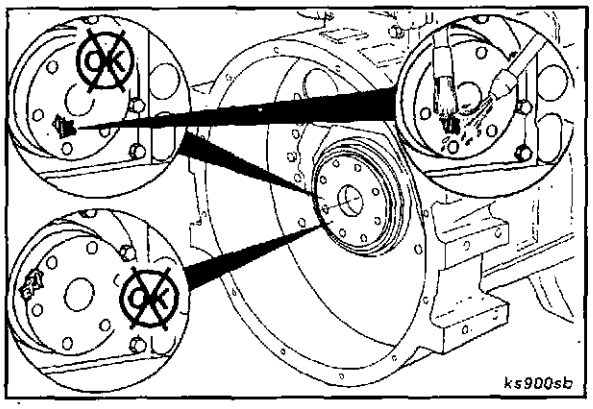
NOTE: If the TIR is greater than the specification, do the following:

- Remove the flywheel.



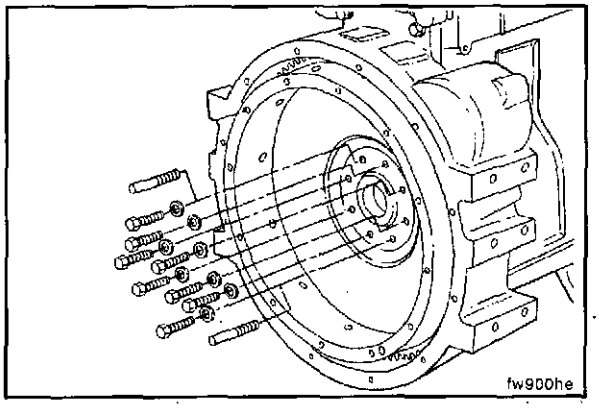
- Inspect the flywheel mounting surface for dirt or damage.



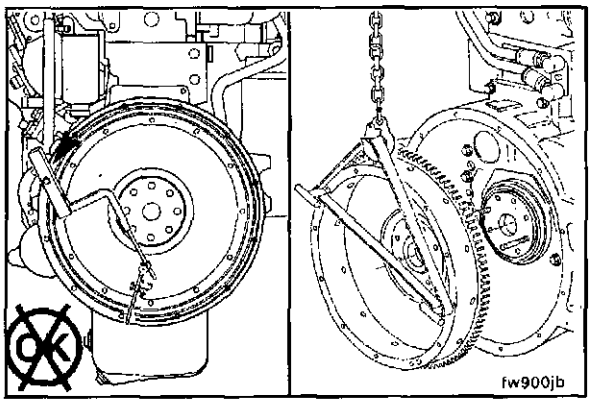


- Inspect the crankshaft for dirt or damage.

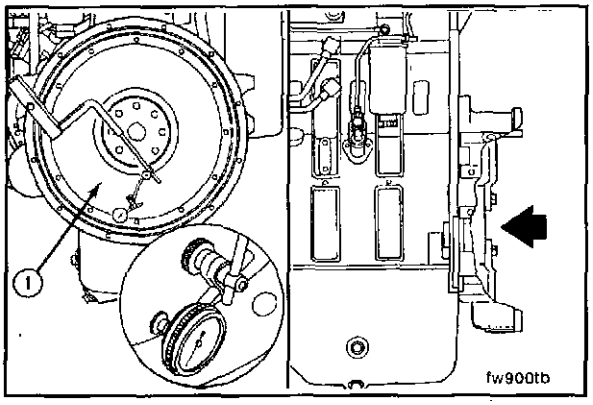
NOTE: Refer to the C Series Shop Manual to replace the crankshaft.



- Install the flywheel, and inspect the bore runout again.



- Replace the flywheel if the runout does **not** meet specifications.



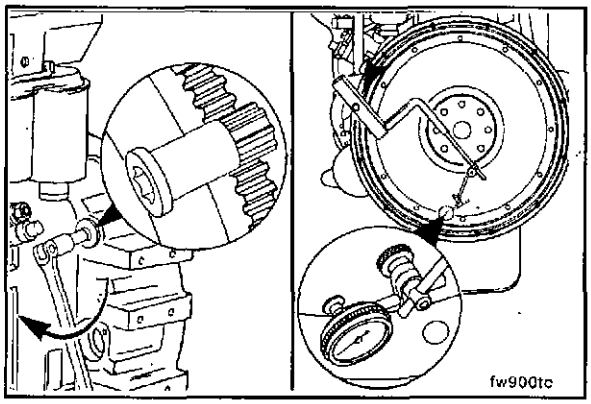
Flywheel Face Runout Measurement

Install the contact tip of the indicator against the flywheel face, *as close to the outside diameter as possible, to* inspect the face (1) runout.

NOTE: Push the flywheel forward to remove the crankshaft end clearance. Adjust the dial on the indicator until the needle points to "0" (zero).

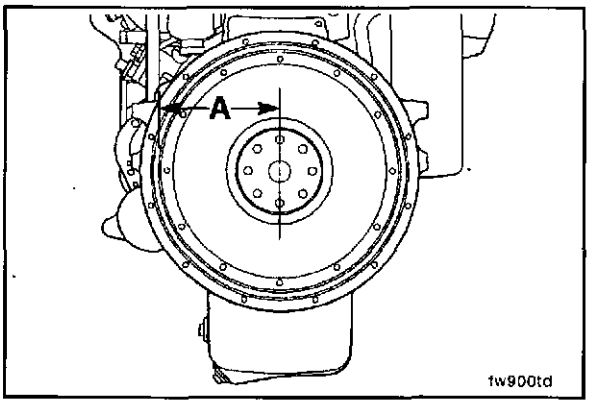
Use the engine barring gear, Part No. 3377371, to rotate the crankshaft one complete revolution. Measure the flywheel runout at four equal points on the flywheel.

NOTE: The flywheel **must** be pushed toward the front of the engine to remove the crankshaft end clearance each time a point is measured.

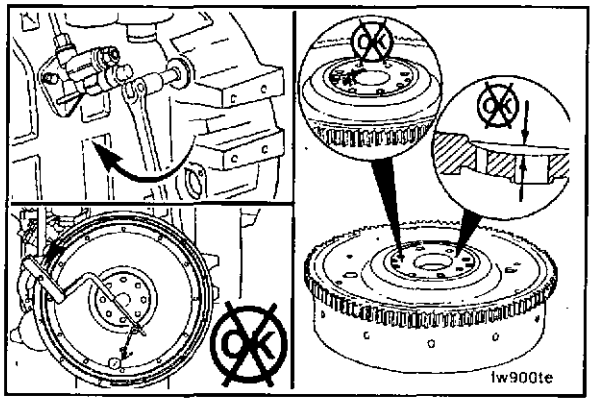


The total indicator reading (TIR) **must not** exceed the following specifications:

Flywheel Radius (A)		Maximum (TIR) of Flywheel Face	
mm	in	mm	in
203	8	0.203	0.008
254	10	0.254	0.010
305	12	0.305	0.012
356	14	0.356	0.014
406	16	0.406	0.016

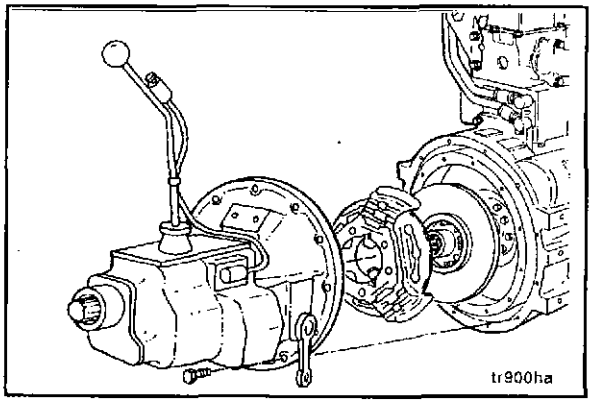


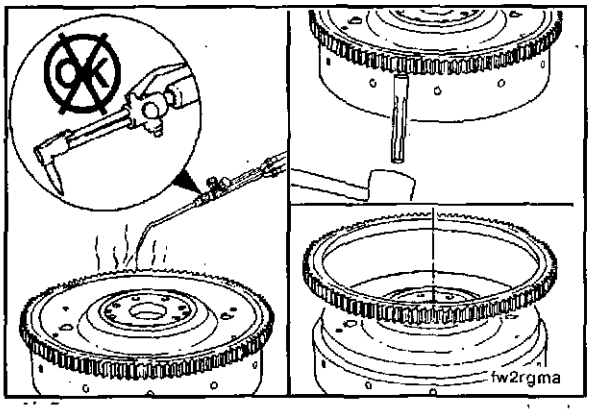
If the flywheel face runout is **not** within specifications, remove the flywheel. Check for nicks, burrs, or foreign material between the flywheel mounting surface and the crankshaft flange.



Install the clutch discs, pressure plate, transmission and drive line (if equipped) in **reverse** order of removal. Refer to the manufacturer's instructions.

NOTE: Align the universal joints on each end of the drive shaft to prevent vibration.





Flywheel Ring Gear - Replacement (7-27)

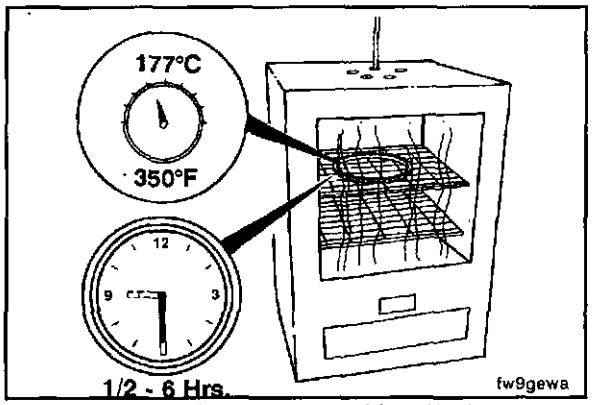
Removal

Caution: Do not use a cutting torch to heat the ring gear, the flywheel can be damaged.

Heat the outside diameter of the ring gear with a heating torch.

Warning: Wear eye protection while driving the gear from the flywheel.

Use a blunt chisel or brass drift and hammer to remove the gear from the flywheel.



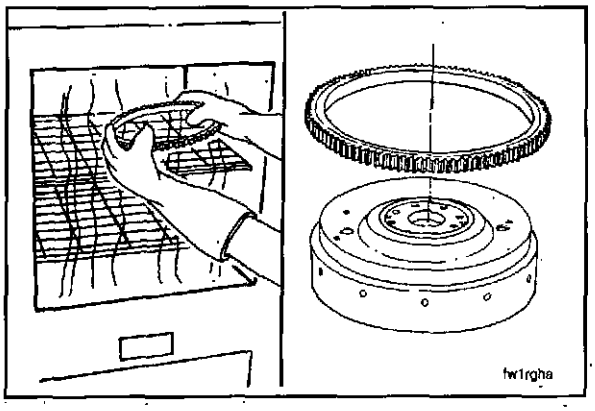
Installation

NOTE: Do **not** attempt to install the ring gear without using heat.

Use an oven to heat the new ring gear. Heat the ring gear for a minimum of 30 minutes in a preheated oven. Do **not** heat the ring gear for more than 6 hours.

Temperature: 177°C [350°F]

NOTE: Do **not** exceed the specified time or temperature. The metal hardness will be changed.

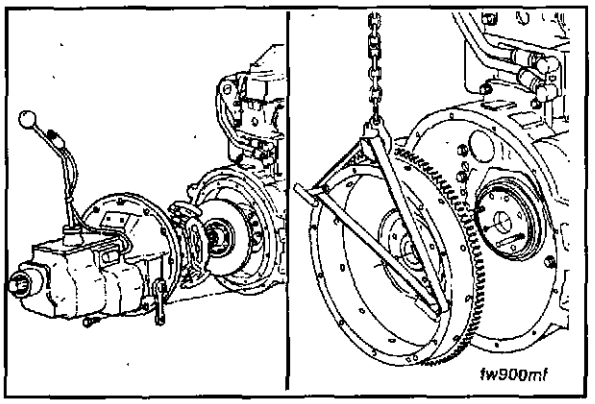


Caution: Wear protective gloves to prevent personal injury when handling parts that have been heated.

NOTE: The gear **must** be installed so the bevel on the teeth is toward the crankshaft side of the flywheel.

Remove the gear from the oven, and install it on the *flywheel before it cools. Allow the air to cool the gear.* Do **not** use water or oil to reduce the cooling time.

NOTE: If an oven is **not** available, use a heating torch to heat the inside diameter of the new ring gear to 177°C [350°F]. Use a Tempilskik® crayon or its equivalent to check the gear temperature before installing it on the flywheel.



Flywheel Housing - Replacement (7-28)

Removal

Remove the transmission, clutch, and all related components. *Refer to the manufacturer's instructions.*

Remove the flywheel. Refer to Procedure 7-26.

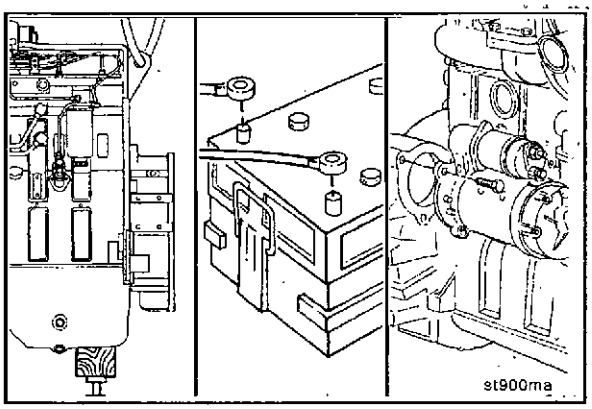
16 mm

Caution: Place a wooden block the width of the oil pan between the floor jack and oil pan to prevent damage to the engine.

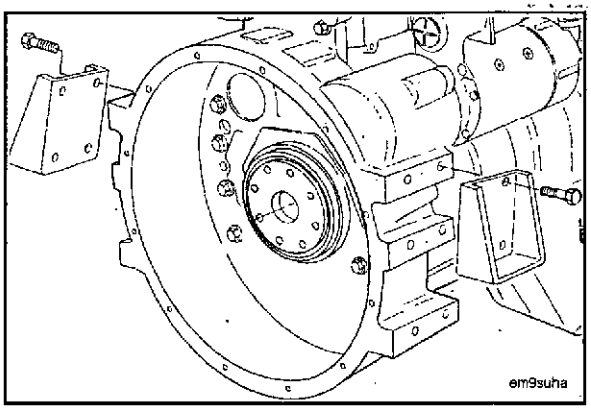
Use a floor jack or a suitable lifting fixture to support the rear of the engine.

Disconnect the battery cables.

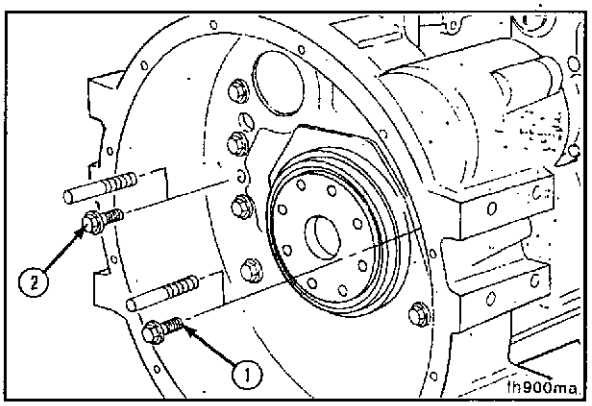
Remove the starting motor. Refer to Procedure 6-02.



Remove the capscrews and both rear engine mounts.



Remove capscrews (1) and (2), and install two M12-1.75X100 mm guide pins.

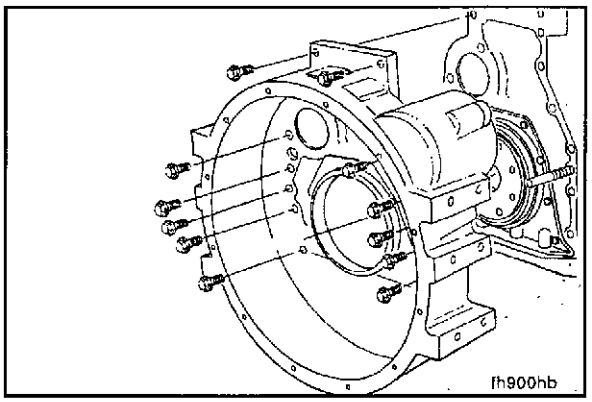


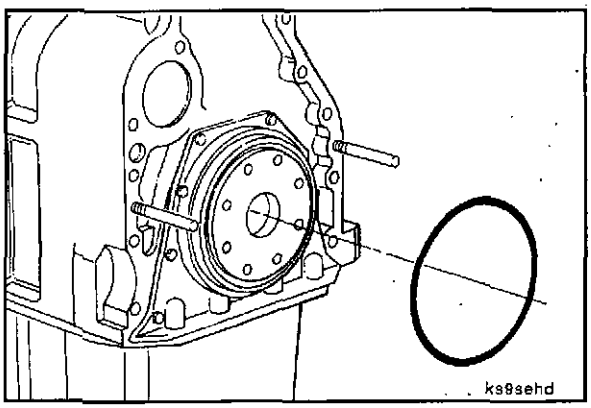
Remove the remaining capscrews.

The component weighs 23 kg [50 lb] or more. To avoid personal injury, use a hoist or get assistance to lift the component.

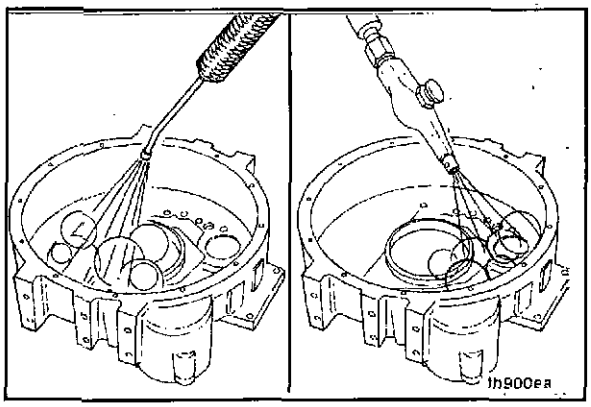
Use a rubber hammer to loosen the flywheel housing.

Remove the flywheel housing.





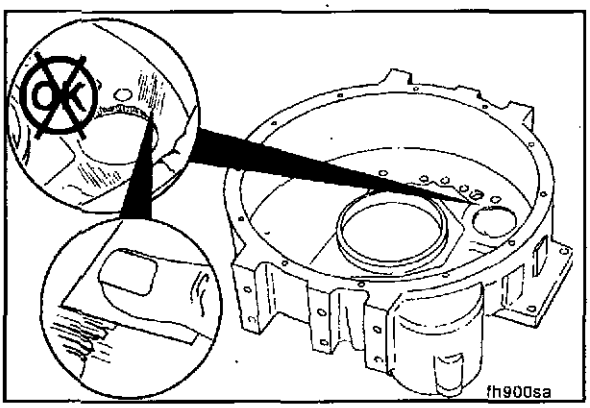
Remove the o-ring from the rear seal cover.



Cleaning and Inspection

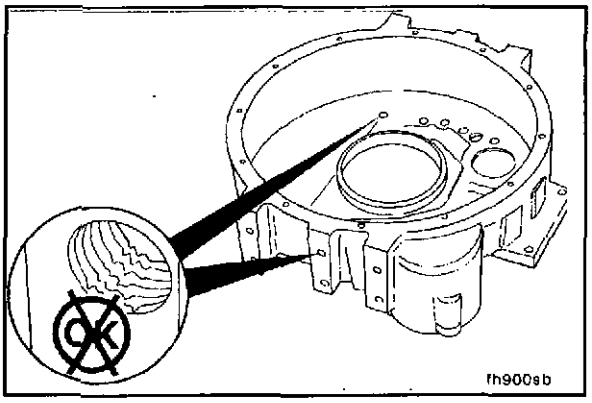
Warning: When using a steam cleaner, wear protective clothing and safety glasses or a face shield. Hot steam can cause serious personal injury.

Use steam or solvent to clean the flywheel housing. Dry with compressed air.



Visually inspect all surfaces for nicks, burrs, or cracks.

Use a fine crocus cloth to remove small nicks and burrs.



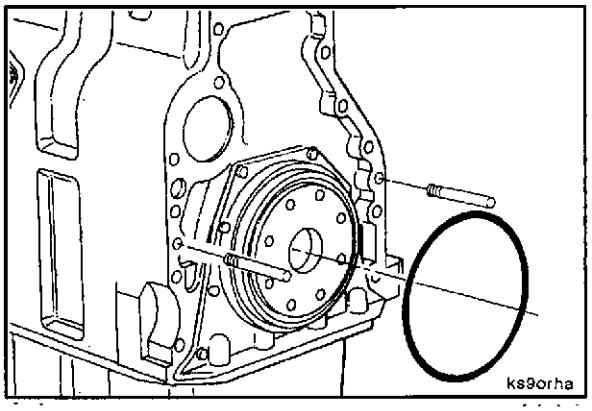
Inspect all threaded capscrew holes for damage.

Repair or replace the housing if the capscrew holes are damaged.

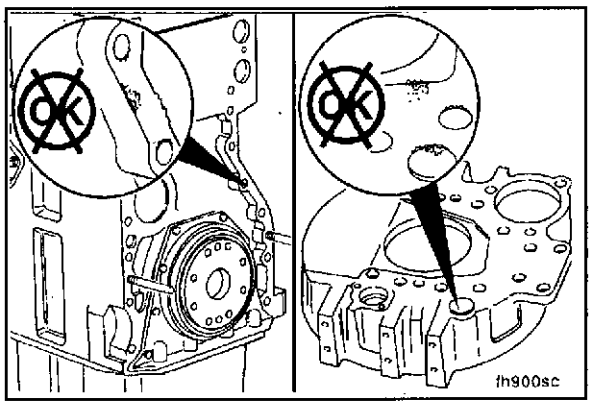
Installation (Dry Clutch Application)

Install two M12X1.75X100 mm guide pins into the cylinder block to help support and align the housing during installation.

NOTE: Some dry clutch applications require a sealing ring on the seal housing. Install the sealing ring in the machined surface of the seal housing and lubricate with Lubriplate™ 105.



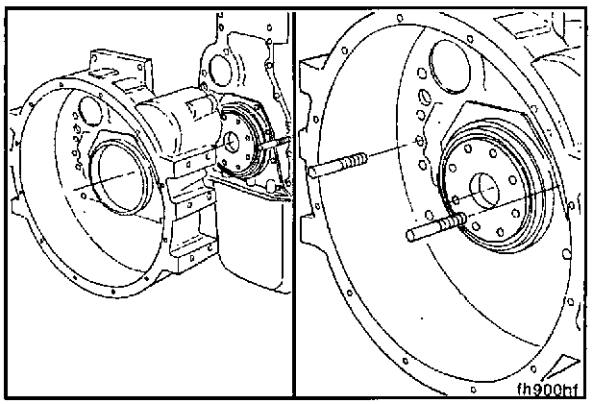
Visually inspect the rear face of the cylinder block and flywheel housing mounting surface for cleanliness and raised nicks or burrs.



Install the flywheel housing making sure the housing is positioned on the alignment dowels and guide pins.

NOTE: Be sure the sealing ring is **not** damaged during installation.

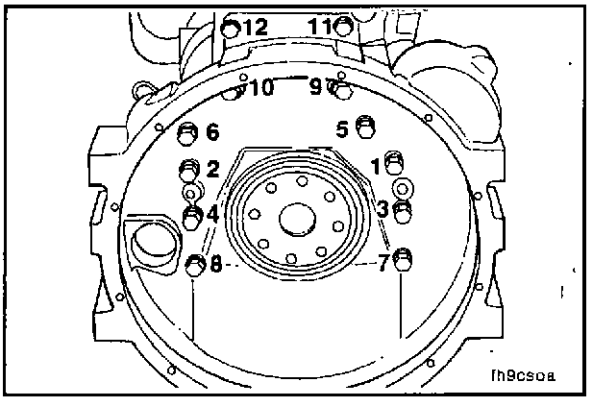
Remove the two M12X1.75X100 mm guide pins.

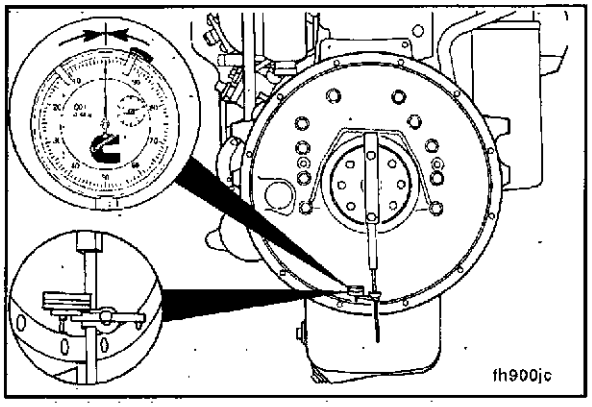


15 mm

Install and tighten the mounting capscrews using the pattern shown in the chart.

Torque Value: 77 N•m [57 ft-lb]



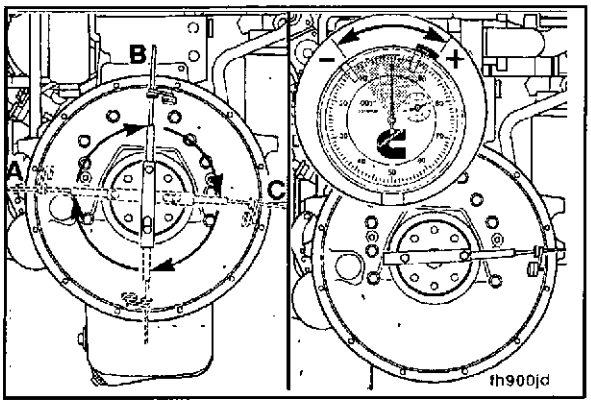


Concentricity - Checking

Part No. ST-1325, Dial Gauge Attachment

Attach a dial indicator to the crankshaft. The dial indicator can be mounted by any method that holds the extension bar of the indicator rigid so it does **not** sag. If the bar sags or the indicator slips, the readings obtained will not be accurate.

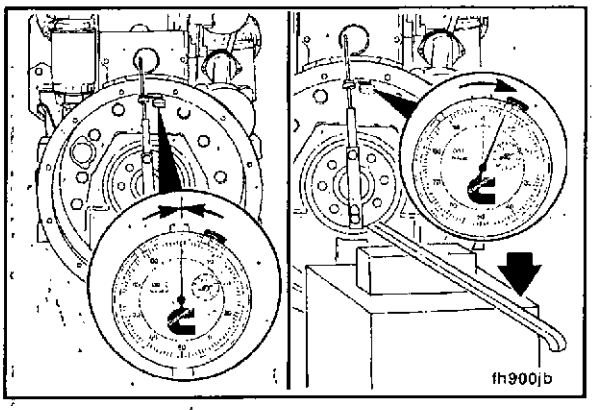
Position the indicator in the 6:00 o'clock position and zero the gauge.



Part No. 3377371, Engine Barring Gear.

Slowly rotate the crankshaft. Record the readings obtained at the 9:00 o'clock, 12:00 o'clock, and 3:00 o'clock positions as [a], [b], and [c] in the concentricity work sheet. Recheck zero at the 6:00 o'clock position.

The values for [a], [b], and [c] could be positive or negative. Refer to the accompanying figure to determine the correct sign when recording these values.



Rotate the crankshaft until the dial indicator is at the 12:00 o'clock position and zero the gauge.

NOTE: Do **not** force the crankshaft beyond the point where the bearing clearance has been removed. Do **not** pry against the flywheel housing. These actions could cause false bearing clearance readings.

Use a pry bar to raise the rear of the crankshaft to its upper limit. Record the value as [d] in the concentricity work sheet. This is the vertical bearing clearance adjustment and will always be positive.

Use the concentricity work sheet to determine the values for the 'total vertical' and 'total horizontal' values.

The 'total horizontal' is equal to the 9:00 o'clock reading, [a], minus the 3:00 o'clock reading, [c].

The 'total vertical' is equal to the 12:00 o'clock reading, [b], plus the bearing clearance, [d].

Example:

6:00 o'clock = ref = 0
9:00 o'clock = [a] = 0.004 inch
12:00 o'clock = [b] = 0.003 inch
3:00 o'clock = [c] = -0.002 inch

Using the work sheet and the numbers from the example, the 'total horizontal' value = 0.006 inch and the 'total vertical' value = 0.005 inch.

Concentricity Worksheet

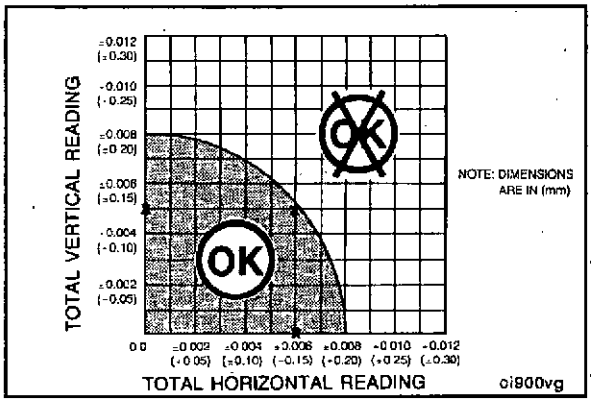
9 o'clock	a = 0.004
3 o'clock	c = -0.002
Total Horizontal	a – c = .006
12 o'clock	b = .003
Bearing Clearance	d = .002
Total Vertical	b + d = .005

oi900vf

Mark the 'total horizontal' value on the horizontal side of the chart and the 'total vertical' on the vertical side of the chart.

Use a straight edge to find the intersection point of the 'total horizontal' and 'total vertical' values. The intersection point **must** fall within the shaded area for the flywheel housing concentricity to be within specification.

Use the 'total horizontal' and 'total vertical' values from the previous example, the intersection point falls within the shaded area. Therefore, the flywheel housing concentricity is within specification.



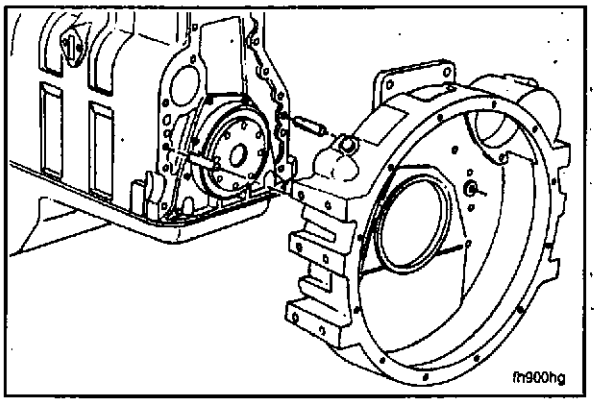
If the intersection point falls outside the shaded area, the ring dowels **must** be removed and the housing repositioned.

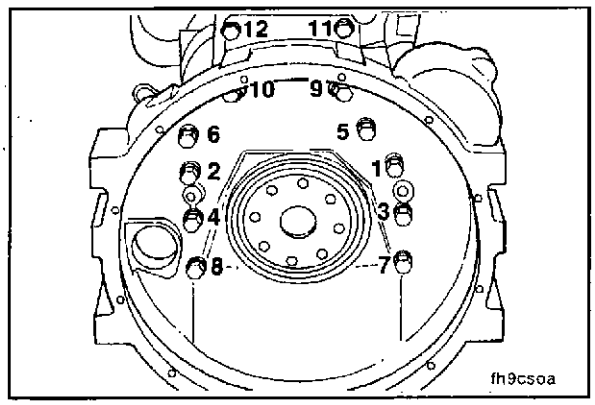
NOTE: The ring dowels are **not** required to maintain concentricity of the housing/ the clamping force of the capscrews holds the housing in position.

After the ring dowels are discarded, install the flywheel housing on the engine.

To position the housing, tighten the capscrews enough to hold the flywheel housing in place, but loose enough to enable small movement when struck lightly with a mallet.

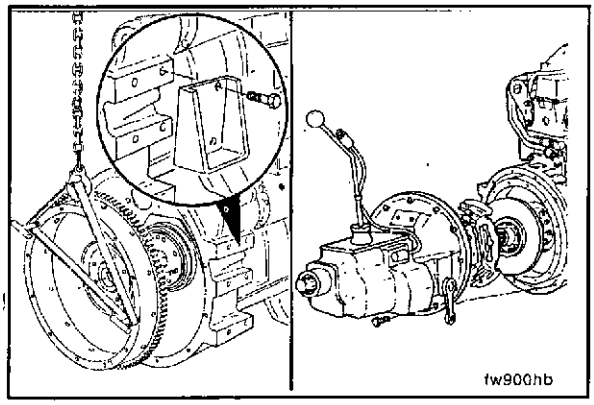
Check the concentricity again by following the above procedure.





Use the pattern shown in the chart to install and tighten the mounting capscrews.

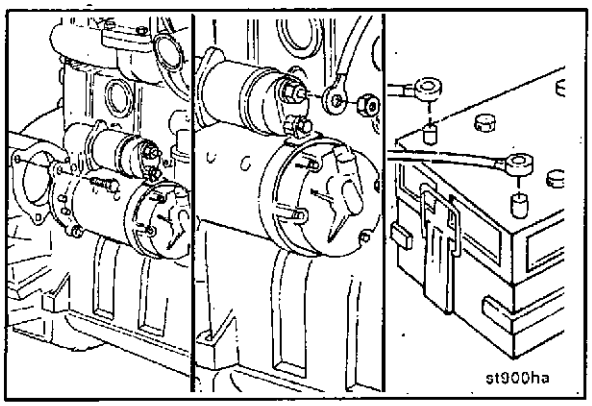
Torque Value: 77 N•m [57 ft-lb]



Install the rear engine mounts.

Install the flywheel. Refer to Procedure 7-26.

Install the clutch, transmission, and all related components. Refer to the manufacturer's instructions.



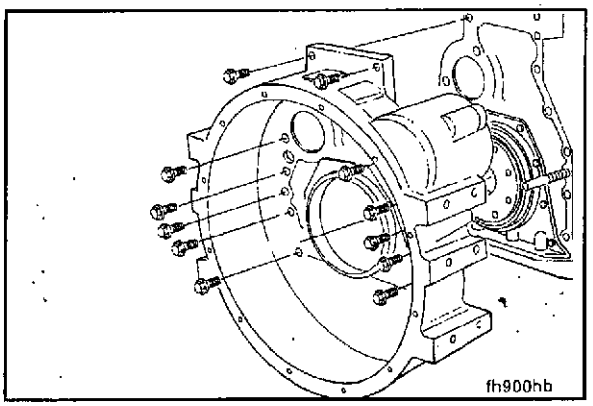
16 mm

Install the starting motor.

Install and tighten the starting motor capscrews.

Torque Value: 77 N•m [57 ft-lb]

Connect the battery cables.



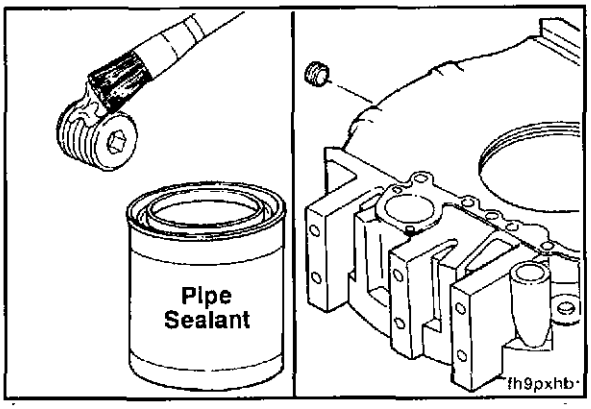
Installation (Wet Clutch Application)

Perform all the steps in the procedure for dry clutch installation in addition to the following:

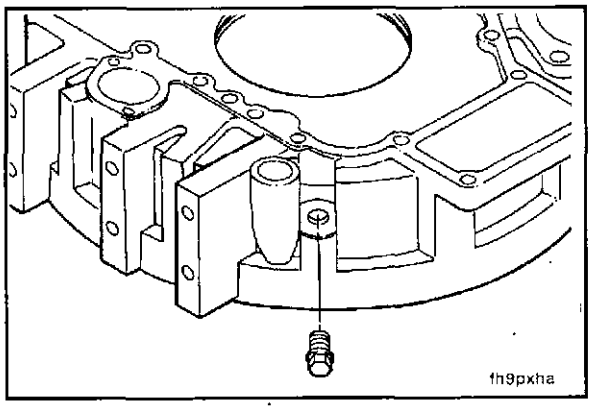
Coat the flywheel housing drain plug with pipe sealant and install into the hole in the bottom of the flywheel housing.

Tighten the plug.

Refer to the pipe plug torque values in Section V for different plug sizes.



Install the plastic plug into the tachometer drive access hole.

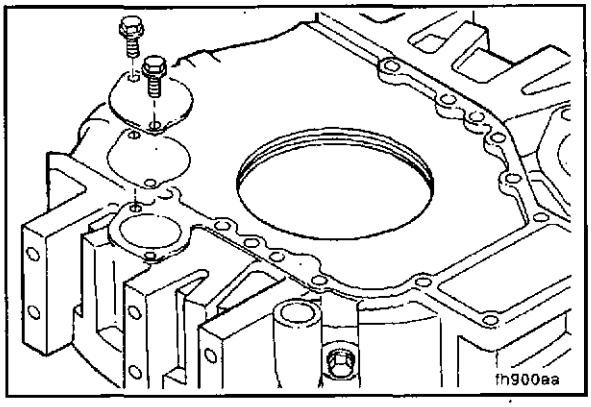


13 mm

Install the access plate and new gasket.

Install the capscrews and tighten.

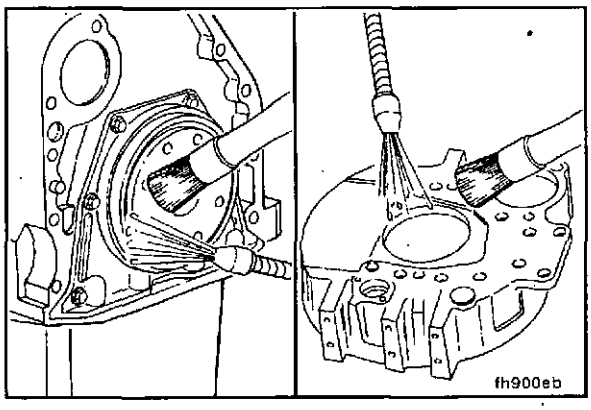
Torque Value: 24 N•m [18 ft-lb]

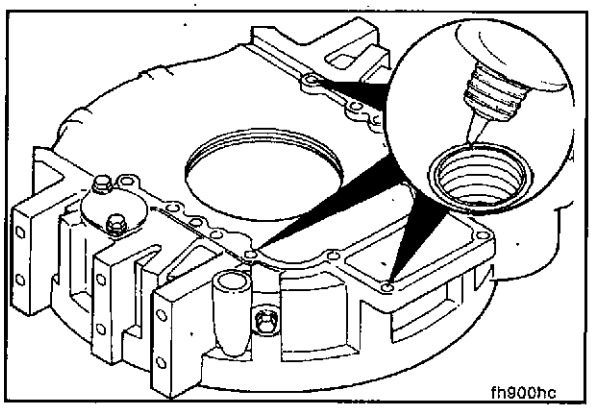


Thoroughly clean the flywheel housing and cylinder block mating surfaces. These surfaces **must be** clean and free of oil or debris.

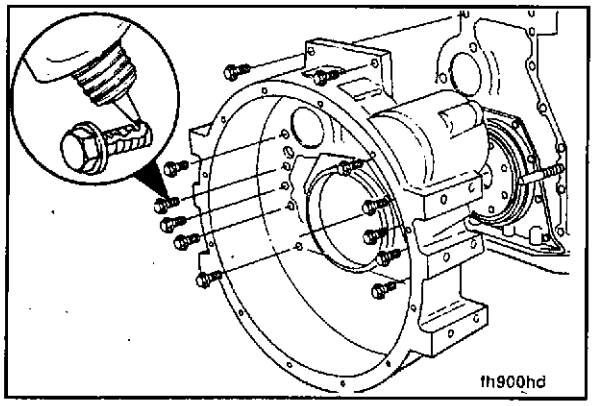
NOTE: The capscrew holes on the mounting pads are drilled through. Coat set screws with Loctite™ 277 and install into holes.

Set Screw Installation Depth		
mm		in
0.00	MIN	0.000
3.00	MAX	0.118





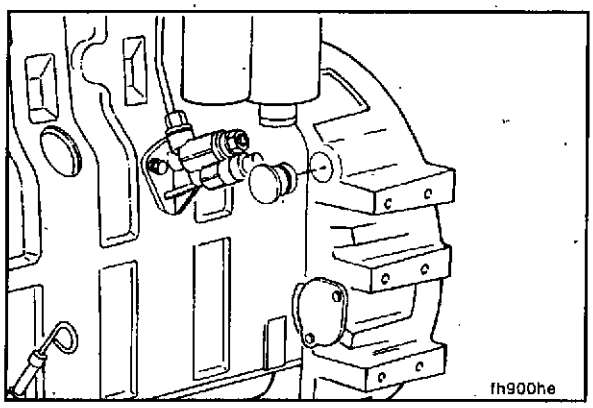
Apply a continuous bead of Three Bond Sealant around all capscrew holes on the mounting surface of the flywheel housing.



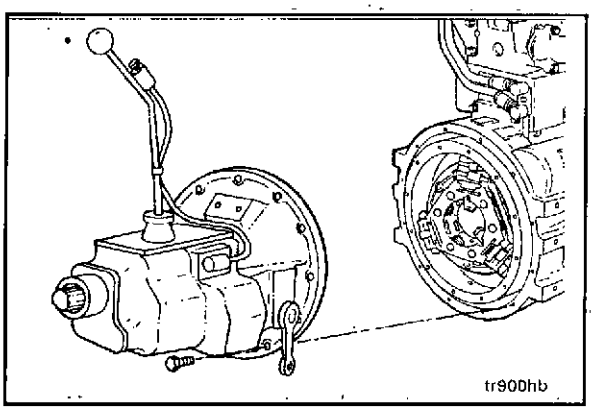
Coat the threads of the mounting capscrews with Loctite™ 277.

Install and tighten the capscrews.

Torque Value: 77 N•m [57 ft-lb]



Install the plug into the barring gear hole.



Seal, Rear Crankshaft - Replacement (7-29)

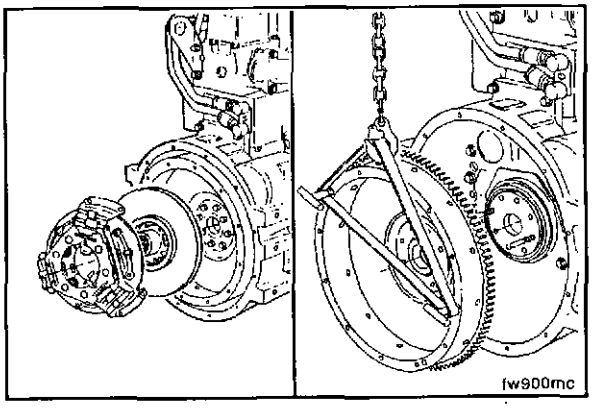
Removal

NOTE: It is **not** necessary to remove the rear cover in order to remove the rear crankshaft seal.

Disconnect the driveline and remove the transmission, if equipped. Refer to the manufacturer's instructions.

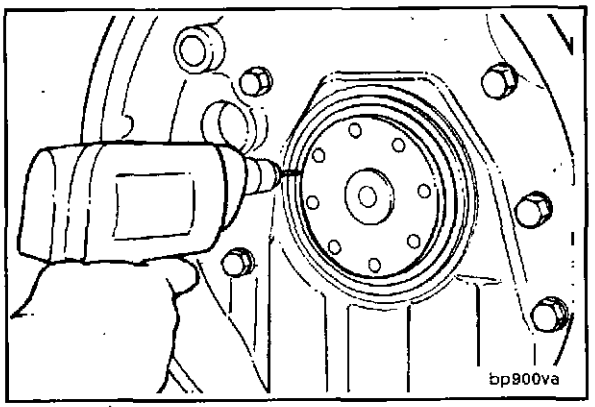
19 mm

Remove the clutch and flywheel, if equipped. Refer to Procedure 7-26.



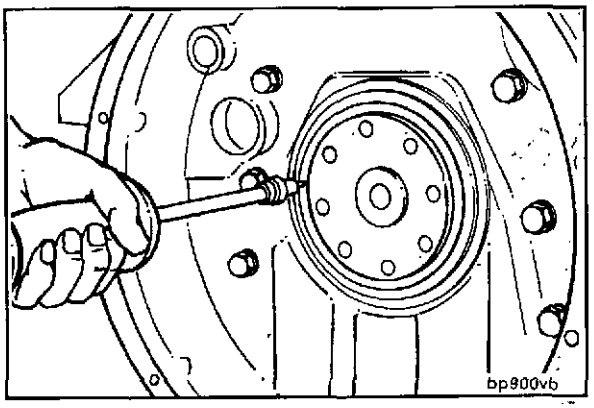
3 mm Drill Bit, Drill Motor

Drill two holes, 180 degrees apart, into the outside metal part of the seal.



No. 10 Sheet Metal Screw, Slide Hammer

Remove the seal.

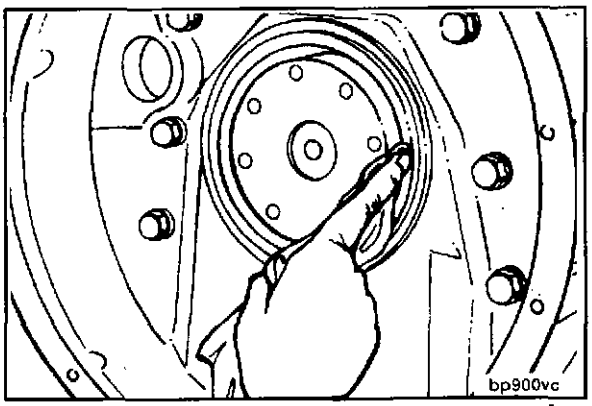


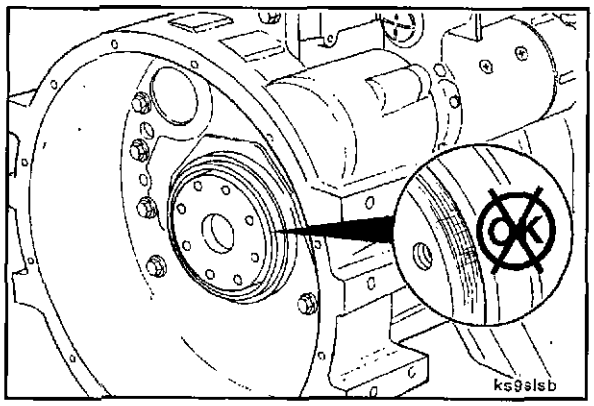
Cleaning and Inspection

Use a crocus cloth to remove any rust or other deposits from the crankshaft flange.

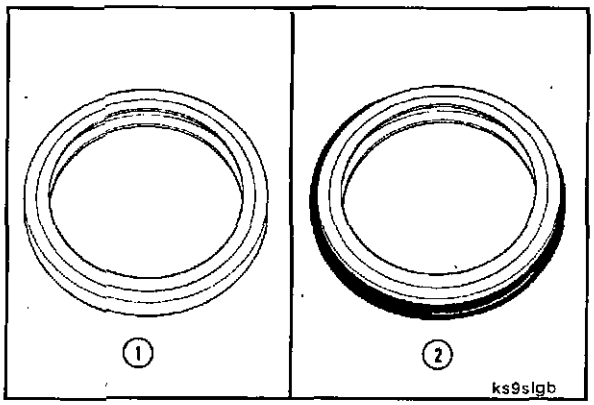
Use a clean cloth to clean the crankshaft flange.

NOTE: Do **not** use any kind of lubricant to install the seal. The oil seal **must** be installed with the lip of the seal and the crankshaft clean and dry.



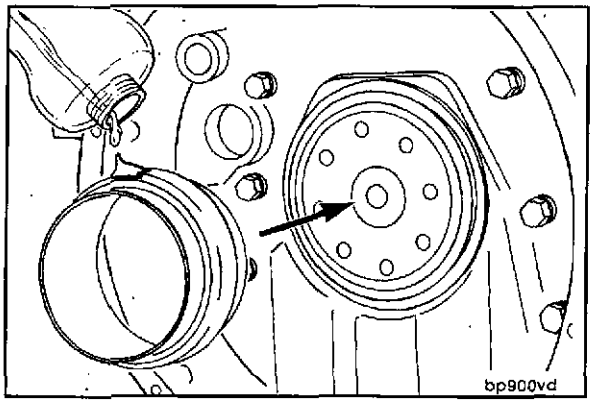


Visually inspect the seal contact area for wear. If the seal contact area has a groove worn deep enough to feel with a fingernail or sharp object, it will be necessary to install a wear sleeve. Refer to Procedure 7-30.

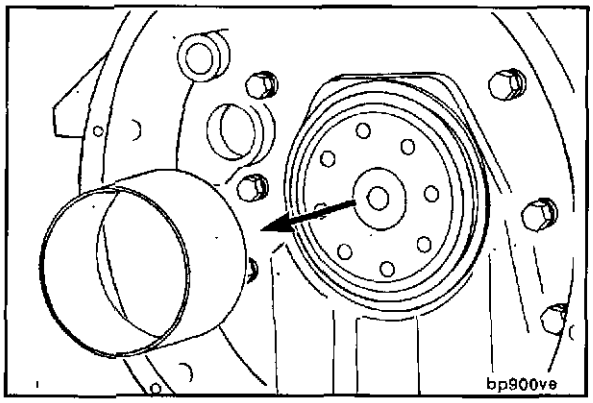


Installation

NOTE: There are two rear seal configurations used; one for dry flywheel housings (1) and one for wet housings (2). The seal for dry housings has an aluminum case with urethane coated outside diameter. The seal for wet housings has a steel case with silicone coated outside diameter. Refer to the appropriate C Series Parts Catalog for the correct part number.



Install the pilot and seal from the seal replacement kit onto the crankshaft. For wet flywheel housings, apply a coat of mild soap to the outside diameter of the seal case. For dry housings, nothing is required on the outside diameter of the seal case.



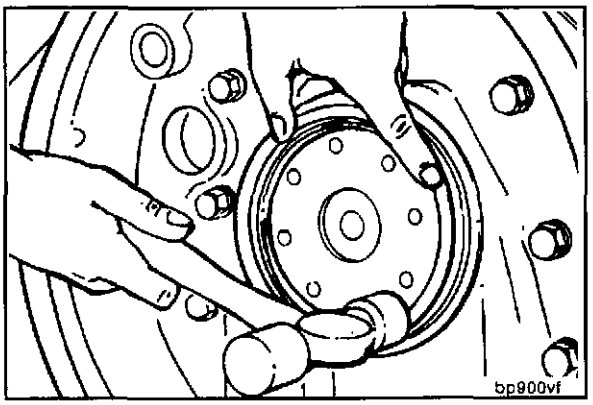
Push the seal onto the pilot and into the bore of the housing. Remove the pilot.

Do not use any sealant on the rear crankshaft seal.

Hammer

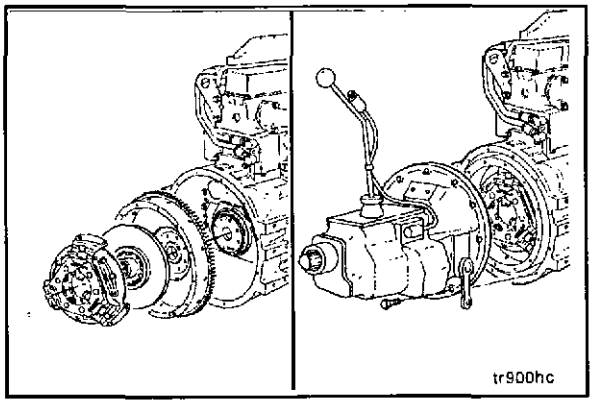
Use the installation tool from the seal replacement kit to install the seal to the correct depth. To prevent damage to the seal, hit the installation tool alternately at the 12:00, 3:00, 6:00 and 9:00 o'clock positions.

NOTE: Make sure the seal is completely installed into the rear housing.

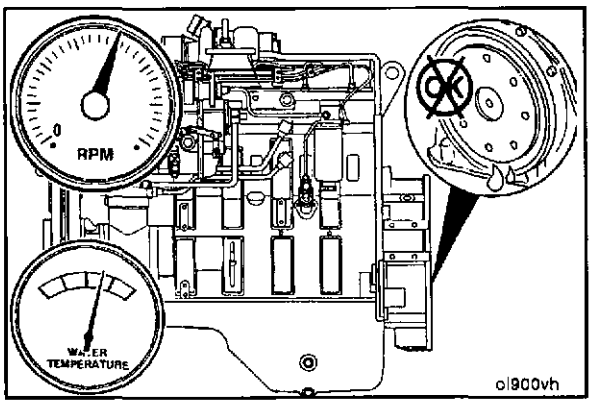


Install the flywheel and clutch, if equipped. Refer to Procedure 7-26.

Install the transmission and driveline. Refer to the manufacturer's instructions.



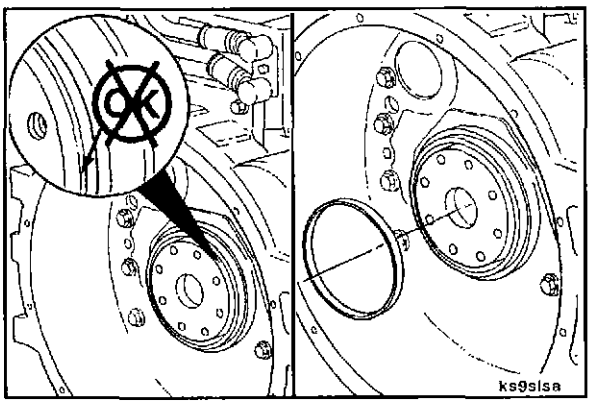
Operate the engine until the coolant temperature reaches 82°C [180°F], and check for leaks and proper operation.

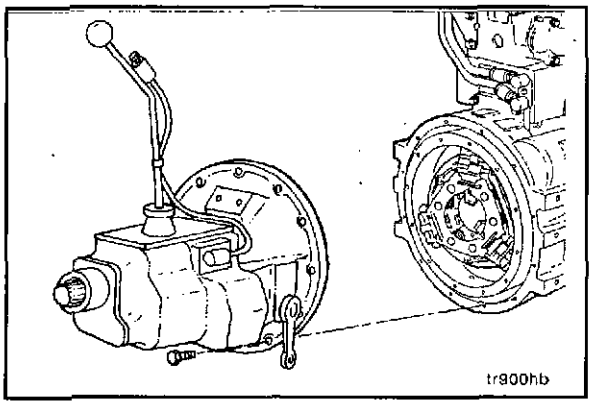


Wear Sleeve, Rear Crankshaft Seal - Replacement (7-30)

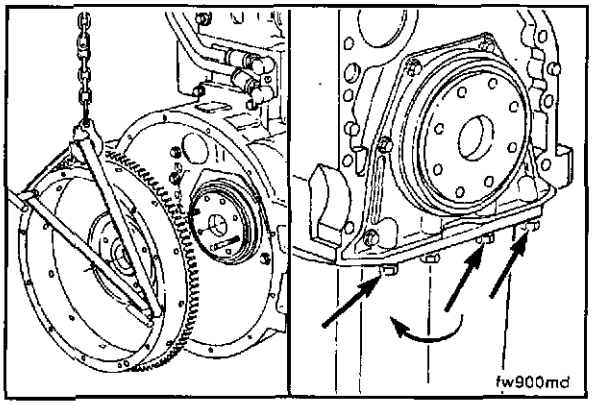
Removal

If the crankshaft seal has worn a groove in the crankshaft flange, a wear sleeve **must** be installed to prevent oil leakage.





Disconnect the driveline and remove the transmission, if equipped. Refer to the manufacturer's instructions.

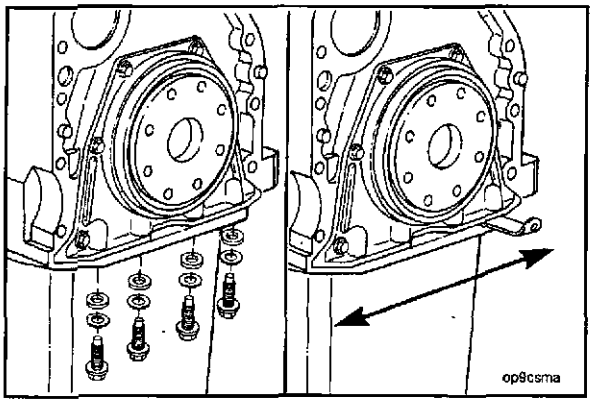


10 mm, 19 mm

Remove the clutch and flywheel, if equipped. Refer to Procedure 7-26.

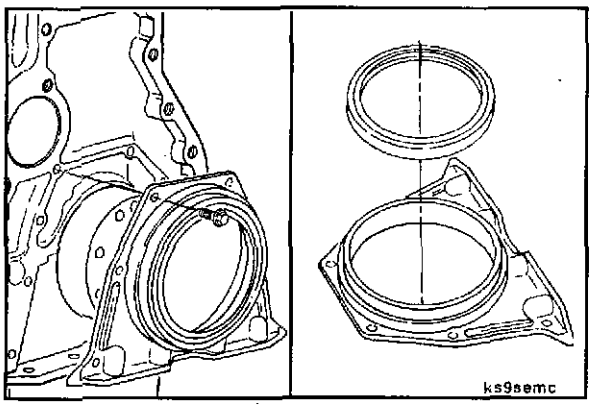
Remove the flywheel housing. Refer to Procedure 7-28.

Remove the four lubricating oil pan mounting capcrews which secure the oil pan to the rear cover.



Caution: Use extreme care when releasing the oil pan gasket from the rear cover to prevent damage to the gasket. If the gasket is damaged, the oil pan must be removed and the gasket replaced. Refer to Procedure 2-13.

Insert a feeler gauge or shim stock between the rear cover and the oil pan gasket. Move the feeler gauge or the shim stock back and forth to release the gasket from the rear cover.



Remove the capscrews from the rear cover, and remove the cover from the crankshaft flange.

Remove the seal from the rear cover.

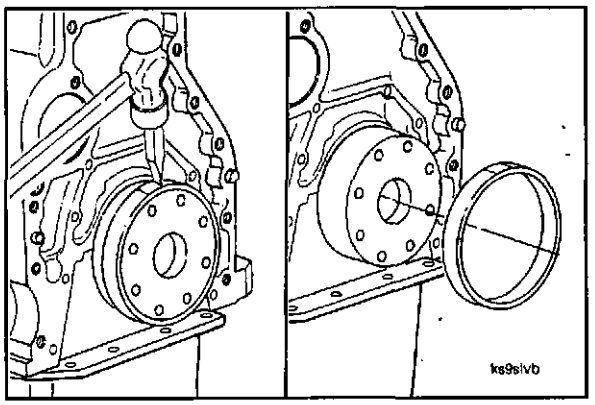
Hammer, Chisel

If the crankshaft currently has a wear sleeve, it **must** be removed before installing a new one.

Caution: Do not nick or gouge the crankshaft with the chisel. If the crankshaft is damaged, it must be replaced.

Use a dull chisel that is only as wide as the wear sleeve.

Make one or two soft blows with a hammer to make chisel marks across the wear sleeve. This will expand the wear sleeve allowing the sleeve to be removed.

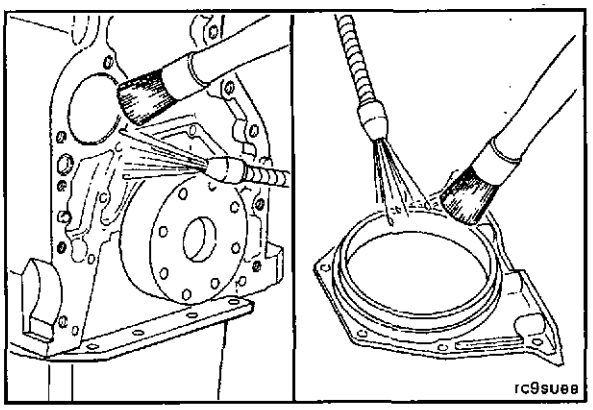


Cleaning and Inspection

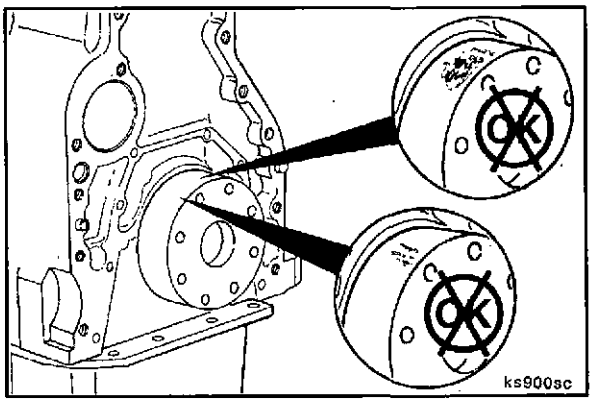
Clean the gasket surface of the cylinder block and rear cover.

Use a crocus cloth to remove any rust or other deposits from the crankshaft flange.

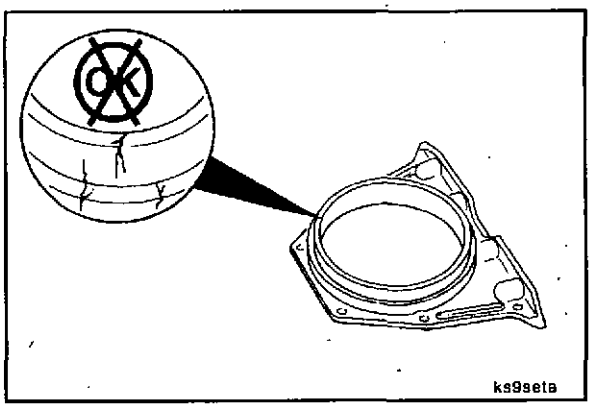
Use a clean cloth to clean the crankshaft flange.

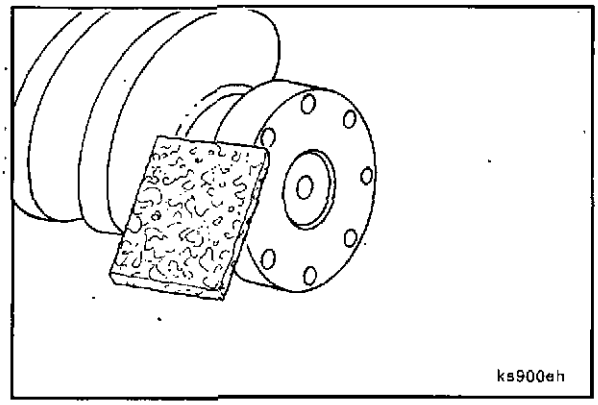


Inspect the crankshaft flange for dirt or nicks.



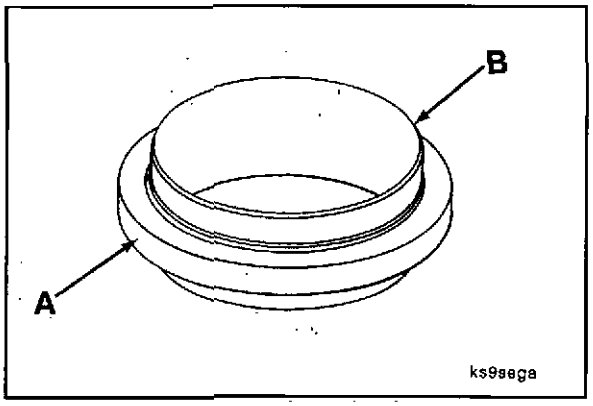
Inspect the rear cover for cracks or other damage.



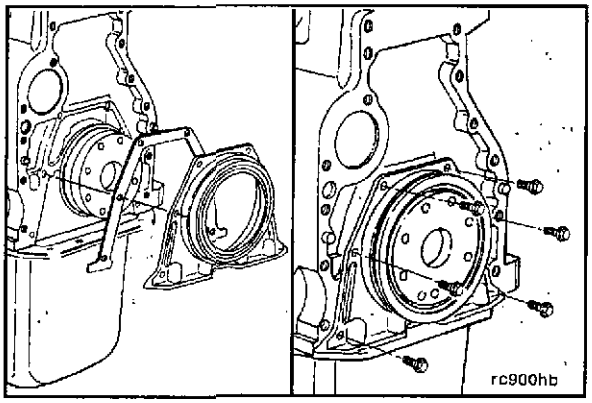


Installation

NOTE: Do **not** use any kind of lubricant to install the seal. The oil seal **must** be installed with the lip of the oil seal and the crankshaft clean and dry to ensure proper oil sealing.



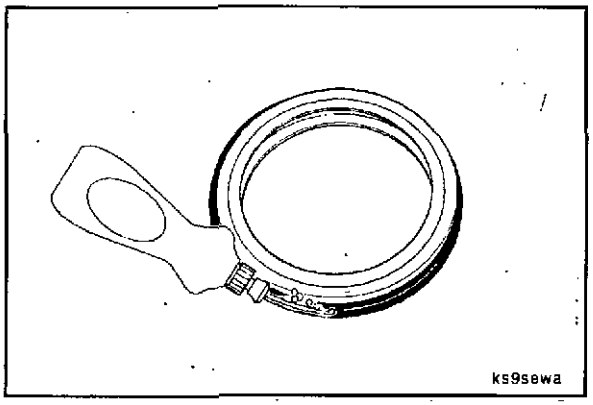
NOTE: The combination crankshaft oil seal (A)/wear sleeve (B) replacement kit for service usage is installed on the crankshaft as an assembly. The crankshaft rear oil seal should not be removed from the crankshaft rear seal wear sleeve.



Install the rear cover and gasket.

NOTE: Install the rear cover capscrews. Do not tighten. If the oil pan is installed, loosen the oil pan capscrews to allow clearance for rear cover and gasket clearance.

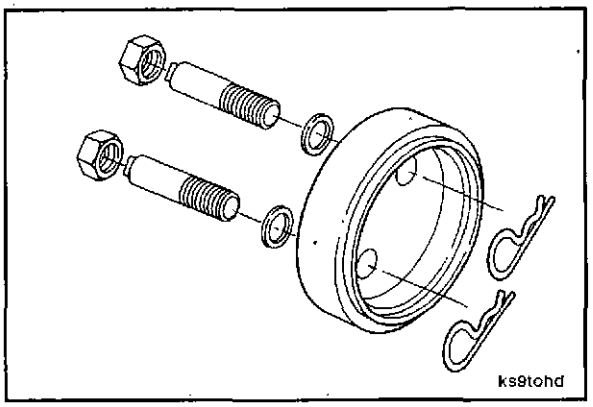
NOTE: The seal installation is being used to properly align the rear cover. Do not push or force the cover in any direction to prevent irregular seal lip position after the seal installation.



NOTE: The oil seal for a wet flywheel housing requires soap on the outside diameter of the seal case. Nothing is required on the outside diameter of the seal case for dry housings.

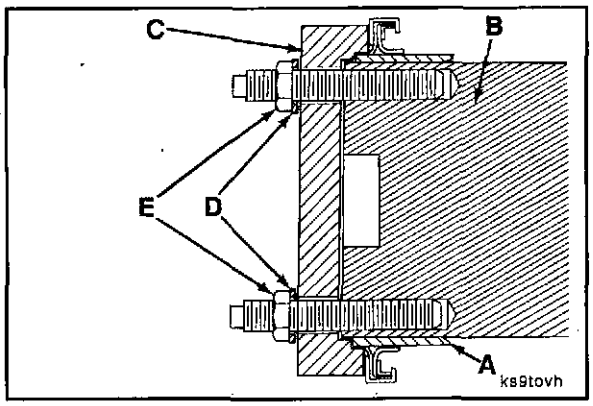
Use service tool, Part No. 3824078, to install oil seal/wear sleeve assembly. Install two (2) threaded studs into the crankshaft capscrew holes.

Apply a small amount of clean 15W-40 engine oil to the crankshaft, threaded studs, and inside diameter of the crankshaft rear seal/wear sleeve installation tool.



Position the chamfered end of the wear sleeve (A) onto the end of the crankshaft (B). Position the counterbore end of installation tool (C) over threaded studs and align with wear sleeve, perpendicular to the end of the crankshaft. Install the washers (D) and nuts (E) onto the threaded studs.

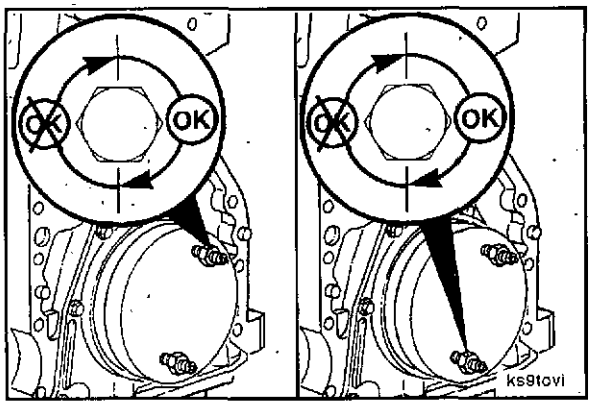
Alternately tighten the nuts until the installation tool contacts the end of the crankshaft.



NOTE: Do not exceed 1/2 revolution of each nut to prevent wear sleeve binding and irregular stretch.

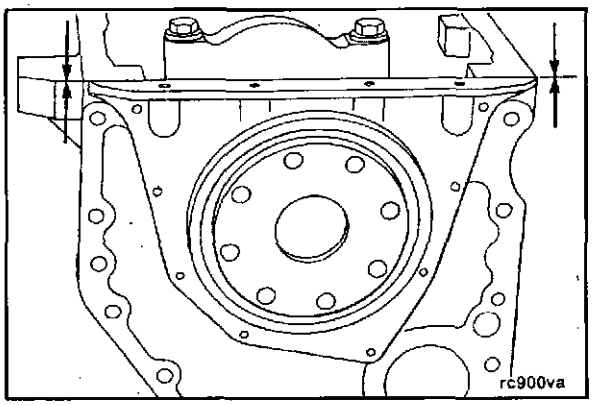
Torque Value: 20 N•m [15 ft-lb]

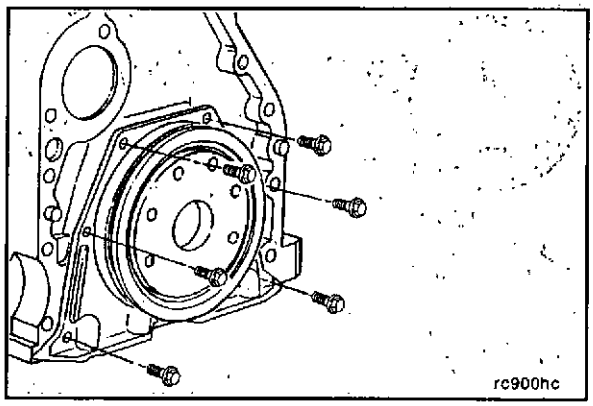
Remove the installation tool and threaded studs.



10 mm

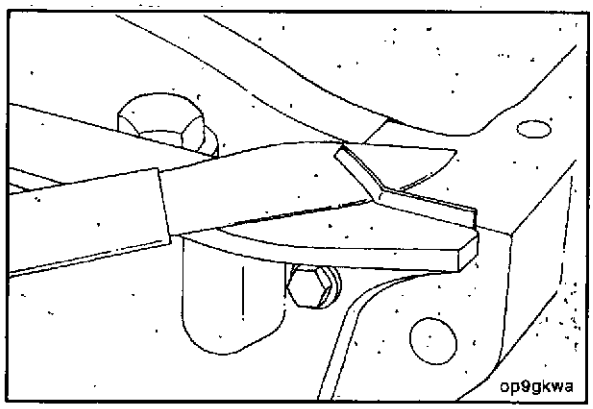
Align the rear cover even with both sides of the oil pan rail on the cylinder block.





Tighten the rear cover capscrews.

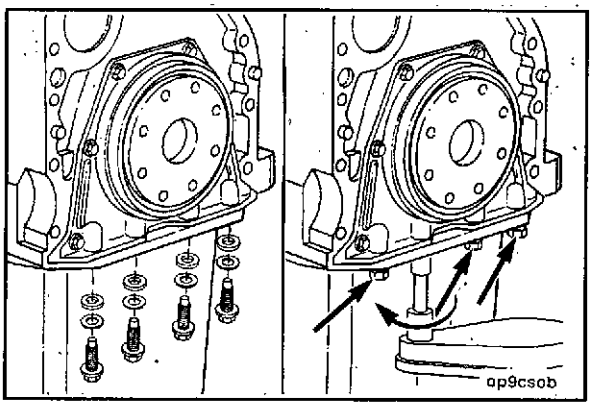
Torque Value: 9 N•m [80 in-lb]



Trim the gaskets even with the oil pan mounting surface.

Make sure the gasket trim does **not** enter the engine.

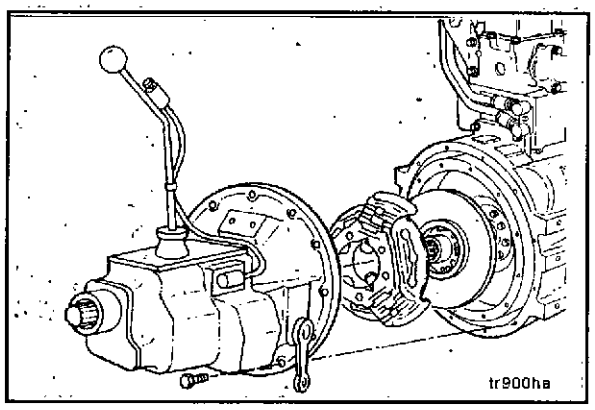
NOTE: Be sure to fill the joint between the lubricating oil pan rail and the rear cover with Three-Bond RTV sealant, Part No. 3823494.



Install the four capscrews which hold the oil pan to the rear cover.

NOTE: The lubricating oil pan capscrews should be torqued within 15 minutes after applying the sealant.

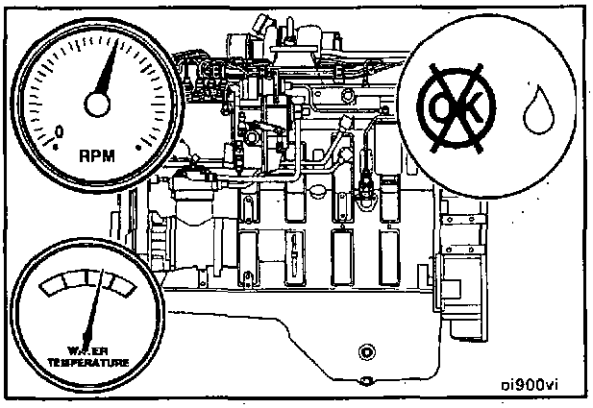
Torque Value: 24 N•m [18 ft-lb]



Install the flywheel housing, flywheel and clutch, if equipped. Refer to Procedure 7-28.

Install the transmission and the driveline. Refer to the manufacturer's instructions.

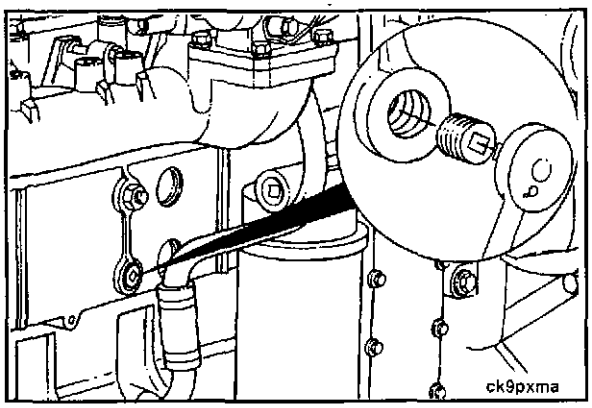
Operate the engine until the coolant temperature reaches 82°C [180°F], and check for leaks and proper operation.



Pipe Plug - Replacement (7-31)

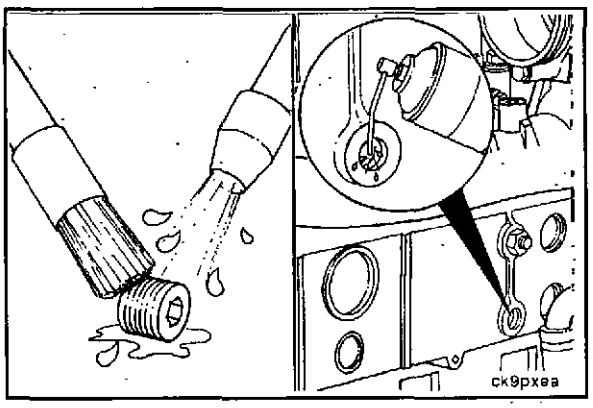
Removal

Select the appropriate size wrench, and remove the pipe plug.



Cleaning and Inspection

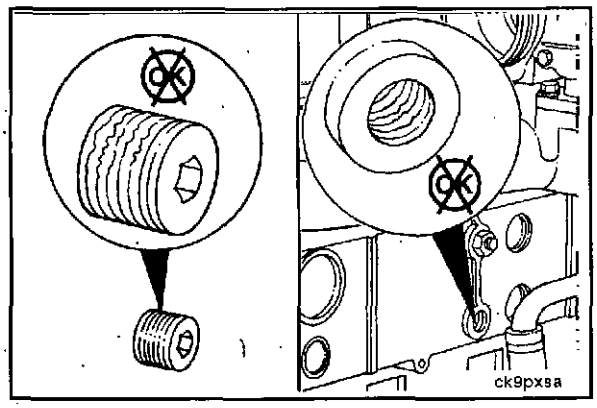
Use spray cleaner, Part No. 3375433, or equivalent to clean the threads of the pipe plug and threaded bore.

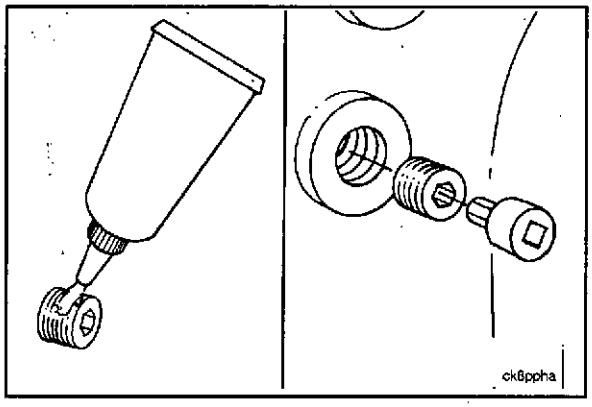


Visually inspect the threads of the pipe plug for mutilation or damage.

Visually inspect the threaded bore for damage.

Repair the bore if necessary.





Installation

Apply a film of pipe plug sealant, Part No. 3375066, or equivalent to the threads.

Install and tighten the pipe plug.

Refer to the following chart for torque values:

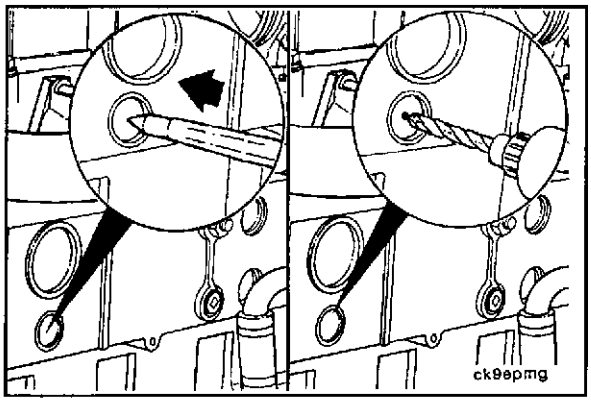
Pipe Plug Torque Values

Size			Torque		Torque	
Thread	Actual Thread O.D.		In Aluminum Components		In Cast Iron or Steel Components	
in.	mm	(in)	N•m	[ft-lbs]	N•m	[ft-lbs]
1/16	8.1	[0.32]	5	[45 in-lb]	15	[10]
1/8	10.4	[0.41]	15	[10]	20	[15]
1/4	13.7	[0.54]	20	[15]	25	[20]
3/8	17.3	[0.68]	25	[20]	35	[25]
1/2	21.6	[0.85]	35	[25]	55	[40]
3/4	26.7	[1.05]	45	[35]	75	[55]
1	33.5	[1.32]	60	[45]	95	[70]
1¼	42.2	[1.66]	75	[55]	115	[85]
1½	48.3	[1.90]	85	[65]	135	[100]

ck8ppoa

Tighten pipe plugs to the appropriate torque values.

NOTE: The accompanying chart is also provided in Section V "Engine Component Specifications."



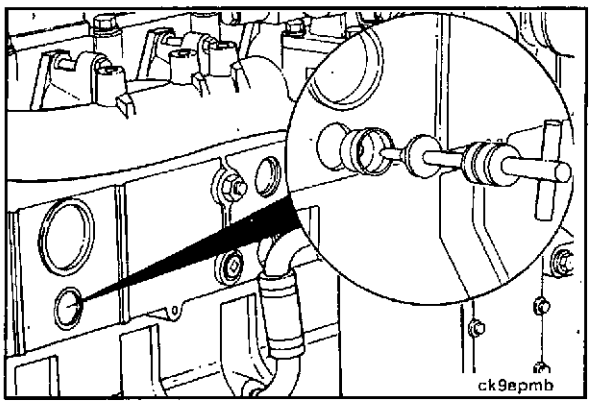
Cup Plug - Replacement (7-32)

Removal

Use a center punch to mark the cup plug for drilling.

Caution: Do not allow metal shavings to fall in the engine when drilling a hole in the cup plug. Damage to engine components can occur.

Drill a 1/8 inch hole into the cup plug.

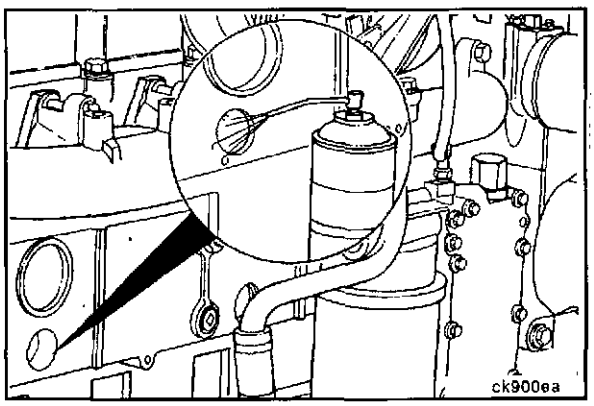


Use a dent puller to remove the plug.

NOTE: Discard all used cup plugs. Do **not** use them again.

Cleaning and Inspection

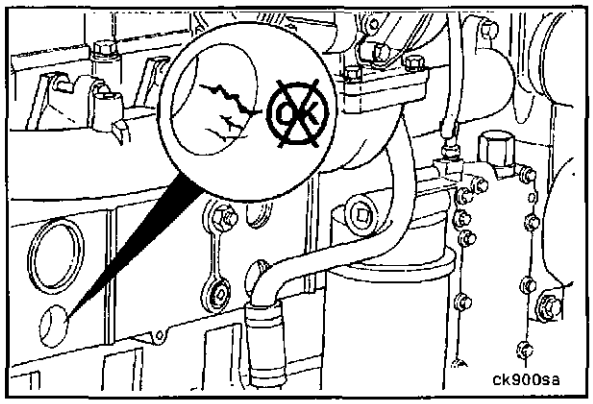
Use spray cleaner, Part No. 3375433, or equivalent to clean the cup plug bore.



Visually inspect the cup plug bore for damage.

Repair the bore if necessary.

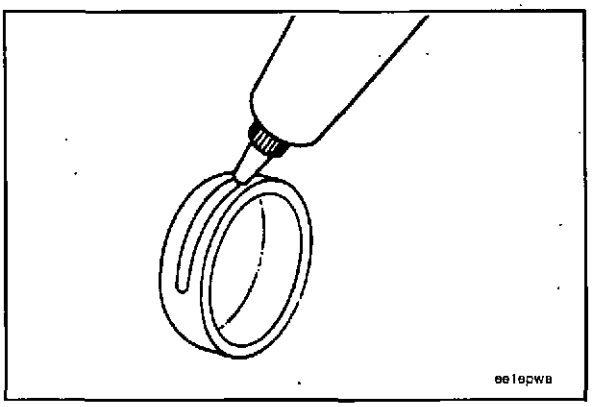
NOTE: Refer to Section V, "Engine Component Specifications," for cylinder block cup plug bore dimensions and cup plug dimensions.



Installation

Caution: Excessive sealant can run back into the engine and cause damage to other components. Allow the sealant to dry for a minimum of 2 hours before operating the engine. The plug can come out of the bore if the sealant is not dry.

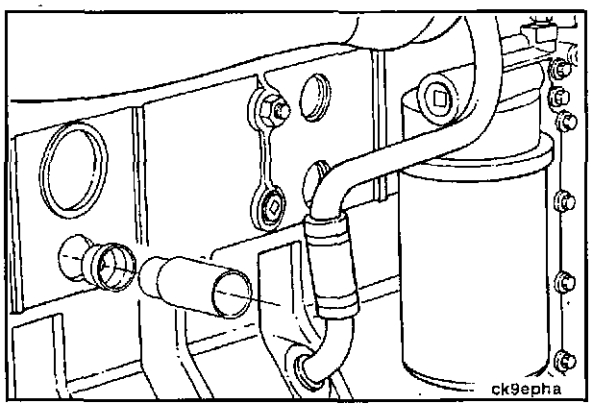
Apply a 2 mm [1/16 inch] bead of cup plug Lock 'N Seal, Part No. 3375068, or equivalent to the outside diameter of the cup plug and the inside diameter of cup plug installation bore.

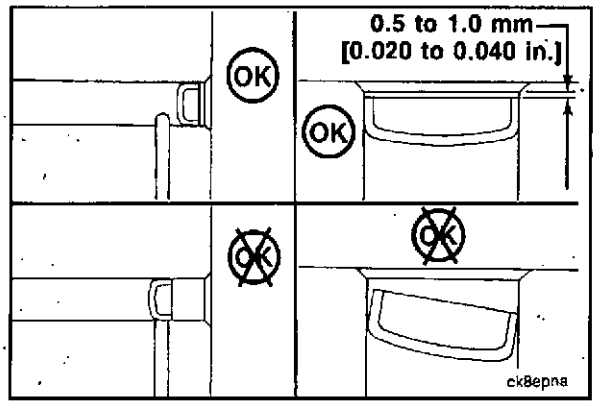


NOTE: Use a cup plug driver to install the cup plug to the correct depth in the cup plug bore.

Use the following cup plug drivers:

Tool P/N	Cup Plug P/N	Cup Plug Dimension
3822372	3900955	0.375 inch
3823521	3902606	0.8125 inch
3376816	3900957	1.00 inch
3823522	156075	1.1875 inch
3823523	3905401	1.375 inch
3823524	3900965	2.250 inch





Caution: Do not install the plug too deeply. The cross drillings in the cylinder block may be blocked. If the plug is not installed straight and flat, it must be replaced with a new cup plug.

The cup plug **must** be installed with the edge of the plug 0.5 to 1.0 mm [0.020 to 0.040 inch] deeper than the entrance chamber of the bore.

Section 8 - Engine Testing

Section Contents

Engine Testing - General Information

The engine test is a combination of an engine run-in and a performance check. The engine run-in procedure provides an operating period that allows the engine parts to achieve a final finish and fit. The performance check provides an opportunity to perform final adjustments needed to optimize the engine performance.

An engine test can be performed by using a chassis dynamometer. If a dynamometer is **not** available, an engine test **must** be performed in a manner that simulates a dynamometer test.

Check the dynamometer before beginning the test. The dynamometer **must** have the capability to test the performance of the engine when the engine is operating at the maximum RPM and horsepower range (full power).

The engine crankcase pressure, often referred to as engine blowby, is an important factor that indicates when the piston rings have achieved the correct finish and fit. Rapid changes of blowby or values that exceed specification more than 50 percent indicate that something is wrong. The engine test **must** be discontinued until the cause has been determined and corrected.

Engine Test General Specifications

NOTE: Due to variations in ratings of different engine models, refer to the specific engine data sheet for the particular engine model being tested.

Maintain the following limits during a chassis dynamometer test:

Intake Restriction: (Maximum)

- Clean Filter ..... 380 mm H_20 [15 in. H_20]
- Dirty Filter ..... 635 mm H_20[25 in. H_20]

Air Inlet Temperature (Maximum) ..... 38°C [100°F]

Exhaust Temperature ..... 700°C [1290°F]

Exhaust Back Pressure: (Maximum)

- Industrial ..... 76 mm Hg [3.0 in. Hg]
- EPA Certified (Automotive without Catalyst) ..... 114 mm Hg [4.5 in Hg]
- EPA Certified (Automotive with Catalyst) ..... 152 mm Hg [6.0 in. Hg]

Smoke:

- Bosch Smoke Meter (Maximum) ..... 2.5 Units
- Celesco Smoke Meter (Maximum) ..... 4% Opacity

Coolant Temperature (Maximum) ..... 100°C [212°F]

Lubricating Oil Temperature (Maximum) ..... 126.6°C [260°F]

Lubricating Oil Pressure:

- Low Idle (Minimum Allowable) ..... 69 kPa [10 psi]
- Rated Speed (Minimum Allowable) ..... 207 kPa [30 psi]

Fuel Filter Restriction (Maximum)

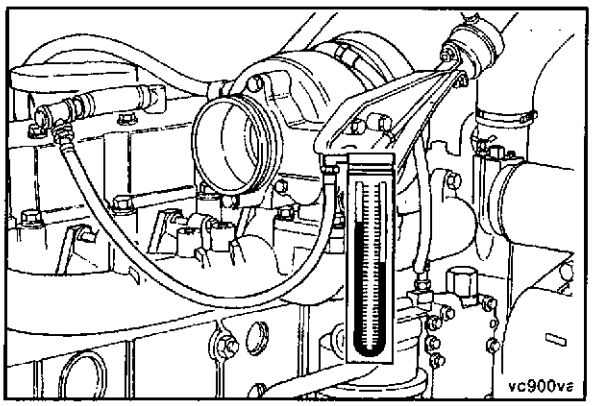
- Dirty Filter ..... 89 mm Hg [3.5 in. Hg]

Fuel Return Restriction (Maximum) ..... 35 kPa [5 psi]

Blowby:	*New (L/Min)	*Used (L/Min)
• 6C8.3 Rectangular intermediate ring	44	119
• 6CT8.3 Rectangular intermediate ring	113	226
• 6CTA8.3 Rectangular intermediate ring	113	226
• All engines built after ESN: CDC 44531927, DEP 21087046	164	226

* Blowby checking tool, Part No. 3822566, has a special 7.67 mm [0.302 in.] orifice that **must** be used to obtain an accurate reading.

Refer to the blowby conversion chart on the following page to convert liters/minute into inches/water:



Blowby Measurement (8-01)

Blowby is generally recorded in liters/minute.

Install the Part No. 3822566 Engine Blowby Tool, to the crankcase breather tube in the valve cover.

Install a water manometer to the engine blowby tool.

Use the Blowby Conversion Chart to convert the manometer reading to liters/minute.

NOTE: A pressure gauge can be used to record the engine blowby.

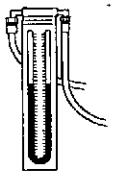
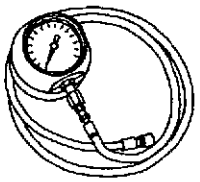
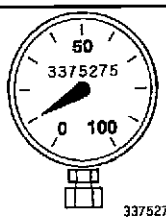
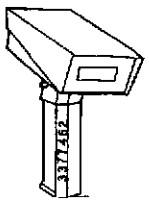
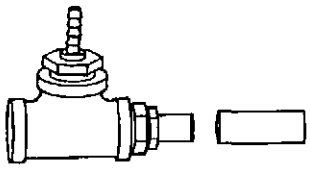
Minimum Gauge Capacity: 1270 mm H_20 [50 inches H_20]

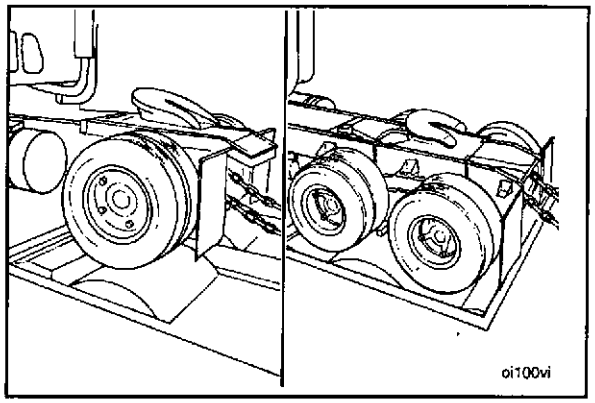
Blowby Conversion Chart (7.67mm [0.302 in]) Orifice

Inches of Water	Liters/Minute
1	50
2	84
3	103
4	119
5	133
6	145
7	155
8	164
9	172
10	180
11	187
12	193
13	200
14	206
15	211
16	217
17	222
18	226
19	229
20	232

Engine Testing - Service Tools

The following special tools are recommended to perform procedures in Section 8. The use of these tools is shown in the appropriate procedure. These tools can be purchased from your local Cummins Authorized Repair Location.

Tool No.	Tool Description	Tool Illustration
ST-434	**Vacuum Gauge** Check the fuel filter restriction during the engine performance test. Hose adapter, Part No. ST-434-2 and vacuum gauge, Part No. ST-434-12, are used to perform the test.	
ST-1111-3	**Manometer** Used with the blowby check tool to measure engine crankcase pressure.	
ST-1273	**Pressure Gauge** Used to measure the engine intake manifold pressure.	
3375275	**Pressure Gauge (0-160 psi)** Used to measure lubricating oil pressure.	
3377462	**Digital Optical Tachometer** Used to measure engine speed (RPM).	
3822566	**Blowby Check Tool** Used with manometer, Part No. ST-1111-3, to measure the engine crankcase pressure.	



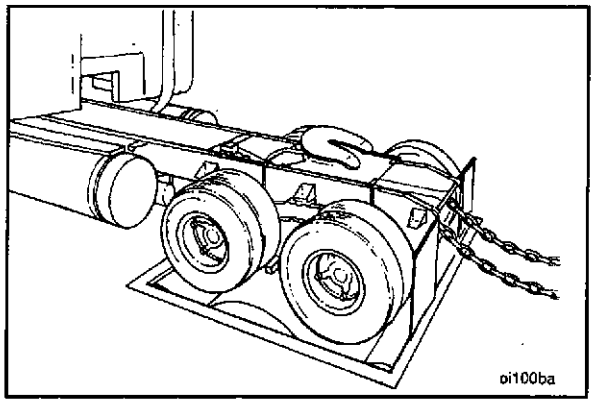
Chassis Dynamometer - Operation (8-02)

The performance of an engine installed in on-highway vehicles can be tested on a chassis dynamometer.

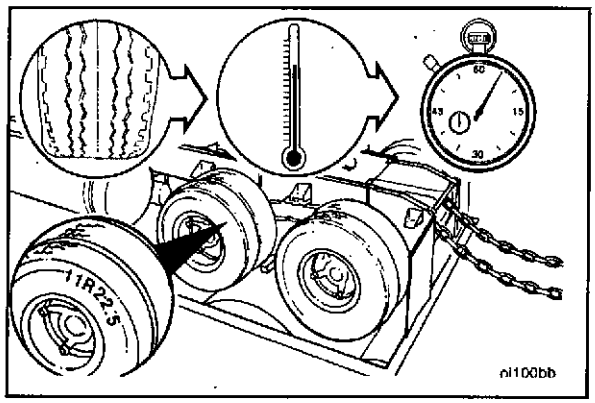
NOTE: Due to driveline efficiency and engine-driven accessories, the engine horsepower when measured at the rear wheels will be reduced by approximately:

- 20 percent for single axle vehicles
- 25 percent for tandem axle vehicles

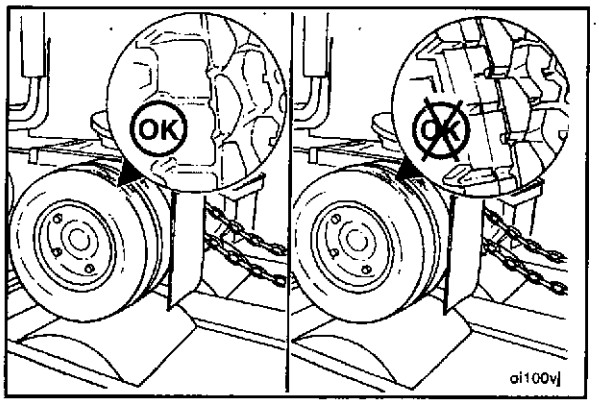
NOTE: These percentages are used for engine run-in only and are **not** to be used as absolute figures.



Caution: Follow all the vehicle manufacturer's safety precautions before installing or operating a vehicle on a chassis dynamometer.



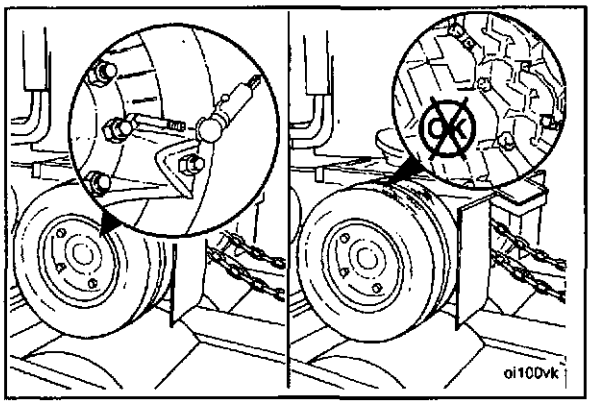
Caution: Low profile radial tires are more sensitive to heat than bias ply tires. Excessive operating time at full load can damage tires due to overheating. Check the tire manufacturer's recommendations for the maximum allowable chassis dynamometer operating time.



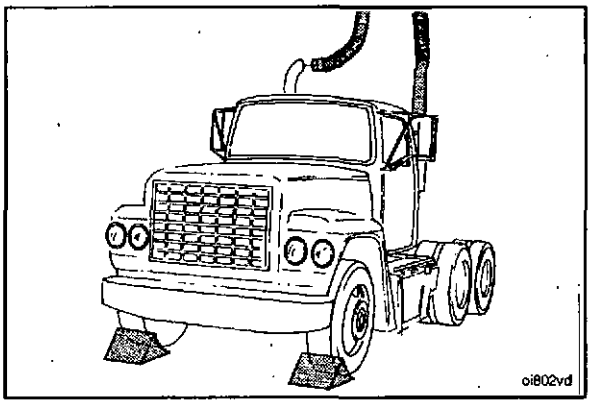
Follow the general safety precautions listed below while operating the chassis dynamometer:

- Use tires that have more than 160 kilometers [100 miles] on them. Do **not** use new tires.
- Do **not** use recapped tires or tires of different sizes or designs.

- Make sure the tires are inflated to the manufacturer's specifications.
- Remove all rocks or other material from the tread of all tires that will be rotating on the dynamometer rollers.



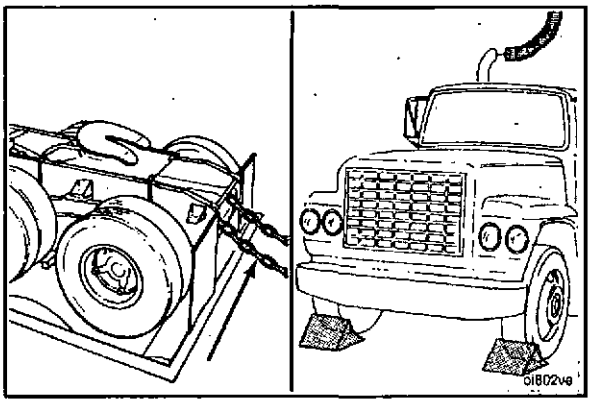
- Make sure there is correct overhead clearance for exhaust stacks, air deflectors, or other attachments above the cab.



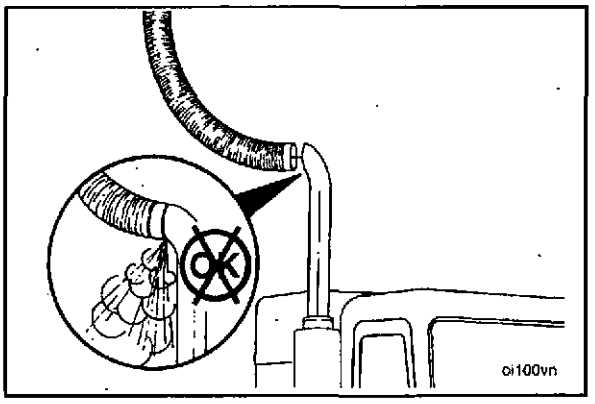
- Carefully position the vehicle on the rollers.

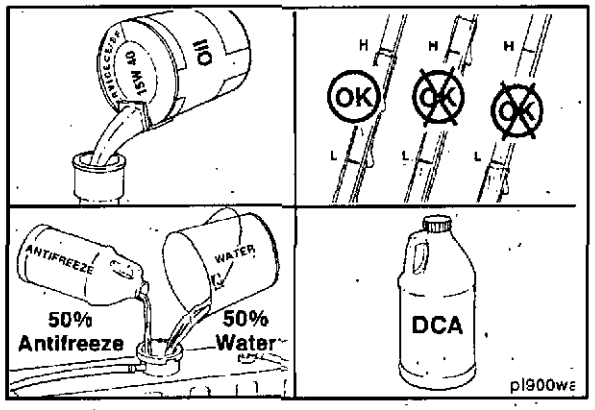
Caution: To prevent damage to the chassis dynamometer, there must be some slack in the tension of the tie-down chains.

- Attach the tie-down chains to the rear of the vehicle, and put wheel chocks in front of the front wheels.



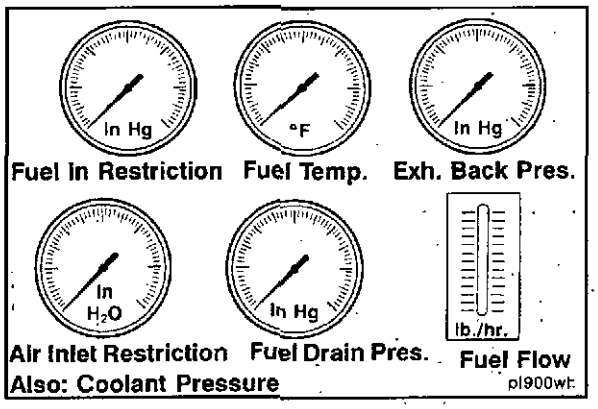
- Adjust the vehicle and dynamometer room exhaust system to make sure all exhaust gases are removed from the room.
- Refer to the chassis dynamometer and vehicle manufacturer's recommendations and specifications for testing procedures.
- Make sure all instrumentation is removed before removing the vehicle from the dynamometer.





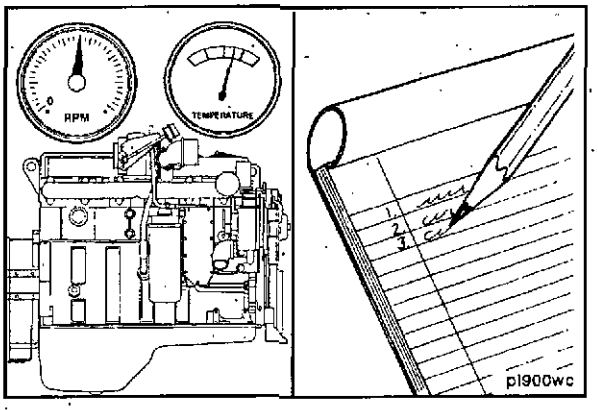
Chassis Dynamometer - General Engine Test Procedures (8-03)

The following procedure assumes that the lubricating oil and fuel systems were correctly primed, the dipstick calibrated, and the engine filled to the correct levels with oil and coolant during installation of the engine into the chassis. If these systems were **not** serviced during installation of the engine, refer to appropriate sections in this manual or to the latest C Series Operation and Maintenance Manual, Bulletin No. 3810248, for instructions on filling the lubricating oil and the cooling systems.



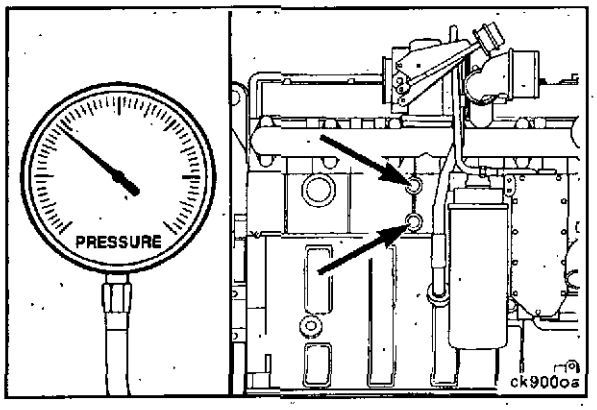
The number of instruments and gauges required to perform a chassis dynamometer test will vary according to the type and the capability of the test equipment used.

It is a good practice to observe these measurements even *if engine performance meets specifications. If engine performance* does **not** meet specifications, these measurements can indicate possible reasons for poor performance.



To correctly monitor an engine's performance, record the following parameters:

- Lubricating oil pressure (vehicle instrument panel)
- Coolant temperature (vehicle instrument panel)
- Coolant pressure
- Intake manifold pressure
- Inlet air restriction
- Blowby
- Engine speed (RPM) (vehicle instrument panel)
- Wheel horsepower (WHP) (dynamometer controls)
- Exhaust back pressure

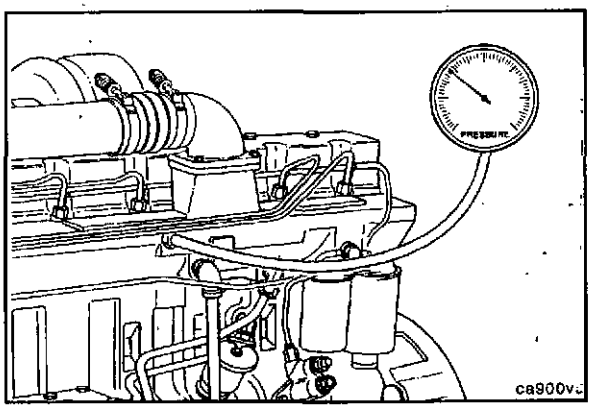


Measure the coolant pressure at the exahust side of the cylinder block.

Minimum Gauge Capacity: 415 kPa [60 psi]

Measure the intake manifold pressure (turbocharger boost). Install a pressure gauge, Part No. ST-1273, in the location shown.

Minimum Gauge Capacity: 1905 mm Hg [75 in. Hg]

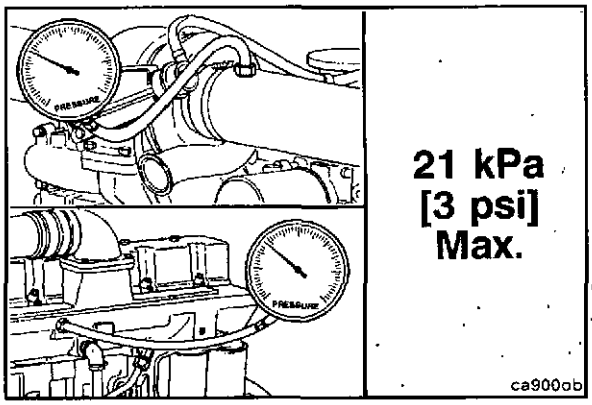


Connect a water manometer to the turbocharger air inlet pipe to test air restriction.

NOTE: The manometer connection **must** be installed at a 90 degree angle to the air flow in a straight section of pipe, one pipe diameter before the turbocharger.

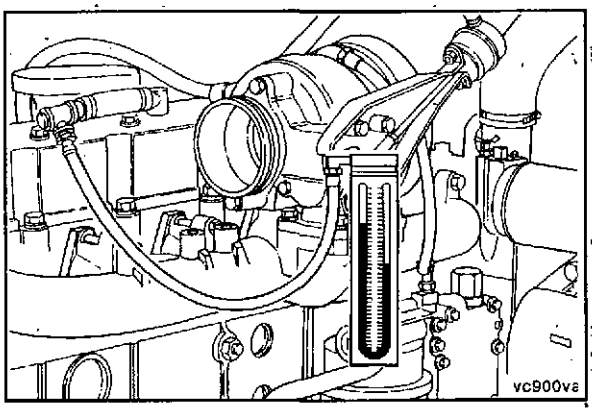
NOTE: A vacuum gauge can be used in place of the water manometer.

Minimum Gauge Capacity: 760 mm H_20 [30 in. H_20]

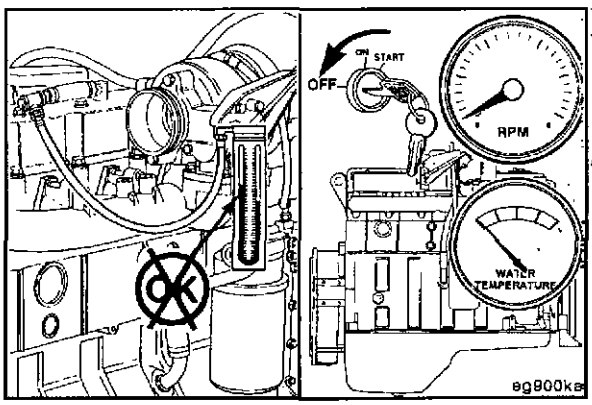


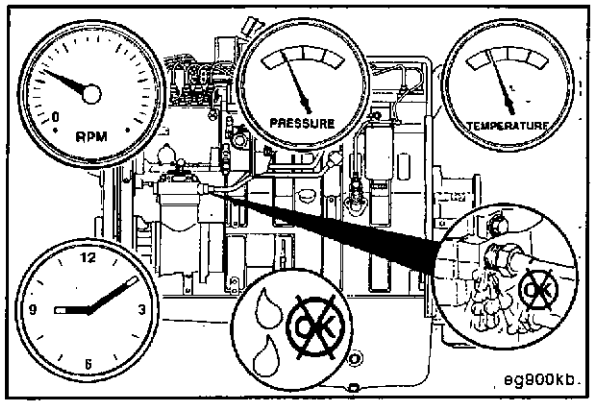
Measure the blowby by installing blowby checking tool, Part No. 3822566, in the crankcase breather vent. Connect the blowby tool to a water manometer. Refer to page 8-3 for blowby specifications.

NOTE: Excessive blowby indicates an engine internal components malfunction or a turbocharger malfunction, allowing combustion gases to enter the crankcase.

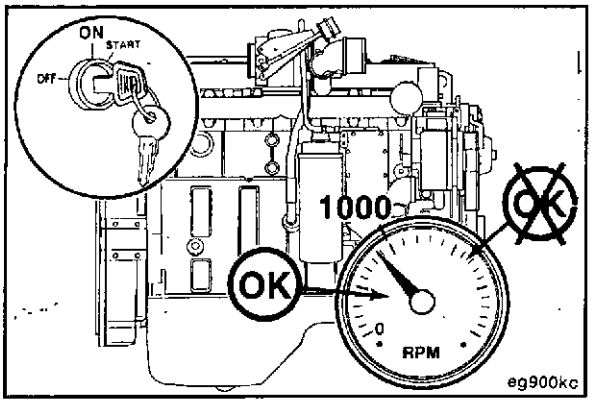


NOTE: If a sudden increase in blowby occurs, or if blowby exceeds the maximum allowable limit during any run-in step, return to the previous step and continue the run-in. If blowby does **not** reach an acceptable level, discontinue the run-in and determine the cause.

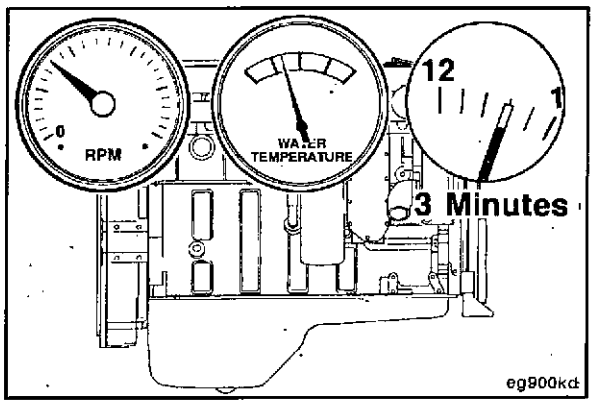




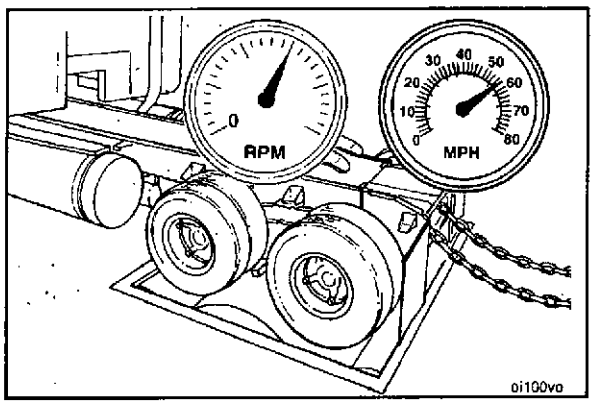
NOTE: Avoid long idle periods. Operate the engine at low idle only long enough (3 to 5 minutes) to check for correct oil pressure and any fuel, oil, water, or air leaks.



Caution: Do not allow the engine speed to exceed 1000 RPM before run-in. The internal components can be damaged.



Caution: Do not shut off the engine immediately after the last step of the run-in is completed. Allow the engine to cool by operating at low idle for a minimum of 3 minutes to avoid internal component damage.



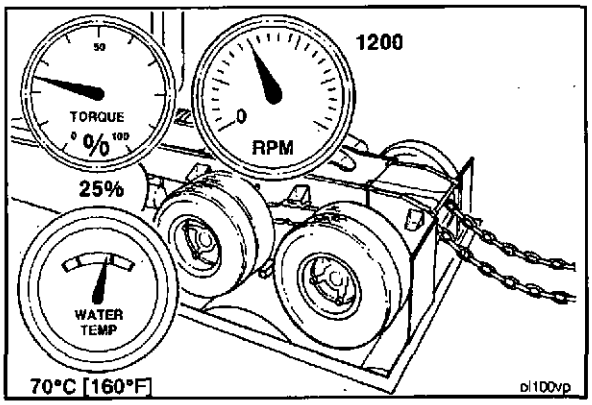
Engine Run-In Procedure - (Chassis Dynamometer) (8-04)

Caution: To avoid internal component damage, refer to Chassis Dynamometer General Engine Test Procedures (8-03) before operating the engine.

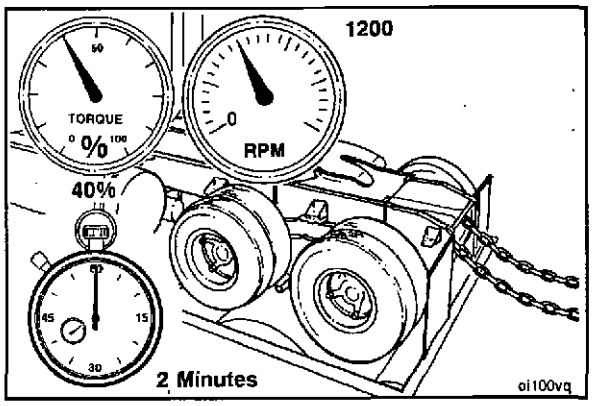
NOTE: Refer to Chassis Dynamometer Operation on page 8-6 for general operating procedures and safety precautions.

NOTE: Operate the vehicle in a gear that produces a road speed of 90 to 95 kmh [55 to 60 mph].

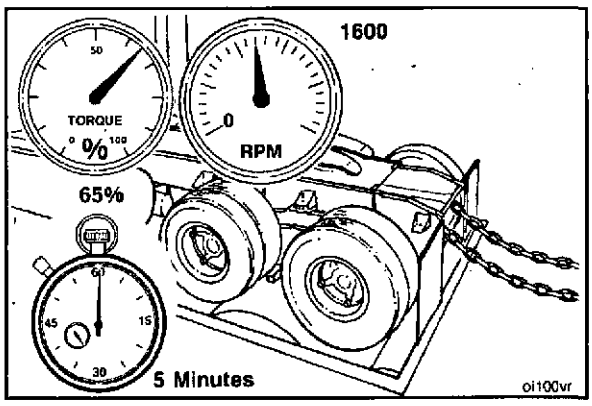
Operate the engine at 1200 RPM and 25 percent of rated load until the coolant temperature reaches 70°C [158°F].



Operate the engine at 1200 RPM and 40 percent of rated load for 2 minutes. Check the gauges and record the readings.

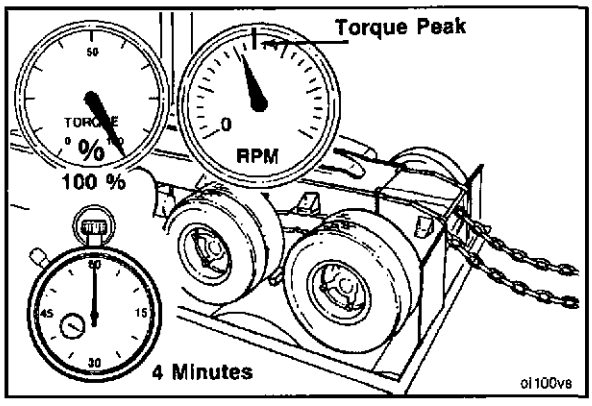


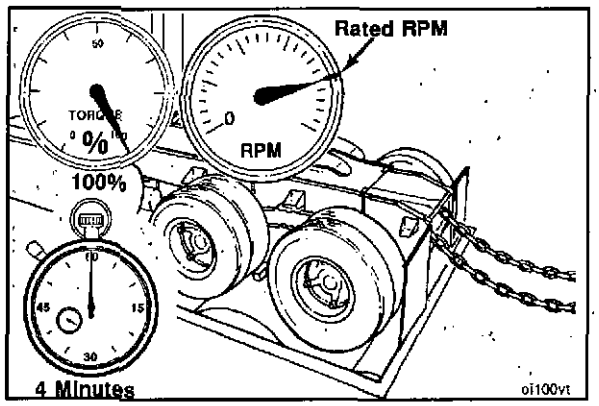
Operate the engine at 1600 RPM and 65 percent of rated load for 5 minutes. Check the gauges and record the readings.



Operate the engine at torque peak RPM and full load for 4 minutes. Check the gauges and record the readings.

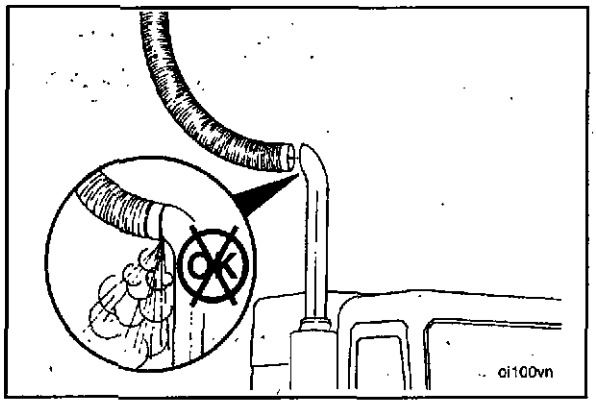
NOTE: Refer to the engine data sheet for the torque peak RPM of the engine model being tested.



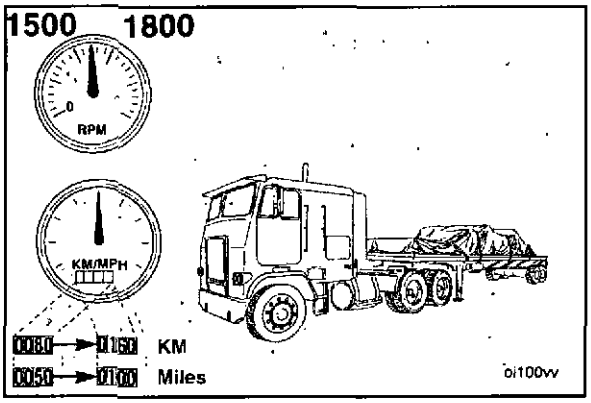


Operate the engine at rated speed (RPM) and full load for 4 minutes. Check the gauges and record the readings. Compare the readings to those published on the appropriate engine data sheet.

Caution: Do not shut off the engine immediately after the run-in is completed. Allow the engine to cool by operating it at low idle for a minimum of 3 minutes to avoid internal component damage.



Make sure all instrumentation is removed before removing the vehicle from the dynamometer.

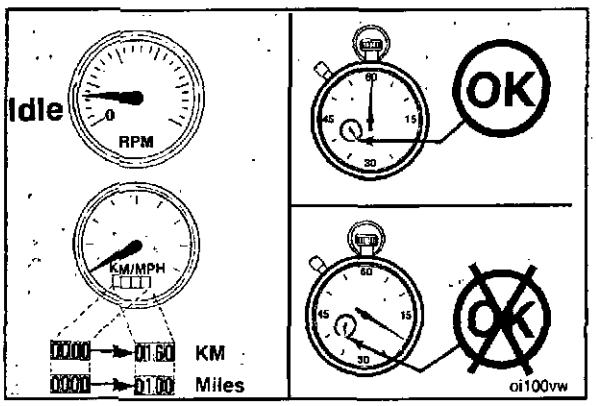


Engine Run-In Procedure "In-Chassis" (8-05)

On-Highway

Caution: Refer to Chassis Dynamometer-General Engine Test Procedures (8-03) before operating the engine to avoid internal component damage.

Operate the engine at 1500 to 1800 RPM in high gear for the first 80 to 160 kilometers [50 to 100 miles] after rebuild.

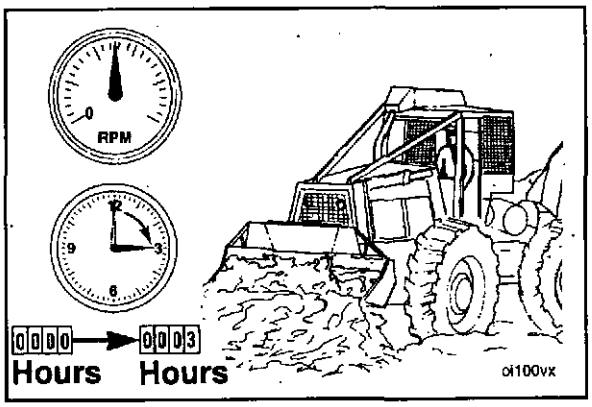


NOTE: Do **not** idle the engine for more than 5 minutes at any one time during the first 160 kilometers [100 miles] of operation.

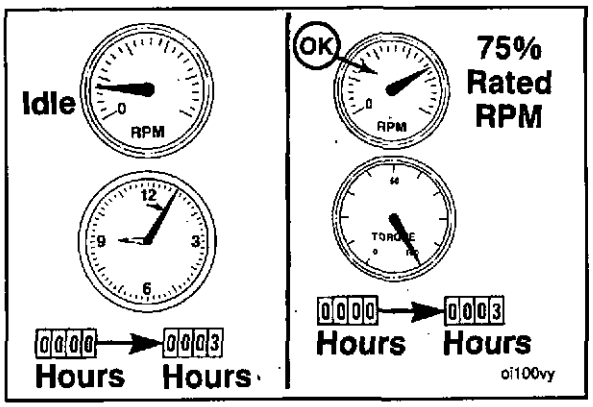
Off-Highway

Caution: Refer to Chassis Dynamometer-General Engine Test Procedures (8-03) before operating the engine to avoid internal component damage.

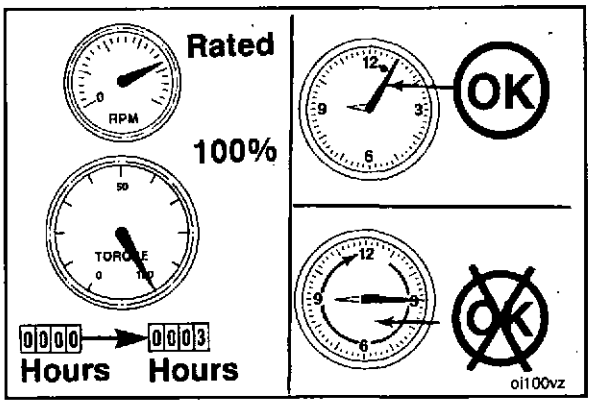
Operate the engine as follows during the first 3 hours after rebuild:



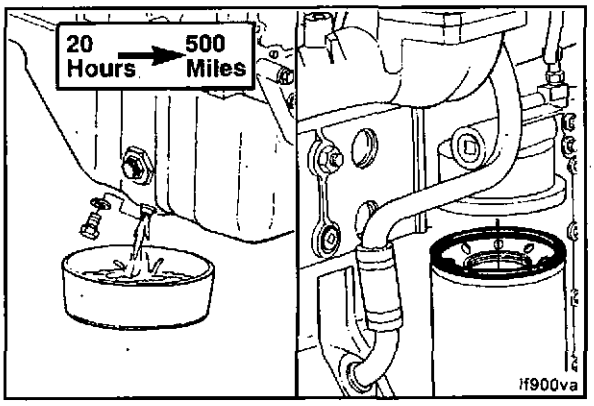
1. Do **not** idle the engine for more than 5 minutes at any one time.
2. Operate the engine at 75 percent throttle while loaded.



3. Do **not** operate the engine at rated speed (RPM) and full load for more than 5 minutes at any one time.



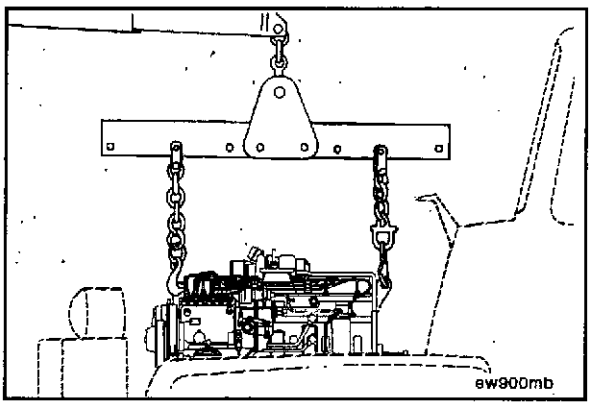
Change the lubricating oil and filter after 800 km [500 miles] or 20 hours of operation. Refer to Procedure 2-04.



NOTES

Section 9 - Engine Removal and Installation

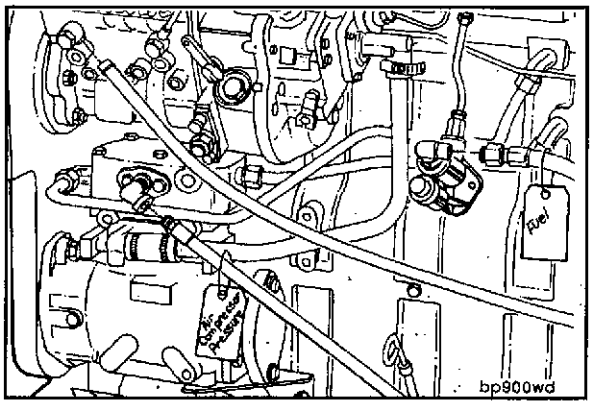
Section Contents



Engine Removal and Installation General Information

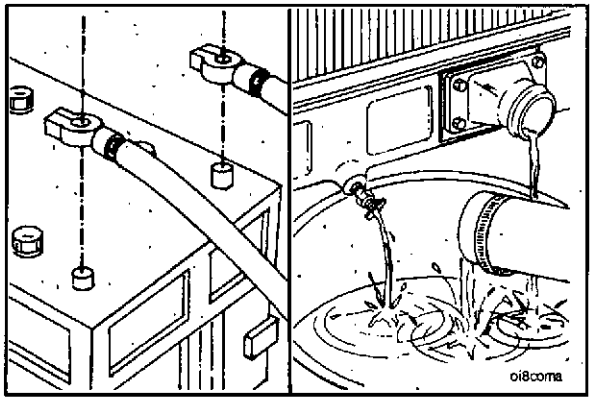
The procedures required to replace an engine will vary with different engine models, the type of equipment, optional equipment, and the shop facilities. Use the following procedures as a guide:

NOTE: All replacement steps will not apply to all types of equipment. Complete only the steps which apply to the equipment involved. Use the equipment manufacturer's recommendations and precautions for removal of chassis parts to gain access to the engine.



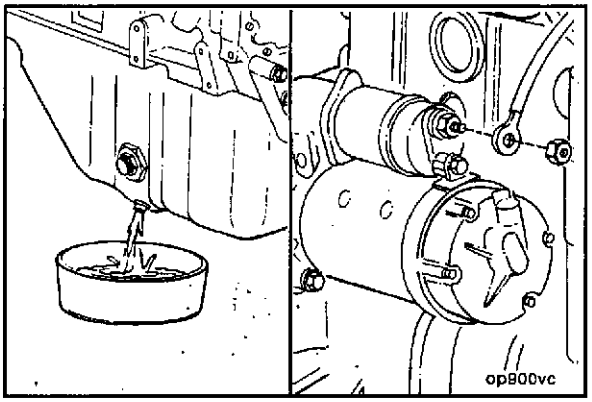
Engine - Removal (9-01)

Place a tag on all hoses, lines, linkage, and electrical connections as they are removed to identify their locations.



Disconnect the battery cables.

Drain the engine coolant.

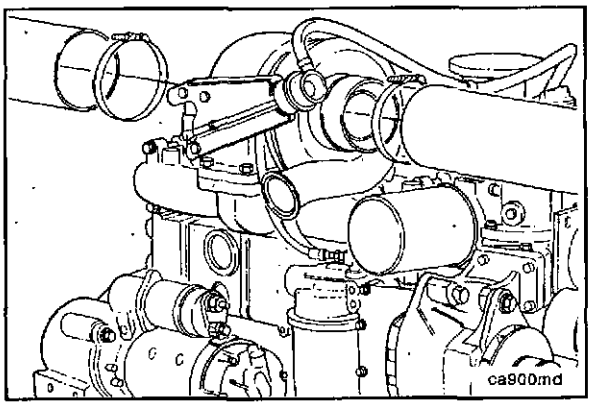


Drain the lubricating oil.

Disconnect the starter cable, engine ground straps, cab or chassis to engine hoses, tubing, electrical wires and hydraulic lines.

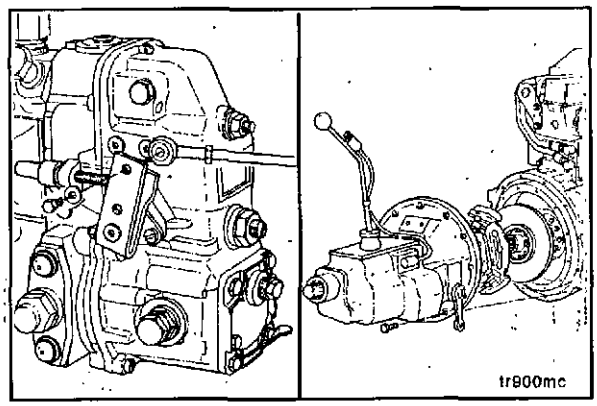
Disconnect the intake and exhaust pipes.

Disconnect all chassis mounted engine driven accessories.

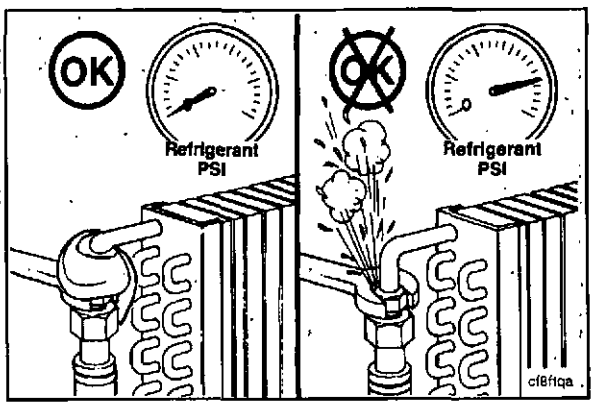


Disconnect the throttle linkage from the injection pump control lever.

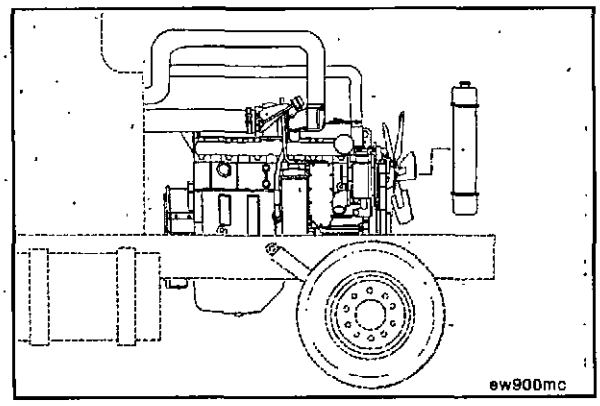
Disconnect the drive units from the flywheel.

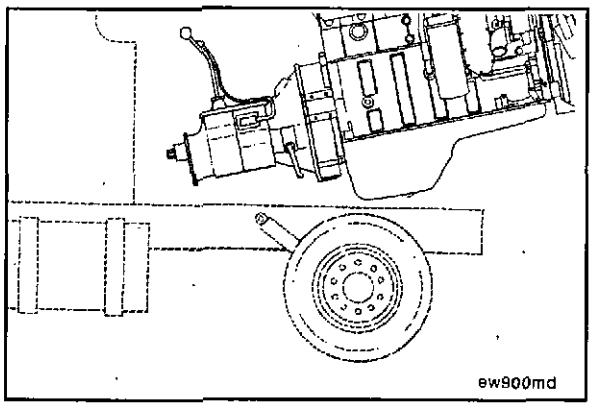


Warning: If a liquid refrigerant system (air conditioning) is used, wear eye and face protection and wrap a cloth around the fittings before removal. Liquid refrigerant can cause serious eye and skin injury.



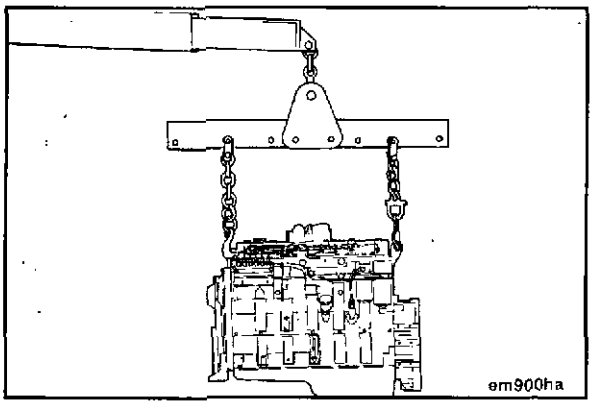
Remove all chassis components necessary to remove the engine from the equipment.





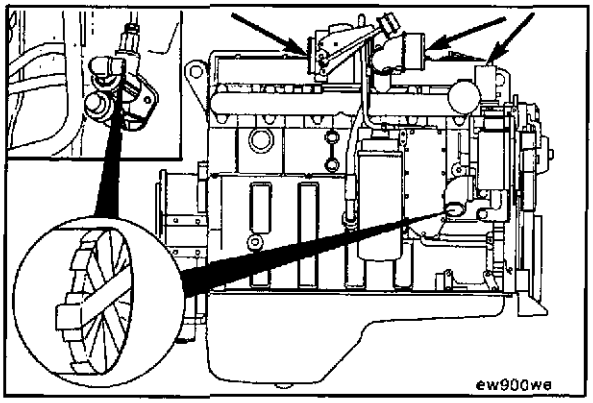
NOTE: On applications where the rear engine mounts are attached to the transmission, it may be necessary to remove the engine and transmission as an assembly.

Warning: The engine lifting equipment must be designed to safely lift the engine and transmission as an assembly. The dry weight of the standard engine without accessories is 606 kg [1335 lb]. Refer to the equipment manufacturer's specifications for the transmission weight.



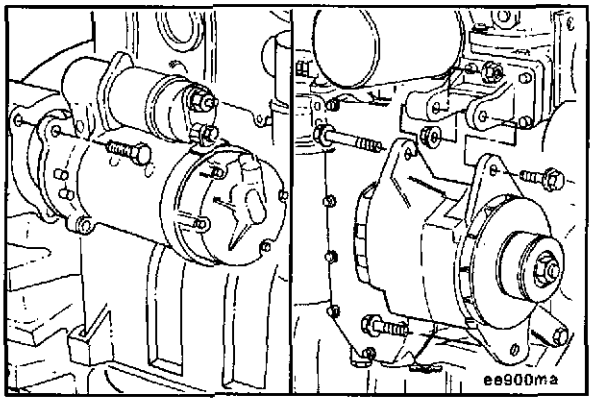
Use a properly rated hoist and engine lifting fixture, attached to the engine mounted lifting brackets to remove the engine.

NOTE: If the transmission is **not** removed, place a support under the transmission to prevent it from falling.



Cover all engine openings to prevent dirt and debris from entering the engine.

Place the engine on suitable engine support stands.



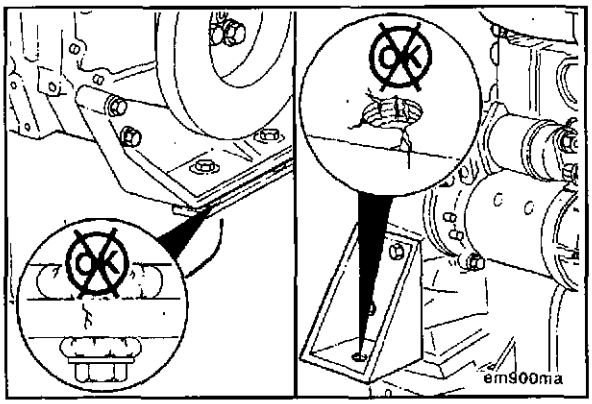
Remove all remaining accessories and brackets to use with the replacement engine.

Engine Mount - Inspection (9-02)

Inspect all rubber-cushioned mounts for cracks or damage.

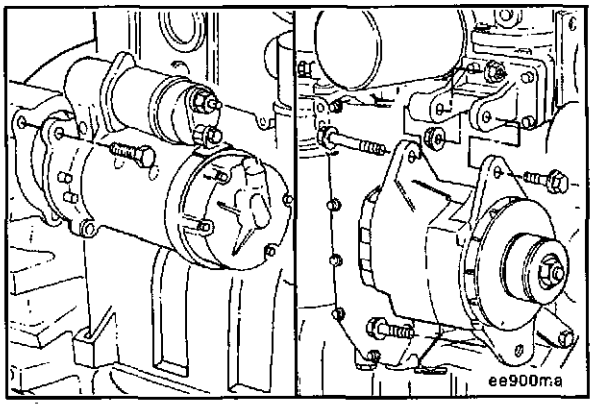
Inspect all mounting brackets for cracks or damaged bolt holes.

NOTE: Damaged engine mounts and brackets can cause engine misalignment, drive line components damage, and result in vibration complaints.



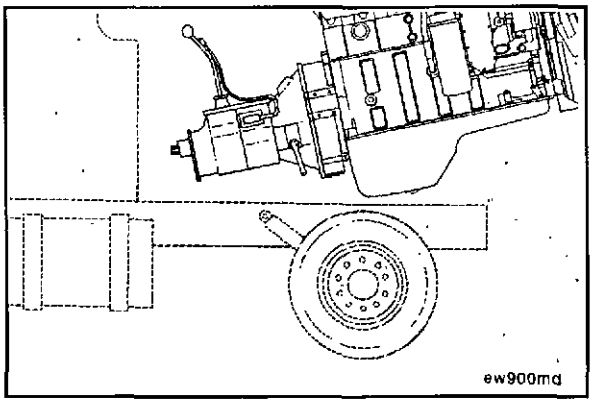
Engine - Installation (9-03)

Install all accessories and brackets that were removed from the previous engine.

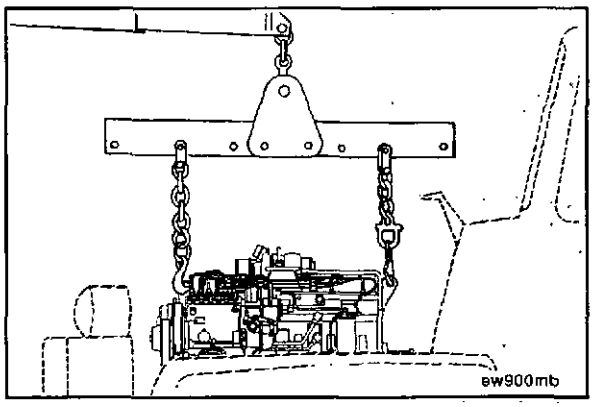


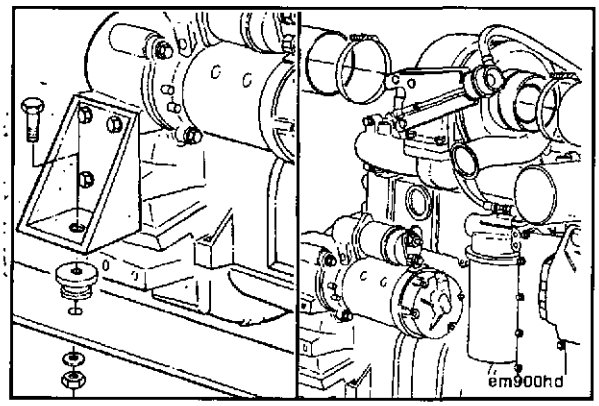
NOTE: On applications where the rear engine mounts are attached to the transmission, it may be necessary to install the engine and transmission as an assembly.

Warning: The engine lifting equipment must be designed to safely lift the engine and transmission as an assembly. The dry weight of the standard engine without accessories is 606 kg [1335 lb]. Refer to the equipment manufacturer's specifications for the transmission weight.



Use a properly rated hoist and engine lifting bracket, attached to the engine mounted lifting brackets to install the engine.

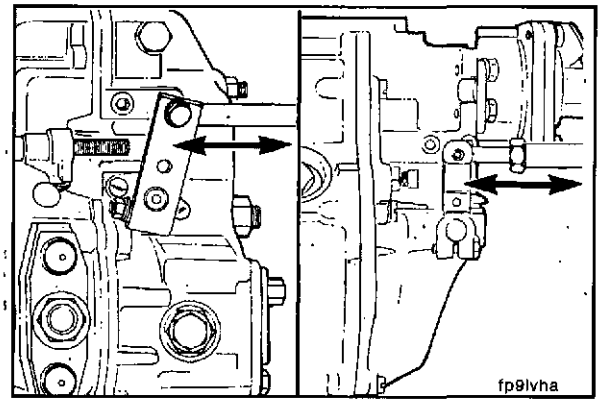




Align the engine in the chassis and tighten the engine mounting capscrews. Refer to the equipment manufacturer's torque specifications.

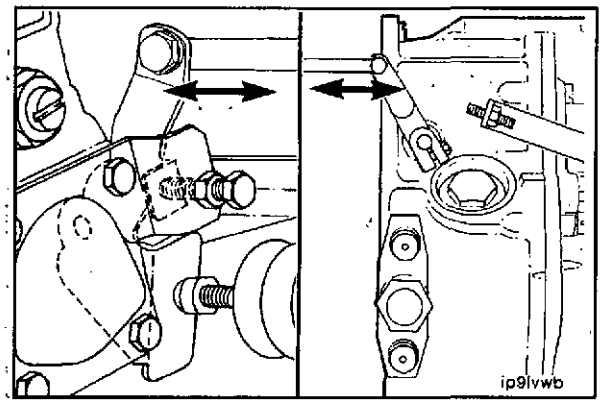
Connect all engine and chassis mounted accessories that were removed.

NOTE: Be sure all lines, hoses, and tubes are properly routed and fastened to prevent damage. Be sure the air intake and exhaust pipe connections are tight and free of leaks.

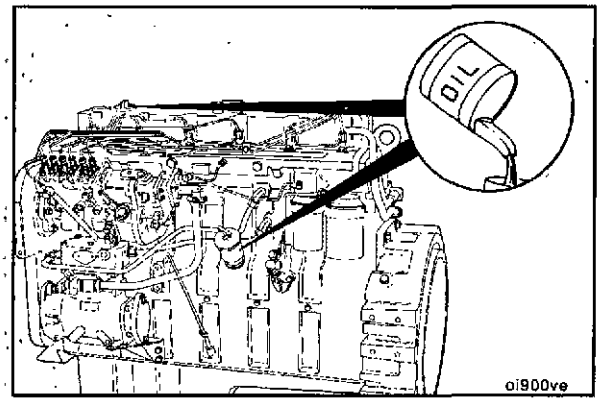


Throttle Control Lever Connection

When connecting the cable/rod to the control lever, adjust the length so the lever has stop-to-stop movement.



Adjust the length of the cable/rod to the mechanical shut down lever so there is stop-to-stop movement.



Fill the engine with clean 15W-40 lubricating oil. Refer to Procedure 2-05.

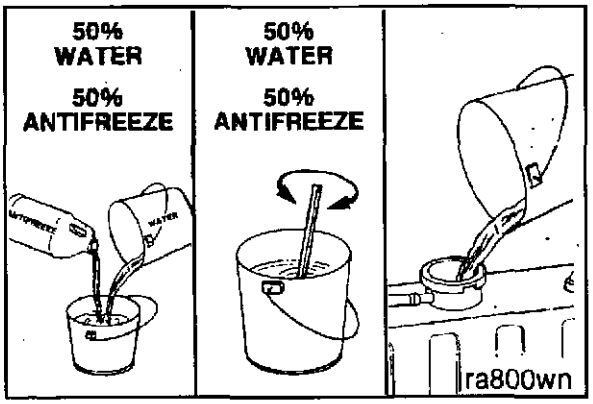
NOTE: The total oil system capacity, including full flow and bypass filters is, 23.6 liters [25.0 U.S. Quarts] for the naturally aspirated engines and 23.8 liters [25.2 U.S. Quarts] for pre 1991 turbocharged engines.

Fill the cooling system with a premixture of 50 percent water, 50 percent ethylene glycol base antifreeze and DCA4 corrosion protection. Refer to Procedure 1-01.

NOTE: The total coolant capacity (engine only) is:

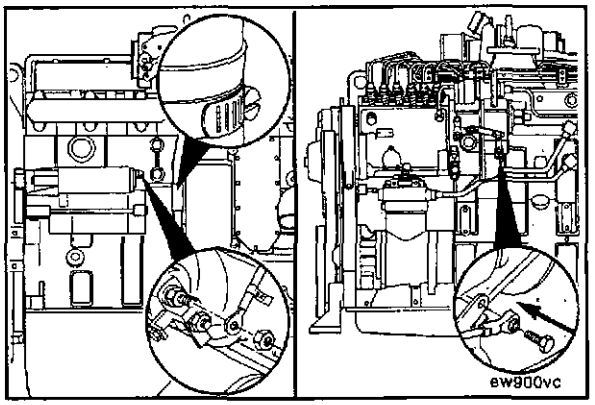
Air Aftercooled: 9.9 liters [10.5 U.S. quarts]

Water Aftercooled: 10.9 liters [11.5 U.S. quarts]

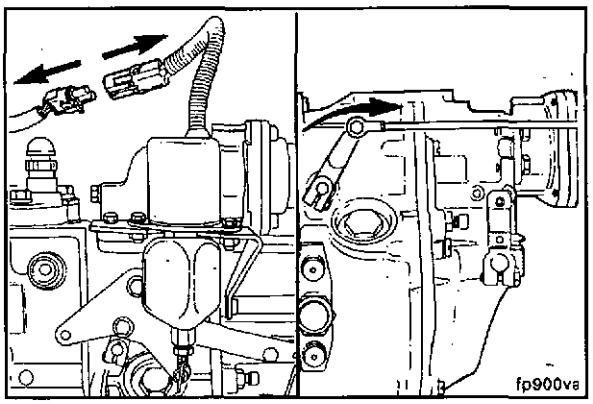


Caution: Installation of the radiator cap at this point is critical to proper purging of air trapped in the cooling system. Improper purging of air from the cooling system will result in engine damage from overheating.

Perform a final inspection to make sure that all hoses, wires, linkages, and components have been properly installed and tightened.

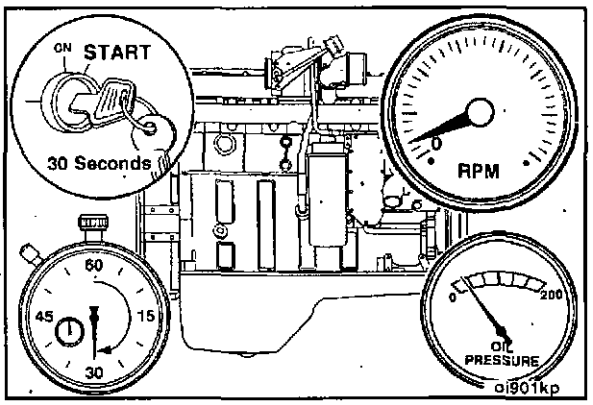


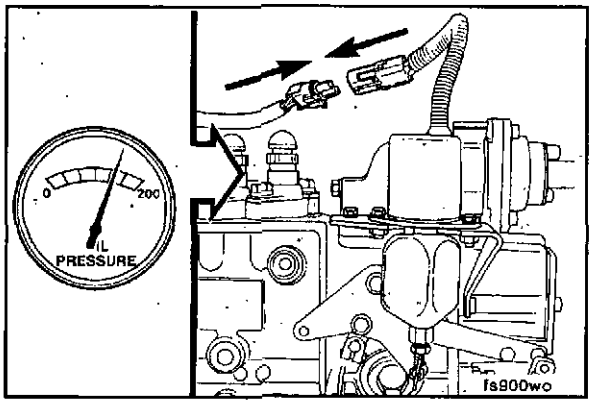
Make sure the fuel is shut off by removing the wire from the fuel solenoid or the mechanical fuel shutoff is in the "OFF" position. This is necessary to prevent the engine from starting during the oil rifle pressure charging operation.



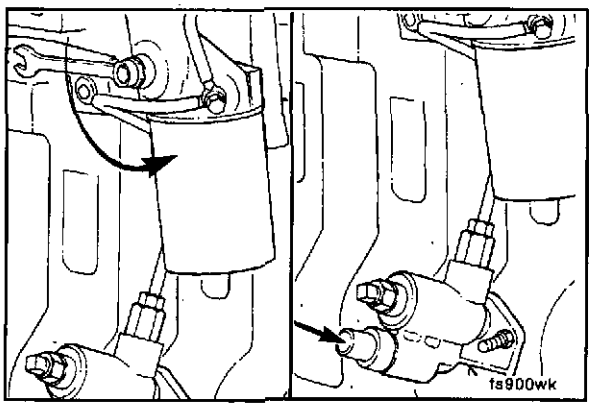
Caution: Do not engage the starting motor for more than 30 seconds. Wait 2 minutes between starter engagements to cool the starting motor.

Crank the engine until the oil pressure gauge indicates a positive pressure.





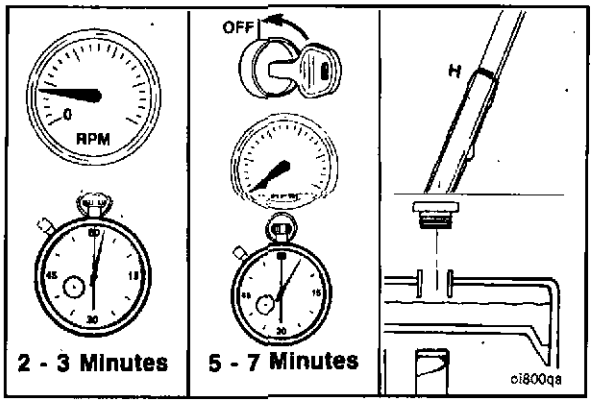
After pressure is observed, connect the wire to the fuel solenoid.



Prime the low pressure fuel system by opening the bleed screw.

Operate the plunger on the fuel transfer pump until the fuel flowing from the fitting is free of air.

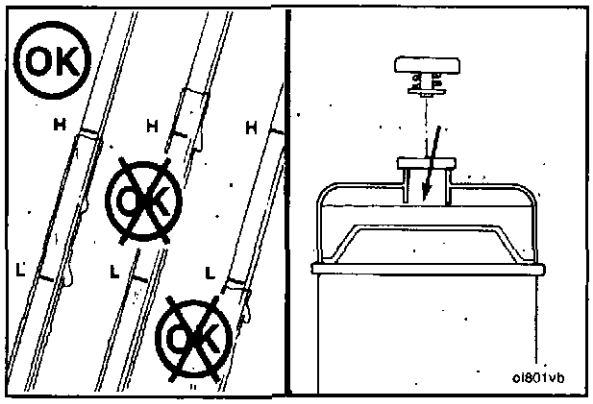
Tighten the bleed screw.



Operate the engine at low idle for 2 to 3 minutes.

Warning: Do not remove the radiator cap from a hot engine. Hot steam can cause serious personal injury. The engine coolant temperature must be below 50°C [122°F].

Shut off the engine and wait 5 to 7 minutes for the oil to drain to the oil pan and check the oil and coolant levels again.

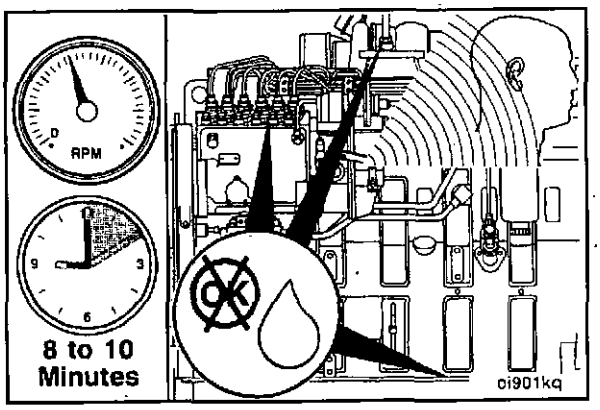


Fill the engine to the correct oil and coolant levels if necessary. Refer to the Lubricating Oil Specifications and Cooling System Procedures 2-05 and 1-01 respectively.

Operate the engine at 1000 to 1200 RPM for 8 to 10 minutes. Check for proper operation, unusual noises, and coolant, fuel or lubricating oil leaks.

Repair all leaks and component problems. Refer to the appropriate procedures.

Refer to Section 8 for the Engine Run-In and Test Procedures.



NOTES

Section V - Engine Component Specifications

Section Contents

Specifications - General Information

This section contains the engine and component specifications used in this manual, separated by systems in the same sequence they appear in the manual. A procedure number will appear with each component description to aid in locating illustrations that describe inspection procedures. Component capscrew installation torque values will follow the specifications in each systems procedure.

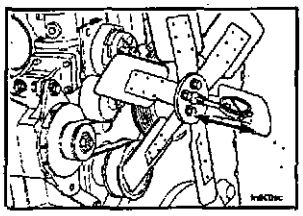
Note: There are some component rebuild specifications listed in this section. The procedures for rebuilding these components are not included in this manual. If the procedure number is not listed, refer to the C Series Shop Manual for rebuild information.

Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.

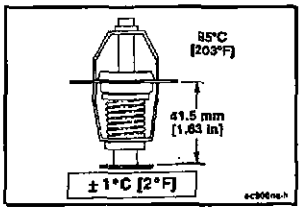
Component Specifications and Torque Values

Cooling System Specifications

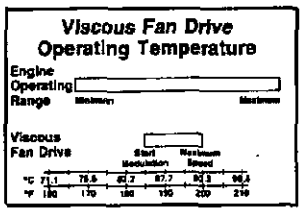
Fan Hub Shaft End Clearance	0.15 mm	MAX	0.006 in



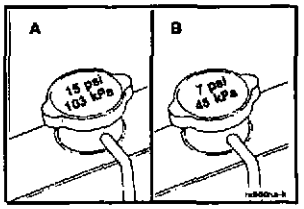
Thermostat Operating Temperature			
Initial Opening Temperature	81°C	MIN	178°F
	83°C	MAX	182°F
Fully Open Temperature	95°C	MAX	203°F
Maximum Open Distance	41.5 mm	MAX	1.63 in



Viscous Fan Drive Operating Temperature			
Start Modulation	85°C		185°F
Maximum Speed	93°C		200°F

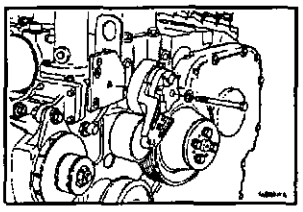


Radiator Cap Pressure Test			
A - 104°C [220°F]	103 kPa	MIN	15 psi
B - 99°C [210°F]	48 kPa	MIN	7 psi

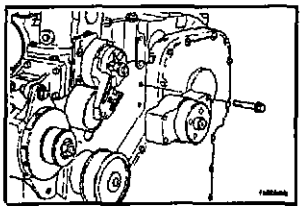


Cooling System Torque Values

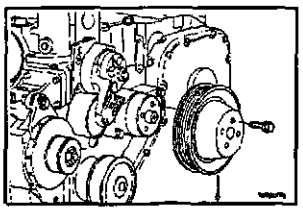
Belt Tensioner Mounting Capscrew	43 N•m	32 ft-lb

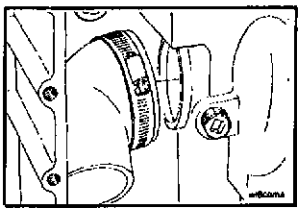
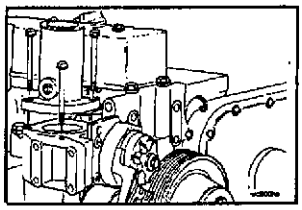
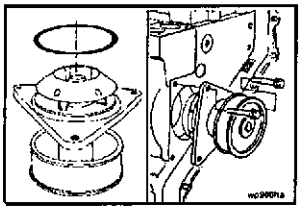
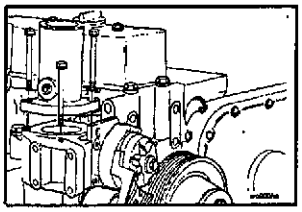


Fan Hub Mounting Capscrew	*24 N•m*	*18 ft-lb*

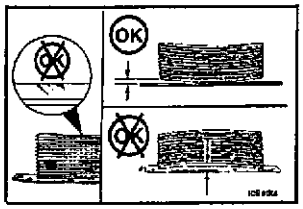
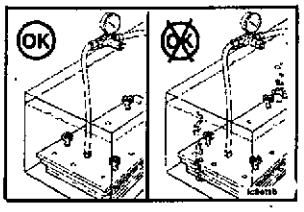
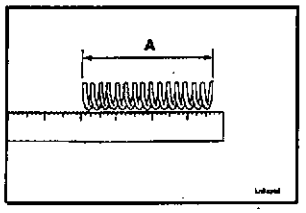


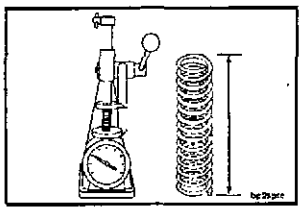
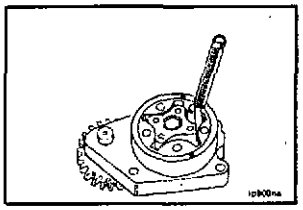
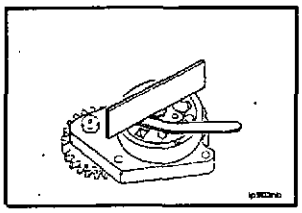
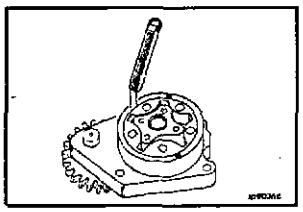
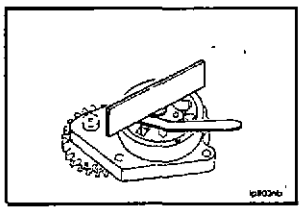
Fan Hub Pulley Mounting Capscrews	43 N•m	32 ft-lb



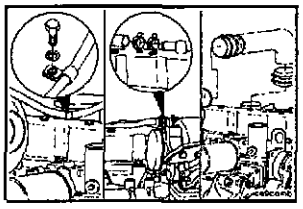
Component or Assembly (Procedure)	Ref.No./Steps	Metric	U.S.
	**Hose Clamps**	5 N•m	44 in-lb
	**Thermostat Housing Mounting Capscrews**	24 N•m	18 ft-lb
	**Water Pump Mounting Capscrews**	24 N•m	18 ft-lb
	**Water Outlet Connection**	24 N•m	18 ft-lb

Lubricating Oil System Specifications

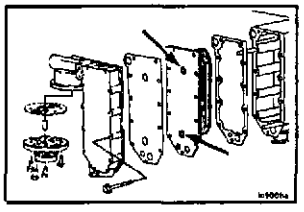
	**Oil Cooler Distortion**	0.8 mm MAX	0.031 in
	**Oil Cooler Element Pressure Test** Pressurize the cooler to 483 kPa [70 psi], and check for leaks by submerging in water.		
	**Oil Pressure Regulator Spring** Spring Free Length 13-coils	86.63 mm Nominal	3.411 in

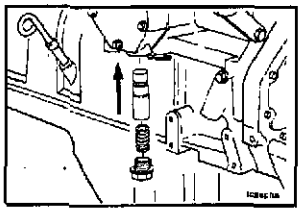
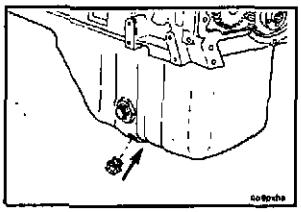
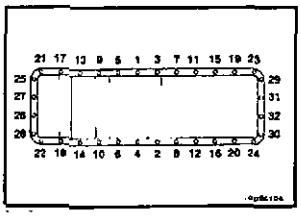
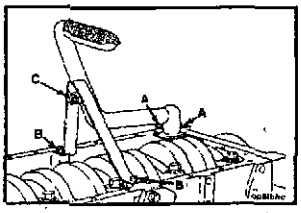
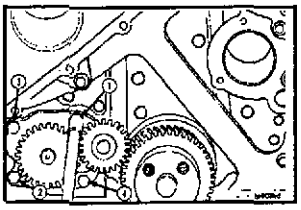
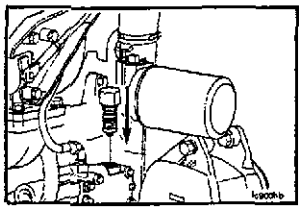
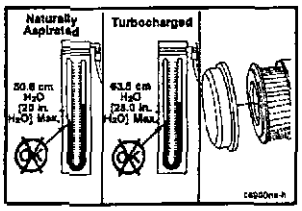
Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.	
Spring Load at 53.98 mm [2.125 in] Valve Open		190 N	MIN	42.8 lbf	
Spring Load at 60.33 mm [2.375 in] Assembled		153 N	MIN	34.4 lbf	
Oil Pump Gerotor Tip Clearance		0.025 mm 0.178 mm	MIN MAX	0.001 in 0.007 in	
Oil Pump Port Plate Clearance		0.025 mm 0.127 mm	MIN MAX	0.001 in 0.005 in	
Oil Pump Body Bore Clearance		0.127 mm 0.381 mm	MIN MAX	0.005 in 0.015 in	
Oil Pump Drive Gear Backlash		0.08 mm 0.33 mm	MIN MAX	0.003 in 0.013 in	
Oil Pump Idler Gear Backlash		0.08 mm 0.33 mm	MIN MAX	0.003 in 0.013 in	

Lubricating Oil System Torque Values



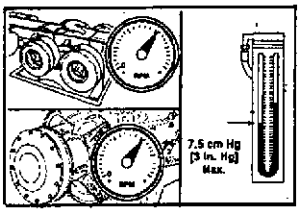
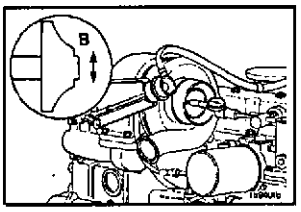
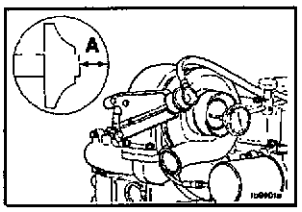
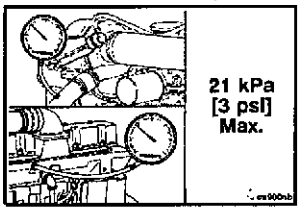
Crankcase Breather Tube Bracket				
M8 (Rocker Cover)		24 N•m		18 ft-lb
M12 (Cylinder Head)		77 N•m		57 ft-lb
Oil Cooler Mounting Capscrews		24 N•m		18 ft-lb
Oil Filter Head Mounting Capscrews		24 N•m		18 ft-lb



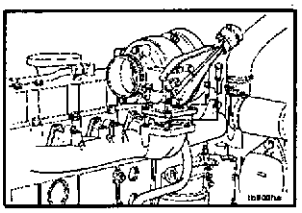
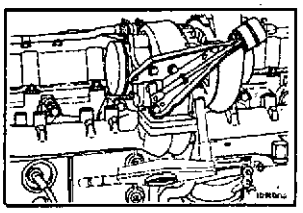
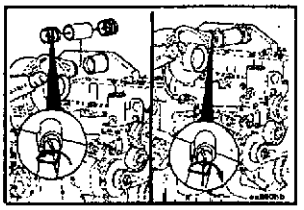
Component or Assembly (Procedure)	Ref.No./Steps	Metric	U.S.
 **Oil Pressure Regulator Plug**		80 N•m	59 ft-lb
 **Oil Drain Plug**		80 N•m	59 ft-lb
 **Oil Pan Mounting Capscrews** **Note:** Tighten the capscrews in the sequence shown. Start at the center of the oil pan and alternate toward both ends.		24 N•m	18 ft-lb
 **Oil Pump Suction Tube Bracket**			
Suction Tube to Block	A	9 N•m	80 in-lb
Brace to Block	B	9 N•m	80 in-lb
Brace to Suction Tube	C	9 N•m	80 in-lb
 **Oil Pump Mounting Capscrews**		24 N•m	18 ft-lb
 ***Oil Temperature Thermostat***		50 N•m	37 ft-lb
			

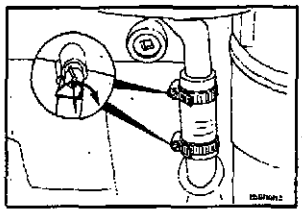
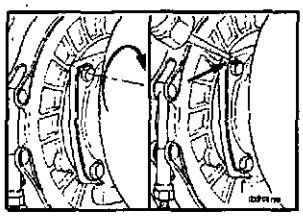
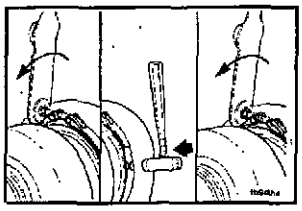
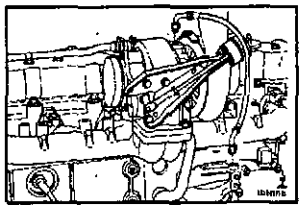
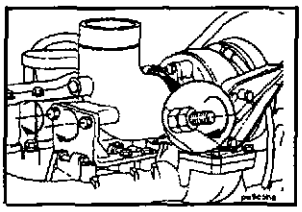
Combustion Air System Specifications

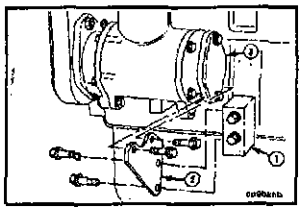
Intake Air Restriction		
Naturally Aspirated	50.8 cm H_2O	MAX 20.0 in H_2O
Turbocharged	63.5 cm H_2O	MAX 25.0 in H_2O

Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.	
Exhaust Restriction		76.2 mm 152.4 mm Hg	MAX MAX	3.0 in Hg 6.0 in Hg with catalyst	
Turbocharger Radial Clearance (Side to Side)		0.21 mm 0.46 mm	MIN MAX	0.008 in 0.018 in	
Turbocharger Axial Clearance (End Clearance)		0.03 mm 0.08 mm	MIN MAX	0.001 in 0.003 in	
Charge Air Cooler Differential Pressure Across Cooler		21 kPa	MAX	3 psi	

Combustion Air System Torque Values

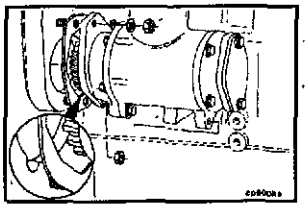
Turbocharger Mounting Nut		45 N•m		33 ft-lb	
Turbocharger Oil Drain Mounting Capscrew		24 N•m		18 ft-lb	
Turbocharger Air Crossover Hose Clamps		5 N•m		44 in-lb	

Component or Assembly (Procedure)	Ref.No./Steps	Metric	U.S.
 **Turbocharger Oil Drain Line Hose Clamps**		5 N•m	44 in-lb
 **Turbocharger Turbine Housing Capscrews**		11 N•m	97 in-lb
 **Turbocharger Compressor Housing Clamp**		8 N•m	71 in-lb
 **Turbocharger Oil Supply Line Connection** **Note:** Hold turbo supply fitting when tightening turbo oil supply line.		35 N•m	26 ft-lb
 **Turbocharger Discharge Elbow**		8 N•m	71 in-lb

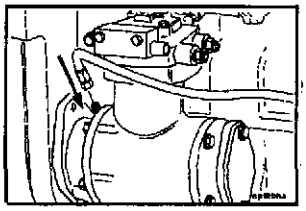
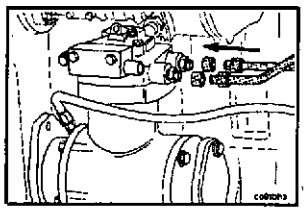


Compressed Air System Torque Values

Air Compressor Brace to Air Compressor Mounting Capscrews	2		
Holset		43 N•m	32 ft-lb
Bendix		43 N•m	32 ft-lb
Midland		32 N•m	24 ft-lb
Air Compressor Brace to Cylinder Block Mounting Capscrew	1	43 N•m	32 ft-lb

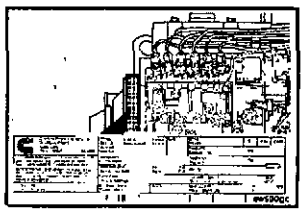


Air Compressor Flange Mounting Nuts			
Nut		77 N•m	57 ft-lb
Stud to Gear Housing		Hand Tight	

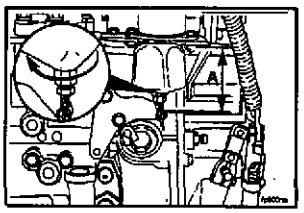
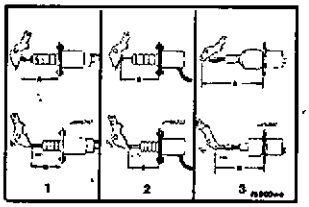
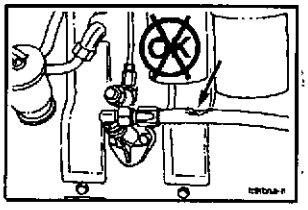
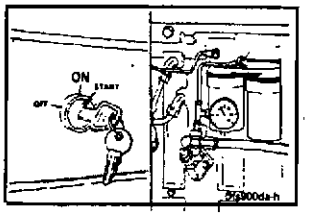
Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.	
Air Compressor Oil Supply Line		15 N•m		12 ft-lb	
Air Compressor Coolant Lines		35 N•m		26 ft-lb	

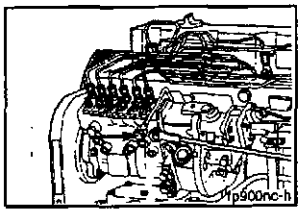
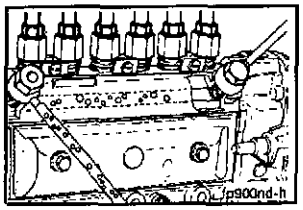
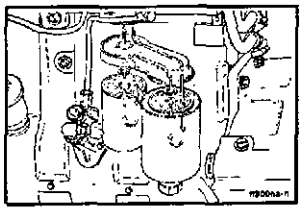
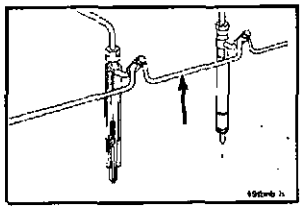
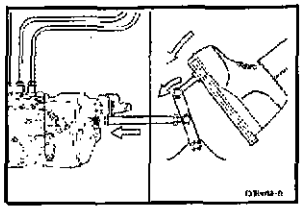
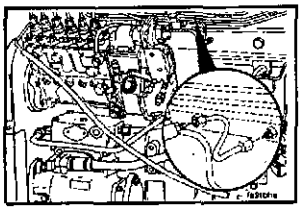
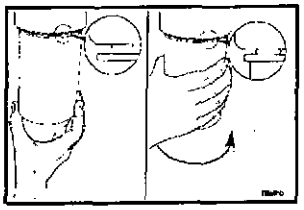
Fuel System Specifications

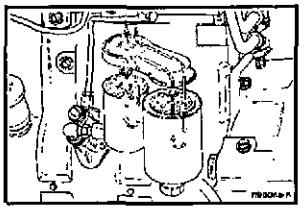
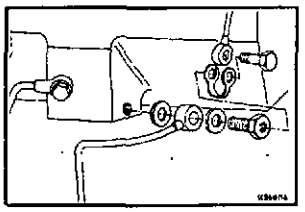
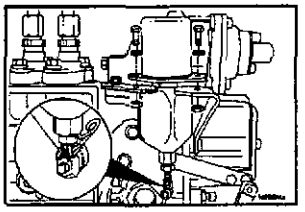
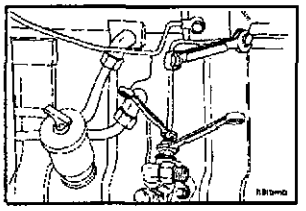
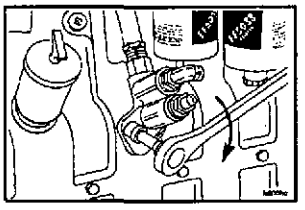
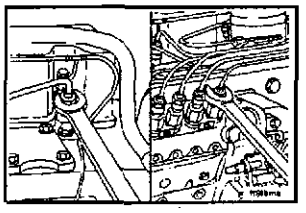
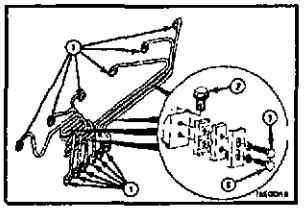
Engine Low Idle Speed
Refer to the engine dataplate.

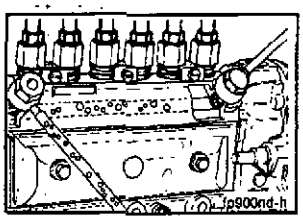
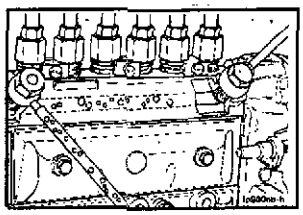
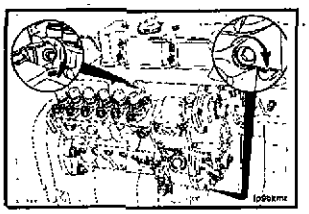
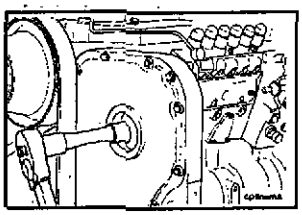
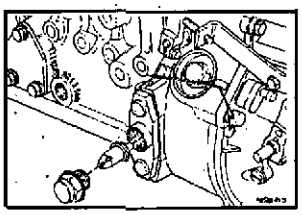
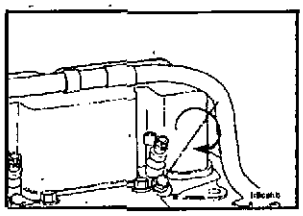
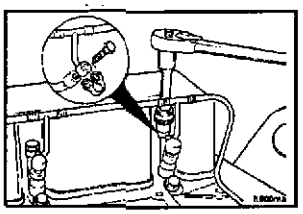


Fuel Shutoff Solenoid Adjustment

RQVK Governor	A =	66.9 mm		2.64 in	
RSV Governor					
1. Synchro-Start	A =	86.6 mm		3.4 in	
	B =	60.2 mm		2.5 in	
2. Trombeta	A =	91.4 mm		3.6 in	
	B =	63.5 mm		2.51 in	
3. Direct Link	B =	117.1 mm		4.61 in	
Fuel Transfer Pump Inlet Restriction					
6C, 6CT		100 mm Hg	MAX	4 in Hg	
6CTA		153 mm Hg	MAX	6 in Hg	
Fuel Transfer Pump Outlet Pressure at Rated Speed					
6C, 6CT, 6CTA, C8.3	High Flow	172 kPa	MIN	25 psi	
	Low Flow	83 kPa	MIN	12 psi	

Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.
 **Fuel Injection Pump** Fuel Inlet Pressure	High Flow Low Flow	138 kPa 48 kPa	MIN MIN	20 psi 7 psi
 **Fuel Injection Pump** Fuel Return Line Restriction		518 mm Hg	MAX	20.4 in Hg
 **Fuel Filter Restriction** Pressure Drop Across Filter		35 kPa	MAX	5 psi
 **Fuel Drain Line Restriction**		70 kPa	MAX	10 psi
 **Injection Pump Throttle Lever** Breakover		3.18 mm 6.35 mm	MIN MAX	0.125 in 0.250 in
 **Fuel System Torque Values**				
AFC Air Fuel Control Fitting		24 N•m		18 ft-lb
 **Fuel Filter** **Caution: Hand tighten only. Mechanical tightening will damage the fuel filter.**				

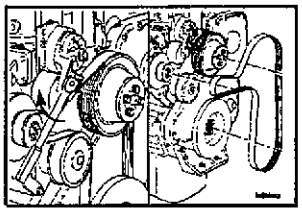
Component or Assembly (Procedure)	Ref.No./Steps	Metric	U.S.	
Fuel Filter Head Adapter		4 N•m	35 in-lb	
Fuel Filter Adapter Nut		32 N•m	24 ft-lb	
Fuel Filter Head Banjo Fittings		24 N•m	18 ft-lb	
Fuel Pump Solenoid Mounting Capscrews		10 N•m	89 in-lb	
Fuel Transfer Pump Fuel Line Fittings		24 N•m	18 ft-lb	
Fuel Transfer Pump Mounting Capscrews		24 N•m	18 ft-lb	
High Pressure Fuel Line Fittings		30 N•m	22 ft-lb	
High Pressure Fuel Line Support Bracket		24 N•m	18 ft-lb	
Vibration Isolator Capscrew		6 N•m	53 in-lb	

	Component or Assembly (Procedure)	Ref.No./Steps	Metric	U.S.
	**Injection Pump Supply Banjo Fitting**		32 N•m	24 ft-lb
	**Injection Pump** Mounting Nuts Studs		44 N•m Hand Tight	32 ft-lb
	***Injection Pump Lower Support Bracket*** M10 Pump to Support Bracket Capscrew M10 Support Bracket to Block Capscrew		24 N•m 77 N•m	18 ft-lb 57 ft-lb
	**Injection Pump Drive Gear Nut** A Pump MW Pump P Pump		 92 N•m 104 N•m 165 N•m	 68 ft-lb 77 ft-lb 122 ft-lb
	**Injection Pump Timing Pin Access Plug**		15 N•m	11 ft-lb
	**Injection Nozzle Clamp Capscrew**		24 N•m	18 ft-lb
	**Injection Nozzle Banjo Fitting**		10 N•m	89 in-lb

Component or Assembly (Procedure)	Ref.No./Steps	Metric	U.S.

Electrical System Specifications

Alternator Belt
Belt tensioner, no adjustment necessary.



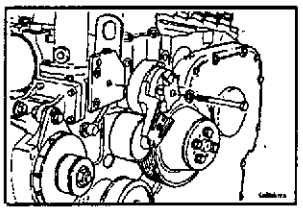
Batteries

Specific Gravity at 27°C [80°F]	State of Charge
1.260 to 1.280	100%
1.230 to 1.250	75%
1.200 to 1.220	50%
1.170 to 1.190	25%
1.110 to 1.130	Discharged

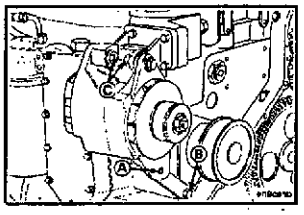
Battery State of Charge	Specific Gravity @ 27°C [80°F]
100%	1.260-1.280
75%	1.230-1.250
50%	1.200-1.220
25%	1.170-1.190
Discharged	1.110-1.130

Electrical System Torque Values

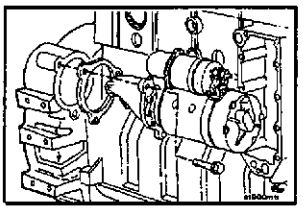
Alternator Belt Tensioner Capscrew		44 N•m	32 ft-lb



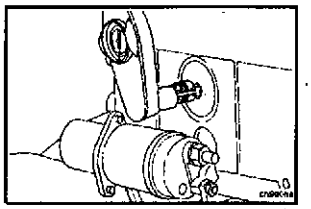
Alternator Mounting Pivot	A		
M10 Capscrew		44 N•m	32 ft-lb
Alternator Lower Support Bracket	B		
M8 Capscrew		24 N•m	18 ft-lb
M10 Capscrew		44 N•m	32 ft-lb
Alternator Mounting Capscrews	C	77 N•m	57 ft-lb



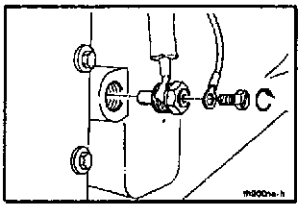
Starting Motor Mounting Capscrew	77 N•m	57 ft-lb

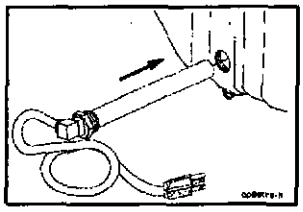
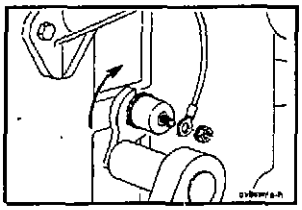
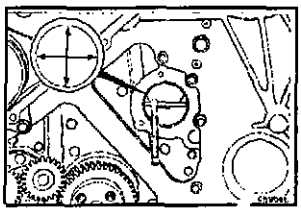
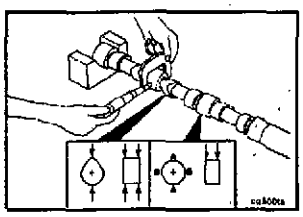
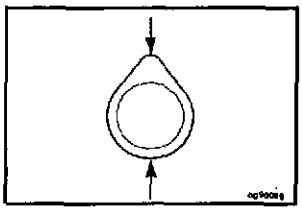
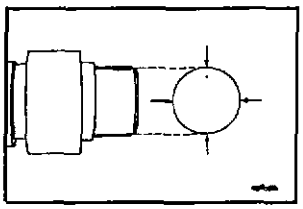
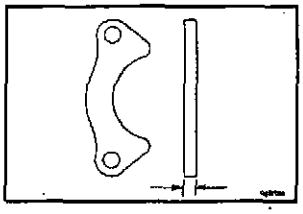


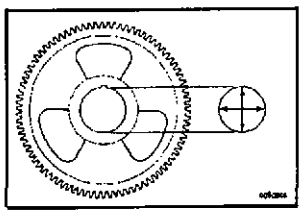
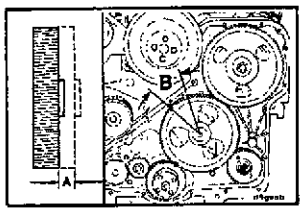
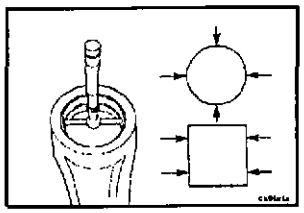
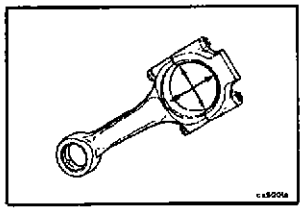
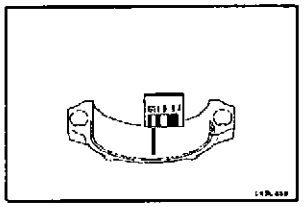
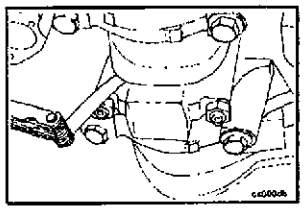
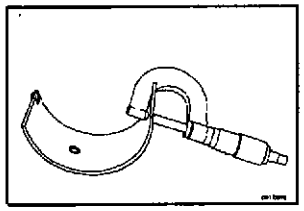
Coolant Heater	12 N•m	106 in-lb

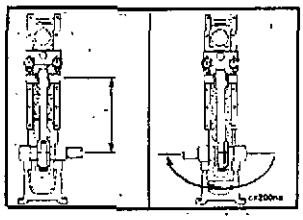
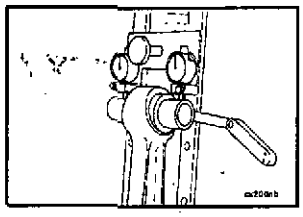
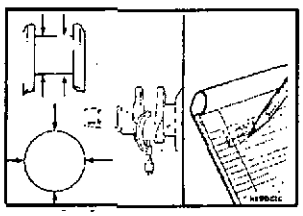
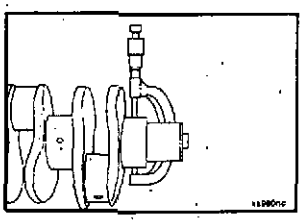
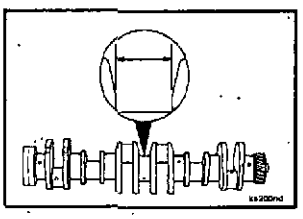
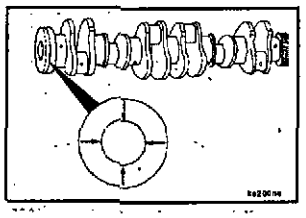
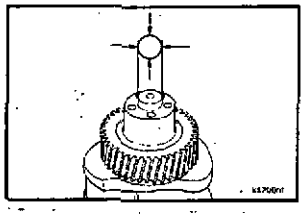


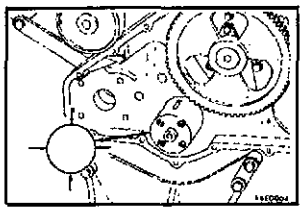
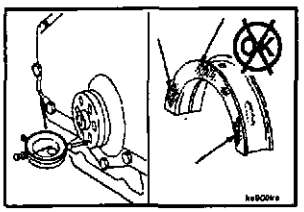
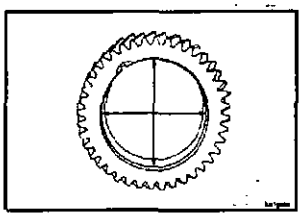
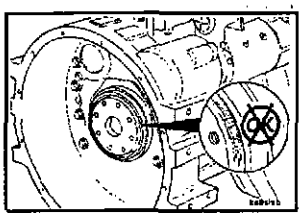
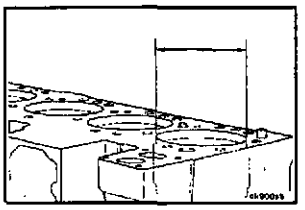
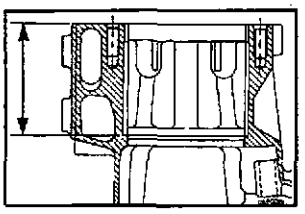
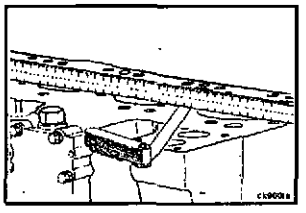
Temperature Sensor		
Installation - Cast Iron	50 N•m	37 ft-lb
Installation - Aluminum	30 N•m	22 ft-lb

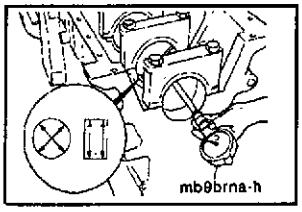
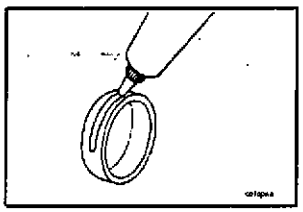
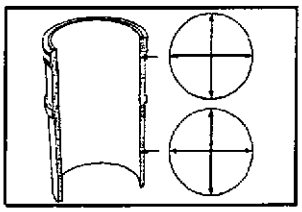
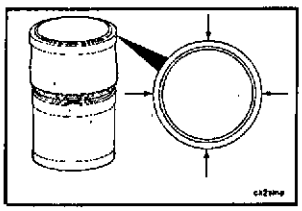
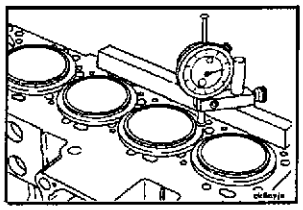
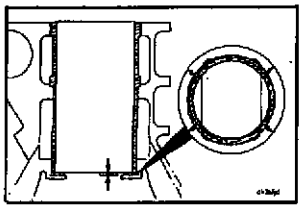
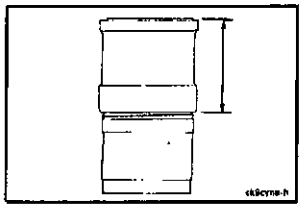


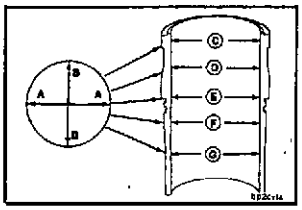
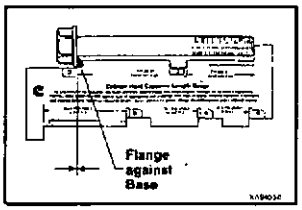
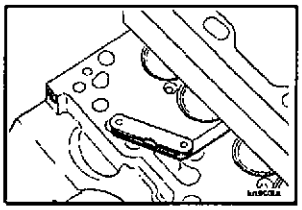
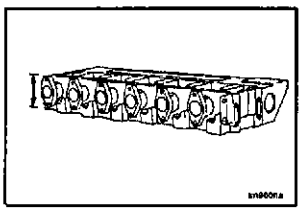
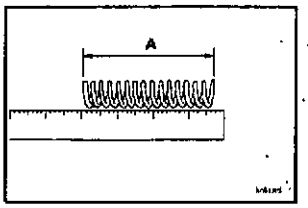
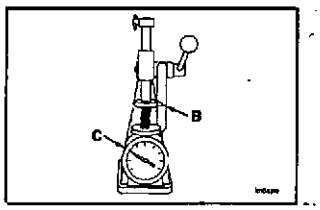
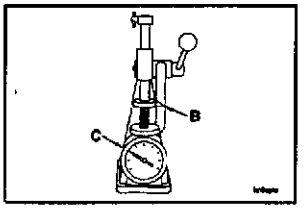
Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.
 **Oil Heater Element**		120 N•m		89 ft-lb
 **Oil Pressure Switch**				
Installation - Cast Iron		16 N•m		12 ft-lb
Installation - Aluminum		10 N•m		89 in-lb
 **Base Engine Component Specifications**				
Camshaft Bore Diameter				
With Bushing		60.12 mm		2.367 in
Without Bushing		64.01 mm		2.520 in
Note: If one of the bushings exceeds the specifications, all of the bushings must be replaced.				
 **Camshaft Journal O.D.**		59.962 mm	MIN	2.3607 in
		60.013 mm	MAX	2.3627 in
 **Camshaft Lobe Diameter**				
Intake Lobe		51.774 mm	MIN	2.0383 in
		52.251 mm	MAX	2.0571 in
Exhaust Lobe		51.596 mm	MIN	2.0313 in
		52.073 mm	MAX	2.0501 in
Fuel Transfer Pump Lobe		41.310 mm	MIN	1.6264 in
		41.829 mm	MAX	1.6468 in
 **Camshaft Nose (Gear Mounting Surface) O.D.**		41.562 mm	MIN	1.6363 in
		41.580 mm	MAX	1.6370 in
 **Camshaft Thrust Plate Thickness**		9.340 mm	MIN	0.3677 in
		9.580 mm	MAX	0.3772 in

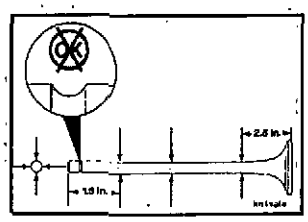
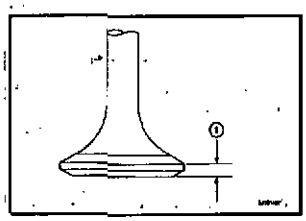
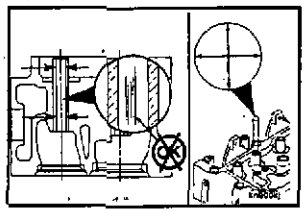
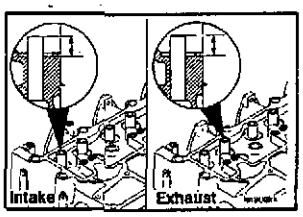
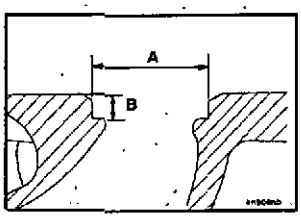
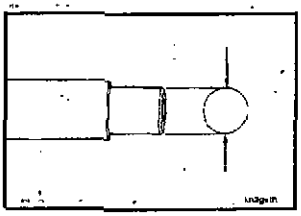
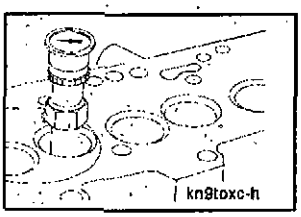
Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.	
Camshaft Gear Bore I.D.		41.480 mm 41.505 mm	MIN MAX	1.6331 in 1.6341 in	
Camshaft End Clearance	(A)	0.12 mm 0.46 mm	MIN MAX	0.0047 in 0.018 in	
Camshaft Gear Backlash Limits	(B)	0.08 mm 0.33 mm	MIN MAX	0.003 in 0.013 in	
Connecting Rod Piston Pin I.D. (With Bushing)		45.023 mm 45.060 mm	MIN MAX	1.7726 in 1.7740 in	
Connecting Rod Crankshaft Bore I.D. (With Bearings)		76.046 mm 76.104 mm	MIN MAX	2.9939 in 2.9962 in	
Connecting Rod Bearing Clearance (With Plastigauge)		0.033 mm 0.117 mm	MIN MAX	0.0013 in 0.0046 in	
Connecting Rod Bearing Side Clearance		0.100 mm 0.330 mm	MIN MAX	0.0039 0.0130	
Connecting Rod Bearing Thickness Standard		2.455 mm 2.471 mm	MIN MAX	0.0966 in 0.0973 in	

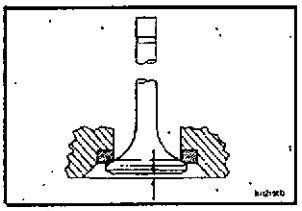
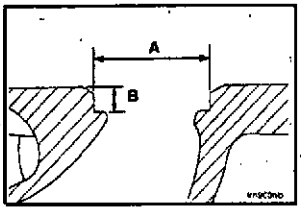
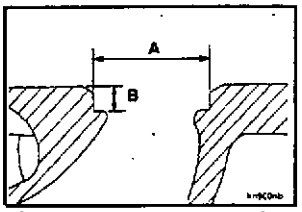
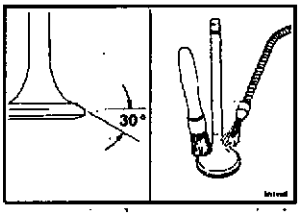
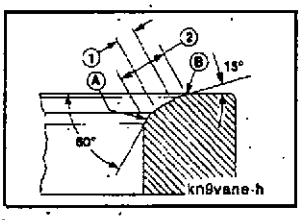
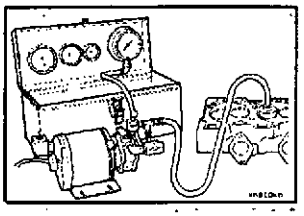
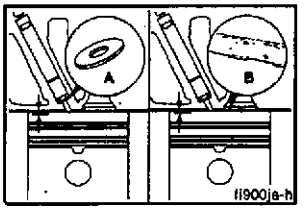
Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.
 **Connecting Rod Length**		215.975 mm 216.025 mm	MIN MAX	8.5029 in 8.5049 in
Connecting Rod Bend (Alignment)				
• Without Bushing		0.20 mm	MAX	0.008 in
• With Bushing		0.15 mm	MAX	0.006 in
 **Connecting Rod Twist**				
• Without Bushing		0.50 mm	MAX	0.020 in
• With Bushing		0.30 mm	MAX	0.012 in
 **Crankshaft Connecting Rod Journal**				
• O.D.		75.962 mm 76.013 mm	MIN MAX	2.9906 in 2.9926 in
• Out-of-Round		0.050 mm	MAX	0.0020 in
• Taper		0.013 mm	MAX	0.0005 in
 **Crankshaft Main Bearing Journal**				
• O.D.		97.962 mm 98.031 mm	MIN MAX	3.8568 in 3.8595 in
• Out-of-Round		0.050 mm	MAX	0.0020 in
• Taper		0.013 mm	MAX	0.0005 in
 **Crankshaft Thrust Face Width (Standard)**		42.975 mm 43.076 mm	MIN MAX	1.6919 in 1.6959 in
 **Crankshaft Rear Oil Seal Flange O.D.**		129.975 mm 130.025 mm	MIN MAX	5.1171 in 5.1191 in
 **Crankshaft Damper Pilot O.D.**		23.924 mm 24.000 mm	MIN MAX	0.9419 in 0.9449 in

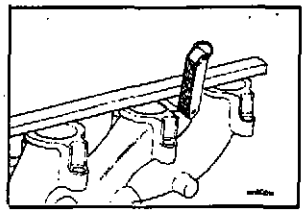
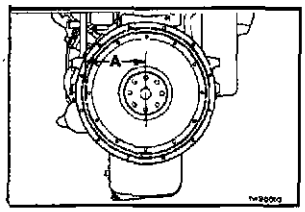
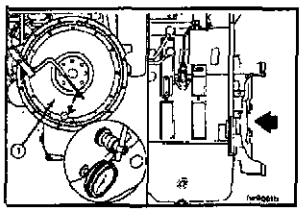
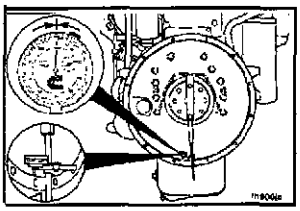
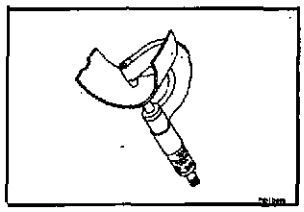
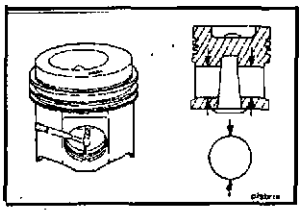
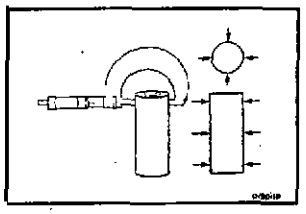
Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.	
Crankshaft Gear Journal O.D.		75.987 mm 76.006 mm	MIN MAX	2.991 in 2.992 in	
Crankshaft End Clearance New Used		0.127 mm 0.330 mm 0.533 mm	MIN MAX MAX	0.005 in 0.013 in 0.021 in	
Crankshaft Gear Bore I.D.		75.898 mm 75.923 mm	MIN MAX	2.9881 in 2.9891 in	
Crankshaft Rear Oil Seal Wear Groove		0.25 mm	MAX	0.010 in	
Cylinder Block Upper Liner Bore I.D.		130.900 mm 130.990 mm	MIN MAX	5.1535 in 5.1570 in	
Cylinder Block Upper Deck To Midstop Liner Seat Area		122.930 mm 123.000 mm	MIN MAX	4.8397 in 4.8425 in	
Cylinder Block Surface Flatness Overall Surface Flatness Within 50 mm [2.0 in]		0.075 mm 0.012 mm	MAX MAX	0.0030 in 0.0005 in	

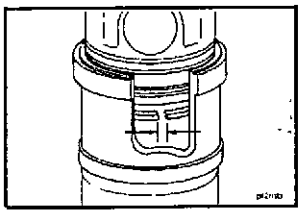
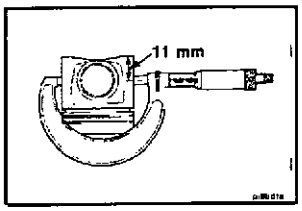
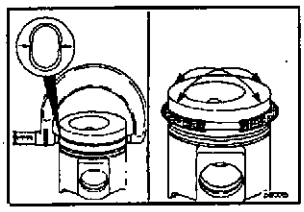
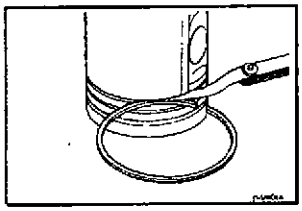
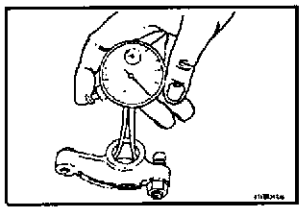
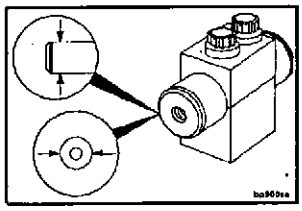
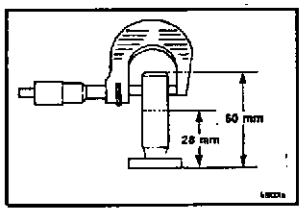
Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.
		**Cylinder Block Main Bearing Bore I.D.**		
		• Without Bearing		
			104.982 mm MIN	4.1333 in
			105.018 mm MAX	4.1344 in
		• With Bearing		
			98.079 mm MIN	3.8614 in
			98.123 mm MAX	3.8632 in
		**Cylinder Head Cup Plug Requirements**		
		Apply a bead of Loctite™ 277 or		
	1	Cummins sealant, Part No. 3375068,	30.43 mm	1.198 in
	2	around the outside diameter of all cup plugs before installation.	58.06 mm	2.286 in
		**Cylinder Liner I.D.**		
			114.000 mm MIN	4.4882 in
			114.040 mm MAX	4.4897 in
		**Cylinder Liner Top Press Fit O.D.**		
			130.938 mm MIN	5.1550 in
			130.958 mm MAX	5.1558 in
		**Cylinder Liner Protrusion**		
			0.025 mm MIN	0.0010 in
			0.122 mm MAX	0.0048 in
		**Cylinder Liner-to-Block Clearance**		
			0.229 mm MIN	0.0090 in
		**Cylinder Liner Seat Area Depth**		
			123.026 mm MIN	4.8435 in
			123.052 mm MAX	4.8445 in

Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.	
Cylinder Liner Out-of-Round		0.08 mm	MAX	0.003 in	
Cylinder Liner Taper		0.08 mm	MAX	0.003 in	
Cylinder Head Capscrew Free Length					
• Short		81.5 mm	MAX	3.21 in	
• Long		162.6 mm	MAX	6.40 in	
Cylinder Head Flatness					
End to End		0.200 mm	MAX	0.0079 in	
Side to Side		0.076 mm	MAX	0.0030 in	
Cylinder Head Thickness		115.75 mm	MIN	4.557 in	
		116.25 mm	MAX	4.577 in	
Valve Spring Free Height					
(7 1/2 coils)		65.66 mm	Nominal	2.585 in	
Valve Spring Working Height		50.80 mm	Nominal	2.00 in	
Spring Force at Assembled Height					
New		464.5 N	MIN	104.4 lbf	
		513.5 N	MAX	115.4 lbf	
Used		450.0 N	MIN	101.2 lbf	
Valve Spring at Opening Height		37.90 mm	Nominal	1.492 in	
Spring Force at Opening Height					
New		959.5 N	MIN	215.7 lbf	
		1060.5 N	MAX	238.4 lbf	
Used		940.0 N	MIN	211.3 lbf	

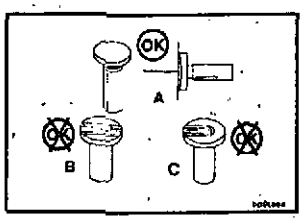
	Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.
	**Valve Stem O.D.**		9.48 mm 9.50 mm	MIN MAX	0.373 in 0.374 in
	**Valve Head Thickness at O.D.** Intake Exhaust		 3.01 mm 2.22 mm	 MIN MIN	 0.119 in 0.087 in
	**Valve Guide I.D. (Installed)**		9.539 mm 9.559 mm	MIN MAX	0.3756 in 0.3763 in
	**Valve Guide Height (Installed)** Intake Exhaust		 20.65 mm 21.16 mm 22.50 mm 23.01 mm	 MIN MAX MIN MAX	 0.813 in 0.833 in 0.886 in 0.906 in
	**Valve Guide Bore I.D.**		15.931 mm 15.971 mm	MIN MAX	0.6272 in 0.6288 in
	**Valve Guide (New) O.D.**		15.988 mm 16.000 mm	MIN MAX	0.6294 in 0.6299 in
	**Valve Seat-to-Valve Guide Concentricity (360 Degrees)**		0.05 mm	MAX	0.002 in

Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.	
Valve Recess In Cylinder Head					
Exhaust		1.09 mm	MIN	0.043 in	
		1.62 mm	MAX	0.064 in	
Intake		0.59 mm	MIN	0.023 in	
		1.12 mm	MAX	0.044 in	
Valve Insert Bore I.D. (Standard Insert)	A				
Intake		53.930 mm	MAX	2.1231 in	
Exhaust		47.027 mm	MAX	2.8515 in	
Valve Insert Bore Depth (Standard Insert)	B				
Intake		12.20 mm	MAX	0.480 in	
Exhaust		9.83 mm	MAX	0.387 in	
Valve Face Angle					
Intake		30°			
Exhaust		45°			
Valve Seat Width Limit Grind area (A) with a 60 degree stone, and (B) with a 15 degree stone to center the seat on the valve face and obtain the valve seat width limits.		1.5 mm 2.0 mm	MIN MAX	0.060 in 0.080 in	
Valve Seat Leakage (Hg)					
New		635 mm Hg	MAX	25 in Hg	
Used		457 mm Hg	MAX	18 in Hg	
Injector Nozzle Tip Protrusion		3.0 mm 4.0 mm	MIN MAX	0.118 in 0.157 in	

	Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.
	**Exhaust Manifold Flatness**		0.20 mm	MAX	0.008 in
	**Flywheel Face Runout T.I.R.**	**Radius (A)** **mm in**			
		203 8	0.203 mm	MAX	0.008 in
		254 10	0.254 mm	MAX	0.010 in
		305 12	0.305 mm	MAX	0.012 in
		356 14	0.356 mm	MAX	0.014 in
		406 16	0.406 mm	MAX	0.016 in
	**Flywheel Bore Runout T.I.R.**		0.127 mm	MAX	0.0050 in
	**Flywheel Bore Alignment T.I.R.**	SAE No.			
		1	0.20 mm	MAX	0.008 in
		2	0.20 mm	MAX	0.008 in
		3	0.20 mm	MAX	0.008 in
	**Main Bearing Thickness (Standard)**		3.446 mm	MIN	0.1357 in
			3.454 mm	MAX	0.1360 in
	Main Bearing Clearance with Plastigauge		0.066 mm	MIN	0.0026 in
			0.134 mm	MAX	0.0053 in
	**Piston Pin Bore I.D.**		45.006 mm	MIN	1.7719 in
			45.025 mm	MAX	1.7726 in
	**Piston Pin O.D.**		44.993 mm	MIN	1.7710 in
			45.003 mm	MAX	1.7718 in

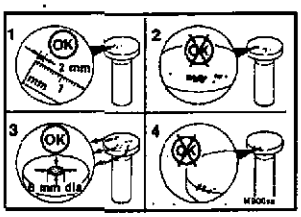
Component or Assembly (Procedure)	Ref.No./Steps	Metric		U.S.	
Piston Ring Gap (New)					
Top Ring Gap		0.35 mm	MIN	0.014 in	
		0.60 mm	MAX	0.024 in	
Intermediate Ring Gap		0.35 mm	MIN	0.014 in	
		0.65 mm	MAX	0.026 in	
Oil Ring Gap		0.30 mm	MIN	0.0118 in	
		0.60 mm	MAX	0.0236 in	
Piston Skirt O.D. (Worn Limit)		113.808 mm	MIN	4.4806 in	
		113.879 mm	MAX	4.4834 in	
Top Ring Groove Keystone Angle Wear					
Use micrometer and Part No. 3823966		113.938 mm	MIN	4.4857 in	
Intermediate Ring Groove Keystone Angle Wear					
Use micrometer and Part No. 3823965		114.323 mm	MIN	4.5009 in	
Intermediate Rectangular Ring Side Clearance		0.070 mm	MIN	0.0028 in	
		0.150 mm	MAX	0.0059 in	
Oil Ring Side Clearance		0.020 mm	MIN	0.0008 in	
		0.130 mm	MAX	0.0051 in	
Rocker Lever Bore I.D.		22.256 mm	MIN	0.8762 in	
		22.301 mm	MAX	0.8780 in	
Rocker Lever Shaft O.D.		22.199 mm	MIN	0.8740 in	
		22.231 mm	MAX	0.8752 in	
Tappet Stem O.D.		15.925 mm	MIN	0.6270 in	
		15.980 mm	MAX	0.6291 in	

Component or Assembly (Procedure)	Ref.No./Steps	Metric	U.S.



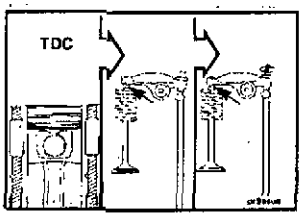
Tappet Visual Limits

Inspect the socket stem and face for excessive wear, cracks or damage.	(A)	Normal Wear	
	(B)	Abnormal (Do not use)	
	(C)	Abnormal (Do not use)	
Concavity	(A)	0.025 mm	0.001 in



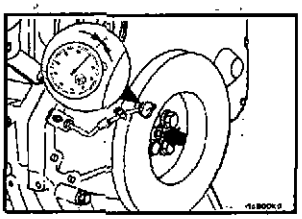
Tappet Face

1. A single pit **cannot** be greater than 2 mm [0.078 in] in diameter.
2. Interconnection of pits is **not** allowed and are treated as one pit.
3. Total pits when added together should **not** exceed 6 mm [0.236 in] diameter or a total of 4 percent of the tappet face.
4. No pitting is allowed on the edges of the wear face of the tappet.



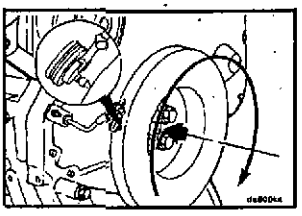
Valve Adjustment Clearance

Intake Valve	0.30 mm	Nominal	0.012 in
Exhaust valve	0.61 mm	Nominal	0.024 in



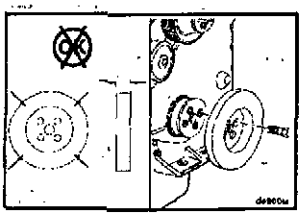
Vibration Damper Face Alignment

(Wobble) TIR	0.28 mm	MAX	0.011 in



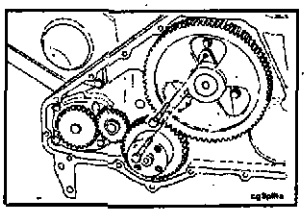
Vibration Damper Eccentricity TIR

	0.28 mm	MAX	0.011 in



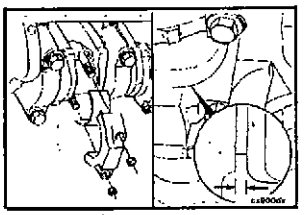
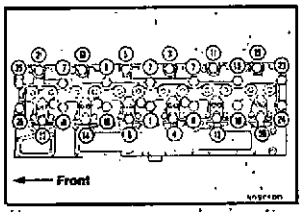
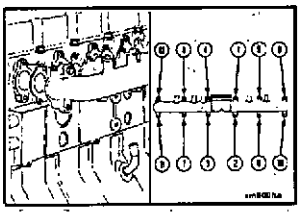
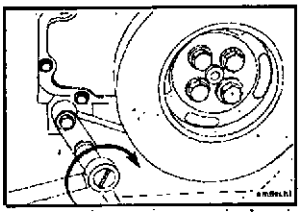
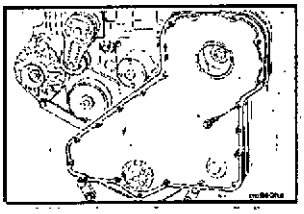
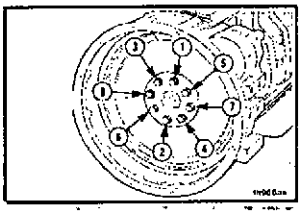
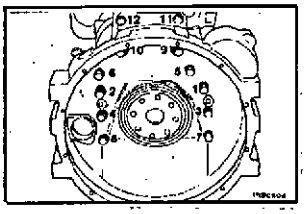
Vibration Damper Thickness

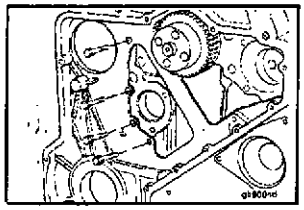
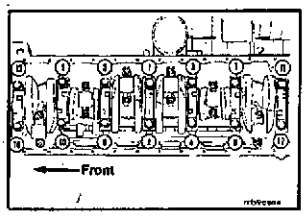
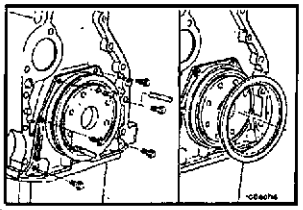
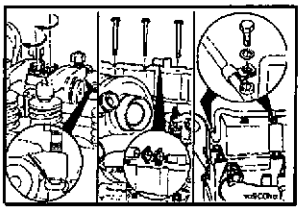
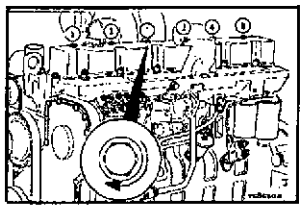
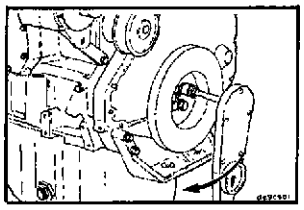
Measure the thickness at four locations 90 degrees apart approximately 3.18 mm [0.125 in] from the outside diameter. The difference between any two of the four measurements **must not** exceed 0.25 mm [0.010 in].



Base Engine Torque Values

Camshaft Thrust Plate Capscrew	24 N•m	18 ft-lb

Component or Assembly (Procedure)	Ref.No./Steps	Metric	U.S.	
Connecting Rod Nuts	Step 1	40 N•m	30 ft-lb	
	2	80 N•m	60 ft-lb	
	3	120 N•m	88 ft-lb	
Cylinder Head Mounting Capscrews	Step 1	70 N•m (All Capscrews)	52 ft-lb	
	2	145 N•m (Long Only)	105 ft-lb	
	3	Rotate 90 Degrees (All Capscrews)		
Exhaust Manifold Capscrews With Lock Tabs		43 N•m	32 ft-lb	
Front Engine Support Bracket Mounting Capscrews		112 N•m	83 ft-lb	
• Without Support		60 N•m	44 ft-lb	
Front Gear Cover Capscrews		24 N•m	18 ft-lb	
Flywheel Mounting Capscrews		140 N•m	101 ft-lb	
Flywheel Housing Mounting Capscrews		77 N•m	57 ft-lb	

	Component or Assembly (Procedure)	Ref.No./Steps	Metric	U.S.
	**Gear Housing Mounting Capscrews**			
	M8		24 N•m	18 ft-lb
	M12		60 N•m	44 ft-lb
	**Main Bearing Cap Capscrews**	Step 1	50 N•m	37 ft-lb
		2	119 N•m	88 ft-lb
		3	176 N•m	129 ft-lb
	**Rear Seal Cover Capscrews**		9 N•m	80 in-lb
	**Rocker Support Capscrews**		55 N•m	41 ft-lb
	**Valve Cover Capscrews**		24 N•m	18 ft-lb
	**Vibration Damper**		200 N•m	148 ft-lb
	Pulley to Vibration Damper		77 N•m	57 ft-lb

Drive Belt Tension

SAE Belt Size	Belt Tension Gauge Part No.		Belt Tension New		Belt Tension Range Used*	
	Click-type	Burroughs	N	lbf	N	lbf
0.380 in.	3822524		620	140	270 to 490	60-110
0.440 in.	3822524		620	140	270 to 490	60-110
1/2 in.	3822524	ST-1138	620	140	270 to 490	60-110
11/16 in.	3822524	ST-1138	620	140	270 to 490	60-110
3/4 in.	3822524	ST-1138	620	140	270 to 490	60-110
7/8 in.	3822524	ST-1138	620	140	270 to 490	60-110
4 rib	3822524	ST-1138	620	140	270 to 490	60-110
5 rib	3822524	ST-1138	670	150	270 to 530	60-120
6 rib	3822525	ST-1293	710	160	290 to 580	65-130
8 rib	3822525	ST-1293	890	200	360 to 710	80-160
10 rib	3822525	3823138	1110	250	440 to 890	100-200
12 rib	3822525	3823138	1330	300	530 to 1070	120-240

* A belt is considered used if it has been in service for ten minutes or longer.
* If used belt tension is less than the minimum value, tighten the belt to the maximum used belt value.

FRACTION, DECIMAL, MILLIMETER CONVERSIONS

8 THS.	16 THS.	32 NDS.	64 THS.	INCHES	MM	8 THS.	16 THS.	32 NDS.	64 THS.	INCHES	MM
			1	0.0156	0.397				33	0.5156	13.097
		1		0.0313	0.794			17		0.5313	13.494
			3	0.0469	1.191				35	0.5469	13.891
	1			0.0625	1.588		9			0.5625	14.288
			5	0.0781	1.984				37	0.5781	14.684
		3		0.0938	2.381			19		0.5938	15.081
			7	0.1094	2.778				39	0.6094	15.478
1				0.1250	3.175	5				0.6250	15.875
			9	0.1406	3.572				41	0.6406	16.272
		5		0.1563	3.969			21		0.6563	16.669
			11	0.1719	4.366				43	0.6719	17.066
	3			0.1875	4.763		11			0.6875	17.463
			13	0.2031	5.159				45	0.7031	17.859
		7		0.2188	5.556			23		0.7188	18.256
			15	0.2344	5.953				47	0.7344	18.653
1/4				0.2500	6.350	3/4				0.7500	19.050
			17	0.2656	6.747				49	0.7656	19.447
		9		0.2813	7.144			25		0.7813	19.844
			19	0.2969	7.541				51	0.7969	20.241
	5			0.3125	7.938		13			0.8125	20.638
			21	0.3281	8.334				53	0.8281	21.034
		11		0.3438	8.731			27		0.8438	21.431
			23	0.3594	9.128				55	0.8594	21.828
3				0.3750	9.525	7				0.8750	22.225
			25	0.3906	9.922				57	0.8906	22.622
		13		0.4063	10.319			29		0.9063	23.019
			27	0.4219	10.716				59	0.9219	23.416
	7			0.4375	11.113		15			0.9375	23.813
			29	0.4531	11.509				61	0.9531	24.209
		15		0.4688	11.906			31		0.9688	24.606
			31	0.4844	12.303				63	0.9844	25.003
1/2				0.5000	12.700	1 IN.				1.0000	25.400

CONVERSION FACTOR: 1 INCH = 25.4MM

Weight and Measures - Conversion Factors

QUANTITY	U.S. CUSTOMARY		METRIC		FROM U.S. CUSTOMARY TO METRIC MULTIPLY BY	FROM METRIC TO U.S. CUSTOMARY MULTIPLY BY
	Unit Name	Abbr.	Unit Name	Abbr.		
Area	sq. inch	in^2	sq. millimeters	m^2	645.16	0.001550
			sq. centimeters	c^2	6.452	0.155
	sq. foot	ft^2	sq. meter	m^2	0.0929	10.764
Fuel Consumption	pounds per horsepower hour	lb/hp-hr	grams per kilowatt hour	g/kw-hr	608.277	0.001645
Fuel Performance	miles per gallon	mpg	kilometers per liter	km/l	0.4251	2.352
	gallons per mile	gpm	liters per kilometer	l/km	2.3527	0.4251
Force	pounds force	lbf	Newton	N	4.4482	0.224809
Length	inch	in	millimeters	mm	25.40	0.039370
	foot	ft	millimeters	mm	304.801	0.00328
Power	horsepower	hp	kilowatt	kw	0.746	1.341
Pressure	pounds force per sq. in	psi	kilopascal	kPa	6.8948	0.145037
	inches of mercury	in Hg	kilopascal	kPa	3.3769	0.29613
	inches of water	*in H2O*	*kilopascal*	kPa	0.2488	4.019299
	inches of mercury	in Hg	millimeters of mercury	mm Hg	25.40	0.039370
	inches of water	in H2O	millimeters of water	mm H2O	25.40	0.039370
	bars	bars	kilopascals	kPa	100.001	0.00999
	bars	bars	millimeters of murcury	mm Hg	750.06	0.001333
Temperature	fahrenheit	°F	centigrade	°C	(°F-32) ÷ 1.8	(1.8 x °C) + 32
Torque	pound force per foot	ft lb	Newton-meter	N•m	1.35582	0.737562
	pound force per inch	in lb	Newton-meter	N•m	0.113	8.850756
Velocity	miles/hour	mph	kilometers/hour	kph	1.6093	0.6214
Volume: liquid displacement	gallon (U.S.)	gal.	liter	l	3.7853	0.264179
	gallon (Imp*)	gal.	liter	l	4.546	0.219976
	cubic inch	in^3	liter	l	0.01639	61.02545
	cubic inch	in^3	cubic centimeter	cm^3	16.387	0.06102
Weight (mass)	pounds (avoir.)	lb	kilograms	kg	0.4536	2.204623
Work	British Thermal Unit	BTU	joules	j	1054.5	0.000948
	British Thermal Unit	BTU	kilowatt-hour	kw-hr	0.000293	3414
	horsepower hours	hp-hr	kilowatt-hour	kw-hr	0.746	1.341

Newton-Meter to Foot-Pound Conversion Chart

N•m	ft-lb	N•m	ft-lb	N•m	ft-lb
1	8.850756 in-lb	55	41	155	114
5	44 in-lb	60	44	160	118
6	53 in-lb	65	48	165	122
7	62 in-lb	70	52	170	125
8	71 in-lb	75	55	175	129
9	80 in-lb	80	59	180	133
10	89 in-lb	85	63	185	136
1	0.737562 ft-lb	90	66	190	140
12	9	95	70	195	144
14	10	100	74	200	148
15	11	105	77	205	151
16	12	110	81	210	155
18	13	115	85	215	159
20	15	120	89	220	162
25	18	125	92	225	165
30	22	130	96	230	170
35	26	135	100	235	173
40	30	140	103	240	177
45	33	145	107	245	180
50	37	150	111	250	184

NOTE: To convert from Newton-Meters to Kilogram-Meters divide Newton-Meters by 9.803.

Capscrew Markings and Torque Values

Caution: When replacing capscrews, always use a capscrew of the same measurement and strength as the capscrew being replaced. Using the wrong capscrews can result in engine damage.

Most of the capscrews used on the C Series engine are metric. Some components, such as the air compressor and fuel pump, are installed using U.S. Customary capscrews.

Metric capscrews and nuts are identified by the grade number stamped on the head of the capscrew or on the surface of the nuts. U.S. Customary capscrews are identified by radial lines stamped on the head of the capscrew.

The following examples indicate how capscrews are identified:

Metric - M8-1.25 X 25

M8	1.25	25
Major Thread Diameter in Millimetres	Distance Between Threads in Millimetres	Length in Millimetres

U.S. Customary [5/16 X 18 X 1-1/2]

5/16	18	1-1/2
Major Thread Diameter in Inches	Number Threads per Inch	Length in Inches

NOTES:

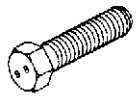
1. **Always** use the torque values listed in the following tables when specific torque values are **not** available.
2. Do **not** use the torque values in place of those specified in other sections of this manual.
3. The torque values in the table are based on the use of lubricated threads.
4. When the ft-lb value is less than 10, give consideration to converting the ft-lb value to in-lb to obtain a better torque with an in-lb torque wrench. Example: 6 ft-lb equals 72 in-lb.

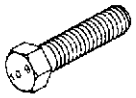
Capscrew Markings and Torque Values - Metric

Commercial Steel Class

8.8	10.9	12.9

Capscrew Head Markings


8.8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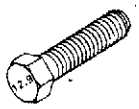

12.9

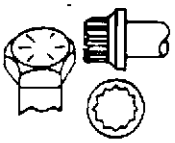
Body Size	Torque				Torque				Torque			
Diam.	Cast Iron		Aluminum		Cast Iron		Aluminum		Cast Iron		Aluminum	
mm	N•m	ft-lb	N•m	ft-lb	N•m	ft-lb	N•m	ft-lb	N•m	ft-lb	N•m	ft-lb
6	9	5	7	4	14	9	11	7	14	9	11	7
7	14	9	11	7	18	14	14	11	23	18	18	14
8	25	18	18	14	32	23	25	18	36	27	28	21
10	40	30	30	25	60	45	45	35	70	50	55	40
12	70	55	55	40	105	75	80	60	125	95	100	75
14	115	85	90	65	160	120	125	95	195	145	150	110
16	180	130	140	100	240	175	190	135	290	210	220	165
18	230	170	180	135	320	240	250	185	400	290	310	230

Capscrew Markings and Torque Values - U.S. Customary

SAE Grade Number 5 8

Capscrew Head Markings

These are all SAE Grade 5 (3) line



Capscrew Body Size	Capscrew Torque - Grade 5 Capscrew				Capscrew Torque - Grade 8 Capscrew			
	Cast Iron		Aluminum		Cast Iron		Aluminum	
	N•m	ft-lb	N•m	ft-lb	N•m	ft-lb	N•m	ft-lb
1/4 - 20	9	7	8	6	15	11	12	9
- 28	12	9	9	7	18	13	14	10
5/16 - 18	20	15	16	12	30	22	24	18
- 24	23	17	19	14	33	24	25	19
3/8 - 16	40	30	25	20	55	40	40	30
- 24	40	30	35	25	60	45	45	35
7/16 - 14	60	45	45	35	90	65	65	50
- 20	65	50	55	40	95	70	75	55
1/2 - 13	95	70	75	55	130	95	100	75
- 20	100	75	80	60	150	110	120	90
9/16 - 12	135	100	110	80	190	140	150	110
- 18	150	110	115	85	210	155	170	125
5/8 - 11	180	135	150	110	255	190	205	150
- 18	210	155	160	120	290	215	230	170
3/4 - 10	325	240	255	190	460	340	365	270
- 16	365	270	285	210	515	380	410	300
7/8 - 9	490	360	380	280	745	550	600	440
- 14	530	390	420	310	825	610	660	490
1 - 8	720	530	570	420	1100	820	890	660
- 14	800	590	650	480	1200	890	960	710

Pipe Plug Torque Values

Size		Torque		Torque	
Thread	Actual Thread O.D.	In Aluminum Components		In Cast Iron or Steel Components	
in	in	N•m	ft-lb	N•m	ft-lb
1/16	0.32	5	45 in-lb	15	10
1/8	0.41	15	10	20	15
1/4	0.54	20	15	25	20
3/8	0.68	25	20	35	25
1/2	0.85	35	25	55	40
3/4	1.05	45	35	75	55
1	1.32	60	45	95	70
1-1/4	1.66	75	55	115	85
1-1/2	1.90	85	65	135	100

Tap-Drill Chart - U.S. Customary & Metric

NOTE ON SELECTING TAP-DRILL SIZES: The tap drill sizes shown on this card give the theoretical tap drill size for approximately 60% and 75% of full thread depth. Generally, it is recommended that drill sizes be selected in the 60% range as these sizes will provide about 90% of the potential holdingpower. Drill sizes in the 75% range are recommended for shallow hole tapping (less than 1 1/2 times the hole diameter) in soft metals and mild steel.

Tap Size		Drill Size
60%	75%	
		48
		1.95mm
		5/64
	3-48	47
		2.00mm
	M2.5x.45	2.05mm
		46
3-48	3056	45
		2.10mm
M2.5x.45	M2.6x.45	2.15mm
3-56	4-36	44
		2.20mm
M2.6x.45		2.25mm
4-36	4-40	43
		2.30mm
		2.35mm
4-40	4-48	42
		3/32
	M3x.6	2.40mm
4-48		41
		2.45mm
		40
M3x.6	M3x.5	2.50mm
		39
	5-40	38
M3x.5		2.60mm
5-40	5-44	37
		2.70mm
5-44	6-32	36
		2.75mm
		7/64
		35
		2.80mm
		34
6-32	6-40	33
	M3.5x6	2.90mm
		32
M3.5x6		3.00mm
6-40		31
		3.10mm
		1/8
		3.20mm
	M4x.75	3.25mm
		30
	M4x.7	3.30mm
M4x.75		3.40mm
M4x.7	8-32	29
		3.50mm
	8-36	28
8-32		9/64
		3.60mm
8-36		27
		3.70mm
		26
	M4.5x.75	3.75mm
	10-24	25
		3.80mm
		24
M4.5x.75		3.90mm
		23
		5/32
10-24		22
	M5x1	4.00mm
	10-32	21
		20
	M5x.9	4.10mm
M5x1	M5x.8	4.20mm
10-32		19
M5x.9		4.25mm
M5x.8		4.30mm
		18
		11/64
		17

Tap Size		Drill Size
60%	75%	
		4.40mm
	12-24	16
		4.50mm
		15
	M5.5x.9	4.60mm
12-24	12-28	14
		13
		4.70mm
M5.5x.9		4.75mm
12-28		3/16
		12
		4.80mm
		11
		4.90mm
		10
		9
	M6x1	5.00mm
		8
		5.10mm
	1/4-20	7
		13/64
		6
M6x1		5.20mm
		5
	M6x.75	5.25mm
		5.30mm
1/4-20		4
M6x.75		5.40mm
	1/4-28	3
		5.50mm
		7/32
		5.60mm
1/4-28		2
		5.70mm
		5.75mm
		1
		5.80mm
		5.90mm
		A
		15/64
	M7x1	6.00mm
		B
		6.10mm
		C
M7x1		6.20mm
		D
	M7x.75	6.25mm
		6.30mm
		E
		1/4
M7x.75		6.40mm
		6.50mm
	5/16-18	F
		6.60mm
		G
		6.70mm
		17/64
	M8x1.25	6.75mm
5/16-18		H
		6.80mm
		6.90mm
	5.16-24	I
M8x1.25	M8x1	7.00mm
		J
		7.10mm
5/16-24		K
		9/32
M8x1		7.20mm
		7.25mm
		7.30mm
		L
		7.40mm
		M

Tap Size		Drill Size
60%	75%	
		7.50mm
		19/64
		7.60mm
		N
		7.70mm
	M9x1.25	7.75mm
		7.80mm
		7.90mm
	3/8-16	5/16
M9x1.25	M9x1	8.00mm
		O
		8.10mm
M9x1		8.20mm
		P
		8.25mm
		8.30mm
3/8-16	1/8-27NPT	21/64
		8.40mm
	3/8-24	Q
	M10x1.5	8.50mm
		8.60mm
		R
3/8-24		8.70mm
1/8-27NPT		11/32
	M10x1.25	8.75mm
M10x1.5		8.80mm
		S
		8.90mm
M10x1.25	M10x1	9.00mm
		T
		9.10mm
		23/64
		9.20mm
M10x1		9.30mm
	7/16-14	U
		9.40mm
	M11x1.5	9.50mm
		3/8
		V
		9.60mm
		9.70mm
		9.75mm
M11x1.5		9.80mm
7/16-14		W
		9.90mm
	7/16-20	25/64
		10.00mm
7/16-20		X
	M12x1.75	10.20mm
		Y
		13/32
		Z
M12x1.75	M12x1.5	10.50mm
	1/2-13	27/64
M12x1.5	M12x1.25	10.75mm
M12x1.25		11.00mm
1/2-13		7/16
1/4-18NPT		
		11.25mm
		11.50mm
		29/64
		11.75mm
		11.50mm
	1/2-20	29/64
	9/16-12	15/32
	M14x2	12.00m
		12.25mm
9/16-12		31/64
M14x2	M14x1.5	12.50mm
	9/16-18	1/2
M14x1.5	M14x1.25	12.75mm
M14x1.25		13.00mm
9/16-18		33/64

Tap Size		Drill Size
60%	75%	
		13.25mm
	5/8-11	17/32
	M15x1.5	13.50mm
M15x1.5		13.75mm
5/8-11		35/64
	M16x2	14.00mm
		14.25mm
	5/8-18	9/16
M16x2	M16x1.5	14.50mm
5/8-18		37/64
		14.75mm
M16x1.5		15.00mm
		19.32
		15.25mm
		39/64
	M17x1.5	15.50mm
M17x1.5	M18x2.5	15.75mm
		5/8
M18x2.5	M18x2	16.00mm
M18x2		16.25mm
	3/4-10	41/64
	M18x1.5	16.50mm
3/4-10	M19x2.5	21/32
M18x1.5		16.75mm
M19x2.5		17.00mm
		43/64
		17.25mm
3/4-16	3/4-16	11/16
	M20x2.5	17.50mm
		17.75mm
		45/64
M20x2.5	M20x2	18.00mm
M20x2		18.25mm
		23/32
	M20x1.5	18.50mm
		47/64
M20x1.5		18.75mm
		19.00mm
		3/4
		19.25mm
	7/8-9	49/64
	M22x2.5	19.50mm
7/8-9		25/32
		19.75mm
M22x2.5	M22x2	20.00mm
	7/8-14	51/64
M22x2		20.25mm
	M22x1.5	20.50mm
7/8-14		13/16
		20.75mm
M22x1.5	M24x3	21.00mm
		53/64
		21/25mm
		27/32
M24x3		21.50mm
		21.75mm
		55/64
	M24x2	22.00mm
	1"-8	7/8
M24x2		22.25mm
	M24x1.5	22.50mm
1"-8		57/64
M24x1.5		22.75mm
	M25x2	23.00mm
	1"-12	29/32
M25x2		23.25mm
1"x12	1"-14	59/64
	M25x1.5	23.50mm
M20x1.5		23.75mm
1"-14		15/16

Section L - Service Literature

Section Contents

Additional Service Literature

The following publications can be purchased by filling in and mailing the Service Literature Order Form:

Bulletin No.	Title Of Publication
3810261	C Series Troubleshooting and Repair Manual (Pre-1991 Engines)
3666003	C Series Troubleshooting and Repair Manual
3810275	C Series Engine Shop Manual (Pre-1991 Engines)
3666008	C Series Engine Shop Manual
3666038	C Series Alternative Repair Manual
3810312	C Series Specifications Manual (Pre-1991 Engines)
3666021	C Series Specification Manual
3810354	C Series Operation & Maintenance Manual - Generator Set
3810428	C Series Operation & Maintenance Manual - Power Unit
3810327	C Series Standard Repair Times Manual
	PARTS CATALOGS
3884358	C8.3 - Automotive
3884251	6CT/CTA-8.3 - Automotive
3884303	6CTA-8.3 Charge Air Cooled - Automotive
3884236	6C/CT/CTA-8.3 - Construction
3884253	6CT/CTA-8.3 - Generator Drive
3884311	6C-8.3 - Power Unit
3884312	6CT-8.3 - Power Unit
3884313	6CTA-8.3 - Power Unit
3884333	Marine (6CTA8.3)
3884360	Marine (6CT8.3)

Service Literature Ordering Location

Region	Ordering Location
United States and Canada	Cummins Distributors or Contact 1-800-DIESELS (1-800-343-7357)
U.K., Europe, Mid-East, Africa, and Eastern European Countries	Cummins Engine Co., Ltd. Royal Oak Way South Daventry Northants, NN11 5NU, England
South and Central America (excluding Brazil and Mexico)	Cummins Americas, Inc. 16085 N.W. 52nd Avenue Hialeah, FL 33104
Brazil and Mexico	Cummins Engine Co., Inc. International Parts Order Dept., MC 40931 Box 3005 Columbus, IN 47202-3005
Far East (excluding Australia and New Zealand)	Cummins Diesel Sales Corp. Literature Center 8 Tanjong Penjuru Jurong Industrial Estate Singapore
Australia and New Zealand	Cummins Diesel Australia Maroondah Highway, P.O.B. 139 Ringwood 3134 Victoria, Australia

Obtain current price information from your local Cummins Distributor or (for U.S.A. and Canada) by calling Cummins Toll Free Number 1-800-DIESELS (1-800-343-7357).

NOTES

Section C - Component Manufacturers

Section Contents

Component Manufacturers' Addresses

NOTE: The following list contains addresses and telephone numbers of suppliers of accessories used on Cummins engines. Suppliers may be contacted directly for any specifications **not** covered in this manual.

Air Compressors

Bendix Heavy Vehicles Systems
Div. of Allied Automotive
901 Cleveland Street
Elyria, OH 44036
Telephone: (216) 329-9000

Midland-Grau
Heavy Duty Systems
Heavy Duty Group Headquarters
10930 N. Pomona Avenue
Kansas City, MO 64153
Telephone: (816) 891-2470

Air Cylinders

Bendix Ltd.
Douglas Road
Kingswood
Bristol
England
Telephone: 0272-671881

Catching Engineering
2101 Roberts Drive
Broadview, IL 60153
Telephone: (312) 344-2334

Air Heaters

Fleetguard, Inc.
P.O. Box 6001
Cookeville, TN 38502
Telephone: (615) 526-9551

Kim Hotstart Co.
West 917 Broadway
Spokane, WA 99210
Telephone: (509) 534-6171

Air Starting Motors

Ingersoll Rand
Chorley New Road
Horwich
Bolton
Lancashire
England
BL6 6JN
Telephone: 0204-65544

Ingersoll-Rand Engine
Starting Systems
888 Industrial Drive
Elmhurst, IL 60126
Telephone: (312) 530-3800

StartMaster
Air Starting Systems
A Division of Sycon Corporation
P. O. Box 491
Marion, OH 43302
Telephone: (614) 382-5771

Alternators

Robert Bosch Ltd.
P.O. Box 98
Broadwater Park
North Orbital Road
Denham
Uxbridge
Middlesex UD9 5HG
England
Telephone: 0895-833633

Butec Electrics
Cleveland Road
Leyland
PR5 1XB
England
Telephone: 0744-21663

C.A.V. Electrical Equipment
P.O. Box 36
Warple Way
London
W3 7SS
England
Telephone: 01-743-3111

A.C. Delco Components Group
Civic Offices
Central Milton Keynes
MK9 3EL
England
Telephone: 0908-66001

C. E. Niehoff
2021 Lee Street
Evanston, IL 60202
Telephone: (708) 866-6030

Delco-Remy
P.O. Box 2439
Anderson, IN 46018
Telephone: (317) 646-7838

Leece-Neville Corp.
1374 E. 51st St.
Cleveland, OH 44013
Telephone: (216) 431-0740

Auxiliary Brakes

The Jacobs Manufacturing Company
Vehicle Equipment Division
22 East Dudley Town Road
Bloomfield, CT 06002
Telephone: (203) 243-1441

Belts

Dayco Rubber U.K.
Sheffield Street
Stockport
Cheshire
SK4 1RV
England
Telephone: 061-432-5163

T.B.A. Ind. Products
P.O. Box 77
Wigan
Lancashire
WN2 4XQ
England
Telephone: 0942-59221

Dayco Corp.
Belt Technical Center
P.O. Box 3258
Springfield, MO 65804
Telephone: (417) 881-7440

Gates Rubber Company
5610 Crawfordsville Road
Suite 2002
Speedway, IN 46224
Telephone: (317) 248-0386

Goodyear Tire and
Rubber Company
49 South Franklin Road
Indianapolis, IN 46219
Telephone: (317) 898-4170

Catalyst

Donaldson Company, Inc.
1400 West 94th Street
P.O. Box 1299
Minneapolis, MN 55440
Telephone: (612) 887-3131

Nelson Industries, Inc.
Exhaust and Filtration Systems
Highway 51 West, P.O. Box 428
Stoughton, WI 53589
Telephone: (608) 873-4373

Walker Manufacturing
3901 Willis Road
P.O. Box 157
Grass Lake, MI 49240
Telephone: (517) 522-5500

Clutches

Twin Disc International S.A.
Chaussee de Namur
Nivelles
Belguim
Telephone: 067-224941

Twin Disc Clutch Co.
Racine, WI 53403
Telephone: (414) 634-1981

Coolant Heaters

Fleetguard, Inc.
P.O. Box 6001
Cookeville, TN 38502
Telephone: (615) 526-9551

Drive Plates

Detroit Diesel Allison
Division of General Motors
Corporation
P.O. Box 894
Indianapolis, IN 46206
Telephone: (317) 244-1511

Electric Starting Motors

Butec Electrics
Cleveland Road
Leyland
PR5 1XB
England
Telephone: 0744-21663

C.A.V. Electrical Equipment
P.O. Box 36
Warple Way
London
W3 7SS
England
Telephone: 01-743-3111

A.C. Delco Components Group
Civic Offices
Central Milton Keynes
MK9 3EL
England
Telephone: 0908-66001

Delco-Remy
P.O. Box 2439
Anderson, IN 46018
Telephone: (317) 646-7838

Leece-Neville Corp.
1374 E. 51st Street
Cleveland, OH 44013
Telephone: (216) 431-0740

Nippondenso Sales, Inc.
24777 Denso Drive
P.O. Box 5133
Southfield, MI 48086-5133
Telephone: (313) 350-7500

Nippondenso of Los Angeles, Inc.
3900 Via Oro Avenue
Long Beach, CA 90810
Telephone: (310) 834-6352

Engine Protection Controls

Teddington Industrial Equipment
Windmill Road
Sunburn on Thames
Middlesex
TW16 7HF
England
Telephone: 09327-85500

The Nason Company
10388 Enterprise Drive
Davisburg, MI 48019
Telephone: (313) 625-5381

Fan Clutches

Holset Engineering Co. Ltd.
P.O. Box 9
Turnbridge
Huddersfield
England
Telephone: 0484-22244

Horton Industries, Inc.
P.O. Box 9455
Minneapolis, MN 55440
Telephone: (612) 378-6410

Rockford Division
Borg-Warner Corporation
1200 Windsor Road
P.O. Box 7007
Rockford, IL 61125-7007
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England
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Telephone: (517) 782-9421

Engineering Cooling Systems
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Telephone: (317) 335-2014

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Filters

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Cavalry Hill Industrial Park
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Northampton NN7 4TD
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Telephone: 0327-41313

Fleetguard, Inc.
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Telephone: (615) 526-9551

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Telephone: (317) 244-1511

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Romulus, MI 48174
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Telephone: 021-359-4876

Kabi Electrical and Plastics
Cranborne Road
Potters Bar
Herts
EN6 3JP
England
Telephone: 0707-53444

Datcon Instrument Co.
P.O. Box 128
East Petersburg, PA 17520
Telephone: (717) 569-5713

Rochester Gauge of Texas
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Dallas, TX 75229
Telephone: (214) 241-2161

Governors

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Slough
Bucks
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England
Telephone: 0753-26835

Woodward Governor Co.
1000 E. Drake Road
Fort Collins, CO 80522
Telephone: (303) 482-5811

Barber Colman Co.
1300 Rock Street
Rockford, IL 61101
Telephone: (815) 877-0241

United Technologies
Diesel Systems
1000 Jorie Blvd.
Oak Brook, IL 60521
Telephone: (312) 325-2020

Hydraulic and Power Steering Pumps

Hobourn Eaton Ltd.
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Rochester
Kent
ME2 2BD
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Honeywell Control Systems Ltd.
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Charles Square
Bracknell
Berks RG12 1EB
Telephone: 0344-424555

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Cheney Manor Trading Estate
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Wiltshire
SN2 2PZ
England
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Sperry Vickers
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Troy, MI 48084
Telephone: (313) 280-3000

Z.F.
P.O. Box 1340
Grafvonsoden Strasse
5-9 D7070
Schwaebisch Gmuend
West Germany
Telephone: 7070-7171-31510

Oil Heaters

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P.O. Box 6001
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Telephone: (615) 526-9551

Kim Hotstart Co.
West 917 Broadway
Spokane, WA 99210
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Twin Disc International S.A.
Chaussee de Namur
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Belgium
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Twin Disc Clutch Co.
Racine, WI 53403
Telephone: (414) 634-1981

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Borg-Warner Corporation
1200 Windsor Road
P.O. Box 7007
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