

25195



Governing Fundamentals

WOODWARD GOVERNOR COMPANY

Manual 25195

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Chapter 1 Introduction

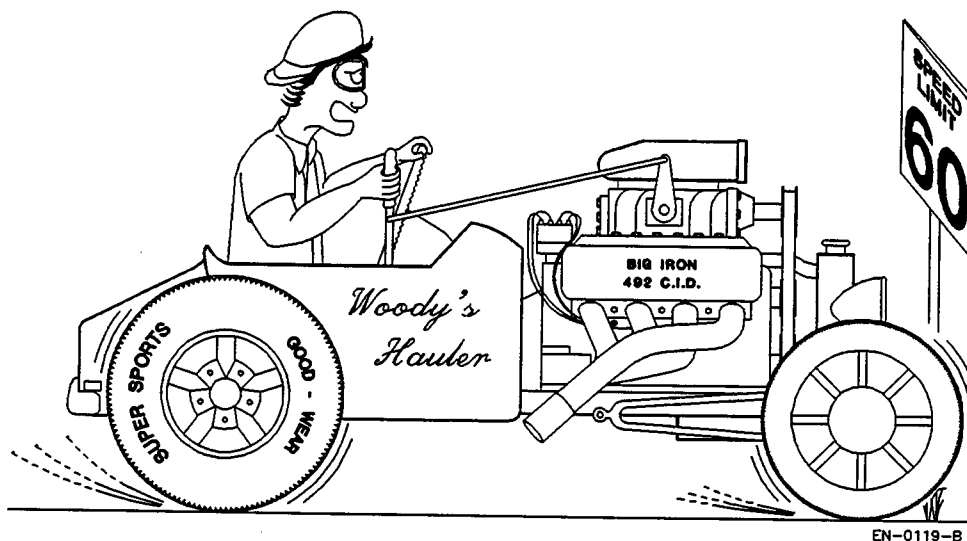
WHY DO WE NEED GOVERNORS?

An uncontrolled horse, running in a pasture, can be a pretty sight. However, if work is to be accomplished the horse must be harnessed and controlled.

All power sources must be controlled if the power is to be converted to useful work. The essential device which controls the speed or power output of an engine or turbine is called a governor.

WHAT IS A GOVERNOR?

In most cases a governor is a device which senses the speed of an engine or turbine and controls the fuel (or steam) to the engine or turbine to maintain the speed at a desired level to meet changes in load or horse power output required. In some cases the device controls load to control the speed and in some cases the device can control other factors determining the speed of the engine. **In all cases a governor ends up controlling the energy source to an engine to control its power so it can be used for a specific purpose.**



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Figure 1-1. The Driver Is the Governor

For a basic understanding of a governor, let's look at the above example.

The driver is the governor for the car. He must make adjustments to the fuel to maintain the speed he wants to run. This governor performs as follows:

- The driver sees the speed sign and wants to go 60 miles per hour. This is the "desired speed."
- The Driver looks at the speedometer (this is the actual speed) and compares the desired speed to the actual speed. If equal he holds the throttle steady. If not equal, he increases or decreases throttle position to make the desired speed and the actual speed the same, or balanced. See Figure 1-2.

- As the car starts up hill the load increases.

Actual speed decreases. The driver notes that actual speed is less than desired speed and moves the throttle to increase speed back to the desired speed at the increased load.
- As the car goes down hill the load decreases.

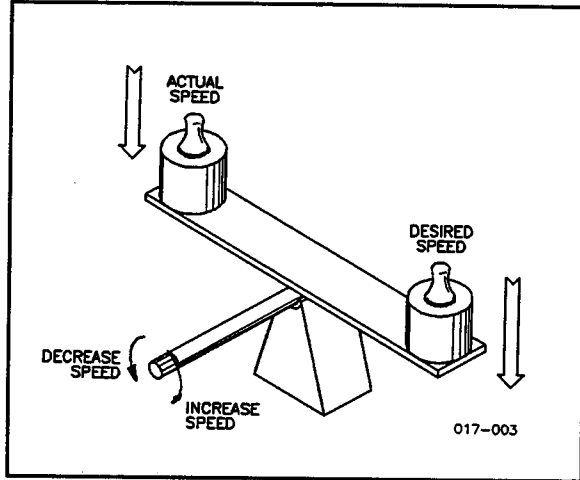


Figure 1-2. Speed Balance

Actual speed increases. The driver notes that actual speed is greater than desired speed and decrease the throttle to return to the desired speed with the decreased load.

CLOSING THE LOOP

The governor functions the same as the driver to automatically change the fuel flow to maintain the desired speed or load. This could be compared to a cruise control on a car.

GOVERNOR COMPONENTS

All governors have five fundamental components:

1. A way to set the desired speed. (The driver sets the desired speed mentally.)
2. A way to sense actual speed. (The driver refers to the speedometer).
3. A way to compare the actual speed to the desired speed. (The driver compares the two items mentally.)
4. A way for the governor to change the fuel to the engine or turbine (moving the rack or fuel valve). (The driver moves the throttle.)
5. A way to stabilize the engine after a fuel change has been made.

In the illustration when the car went up a hill the driver saw the actual speed decrease. He moved the throttle to increase the fuel. He will need to increase the fuel an amount to cause the speed to increase. This will give the engine enough power to make the car return to the desired speed with a bigger load. As he sees the actual speed is about to reach the desired speed he will need to reduce the extra fuel to the exact amount needed to match (balance) the desired

speed with the actual speed. The governor does the same thing, using feedback. This feedback closes the loop in the control system which controls the amount of fuel change, based on the rate the desired speed is being reached. This prevents large overshoots or undershoots of speed which is known as hunting and stabilizes the engine. The opposite is true when the car goes down the hill or load is reduced.

1. Speed Setting

Setting the "desired speed" of a governor is necessary to efficiently control engines and turbines. Modern governors have advanced systems of speed setting which can compensate for a variety of conditions when determining the desired speed. Hydro-mechanical governors use what is known as a speeder spring. The more force applied to this spring, the higher the desired speed setting is. Electronic controls use an electronic force (voltage and current) to set speed. The more the force is increased the more the output to the fuel increases.

Speed setting and the effect on sharing loads between engines will be discussed in other chapters.

2. Sensing Speed

The governor must receive a force that is proportional to the speed of a prime mover. In hydro-mechanical governors it is done by the centrifugal force of flyweights being rotated from a drive system that is connected to the engine or turbine and is directly related to the speed of the engine. In electronic controls this force comes from sensing of the frequency of a magnetic pickup, alternator, or generator which is directly related to the speed of the engine. The frequency is then changed to an electronic force that the control can use. In both cases the faster the engine runs, the stronger the speed sensing force becomes. Sensing speed will be discussed in more detail later, but for now it is important to know that a governor or electronic control must sense the speed of the engine and convert that speed sense into a force that it can use to tell how fast the engine is running.

3. Comparing the "actual speed" to the "desired speed"

The force of the "desired speed setting" and the force of the "actual speed" are compared or "summed" together. "Desired speed setting" is a force in one direction and "actual speed" is a force in the opposite direction. When these opposing forces are the same value their sum will be zero and at that point the governor is controlling actual speed at the point of the desired speed setting. If the "desired speed setting" force is stronger than the "actual speed" force, the governor will increase fuel. If the "actual speed" force is stronger than the "desired speed setting" force, the governor will decrease fuel. As fuel is increased or decreased these forces will change until they balance or "sum to zero." In hydro-mechanical governors, these forces are summed at the "thrust bearing." In electronic controls, these forces are summed at what is known as a "summing point." It should be noted that other forces can be applied along with these forces to allow the governor to be stabilized and perform other functions. These will be discussed in future chapters. For now it is important to know that all forces applied to the "thrust bearing" or "summing point" algebraically sum up to equal zero for the governor to control fuel at a steady state.

4. Ways for the governor to change fuel to the engine

The hydraulic/mechanical governor or actuator normally has a rotational or linear output shaft that is connected to the fuel system of the engine. When the governor needs to make a fuel correction to maintain speed (or load) the output shaft will move in the proper direction to correct the final fuel setting. For electronic controls, an electrical signal is sent to an actuator which converts this electrical signal to a mechanical force to move the fuel setting in the same way the hydraulic/mechanical governors do. Different types of governors and actuators have different amounts of work output and the proper control required needs to be selected for the application. These will be discussed in more detail in other chapters. For now it is important to know that the governor has a way to change the fuel setting of the engine.

5. Ways to stabilize the engine or turbine

Stabilization is accomplished through a variety of ways, but all of them use a "feed back" system to apply a force to the "thrust bearing" or "summing point." This "feed back" is normally in the form of either droop or compensation, or in a combination of both. Droop or compensation is usually related to the amount the output shaft is told to move. These different types of stabilization methods will be discussed in later chapters. For now it is important to know that there needs to be a way to stabilize the governor to make it control the engine at steady state.

SPEED, POWER OUTPUT, AND LOAD

Engine speed, engine power output, load and fuel position are often used interchangeably when discussing governor functions. With a given fuel position engine speed is determined by engine load. In many cases a governor senses engine speed and changes the fuel position to change the power output to match the load. In other cases, the "speed setting" is changed to set a desired load at a fixed speed. The governor controls fuel position to maintain a desired speed or load.

Droop is such an important function in governor control that an entire chapter in this publication deals only with droop, its various functions, and uses.

Development of the Modern Governor System

As quickly as steam engines, windmills, and water wheels were developed, designs were started on methods to automatically control the power and/or speed.

Centrifugal force was an obvious result of speed and was quickly developed in a fly ball governor. This governor was rotated by the engine being controlled. The governor produced a decreasing steam or water schedule as speed increased. This was adequate if the load was constant and the operating speed not critical. In general it was satisfactory for water wheels, or the early applications of steam power.

The fly ball governor has two major drawbacks:

- It will only increase the valve position, and the power of the engine, when speed decreases and the fly balls drop closer to the central shaft. This is droop and provides a stable engine at the expense of constant speed control.
- Friction in the system demands that there is a time delay before speed changes enough to cause the flyballs to move locations. This is known as "deadband." It allows the engine speed to change up and down until the force of the speed change is enough to overcome the friction in the system and cause the fly balls and linkage to move.
- As systems became larger, the flyballs did not have enough force to control the large fuel systems.

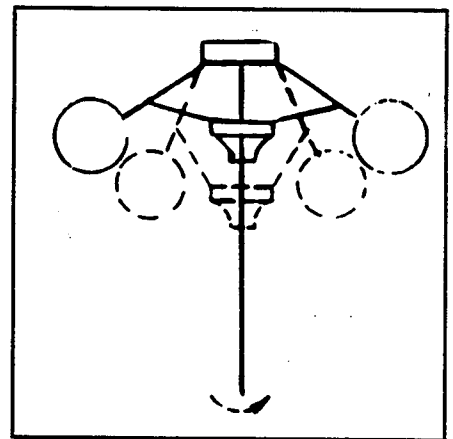


Figure 1-2. Flyball Governor

EARLY WOODWARD CONTROL DEVICES

Woodward Governor Company founder Amos Woodward attacked the problems of early governors more than 120 years ago when he developed and patented the first control device which provided a constant speed with mechanical compensation which alleviated the droop and increased the speed of the ballhead to help overcome some of the deadband related to friction.

This early Woodward governor responded approximately 20-times faster than governors being used at that time.

These early controls were used on water wheels and steam engines to control speed for line shafts used to power machine tools. The compensated mechanical system was superior for its day.

As engines developed (especially internal combustion gas and diesel engines) new control devices were designed to provide minimum deadband, quick response to minimize off-speed on load changes, and precise speed and load control that would allow load sharing and precise control for power generation.

The need for precise speed control in connection with the generation of electrical power was probably the largest incentive for precise governor control. Early direct current (DC) systems would change the brightness of lighting and reduce the life of lighting filaments with differences in generator speed. The need to hold precise speed increased with alternating current (AC) generation. As more and more electrically driven equipment came into use the need to hold precise frequency from no load to full load became necessary.

Utility busses presented the need to parallel many generators to an existing bus. This required precise speed control and provided the incentive to build the first hydraulic/mechanical governor capable of holding speed within 1/4 of 1% of the desired speed over the entire power output range of the engine or turbine.

In attempting to build precise governors with mechanical linkage it soon became obvious that there was too much friction involved and too large a deadband. Governor makers also ran out of governor work force output as larger fuel valves became harder to move quickly and accurately.

Hydraulic amplification was selected by Woodward in the early 1900's as the logical solution to the challenges being presented.

Pressure changes in a hydraulic system are instantaneous and flows of hydraulic fluid can be minutely controlled through valves. In addition to the fast response gained through having work amplified in the hydraulic system most of the friction which caused excessive deadband in mechanical controls was overcome.

For much of this century the advancement of precise governing was connected with using and controlling hydraulic pressures. In recent years electronics have proved superior to hydraulic/mechanical devices in anticipating the needs of engines and in being versatile in the types of control that can be achieved. Electronics not only control engine speed and power output but now also can control electrical loads, exhaust emissions, and many other parameters. Electronics have also been extremely important to engine makers as the controls can provide changeable dynamics for changing load condition, fuel limiting and isochronous load sharing along with complete power management and system sequencing..

This manual will cover the basic hydraulic/mechanical governors and actuators first, and then the basic electronic controls. The hydraulic/mechanical governor will be compared to the electronic control to show what is being done in the hydraulic/mechanical governor is being done similarly in electronic controls. This manual will contain information on basic adjustments, installation, and troubleshooting.

This publication is not meant to replace specific manuals for specific governors, but to aid the reader in understanding governing. In all cases, refer to the specific manual for your governor for specific details.

Chapter 2

The Basic Hydraulic/Mechanical Governor Components

The five fundamental components of a governor were mentioned in Chapter 1. Now let's take a closer look at how and why the Basic Hydraulic/Mechanical Governor works.

The key parts of a Woodward ballhead hydraulic/mechanical governor are:

- | | |
|-----------------------|---------------------------|
| ● Speeder Spring | ● Oil Pumps |
| ● Thrust Bearing | ● Oil Pressure Regulation |
| ● Fly Weights | ● Servo (Power) Piston |
| ● Pilot Valve Plunger | ● Compensation. |
| ● Pilot Valve Bushing | ● Drive Shaft |

THE SPEEDER SPRING

The speeder spring is the part that sets the "desired speed" Applying more force down on the speeder spring will cause the governor to increase fuel. This initial force is usually set by the operator for the desired or "reference" speed. It can be set by a screw adjustment, a knob, a lever, an electric motor, air pressure, or solenoids, depending on the specific governor.

The design or shape of a speeder spring is critical to the proper operation of the ballhead.

The speeder spring is generally shaped in a conical design. This shape helps maintain a more rigid design so it won't buckle or flex to the side as force is applied. There are other shapes of speeder springs that offer a variable force over the length.

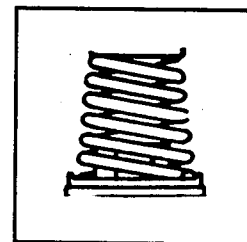


Figure 2-1. Speeder Spring

Some springs are designed to be close to a linear operation and some are designed to be non-linear depending on the specific governor. Most governors use the linear type speeder spring. The PG type governor uses a non-linear speeder spring.

THRUST BEARING

The thrust bearing is the part where the force of the speeder spring and the force of the flyweights sum together.

If the speeder spring force and the flyweight force are equal, there is no load on the thrust bearing.

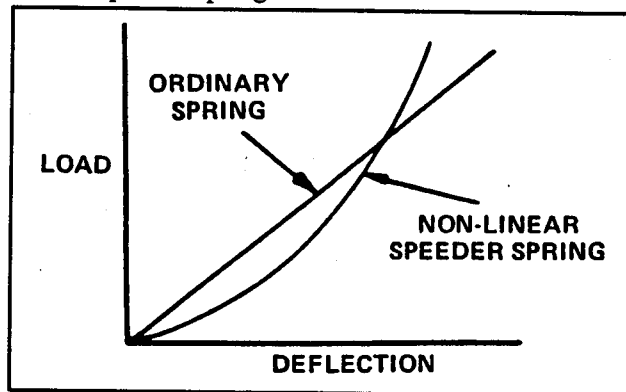


Figure 2-2. Speeder Spring Deflection

A thrust bearing has a race on the top and a race on the bottom with the bearing in between the races. Since the flyweights rotate and the speeder spring does not rotate, the thrust bearing is necessary. The pilot-valve plunger moves with the thrust bearing either directly or through a linkage.

The pilot-valve plunger does not rotate.

FLY WEIGHTS

There are two flyweights in most ballheads. The flyweights are rotated by a drive from the engine that is directly related to the speed of the engine.

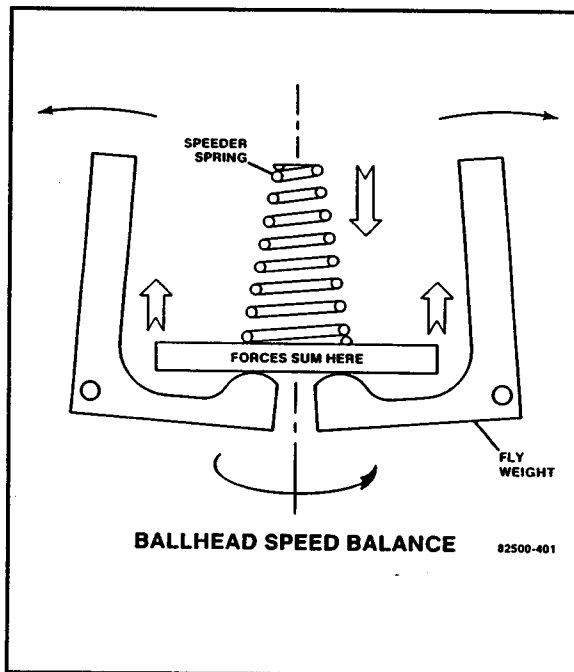


Figure 2-3. Hydraulic Governor Ballhead

In Figure 2-3, the flyweights are pivoted at the lower corners. As speed increases the flyweights move out (tip out) at the top due to increase of centrifugal force. This causes the "toes" of the flyweights to increase the force on the thrust bearing and raise the pilot valve. The opposite effect happens when speed decreases. "The flyweights move in (tip in) and reduce the force on the thrust bearing to lower the pilot valve. In Figure 2-4 the only time when the governor is run at "desired speed setting" is when the flyweights are straight up in the vertical position closing the port in the pilot-valve bushing. If the flyweights are tipped in, the engine is not running at the "desired speed setting" and the governor will increase fuel to increase speed until the flyweights and engine attain the "desired speed setting". If the flyweights are tipped out the engine is running faster than the "desired speed setting" and the governor will decrease fuel until the flyweights and engine return to the "desired speed setting."

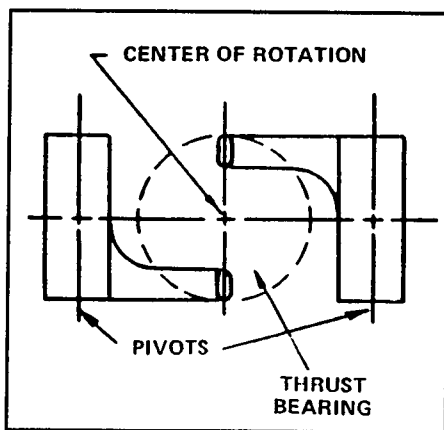


Figure 2-5. Flyweights to Minimize Friction

In the most efficient flyweight design, the toes of the flyweight are offset and contact the thrust bearing on a line at right angles to their plane of movement so

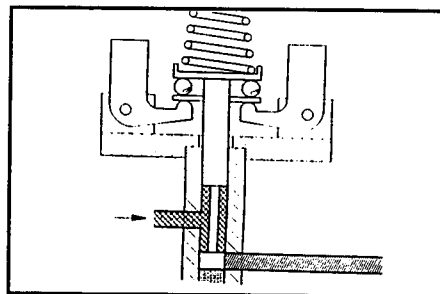


Figure 2-4. Flyweight action

that any movement is converted into a slight rotation of the thrust bearing with a minimum amount of sliding friction. There are other designs of flyweights.

Friction in modern governors is also reduced by the use of low friction bearings. The reduction of friction reduces the dead band between speed change and governor output change.

PILOT VALVE PLUNGER AND BUSHING

The pilot-valve plunger is positioned by the force on the thrust bearing. It moves up and down inside the rotating pilot-valve bushing (due to the flyweights sensing speed changes and tipping in or out). The pilot-valve bushing has high pressure oil coming from the oil pump into the bushing above the control land of the pilot-valve plunger.

The pilot-valve bushing has ports in it to allow the flow of oil to or from the power cylinder assembly. When the governor and engine are at the desired speed setting, the pilot-valve-plunger control land is centered over the port in the pilot-valve bushing. This stops oil from flowing to or from the power cylinder assembly.

If the flyweights tip in, due to a change in speed or load, the pilot-valve plunger will move down and let high-pressure oil into the power-cylinder assembly. This will increase fuel.

If the flyweights tip out, due to a change in speed or load, the pilot-valve plunger will move up to let oil drain from the power-cylinder assembly. This will decrease fuel.

Pilot-valve-bushing ports have different sizes and shapes for different types of governors to allow more or less oil flow, depending on the application.

The pilot-valve bushing is rotating and the pilot-valve plunger is not. This minimizes static friction (called sticktion) and allows the pilot-valve plunger to move with very slight speed changes.

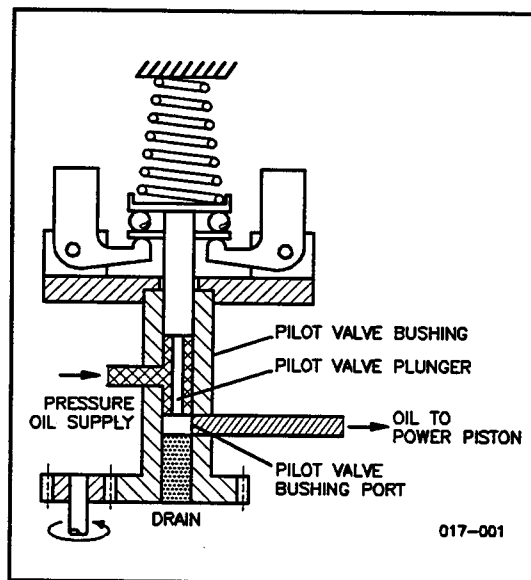


Figure 2-6. Pilot Valve Operation Shown "On Speed."

OIL PUMPS

Most hydraulic/mechanical governors and actuators use the governor drive to rotate a hydraulic pump which provides the pressure oil system controlled by the pilot valve. Woodward uses two different types of pumps. Most governors use the two or three gear positive displacement pump. The 3161 and TG governors and some actuators use an internal gear oil pump.

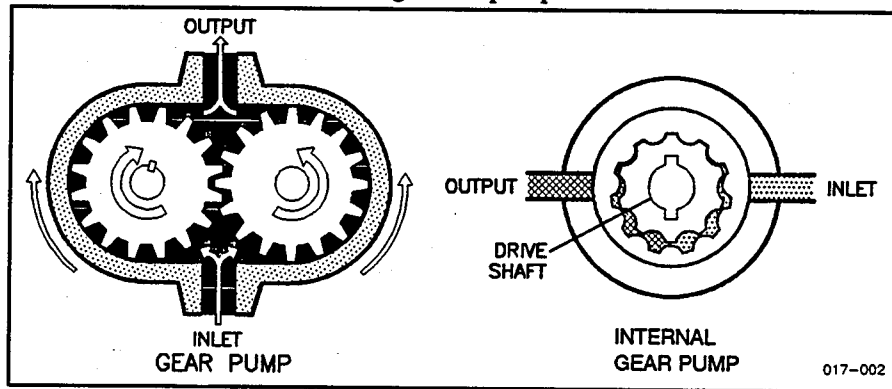


Figure 2-7. Oil Pumps

The constant displacement pump has one drive gear and one or two idler gears that are rotating in a gear pocket. As the gears turn, oil is drawn from the oil supply and carried in the space between the gear teeth and the walls of the gear pocket to the discharge side of the pump. The oil is forced from the space around the gear teeth as the drive and idler gears are rotated and becomes pressurized.

The hydraulic circuits connected to the pumps can be designed to allow either one direction of rotation or reversible rotation for use on diesel engines with drives that run in both directions. Check valves are used to provide pump rotation in either direction. Plugs allow pump rotation in only one direction. Internal gear pumps allow rotation in only one direction. The pump must be removed from the governor and rotated 180° to change direction of rotation for internal gear pumps.

Woodward identifies drive rotation as the drive seen looking down through the governor cover. If the drive coupling on the engine turns CW, then the governor is considered to be a CW governor.

The pumps are designed to provide more pressure and flow than needed within the governor. The extra flow of oil is returned to sump. Smaller governors use a relief valve. Most of the larger governors use an accumulator system which provides a spring compressed reservoir of pressure oil for use during transits which temporarily exceed the output of the pump. SG, PSG, and EGB-2 governors use relief valves. A number of hydraulic actuators do not have accumulators.

The relief valve shown in Figure 2-8 is typical of the valves used in SG, PSG, EGB-2 governors and many hydraulic actuators.

Internal operating oil pressures are specified for each governor. 100 to 500 psi are typical pressures. Different types of governors operate at different pressures. Check the specifications for your governor's pressure. The higher pressures are created to get more output power from the servo controlled by the governor. Higher pressures may require the addition of special heat exchangers to avoid damage to (break down of) the oil being used in the governor.

Accumulator function is shown in the accompanying figure. Pressurized oil on the discharge side of the pump first fills the various oil passages and then forces the accumulator pistons up against the downward force of the

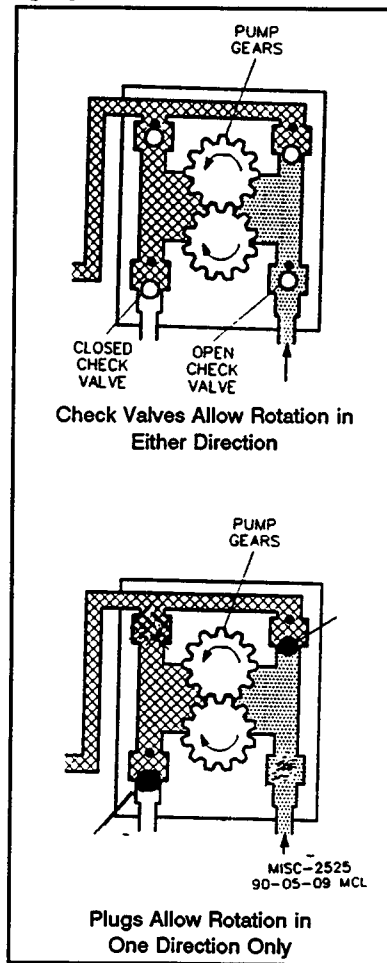


Figure 2-9. Pump Rotation

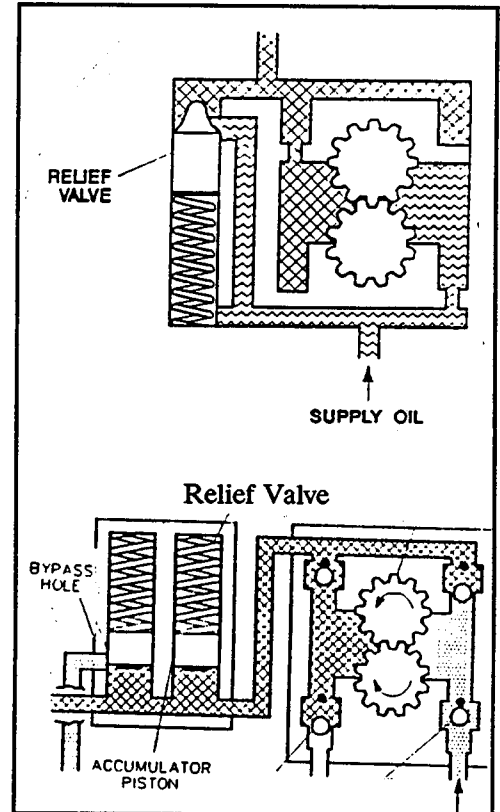


Figure 2-8. Accumulator and Governor Relief Valve

accumulator springs. When the pressure increases enough to move the piston up to uncover the bypass hole, the excess oil from the governor pump returns to sump. The accumulators thus not only provide a reservoir for pressure oil, but also act as a relief valve to limit maximum pressure in the hydraulic circuit. The accumulators shown are from the power case type of governor (PG and larger EGB governors.) UG and 3161 governors use different styles of accumulators, although the function is similar.

DIRECTION OF ROTATION

The arrangement of the four check valves on the suction and discharge sides of the oil pump permits the governor drive shaft to be rotated in either direction, without any changes being made in or to the governor. The direction of pump rotation does not affect the oil pressure system or governor operation.

Some governor models are built without check valves. In these units, two plugs replace the two closed check valves and the governor must always be rotated in one direction only. To change direction of rotation in these governors the location of the plugs must be changed by removing the base.

The internal gear pump rotates in one direction only. To change direction of rotation in an internal gear pump the pump is rotated 180°.

If the plugs or internal gear pump are set up for the wrong direction of pump rotation, the governor will not have any oil pressure and cannot control the engine. This can also cause damage to the governor.

Drive rotation is always shown looking down on the governor.

THE SERVO (POWER) PISTON

The governor pilot valve plunger controls the movement of the power piston. The power piston, acting through the connecting linkage, controls the engine fuel.

Two types of power pistons are used in governors:

1. A spring loaded system where oil pressure is used to increase the output position. When pressure oil under the power piston is directed to sump a return spring (either pushing directly on the piston or connected to linkage from the piston) causes the position to move toward minimum fuel.
2. A Differential Power/Servo piston uses pressure oil to move it in both directions.

Spring-Loaded Power/Servo Piston

The governor pilot valve plunger controls the movement of the power piston. The power piston, acting through the connecting linkage, controls the engine fuel.

The return spring continually pushes the power piston down in the "decrease fuel" direction. However, the power piston will not move down unless the pilot-valve plunger is raised above its centered position. Only when the pilot-valve plunger is above center can the oil trapped in the circuit between the plunger and power piston escape to sump. If the pilot valve plunger is lowered, pressure oil from the governor pump will be directed to the power piston and will push the piston up, against the force of the power spring, in the direction of increase fuel.

Note that the power piston will move only when the pilot-valve plunger is not centered, permitting the oil flow required. With the plunger centered, the power piston is, in effect, hydraulically locked.

The output of the power piston can be a push-pull motion or converted to a rotary motion. It is designed to move the fuel to the minimum position should the oil pressure fail.

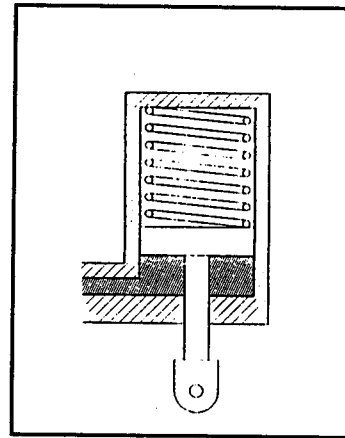


Figure 2-10. Spring Loaded Servo Piston

Differential Power/Servo Piston

The governor pilot-valve plunger controls the movement of the power piston. The power piston, acting through the connecting linkage, controls the engine fuel.

The power piston requires pressure oil to move in either the increase or decrease fuel direction. A differential type piston has more area on one side of the piston than on the other. Pressure oil is constantly directed to the side with the smaller area. This constant pressure pushes the piston in the decrease fuel direction. The piston can only move to decrease fuel when the pilot valve is raised above center, allowing oil to drain to sump.

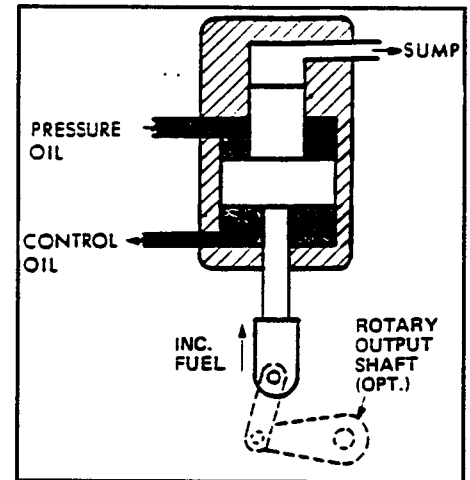


Figure 2-11. Differential Power Piston

If the pilot-valve plunger is below its centered position, control oil flows to the bottom side of the power piston with the larger area. (Pressure oil is always against the top side with the smaller area.) The pressures on both sides of the piston are about the same, the surface area is greater on the bottom side (control oil). This gives it a larger force and moves the piston in the increase fuel direction.

Note that the power piston can move only when the pilot-valve plunger is uncentered to permit the oil flow required. With the plunger centered, the power piston is hydraulically locked.

Two different hydraulic circuits are used for the oil passages between the pilot valve plunger control land and the power piston. The scheme used in a particular model depends upon the size of the power piston.

The output of the power piston can be a push-pull motion or a rotary motion. Oil stored in the governor accumulator is sufficient to move the power piston to minimum fuel in case of governor failure.

WOODWARD
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Chapter 3

Basic Operation of Hydraulic/Mechanical Governors

All hydraulic/mechanical governors need some form of feedback for stability. This is accomplished by the use of DROOP. The droop can be speed droop or temporary droop (Compensation).

Without some form of droop engine-speed regulation will always be unstable.

DROOP FEEDBACK

Droop governors have feedback linkage that connects to either the servo piston or to a lever (terminal lever) that is operated by the power piston.

The feedback is transmitted to the speeder spring, decreasing the force on the speeder spring (decreasing the speed setting) as the power piston moves to increase fuel. This reduces the actual speed setting in relation to the fuel setting (load) on the engine. The lever, as illustrated, is connected directly to the power piston. Some governors have a different setup, with an adjustable cam or adjustable linkage to change the amount of droop in the governor to be adjusted to exactly match the application of acceleration of the engine. In many cases the amount of droop can be adjusted from the outside of the governor, while the engine is running, if desired.

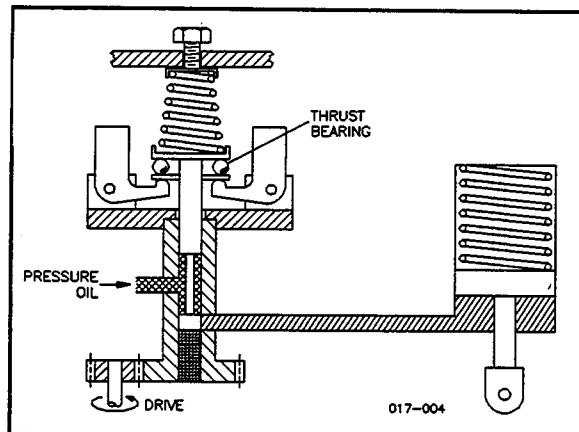


Figure 3-1. Basic Governor without Droop or Compensation

In the example of speed droop feedback, if a load was applied to the engine, the engine would slow down, the flyweights would tip in at the top, and the pilot valve would move down to open. Pressure oil would be ported under the power piston. The power piston would move up to increase fuel. The droop lever, connected to the power piston and speeder spring, would lift up on the speeder spring to reduce the speed setting. The reduction in speed setting will allow the pilot to close the port before the desired speed is reached. This will stabilize the governor by not allowing large overshoots in speed. The power piston will be up higher at the new fuel setting to handle the increased load. The speed setting will remain lower because the power piston being up and the speeder spring having less force on it. The engine will be carrying the new load at a lower speed or frequency. Figure 3-3 describes the basic definition of droop: **A DECREASE IN SPEED SETTING FOR AN INCREASE IN LOAD OR TERMINAL SHAFT POSITION.**

Droop helps prevent hunting and makes the engine run stable. It results in speed decreasing as load increases.

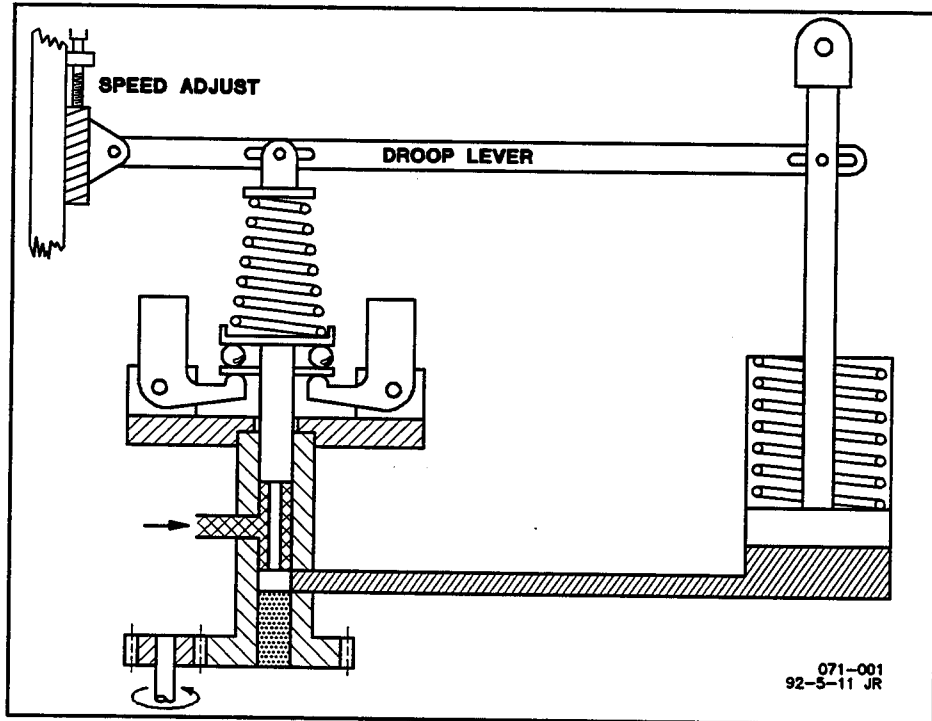


Figure 3-1. Droop Feedback

To maintain a given speed it will be necessary to increase the speed setting as load is applied to the engine. This must be done to offset the decrease of force on the speeder spring.

Droop has been defined as: a decrease in speed setting for an increase in load or terminal shaft position. See Chapter 4 for a detailed explanation of droop and the ways it is applied to governors and system applications.

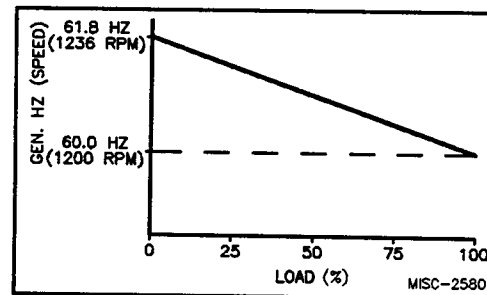


Figure 3-2. Example of 3% Droop

Droop Load Sharing

Droop will let engines operating in droop share load with other engines according to their individual speed setting. To increase load on an individual droop load sharing engine increase the speed setting or decrease the droop setting. This is discussed in more detail in Chapter 4.

Woodward makes two governors that only use droop for feedback and stability. They can only operate in droop. The SG (Simple Governor) primarily used on small and medium sized engines and the TG (Turbine Governor) primarily used on small and medium sized steam turbines.

The other governors use compensation (a temporary droop). This will allow the governors to operate at zero droop or what is called "isochronous." These governors also can be operated in droop with the adjustment for droop set for the proper feedback. 3% to 5% droop is recommended for most applications.

COMPENSATED GOVERNORS

Compensated governors are capable of operating at zero droop. This is called "isochronous." An isochronous governor will maintain a constant speed up to 100% load. When an increase of load is placed on an engine the actual speed will decrease temporarily. The governor will increase the fuel to bring the engine back to the original speed and carry the larger load. If a load is removed from an engine, the speed will increase temporarily. The governor will decrease the fuel to bring the engine back to the original speed and carry the smaller load. To be able to operate in the isochronous mode, compensated governors use what is known as "temporary droop."

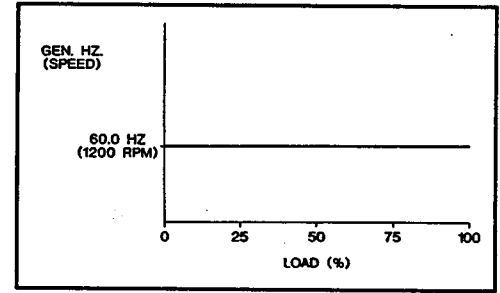


Figure 3-3. Isochronous Application

Compensated governors include PSG (Pressure Compensated Simple Governor), UG (Universal Governor), PG (Pressure compensated Governor), 3161 governors, and EGB (Electric Governor with Ballhead Backup).

There are two types of compensation presently being used in hydraulic/mechanical governors. Dashpot compensation which is used in the UG governors and Pressure Compensation.

Compensation forces in Woodward governors are transmitted directly to the pilot valve, not the speeder spring as is droop. However, the result of adding pressure in the speed correction direction works the same as changing the force of the speeder spring.

Dashpot Compensation

UG governors are unique with dashpot compensation rather than pressure compensation.

The flyweight position in a UG is transmitted to the pilot valve plunger through a floating lever. The other end of this floating lever is connected to the spring-centered receiving piston.

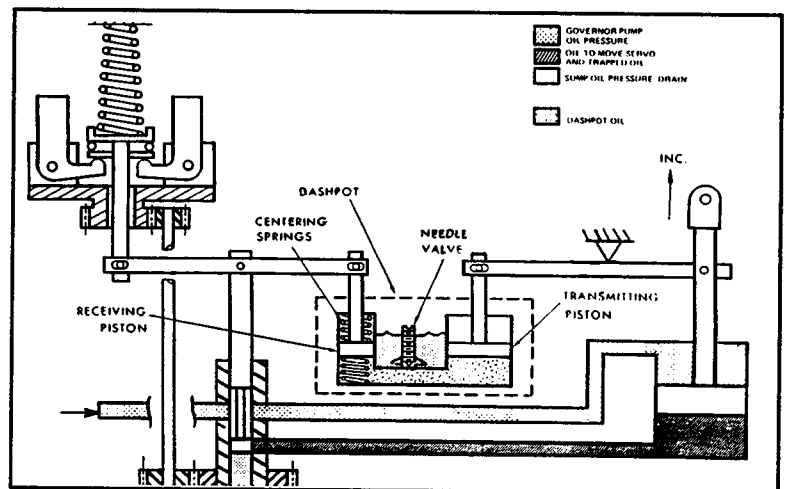


Figure 3-4. UG Governor Compensation

If a load is applied to the engine, the engine feels this load and slows down. The flyweights tip in at the top and the toes move down. This lowers the thrust bearing which in turn lowers the rod connected to the floating lever. The floating lever moves down and lowers the pilot valve plunger which opens the port in the pilot-valve bushing. High pressure oil is ported under the differential servo piston. The differential servo piston moves up to increase fuel.

The compensation lever, that is attached to the rod on the differential servo piston, moves up on the right end. The compensation lever is pivoted over a pivot point (compensation adjust). This pivot point can be moved to adjust the amount of travel of the transmitting piston. This changes the amount of compensation. The left end of the compensation lever is connected to the transmitting piston. It will move down as the differential servo piston moves up. This will pressurize the oil in the dashpot area. The receiving piston will move up due to the pressurized oil under it. This will raise the floating lever and pull the pilot-valve plunger up.

The force of the receiving piston moving up adds with the force of the flyweights (temporary droop) to close the port in the pilot-valve bushing and stop increasing fuel just before the engine has returned to the original speed. The engine speed is still increasing due to the differential servo piston being pushed up and the force of the flyweights is still increasing. The needle valve is adjusted to allow the pressurized oil under the receiving piston to return to sump and lower the receiving piston at the rate the engine is increasing speed. The combined force of the receiving piston and the flyweight force will cause the pilot valve to raise slightly and drain some of the oil out from under the differential servo piston to decrease the fuel setting to the proper amount to maintain the original speed at a new load.

The flyweight force has now increased to its original amount and pulled the pilot valve plunger up to close off the port in the pilot-valve bushing. This holds the new fuel setting.

The needle valve and compensation adjustments must be set properly to match the engine dynamics. If they are not the engine will hunt or have a slow response time.

Many of the above described events happen almost simultaneously, which allows the governor to respond very quickly to changes in load or speed.

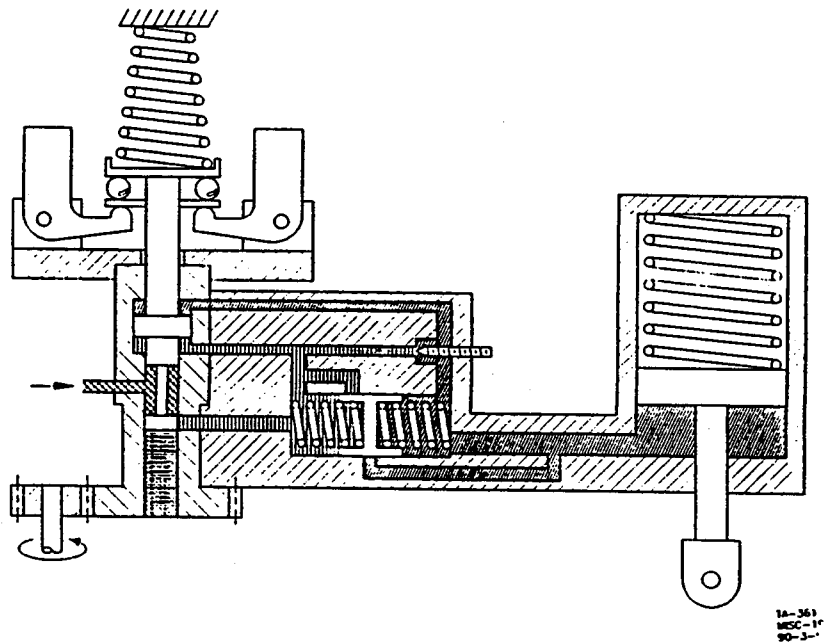


Figure 3-5. Pressure Compensated System

COMPENSATED SYSTEM

Woodward PG, PSG, 3161, and EGB governors use a pressure compensated system to accomplish temporary droop that allows isochronous operation. All of these governors may also have adjustable droop.

Stability of the pressure compensated system is achieved by the use of a temporary feedback signal which biases the speed signal to the pilot-valve plunger. This temporary feedback signal is in the form of a pressure differential applied across the compensating land of the pilot valve plunger. The pressure differential is derived from the "buffer system" and is dissipated through the needle valve as the prime mover speed returns to the desired set speed.

The buffer piston, buffer springs, and needle valve in the hydraulic circuit between the control land of the pilot valve plunger and the power piston comprise the "buffer system" of the governor. Lowering the pilot-valve plunger permits a flow of pressure oil to the buffer system and moves the buffer piston to increase the pressure under the power cylinder to move the power piston to the increase fuel. Raising the pilot-valve plunger lets oil flow from the buffer piston and power cylinder to the sump and the power-piston spring moves the power piston down to decrease fuel.

This flow of oil in the buffer system, in either direction, carries the buffer piston in the direction of flow compressing one of the buffer springs and releasing the

other. This creates a difference in the oil pressures on the two sides of the buffer piston. The higher oil pressure is on the side of the piston opposite the spring being compressed. The difference in oil pressure is proportional to the buffer piston displacement and is dependent upon the spring rate of the buffer springs. The spring rate of the buffer springs determine the pressure differential across the buffer piston. This establishes the "GAIN" of the circuit.

The oil pressure on one side of the buffer piston is transmitted to the lower side of the compensation land on the pilot-valve plunger. The oil pressure on the other side of the piston is transmitted to the upper side of the compensation land. The difference in oil pressures produces a force (often termed a "compensating force") upward or downward. The force assists the flyweights or speeder spring in centering the pilot-valve plunger whenever a fuel correction is made.

The compensation needle valve is an adjustable part of the compensation system. Its setting, which directly affects governor stability, depends upon the individual characteristics of the engine. The more open the needle valve the shorter the period of compensation and the more "responsive" the governor. A compensated governor will not operate satisfactorily with the needle valve completely closed because the differential force across the compensation land could never be equalized.

To Set the Needle Valve

1. With the engine operating at IDLE, open the compensation needle valve several turns to cause the engine to hunt. In some cases, opening the needle valve alone may not cause the engine to hunt, but manually disturbing the governor speed setting will. Allow a few minutes of hunting to remove trapped air in the hydraulic circuits.
2. Close the compensation needle valve gradually until hunting is just eliminated. Keep the needle valve open as far as possible to prevent sluggishness in the governor response. The needle valve setting varies from 1/16 to 2 turns open. Never close it tight, the governor cannot operate satisfactorily when this condition exists.
3. Check the governor stability by manually disturbing the governor speed setting. The compensation adjustment is satisfactory when the governor returns to speed with only a slightly over or undershoot. Once the needle valve adjustment is correct, it is not necessary to change the setting except for large, permanent changes in temperature which affect governor-oil viscosity or replacing the oil with a different viscosity.

Operation of the Buffer System

The following events occur in a compensated governor when the engine slows down because of the addition of a relatively small load:

The decrease in centrifugal force developed by the rotating flyweights permits the speeder spring to push the flyweights in, lowering the pilot-valve plunger and opening the control port in the pilot-valve bushing. Porting high-pressure oil to the buffer piston and under the compensation land on the pilot-valve plunger.

As the buffer piston moves in the direction of the oil flow (from the pilot valve to the power piston) the buffer spring on the power-piston side is compressed and the spring on the pilot-valve side is relieved. The oil displaced by the buffer piston as it moves toward the power piston is pressurized and forces the power piston up, increasing fuel to the prime mover and the prime mover begins to accelerate. Part of this pressurized oil is sent to the top of the compensation land on the pilot-valve plunger. This forms a differential pressure across the compensation land. The buffer piston continues to move to the right, moving the power piston up until the upward force created by the pressure differential across the buffer piston and compensating land is sufficient when added to the centrifugal force from the rotating flyweights to center the pilot-valve plunger. As soon as the pilot-valve plunger is centered, the power-piston movement stops. When the governor is properly adjusted, this new power-piston position corresponds to the fuel increase needed to operate the engine at the desired speed with the new load, even though the engine has not yet returned to the set speed.

As the engine continues to accelerate to the desired speed, the centrifugal force developed by the flyweights increases. To offset this increase in centrifugal force, it is necessary to reduce the upward force created by the pressure differential across the compensation land of the pilot-valve plunger. (Otherwise, the plunger will be lifted above center and the power piston will move down toward decrease fuel.) This is accomplished by equalizing the pressure on both sides of the compensation land at a rate proportional to the rate at which the engine speed returns to normal. As leakage through the needle valve allows the pressure differential to equalize the compensating force decreases. If the decrease in compensating force can be made at the same rate as the centrifugal force is increased, the pilot-valve plunger will remain centered and the power piston will remain stationary.

As the pressure differential is being equalized the compressed buffer spring returns the buffer piston to its spring centered position. When the pressure differential has been returned to zero, the compensating force will be reduced to zero. The this time the engine should be back to the desired speed, developing the centrifugal force necessary for the flyweights to keep the pilot-valve plunger centered.

The rate at which the pressure differential is reduced to zero depends upon the needle-valve setting. The setting allows each governor to be matched to the engine on which it is used. The final setting of the needle valve cannot be made

until the governor is installed on the engine. With the engine running the needle valve is adjusted for the engine's unique dynamics.

When a relatively small load is removed from the engine while it is running on-speed under steady-state condition, the sequence of events is similar, but in the opposite direction.

The engine speed increases. The flyweights develop additional centrifugal force and lift the pilot-valve plunger. The oil between the buffer piston and the pilot-valve plunger is connected to sump. The power piston pushes down, forcing the buffer piston toward the pilot-valve plunger. A pressure differential again exists between the oil ports to the upper and lower sides of the compensating land of the pilot-valve plunger.

The greater pressure is now on the upper side of the compensating land, tending to push the pilot-valve plunger back down to its centered position.

When the power piston pushes down, the fuel to the engine is decreased. The engine speed is decreasing and so is the fly-weight force.

When the compensating force becomes sufficient to combine with the decreasing centrifugal force of the flyweights, the pilot-valve plunger is returned to its centered position, even though the engine speed is still greater than the set speed. As before, the compensating force is dissipated at a rate proportional to the rate at which the engine returns to normal speed so the pilot-valve plunger remains centered.

The sequence of movements within the governor occur almost simultaneously, not in the step-by-step manner described. This allows for quick response to a change in load or speed.

Bypass Passages

Bypass passages are provided in the buffer-piston cylinder to allow for large corrective movements of the power piston. A large increase or decrease in speed setting or a large increase or decrease in load on the engine requires a corresponding large movement of the power piston to make the necessary fuel correction. At such times, the buffer piston moves far enough to uncover the bypass port which provides an unrestricted flow of oil to or from the power cylinder.

The difference in oil pressures on opposite sides of the buffer piston and compensation land cannot exceed the difference which exists when the buffer piston uncovers the bypass port. With the bypass port uncovered, oil flow directly to or from the power piston without additional increase in the pressure differential existing on the compensation land.

The bypass ports permit the power piston to move quickly in response to large changes in load or speed setting. Since the pressure differential across the compensating land of the pilot-valve plunger does not continue to increase, the speed more than returns to normal (or to the new setting). This "over shoot: in

speed is not large and is necessary to obtain the desired fast response. As soon as the speed changes beyond the desired point, normal governor action reverses the power piston movement and stable operation is quickly established.

SPECIAL FEATURES

Power Piston/Servo Piston

Seal grooves (not shown in the schematic) surround the power piston and its piston rod connected to the intermediate oil pressure between the pilot valve and the buffer piston. These grooves are used to insure that any leakage of pressure oil from the power cylinder to the sump comes from a part of the hydraulic circuit where it will not effect the operation of the governor.

Remote Power Cylinder Assemblies

Remote power cylinder assemblies are located away from the governor power case. They have three tubes connecting the power cylinder to the power case. These tubes carry oil to and from the buffer piston, drain oil from the power cylinder, and oil from the power-cylinder seal grooves. To eliminate the possibility of trapping air in the oil, the cylinder must be mounted below the governor oil level and the connecting tubes must slope upward to the governor.

Special Ballhead Assemblies

A "solid" ballhead assembly is used in governors on prime movers which have a smooth drive to the governor.

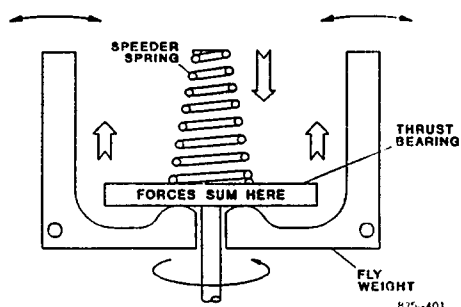


Figure 3-6. Solid Ballhead

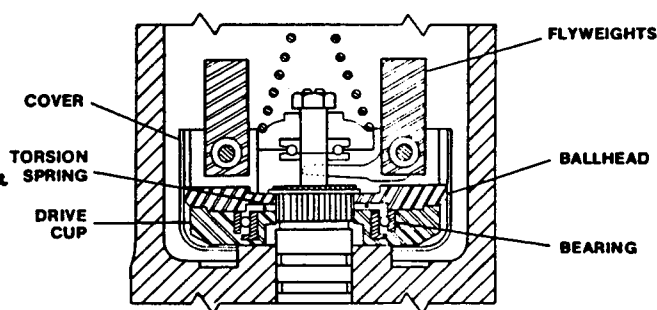


Figure 3-7. Spring-Driven,
Oil-Damped Ballhead

"Spring Driven" and "Spring Driven, Oil Damped" ballhead assemblies are used to filter torsional vibration which may be received by the governor through the drive from the engine. (these torsional vibrations may originate from a source other than the drive itself, but reach the governor through the drive connection.) Unless minimized or eliminated, the flyweight head will sense these torsional vibrations as speed changes and continually adjust the fuel valve or racks in an attempt to maintain a constant speed (This is referred to as "jiggle").

Slotted Pilot Valve Plungers and/or Special Pilot Valve Bushing Ports

Gas fired engines are inherently unstable and often require special bushings or plungers. Some types of engine load are unstable in nature and require special governor considerations.

Special pilot-valve plungers are available for use on UG governors to enhance their ability to match governor response to engine performance. These "chopper" plungers generally slow governor response to speed changes, prevent unacceptable governor output instability, and control the rate of power piston movement.

PG, PSG, EGB, and 3161 governors have special pilot valve bushing conformations to match governor response to particular engines and speed conditions. Bushings are available in slotted, 4-round, 2-round and 1 round configurations. Slotted bushings give the fastest response and 1-round provides the slowest response to speed variations.

Round ports in bushings present special control features as they allow little flow of control oil when only the edge of the round port is exposed by the plunger control land, with progressively more flow allowed as the land opens more of the circular opening.

Special Buffer Springs

Different scales of buffer springs are used in governors to match the compensation system to the particular engine. The heavier the spring scale the "slower" governor response is to speed differences. Note that a "slow" governor does not affect engine response to load changes. The design is to match governor response to the ability of the engine to accelerate.

Preloaded buffer springs are also available for many governors. These adjustable springs are used to set an amount of deadband in the governor and thus stabilize difficult control conditions. The preloaded springs can also be used to provide different governor response in the decrease and increase fuel conditions.

Speed Setting Options

There are a number of speed setting arrangement available. The exact method used depends on the operating scheme of the installation in which it is used and the type of governor.

It is important to observe that no matter how simple or complex the means employed may be, the ultimate objective is to increase or decrease the force of the speeder spring. An increase in speeder-spring force requires that the engine run faster so the flyweights will develop the additional centrifugal force needed to recenter the pilot valve plunger. Conversely, a decrease in spring force requires a slower engine speed to center the control land on the pilot-valve plunger.

Pneumatic heads and electric motors are popular speed setting devices for remote control of engine speed. Lever speed setting is available on some governors to allow changes in speed setting with cable. In addition almost all governors have a method to manually change the speed setting at the governor either with a knob or a screw.

Limiters and special shutdown devices are also available to prevent over fueling or to allow automatic or remote engine shutdown. Refer to the manual for your specific governor for information about these special features.

DRIVE SHAFTS

The drive shaft is the part that is connected or coupled to the governor drive on the engine. It has an important part in the operation of the governor. The drive shaft is rotated by the governor drive on the engine at a speed proportional to the engine speed. The drive shaft is the point where most of the rotating parts are driven from, either directly or indirectly. It rotates the oil pump, the flyweights, and the pilot valve bushing.

There are many sizes and shapes of drive shafts. Some of the types are splined, keyed, and round with a flat side. There are many diameters and lengths. The design of the drive depends on the governor type and governor drive of the engine. The drive shafts usually have a bearing and seal on them and are mounted in the bottom of the governor.

Chapter 4

Droop

Droop has many uses and applications in the control of engines.

Without some form of droop, engine-speed control would be unstable in most cases.

Droop is defined as a decrease in speed setting at the load increases.

Droop is expressed as a percentage of the original speed setting from no load to full load. 3 or 5% droop is the normal recommended percent of droop. A minimum of 2.5% is required to maintain stability in a speed-droop governor.

Droop is calculated with the following formula:

$$\% \text{ Droop} = \frac{\text{No Load Speed} - \text{Full Load Rated Speed}}{\text{Full Load Rated Speed}} \times 100$$

If, instead of a decrease in speed setting an increase takes place, the governor is showing negative droop. Negative droop will cause instability in a governor.

Simple hydraulic/mechanical governors have the droop function built in and always operate in droop. More complex governors include temporary droop, which returns the speed setting to its original speed setting after the engine has recovered from a change in speed or load. The temporary droop is called "compensation."

WHY IS DROOP NECESSARY?

In a system without droop a load increase will cause the engine to slow down. The governor will respond by increasing the fuel until the engine speed has returned to the original speed.

Due to the combined properties of inertia and power lag the engine speed will continue to increase beyond the original speed setting, causing an overshoot in speed. The governor again will respond to decrease speed to correct for the overshoot. It will over correct the speed in the other direction causing an undershoot. This overcorrection of speed in both directions (instability) will amplify until the engine trips out on over speed.

This instability problem can be eliminated with droop. As the load increases, the speed setting is decreased. When the governor moves to correct for the speed decrease caused by the increased load, it will be correcting to a lower speed setting. This lower speed setting prevents the speed from over shooting.

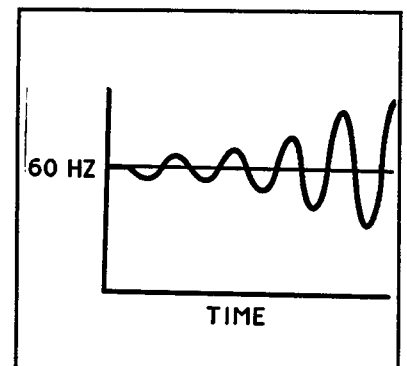


Figure 4-1. Response Curves of Governor Without Droop or Compensation.

SPEED DROOP OPERATION
Simple Speed Droop Governor (See Chapter 2)

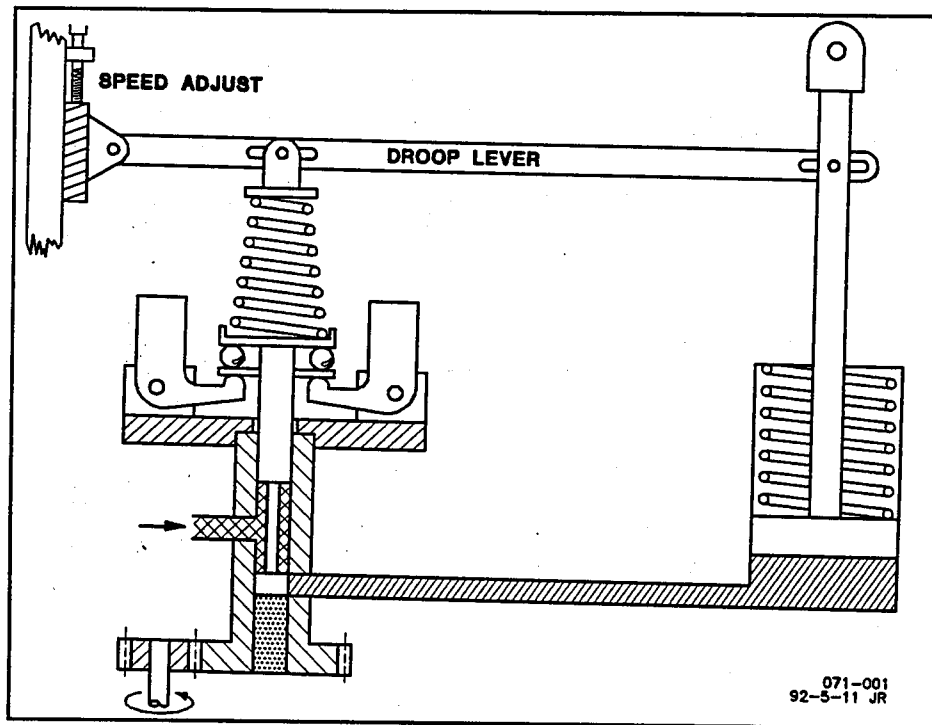


Figure 4-2. Droop Feedback

As load is applied to the engine, the power piston moves up to increase fuel. The droop feedback lever is connected to the power piston and speeder spring. The feedback lever pulls up on the speeder spring to reduce its force. With less force on the speeder spring, the speed setting is decreased, causing the droop action which maintains the load at a lower speed.

**Compensated
Governors**

For compensated governors, when a load is applied the temporary force of the compensation system pushes up on the pilot valve compensation land. This force adds to the force of the flyweights to close the pilot valve before the engine speed is reached. This temporary force addition

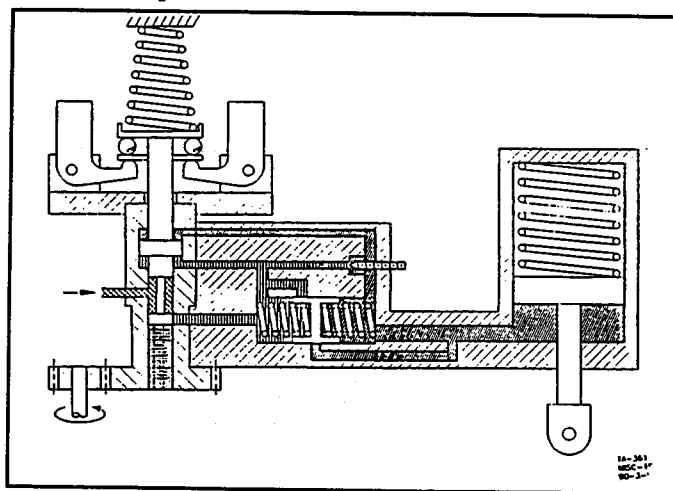


Figure 4-3. Compensated Governor Schematic

works in the same way as if the speed setting had been reduced. The force through the needle valve of the compensation system is reduced to zero at the engine returns to speed. This is known as "temporary droop."

The Droop Curve

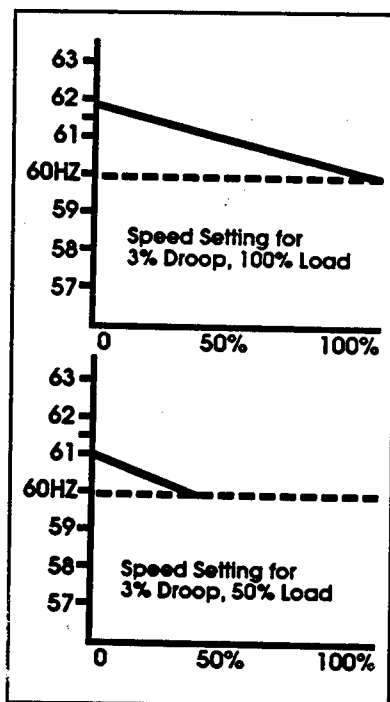


Figure 4-4. Comparison of 3% Droop Speed Settings for 50% and 100% Load.

If the linkage is changed, altering the amount of governor output shaft travel from no load to full load, the droop must be reset. Be sure to use a least 2/3 of the governor output shaft travel to ensure stability and allow sufficient droop range adjustment.

Droop is a straight line function, with a certain speed reference for every fuel position. Normally a droop governor lowers the speed reference from 3 to 5 percent of the reference, from no load to full load. Thus, a 3-percent droop governor with a reference speed of 1236 rpm at no load would have a reference speed of 1200 rpm at full load. (61.8 Hz at no load and 60 Hz at full load.

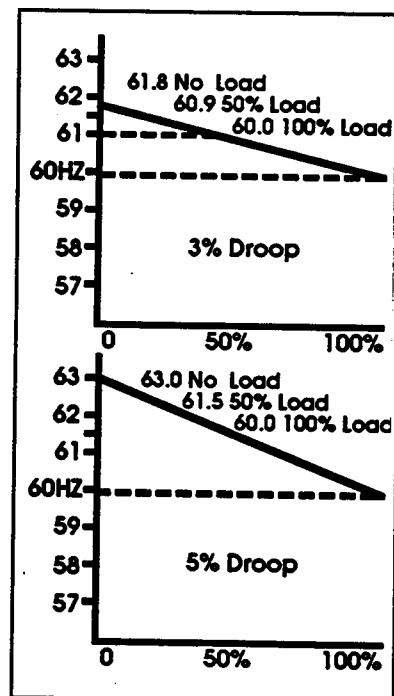


Figure 4-5. 3 and 5 Percent Droop Curves

USES OF DROOP

Isolated Unit

Most governors are capable of operating in the isochronous mode. However, droop operation is necessary for many application.

Isolated, single-engine applications can operated in either isochronous or droop. In single engine applications the engine operation is not affected by any other engines or the utility. In isochronous operation, the speed will return back to the original speed after a load has been applied up to 100% load. In droop operation the speed will decrease by a set percentage after a load has been applied. In the droop mode, if the original speed is desired, the operator must raise the speed setting to return to the original speed when a load is applied.

Isolated Systems

An isolated system is an application where two or more engines are driving a common load. This load could be electrical generators, pumps, ship propellers, or combinations of these and any other mechanical loads. These isolated systems are not connected to any other systems or to a utility.

Without some form of isochronous load sharing scheme like the electronic isochronous load sharing control, droop must be used to share these loads.

The isochronous mode can also be used on one engine, running in parallel with any other engine. However, unless the governors have isochronous load sharing capabilities, no more than one of the engines running in parallel can be in the isochronous mode. If two engines are operating in the isochronous mode without load sharing controls are supplying power to the same load, one of the units will try to carry the entire load and the other will shed all of its load. In order for the two units to share load, some additional means must be used to keep each engine from either trying to take all the load, or from motorizing.

The reason for one unit taking all the load and the other unit dropping all the load is shown in the following example:

If two isochronous units are to be coupled together on the same load and the speed settings are not the same, the system will become unbalanced when coupled together. Since there can not be two different speeds on one system coupled together, one engine will have to decrease its actual speed and the other will have to increase its actual speed to an average speed between the two. The governor on the engine that decreased speed will move to increase fuel to try to correct for the decrease in speed. While the governor on the other unit that increased speed will move to decrease fuel to try to correct for the increase in speed. The result will be the engine with the higher speed setting continuing to take all of the load until it reaches its horse-power limit and the other engine will shed all of its load and become motored (driven by the other engine).

As seen by the example, units running in isochronous cannot share loads without an isochronous load sharing scheme which is discussed in the electronic controls chapter.

Using Droop to Share Loads

If all engines in a droop system have the same droop setting, they will each share load proportionally. The amount of load each carries will depend on their speed settings. If the system load changes, the system speed/frequency will also change. A change in the speed setting will then be required to offset the effect of droop and return the system to its original speed/frequency. In order for each engine in the system to maintain its proportion of the shared load, the operator will need to adjust the speed set point equally for each engine.

If all engines in a droop system do not have the same droop setting, they will not share loads proportionally with the same speed settings. If the system load

changes, the system speed/frequency will also change but the percent of load on each engine-generator set will not be changed proportionately.

The operator will need to adjust speed set point differently for each engine to make them carry their proportional share of the load.

This could result in running out of speed set point adjustment on an engine before it is fully loaded and limiting the system load sharing capability. It is best to have the same percent of droop set on each engine (3 to 5% is recommended).

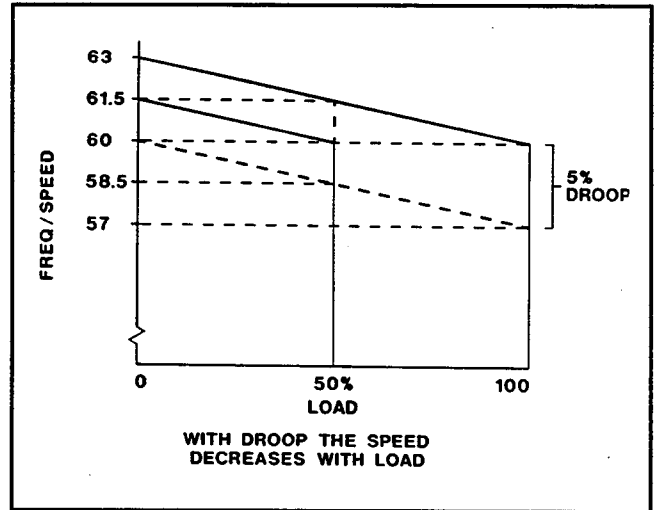


Figure 4-6. Droop Mode

ISOLATED SYSTEMS

DROOP/ISOCRONOUS

Droop/Isochronous combines the first two modes. All engines in the system are operated in the droop mode except for one which is operated in the isochronous mode. It is known as the swing machine. In this mode, the droop machines will run at the speed/frequency of the isochronous unit. The droop percentage and speed settings of each droop unit are adjusted so that it generates a set amount of power. The output power of the swing machine will change to follow variations in the load demand while maintaining constant speed/frequency of the system. (See Figures 4-3 and 4-4.)

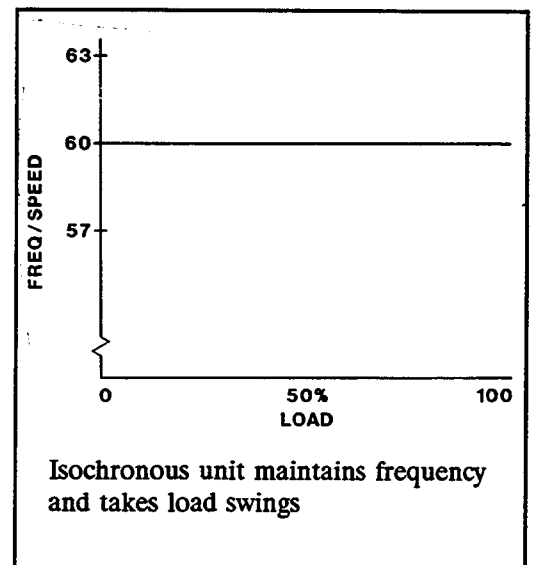


Figure 4-7. Swing Machine

Maximum load for this type of system is limited to the combined output of the swing machine and the total set power output of the droop machines. A load above this maximum will result in a decrease in speed/frequency. The minimum system load can not be allowed to decrease below the combined output set for the droop machines. If it does, the system frequency will increase and the swing machine can be motorized.

The machine with the highest output capacity should normally be operated as the swing machine so that the system will accept the largest load changes within its capability. This is not a hard and fast rule. Selection of the swing machine will depend on such things as efficiency of different engines and the amount the load is expected to change.

System Tied to a Utility Grid

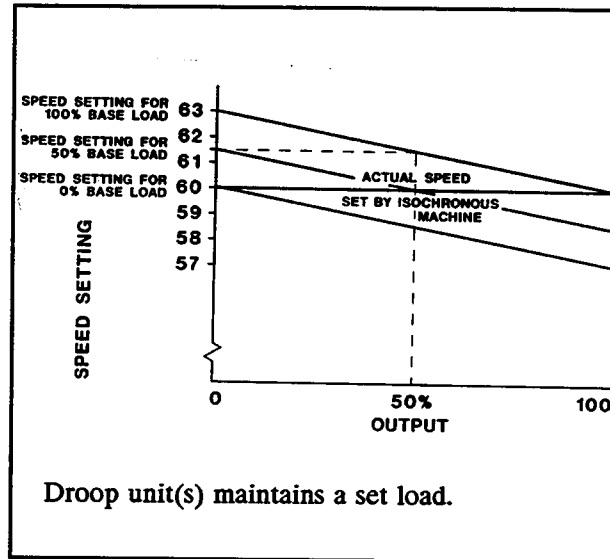


Figure 4-8. Droop Units

Previously the use of droop has been discussed for systems that were isolated (not tied to another larger system such as a utility). When an engine-generator set is paralleled with a utility, there are a few things to consider:

The utility will basically act as an isochronous unit. The utility will set the speed/frequency for any units being paralleled to it. A simple isochronous unit cannot be paralleled to the utility.

When an isochronous engine-generator set is connected to a utility bus the utility will determine the speed/frequency of the generator. Should the governor speed reference be less than the utility frequency, power in the utility bus will flow to the generator and motor the unit. If the governor speed is even fractionally higher than the frequency of the utility, the governor will go to full load in an attempt to increase the bus speed. Since the definition of a utility is a frequency which is too strong to influence, the engine will remain at full load.

Droop provides the solution to this problem. Droop causes the governor speed reference to decrease as load increases. This allows the governor to vary the load with the speed setting since the speed cannot change.

DROOP BASE LOAD

Droop base load is the same as droop, with the exception that the utility or grid will control the frequency and act as does the swing machine, absorbing any change in load. The speed and droop settings are adjusted so that the engine-generator set supplies a fixed, or base amount, of power to the utility (see Figure 4-7).

Based on 5% droop, increasing the speed setting to 61.5 Hz will produce 50% power output. Following the droop line from the 61.5 Hz setting to the point where it crosses the 60 Hz line (controlled by the utility) it can be seen that the engine-generator set is at 50% power output. If the speed setting is increased to

63 Hz the power output will be at 100%. Where the droop line crosses the utility frequency line is the amount of power output produced. If the utility frequency varies, the amount of output power will vary inversely. If the utility frequency increases, the droop line will cross the higher utility frequency line closer to zero power

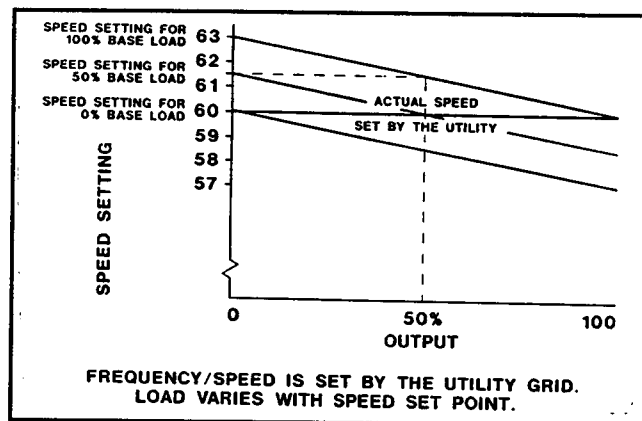


Figure 4-9. Base Load with 5% Droop

and produce a lower output or power. If the utility frequency decreases the droop will cross the lower utility frequency line farther from zero producing a higher output power. This condition is often mistaken for a governor problem, which it is not.

If the engine-generator set is to be unloaded and disconnected from the Utility simply decrease the speed setting slowly until the engine generator set is at minimum power output, then open the tie breaker.

If the engine generator set is running in a loaded condition and the tie breaker opens, separating the engine generator set from the utility, the frequency will increase to the speed setting point. The amount the frequency increases depends on where the speed setting was when the tie breaker opened.

BASIC COMPENSATED MECHANICAL GOVERNOR WITH DROOP

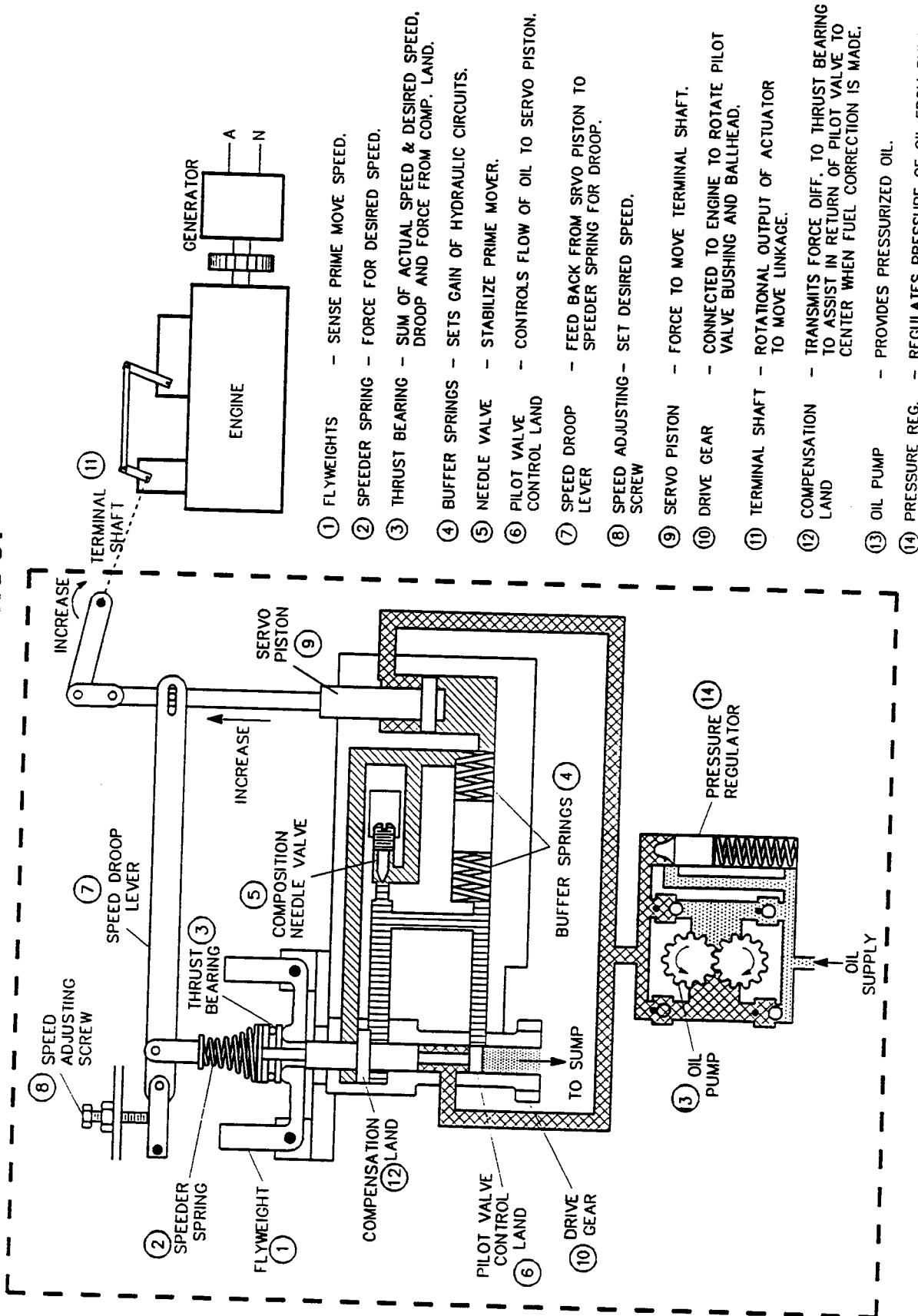
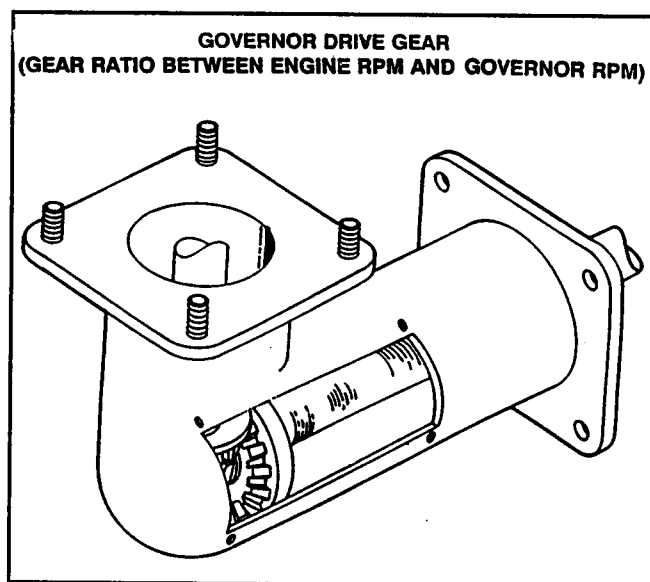


Figure 4-10. Schematic of Woodward Droop Governor

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Chapter 5

Governor Drive and Installation



GOVERNOR DRIVE

The governor drive becomes an important part of the governor system, although it is supplied by the engine manufacturer. The drive must provide an accurate transmission of engine RPM, without backlash in the gears or other problems which the governor would recognize as speed variations.

Figure 5-1. Governor Drive

There is usually a gear ratio in the governor drive. This will allow the governor to be driven at the proper governor RPM based on the RPM the engine is designed to operate at. The governor RPM will be proportional to the engine RPM and operate in the designed speed range for the governor.

When installing a governor:

1. Determine that the installation surfaces of the governor and of the drive are smooth and flat. It is good procedure to lightly stone both surfaces to eliminate any nicks which could prevent a good fit.
2. Make sure the drive shaft rotates freely.
3. Select the correct length of coupling between the governor and the prime mover drive.
4. Install the proper gasket. Many governors have sealed sumps but the gasket is still used to absorb any irregularities which may exist in the mounting surface of the engine or governor.
5. Mount the governor squarely on its mounting pad. Make sure there is no side loading on the drive shaft which will wear out drive shaft seals and bearings.
6. Make sure there is no force pushing the drive shaft into the governor.

7. Make sure the coupling rotates freely but without backlash (looseness). Incorrect alignment of the governor shaft to the coupling, or not enough clearance between any of the parts, can result in excessive wear and/or seizure of parts. It can also cause an undesirable high frequency vibration or "jiggle" in the governor output shaft.

Chapter 6 Linkage

GENERAL

Linkage between the governor output and the engine fuel control system is responsible for many unacceptable control conditions that appear to be governor connected. When acceptable governor control deteriorates or changes, linkage is one of the first areas to troubleshoot. Loose or worn linkage not only can cause unacceptable governor control but it can also present dangerous conditions should it fail completely and leave the engine uncontrolled. **GOOD LOCKING METHODS MUST BE USED AT ALL LINKAGE CONNECTIONS.**

There must be no lost motion or binding in the linkage attached between the governor and the engine. Binding or "catches" in the linkage can cause speed excursions and other problems which may appear as being caused by the governor. Lost motion in the linkage will cause the governor to have to travel the distance of the lost motion before any fuel change is made. The governor will become over active in fuel control. This overly active governor will provide less than optimum control. An overactive governor will also cause excessive wear in linkage and in the governor. The engine will tend to move up and down in speed or wander.

Governor operation is based on the assumption that linkage is so arranged that a given movement in the governor output will provide a proportional change in the fuel to the engine.

Many fuel control systems provide a nearly linear response in engine output . (This is usually true of diesel engines.) Other fuel control systems provide a nonlinear response to changes in the control device position and engine outputs. (This is particularly true of carbureted engines with butterfly valves.) All governors tend to provide nearly linear travel. Differences between the linearity of governor travel and the linearity in the engine fuel control system or valve are accomplished by the design of the linkage between the governor and the engine fuel system or valve.

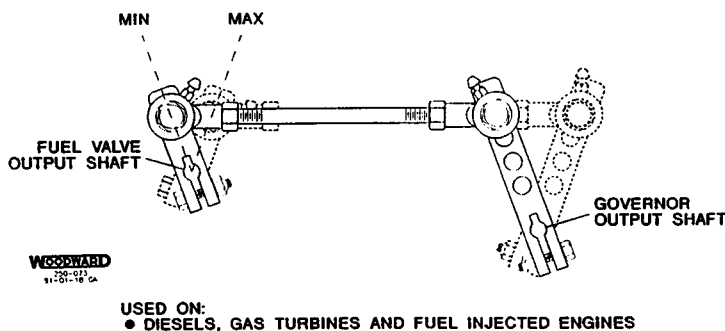


Figure 6-1. Linear Fuel Control

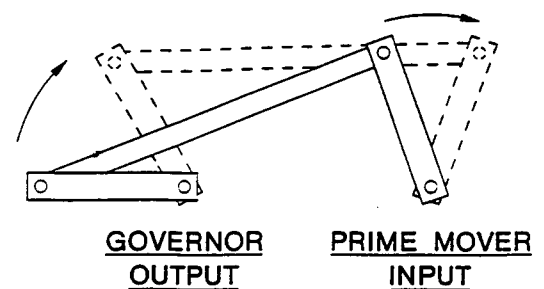
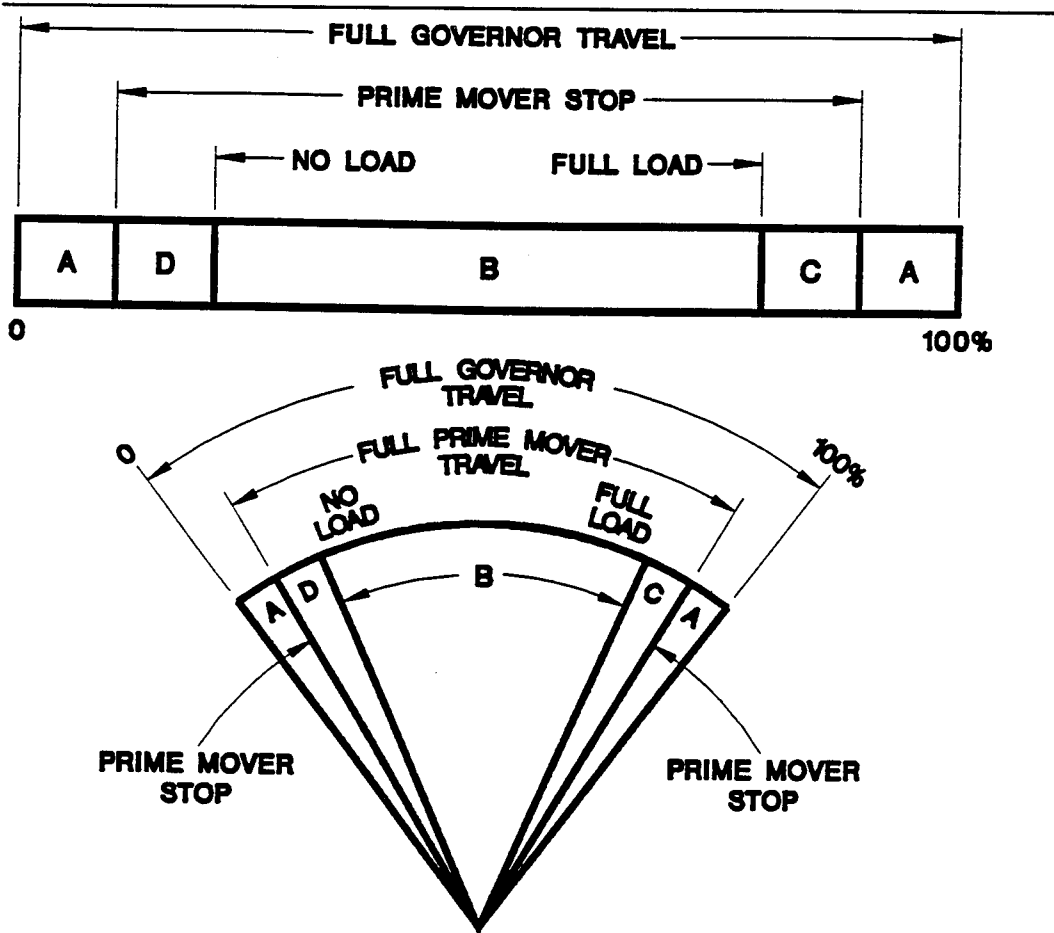


Figure 6-2. Non-Linear Fuel Control



- A - OVERTRAVEL TO INSURE PRIME MOVER STOPS ARE REACHED**
 - B - NO LOAD TO FULL LOAD TRAVEL - NORMALLY 2/3 OF FULL GOVERNOR TRAVEL IS RECOMMENDED**
 - C - TRAVEL REQUIRED TO ACCELERATE THE PRIME MOVER**
 - D - TRAVEL REQUIRED TO ACCELERATE OR SHUT DOWN PRIME MOVER**
- IN SPECIAL APPLICATIONS MIN AND MAX PRIME MOVER STOPS MAY BE OUTSIDE THE GOVERNOR STOPS.**

Figure 6-3. Correct Use of Governor Travel

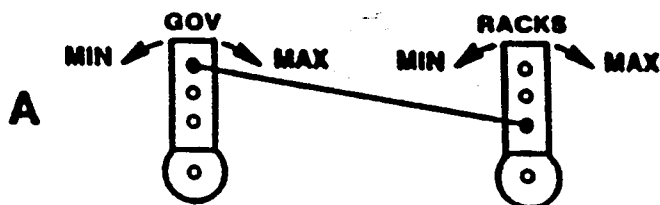
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GOVERNOR TRAVEL

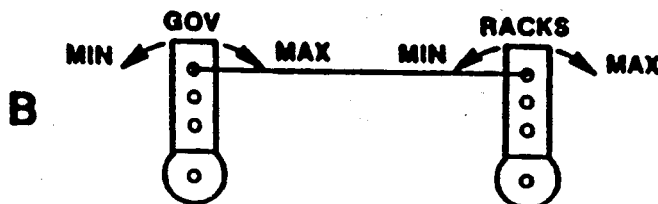
Design of the fuel linkage must provide for control of fuel from "FUEL OFF" to "FULL FUEL" within the limits of the travel of the governor output shaft. The design must also provide for about 2/3 output shaft travel between "NO LOAD" and "FULL LOAD." If less than 2/3 travel from no load to full load is not used, the stabilizing of the engine may not be possible.

If a lot more than 2/3 travel from no load to full load is used there may not be enough travel to be sure the fuel is shut off at minimum governor travel and at maximum governor travel full fuel may not be reached. This can make the engine appear sluggish. In both cases, the misadjusted linkage can appear as a governor problem when it really is not a governor problem.

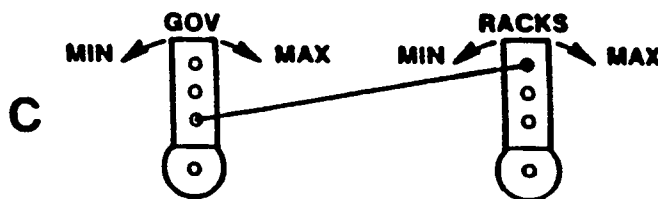
LINEAR LINKAGE ARRANGEMENTS



This Linkage design provides a large amount of engine fuel motion for a small amount of governor motion.



This Linkage design provides equal amounts of engine fuel motion and governor motion.



This Linkage design provides a large amount of governor motion for a small amount of engine fuel motion.

Figure 6-4. Linear Linkage Used to Accommodate Different Amounts of Travel in the Governor Output and the Fuel Control

A linear linkage arrangement is used in applications where the governor output shaft positioning is directly proportional to the torque output of the engine. A linear linkage is a linkage design which provides as much movement of the governor output shaft per increment of engine fuel movement at light loads as at heavy loads.

Using less than the recommended amount of governor travel will provide governor control which exhibits fast response and is, or tends to be, unstable. Droop load sharing could be impossible if too little governor output shaft travel is being used.

Using a lot more than $2/3$ of the governor travel may not let the fuel system be shut off or may not let the fuel system be opened to maximum.

The linkage must be setup to shut fuel completely off and let fuel be opened to full fuel. Use at least $2/3$ of the full governor travel from zero load to 100% load.

Non-Linear Linkage

Butterfly carburetor valves present extremely non-linear control characteristics. At minimum positions (light load) the valve must move very little to change the amount of fuel flow a large amount. When at higher loads the valve must move a large amount to have any affect on fuel flow. Since governor output travel is essentially linear special linkage is necessary to make the two conditions compatible. This is called "non-linear linkage."

Non-linear linkage is also required on some diesel injection systems, although these conditions are not usually as severe as they are when controlling a butterfly carburetor valve. In all cases the linkage should be designed to provide increased engine output in direct proportion to movement of the governor output.

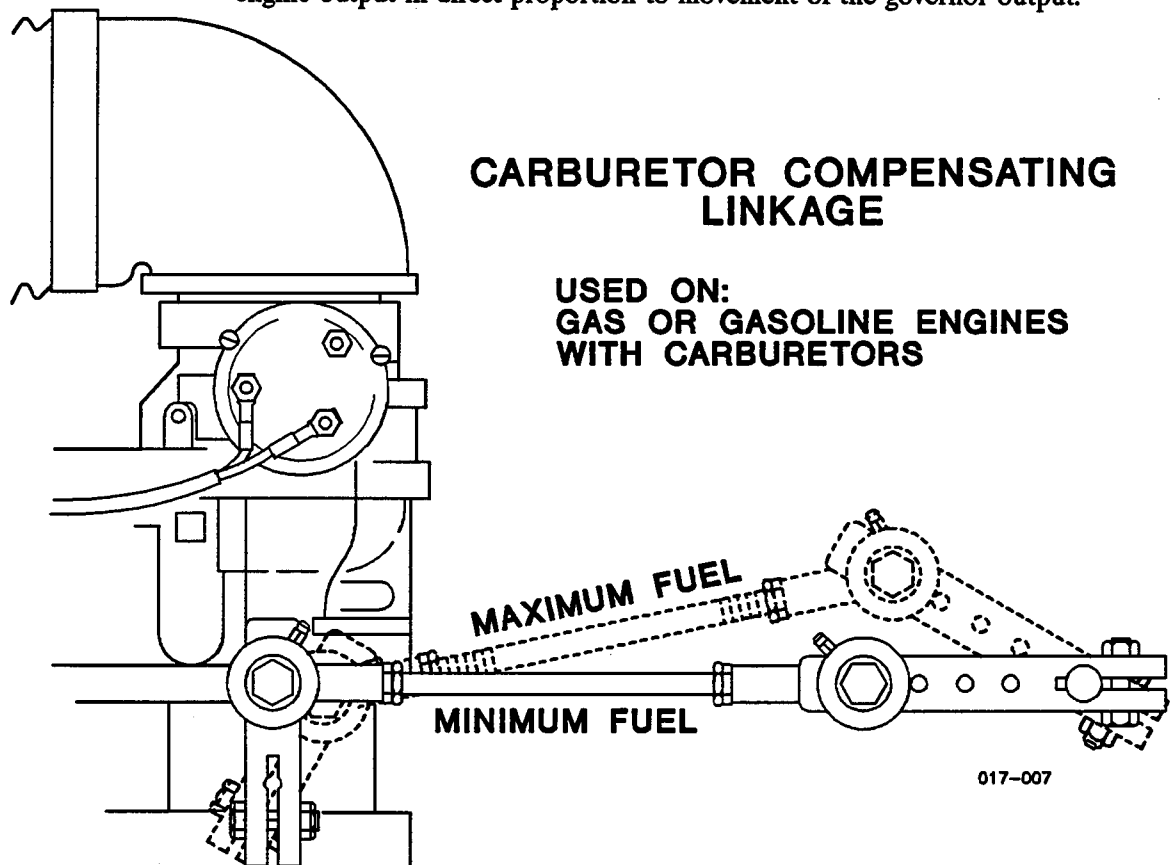


Figure 6-6. Nonlinear Carburetor Linkage

When installing this linkage make sure the following conditions are obtained when the governor output is in the min fuel position:

- The governor lever and connection link are in line with the governor output shaft and the point of attachment on the connecting link to the butterfly carburetor lever.
- The butterfly carburetor lever is 90° with the connecting link.

WOODWARD
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Chapter 7 Governor Oil

INTRODUCTION

Hydraulic governor operation can be seriously affected by incorrect oil. If the proper oil is used and the oil is changed regularly governor operation is enhanced and governor life is extended.

DIRTY OIL CAUSES MOST GOVERNOR/ACTUATOR TROUBLES

Use clean, new, filtered oil. Oil containers used must be perfectly clean. Oil contaminated with water breaks down rapidly, causing foaming and corrodes internal governor parts.

Excessive component wear or seizure in a governor/actuator indicates the possibility of:

1. Insufficient lubrication caused by:
 - a. An oil that flows slowly when it is cold, especially during start ups.
 - b. No oil in the governor or restricted oil supply to the governor.
2. Contaminated oil caused by:
 - a. Dirty oil containers.
 - b. A governor exposed to heating up and cooling down cycles, which creates condensation of water in the oil.
3. Oil not suitable for the operating conditions caused by:
 - a. Changes in ambient temperature.
 - b. An improper oil level which creates foamy, aerated oil.
 - c. Selection of an oil which is not compatible with the operating conditions.

Operating a governor/actuator continuously beyond the high limit operating temperature of the oil will result in oil oxidation (breakdown). This is identified by varnish or sludge deposits on the governor/actuator parts. To reduce oil oxidation, lower the actuator operating temperature with a heat exchanger or other means or change to an oil more oxidation resistant at the operating temperature.

Be sure the governor/actuator is filled with oil to the mark on the oil sight glass. Be sure to use clean containers to store and transport oil. After the engine is started and the governor is at operating temperature, add oil if necessary. Oil must be visible in the glass under all operating conditions. (Oil level may drop slightly when the governor is running due to the oil being pumped into places that don't have oil when the governor is shut down.)

OIL GRADE SELECTION

Oil grade selection is based on the operating temperature range of the governor. Also, use this information to aid in recognizing and correcting common problems associated with oil used in products manufactured by the Engine and Turbine Controls of Woodward Governor Company.

For applications where the governor/actuator shares the oil supply with the engine, use the oil recommended by the engine manufacturer.

Governor/actuator oil is both a lubricating oil and a hydraulic oil. It must have a viscosity index that allows it to perform over the operating temperature range and it must have the proper blending of additives that cause it to remain stable and predictable over that range.

Governor/actuator oil must be compatible with seal materials, i.e.; nitrile, polyacrylic and fluorocarbon.

Many automotive and gas engine oils, industrial lubricating oils and other oils of mineral or synthetic origin meet these requirements. Woodward governors/actuators are designed to give stable operation with most oils with the viscosity, at the operating temperature, between 7.5 and 650 CST (Centistokes). At the normal operating temperature, the viscosity should be 20 to 65 CST. Poor actuator response or instability may be an indication that the oil viscosity is outside this range.

The recommended continuous operating temperature of the oil is between 140°F (60°C) to 200°F (93°C). The ambient temperature limits are -20°F (-30°C) to 200°F (93°C). Measure the temperature of the governor or actuator on the outside lower part of the case. The actual oil temperature will be slightly warmer, approximately 10°F (6°C).

Hydraulic fluid pour point must be below the lowest expected starting temperature. Use SAE 20 or 30 oil for ordinary temperature conditions. If governor operating temperatures are extremely hot, use SAE 40 to 50; if extremely cold, use SAE 10. In most cases the same oil that is used in the engine or turbine lube system may be used in the governor/actuator.

If the average operating temperature of the governor/actuator oil is below 120°F (49°C) S.A.E. 10 oil is usually satisfactory; if between 120°F (49°C) and 140°F (60°C), S.A.E. 20 oil; from 140°F (60°C) to 160°F (71°C), S.A.E. 30 oil; from 160°F (71°C) to 180°F (82°C) S.A.E. 40; and above 180°F (82°C), S.A.E. 50 oil. If the engine oil meets these requirements, it may be used in the governor/actuator as well.

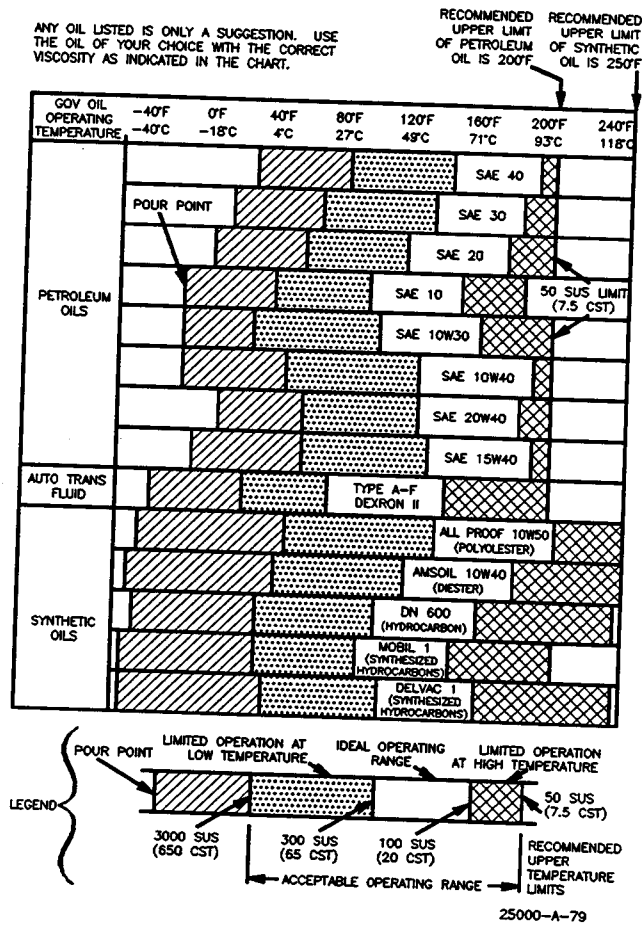


Figure 7-1. Oil Selection Chart

VISCOSITY COMPARISONS				
CENTISTOKES (CST, CS OR CTS)	SAE/BOLT UNIVERSAL SECONDS (SUS) NOMINAL AT 100° F	SAE MOTOR (APPROXIMATE)	SAE GEAR (APPROXIMATE)	ISO
15	60	5W		15
22	106	5W		22
32	161	10W	75	32
46	214	10	75	46
68	310	20	80	68
100	463	30	80	100
150	696	40	85	150
220	1020	50	90	220
320	1483	60	115	320
460	2133	70	140	460

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Figure 7-2. Oil Viscosity Chart

BOOSTERS FOR GOVERNORS WITH SELF CONTAINED OIL SUMP

Includes UG, PG, EGB (except EGB-2), some 3161 Governors,

In applications where a self-contained oil supply is used a booster servo motor is often recommended to force a supply of pressure oil into the power piston section to immediately open the fuel valve as soon as a start signal is given. With a booster servo starting time is much quicker because time is not lost waiting for oil pressure to be built up in the governor before the power piston can move.

CHANGING OIL

Run the prime mover long enough to be sure the governor/actuator is at operating temperature. Reduce the speed setting to minimum and shut down the prime mover. Drain the oil while it is still hot and contaminants are still suspended in the oil. If the oil is contaminated or discolored you may need to flush it. (See cautions and flushing instructions.)

If the governor has an external oil cooler or booster servo, be sure to drain these. After all the oil has drained out, close the drain. Refill the governor with clean oil that meets your operating conditions.

When ready to restart the engine, if an oil cooler or booster servo was drained, allow time for oil to refill these units then recheck the oil level. It may be necessary to exercise the booster to be sure it is filled. Add oil if necessary to achieve the proper level on the sight gauge. Recheck to make sure speed is set for idle or slow speed. Air can become trapped in the governor/actuator. This can cause governor instability when first started and cause the system to be unstable. Since air is compressible, sluggish governor response may be experienced until trapped air is removed. It is possible to have higher than normal speed overshoots when first started. This is the reason to have speed set at idle or slow speed.

The trapped air can be removed by causing the governor to hunt. Open the needle valve until slow, steady hunting occurs. Allow the engine to hunt for 30 seconds to a minute to force the trapped air out of the governor. Then turn the needle valve in the close direction until stable operation occurs. Never leave the needle valve closed tight. The governor/actuator should now be ready for normal operation.

Flushing a Governor

Flushing a new or rebuilt governor on a regular schedule can help clean out contaminants and increase the life of the governor.

WARNING

If the oil is extremely dirty and contaminated and it has not been flushed for several years the governor/actuator should be replaced. Flushing may not remove all of the built-up contaminants and these contaminants can loosen up later and then plug the ballchecks, oil passages and pilot valve which will make the governor become inoperative.

To flush the governor/actuator, drain the oil while the governor is still hot. If it has an oil cooler or booster, be sure to drain these, also. Fill the governor/actuator with a mixture of 50% oil and 50% petroleum based solvent such as kerosene or fuel oil. Do not use any chemical solvents that may damage seals, gaskets or O-rings. With the speed setting set for idle, start the engine and allow it to run for about 10 minutes.

CAUTION

The engine may be unstable with the cleaning mixture. The needle valve may need to be adjusted to cause a slight hunt to circulate the kerosene or fuel oil mixture throughout the governor/actuator.

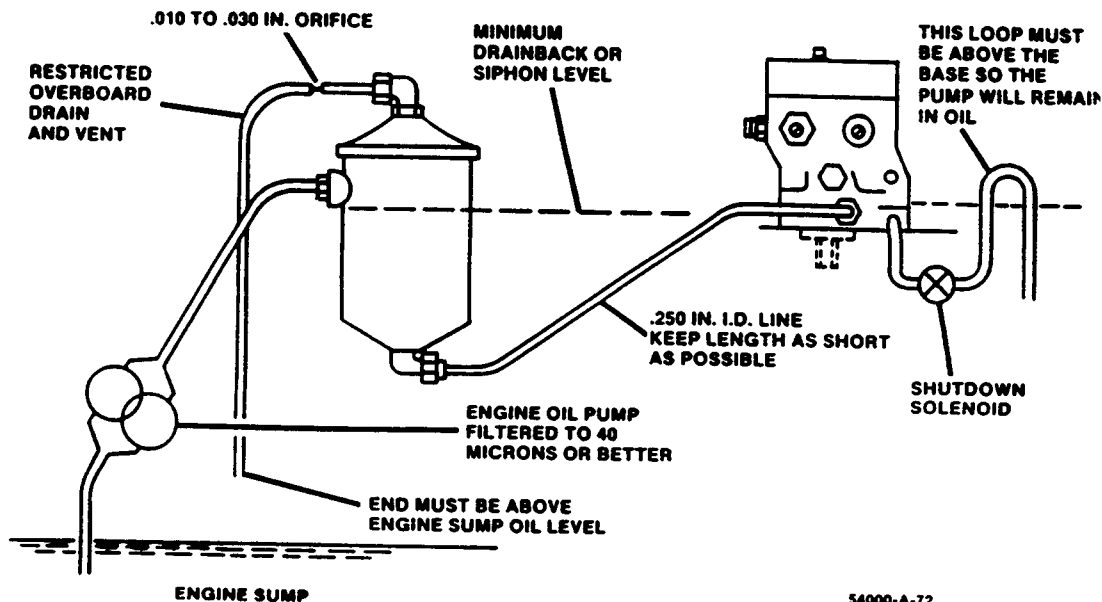
Be sure the governor/actuator is flushed well. Drain the kerosene or fuel oil mixture and refill with clean oil that meets your operating conditions. Don't forget that oil coolers and booster servos must be drained and refilled. Again, start the engine and run at idle with a slight hunt for 5 minutes. Drain the oil again and replace with clean oil. This prevents leaving oil that could be diluted and contaminated by the cleaning mixture. Follow the restart procedure as previously described.

OIL SUPPLIED BY THE ENGINE

SG, PSG, EG actuators, UA Actuators, Most 3161 Governors

These governors use the engine lube oil for governor oil. They must have a continual supply of oil from the engine in order to operate. The oil should be filtered to specific standards before being used in the attached governor.

Engine oil is almost always adequate for use in the governor. However, some multiviscosity oils with long polymers require a special handling. Engine oil supplied to a governor is usually at 25 psi or higher to the governor pump



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Figure 7-3. Engine Oil Connected to PSG Governor for Quick Start Up

For Fast Starts with Engine Lube Oil Supply

When governors/actuators use the engine lube oil supply and are used for emergency start up, it is recommended that an oil sump be used to furnish immediate oil to the governor/actuator. Otherwise, time is lost waiting for the engine lube oil to build pressure and pump oil to the governor/actuator. This can delay starting.

Chapter 8

Actuators

HYDRAULIC ACTUATORS

Electronic controls are widely used in the control of engines. However, some form of "muscle" is still required to move the fuel setting on the engine.

Actuators provide this "muscle" or force to move the fuel setting. These actuators receive a signal (voltage and current) from the electronic control. This signal is converted to mechanical force to move the output shaft. The linkage is connected to the actuator and to the engine fuel system in the same manner as a governor.

There are two basic types of actuators: "Proportional" and "Integrating."

The proportional type is one that gives a proportional change of output travel to a proportional change of input signal. Most proportional actuators designed by Woodward operated over the current range of 0 to 200 mA (Milliamps, Direct Current). They are calibrated to be at min-fuel position and max-fuel position for a given current. Many are calibrated for 20 mA to 160 mA, min to max.

The all electric actuator receives a pulse-width-modulated square wave from the electronic control.

Proportional actuators can be either "direct" or "reverse" acting.

In a direct acting proportional actuator the terminal shaft position increases proportionally as the signal to it increases. With zero signal in, the actuator is at minimum travel.

In a reverse acting actuator the terminal shaft position increases as the signal to it decreases. With zero signal in, the actuator is at maximum travel (full fuel to the engine). The reverse acting actuators are normally combined with a hydraulic/mechanical governor in one unit. This is called an EGB governor/actuator which will be discussed later.

The proportional actuator is the most commonly used actuator.

The integrating type actuator operates on what is known as a "Null" voltage

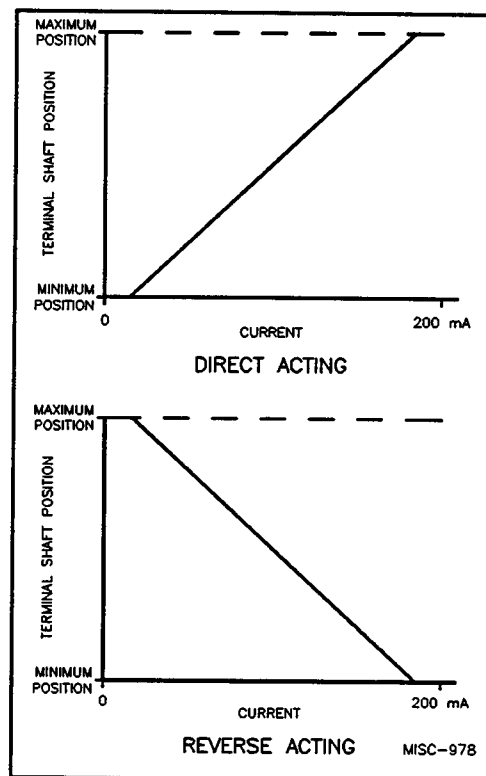
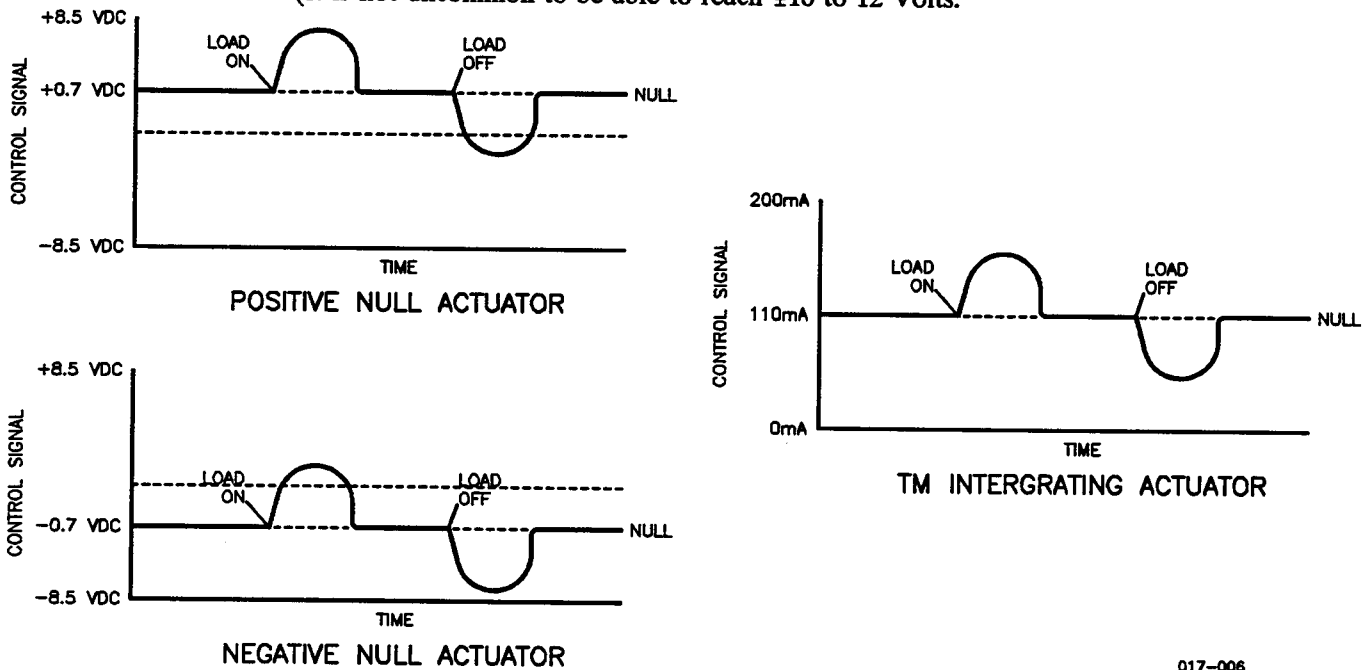


Figure 8-1. Direct and Reverse Acting Actuator Outputs.

or current. When operating at a steady speed or load the voltage and current from the electronic control is at "null". For EG type actuators this is normally 0.7 Vdc to 0.9 Vdc. Some systems use up to 1.5 Vdc. The "Null" voltage amplitude and polarity is adjusted and set by the null screw in the actuator, not by the electronic control. The null signal will be set for either a positive or negative null, depending on the application.

For the TM (torque motor) integrating actuators the null current is normally set for 100 mA to 120 mA by the null adjustment on the actuator. Its polarity cannot be changed.

EG type integrating actuators work with EGA or EGM controls. The output signal from these controls can go to at least +8.5 Vdc and at least (-) 8.5 Vdc. (It is not uncommon to be able to reach ± 10 to 12 Volts.



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Figure 8-2. Integrating Actuator Response Charts

As stated before, when operating at a steady speed on load the voltage and current are at their null level. If a load is applied to the engine, the electronic control will send the amount of volts and current necessary to increase the actuator travel and fuel to the engine to carry that load. As the new load is reached, the voltage and current to the actuator is integrated back to its original null level. The actuator is held at the new fuel setting to carry the load.

When a load is decreased, the null voltage and current will decrease the amount necessary to decrease the fuel the proper amount to the engine. As the new load is reached, the null voltage and current integrates back to the null level. The actuator is held at the new fuel setting.

For EG type integrating actuators, the null voltage and current can be set at either plus or minus. If the null voltage is set plus and the signal from the electronic control is lost, the actuator will go to the minimum fuel position. If

the null voltage is set negative and the signal from the electronic control is lost, the actuator will go to maximum fuel position. In the second case it is best to have the EGB type actuator.

The output of the TM integrating actuator can only go positive. If the signal from the electronic control is lost the output will go to minimum fuel.

ACTUATOR FAMILIES

Actuators may be divided into seven distinct families:

- EG ● UA/TA/UG ● All Electric (EPG) ● TM
- EGB ● Pneumatic ● PGEG

These actuators have many different amounts of work force, mountings, sizes, and features. See the Actuator Families Chart for a list of actuators. Refer to the actuator manual for details.

In many cases hydraulic actuators use many of the same features found in hydraulic governors. Many hydraulic actuators use the same type of oil pumps, rotating pilot-valve bushings, and pilot-valve plungers found in governors.

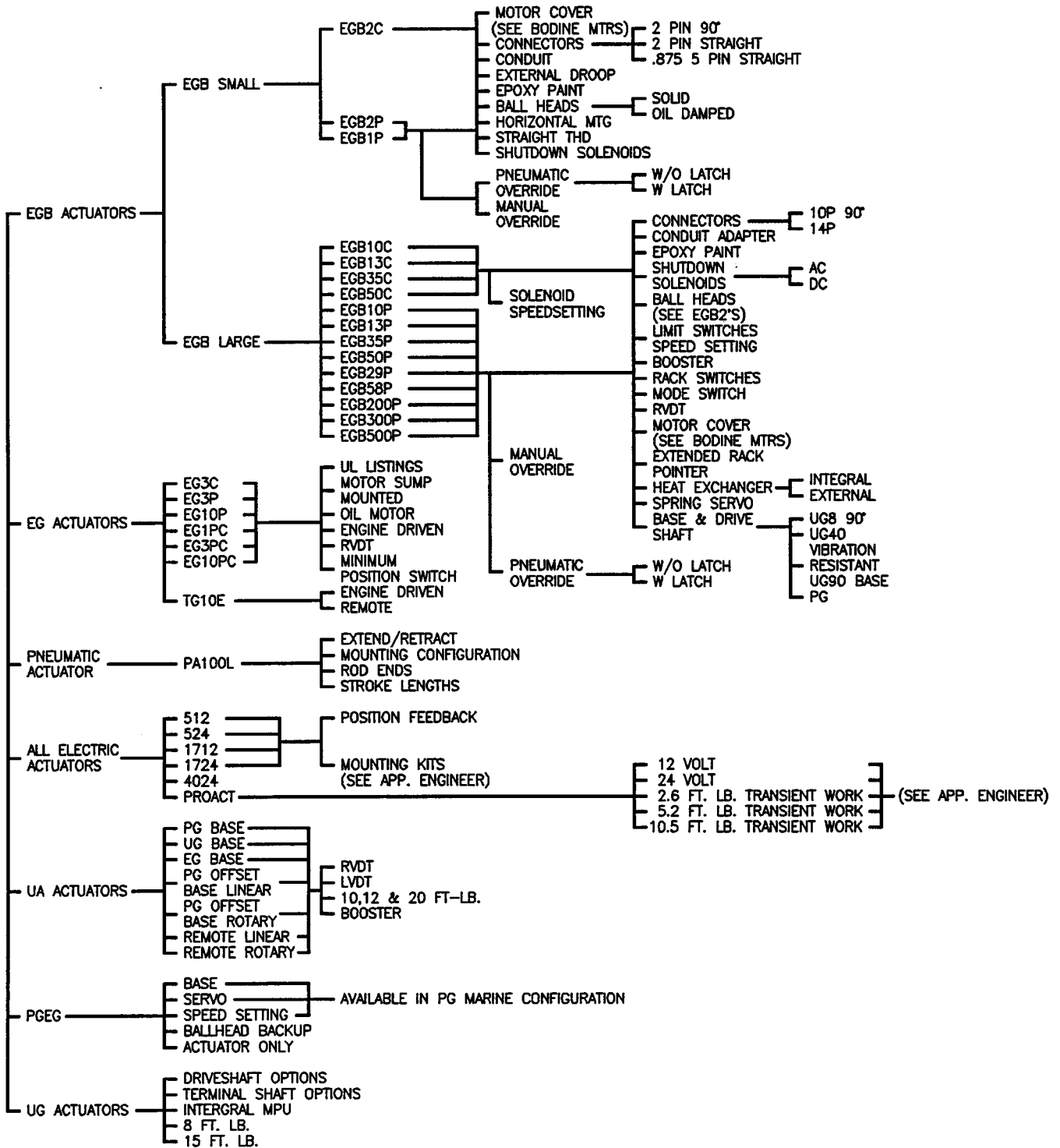


Figure 8-3. Actuator Families

BASIC ACTUATOR ELEMENTS

The five basic elements of an electro-hydraulic actuator are:

- Electrical transducer or torque motor
- Hydraulic pressure source
- Hydraulic Amplification
- Output Servo
- Stabilizing mechanism. if required.

Electrical Transducer or Torque Motor

The signal (voltage and current) from the electronic control is sent to a coil of an electro magnet in either the electrical transducer or a torque motor. The amplitude of this signal is what tells the actuator what position its output should be at.

Electrical Transducer

An electrical transducer is made up of two equal sized coils of wire connected in series. A permanent magnet is suspended on springs and placed in the center of the coils. A pilot valve plunger inside a rotating pilot valve bushing (similar to that in a governor) is connected to the permanent magnet. When the electronic control sends a signal to the actuator, current passes through the coils and makes the coils an electro magnet. The poles of the electro magnet and the permanent magnet are set up to be the same. Magnets with the same polarity repel each other and the permanent magnet is forced to move down, which moves the pilot-valve plunger down, and opens the port in the pilot-valve bushing to port oil to the servo, which will move the output shaft.

A torque motor also has a coil of wire in it which becomes an electro magnet when current flows through it. The force of this electro magnet acts on a metal beam that is pivoted such that as one end is pulled down, the other end goes up. As more signal is sent to the actuator, more current flows through the electro magnet of the torque motor and the beam is moved farther. The other end of the beam is placed over a nozzle or between two nozzles of high pressure oil. When this beam is moved closer to the high pressure oil nozzle it forces a change in pressure to occur. This change in pressure causes a pilot valve or a four-land spool valve to move in direct proportion to the amount of signal being sent to the control. The movement of the pilot valve or four-land spool valve will port oil to the servo piston, which will move the output shaft.

Hydraulic Pressure Source

Some actuators are driven from the engine drive, just like a governor. These have the same type of oil pump and regulators as described in Chapter 3 to make the oil pressure. Since an actuator does not have to sense the engine speed through the drive shaft (except for EGB and PGEG) some actuators can be driven by an electric motor or oil motor which in turn drives the pumps to supply oil pressure. Other actuators get their oil and pressure from an external oil supply. This can be a hydraulic oil pump just for the actuators or it can come from a high pressure lube oil system for the engine or turbine.

Hydraulic Amplification

For an actuator to have the power force or work to move the fuel system, it is necessary to amplify the force of the electrical transducer or torque motor. This is done by high pressure oil controlled by the force of the electrical transducer or torque motor, ported through valves and the use of internal linkage and pistons to increase the work output of the actuator.

Output Servo

The output servo or power piston is basically the same as a hydraulic/mechanical governor. It is used to move the output shaft of the actuator to move the fuel system on the engine.

Stabilizing Mechanism

Most actuators do not need a stabilizing mechanism. The electronic controls have adjustments to do the stabilizing. The EG3PC and EG10PC are the only actuators that have a stabilizing mechanism in the actuator. The reason for having a stabilizing mechanism is to keep the actuator stable at cold temperatures when multi-viscosity oil is used in the actuator. The stabilizing mechanism is similar to the pressure compensation system in a hydraulic/mechanical governor. It has buffer pistons, buffer springs, a compensation land, and a needle valve. This compensation does not provide temporary droop. It only provides a temporary assistance to help move the pilot valve for the above mentioned conditions.

Basic Operation--Proportional Type

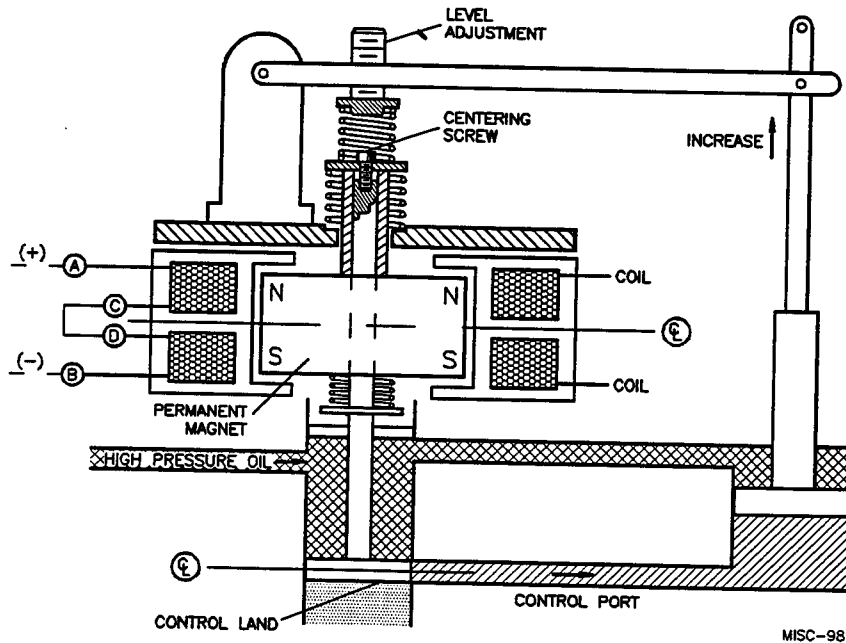


Figure 8-5. EG Proportional Actuator Schematic

When the electronic control sends a signal to the actuator to increase fuel, the transducer forces the permanent magnet and pilot-valve plunger in the down

direction. The port is opened in the pilot-valve bushing and pressure oil is ported under the servo piston. The servo piston moves up to increase fuel. There is a feedback lever that is attached to the springs which are suspending the permanent magnet. The feedback lever pulls up on these springs as the servo piston moves up. The upward pull on the springs pulls up the permanent magnet and the pilot valve plunger to center the pilot-valve plunger and hold the new fuel setting.

If it is necessary to calibrate the actuators, the calibration must be done on a test stand. The permanent magnet must be exactly centered in the coils of the electro magnet. To do this, the coils are temporarily wired from series to parallel and the "centering screw" is adjusted so that the actuator has no movement of the output terminal when the current in to it is changed from zero to 400 mA. The coils are then wired back for normal operation. The level adjustment is set for the proper travel of the output terminal at minimum fuel position for a specified milliamp input. The specified milliamps for the maximum travel is applied and the range adjustment is set for the proper travel of the output terminal. The level and range adjustments interact and these adjustments must be repeated until they are within the test specifications of the actuator being calibrated.

Integrating Type

When the electronic control sends a signal to the actuator to increase fuel, the transducer forces the permanent magnet and pilot-valve plunger down. The port is opened in the pilot-valve bushing and pressure oil is ported to the power piston. The power piston moves up to increase fuel. There is a lever that is connected to the power piston that rotates the terminal shaft. The other end of this lever is connected to the loading piston, which forces the loading piston down.

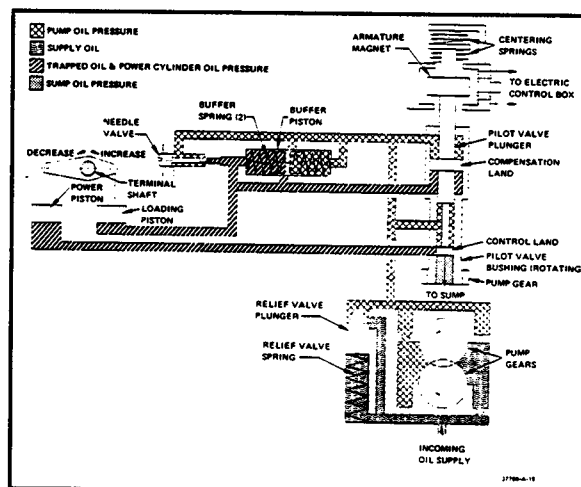


Figure 8-3. Basic EG Integrating Actuator Schematic

The loading piston pressurizes the oil under it and sends this pressurized oil to one side of the buffer piston and also under the compensation land on the pilot-valve plunger. The buffer piston moves over and pressurizes the oil on the top side of the compensation land. As the system is reaching the new fuel setting, less signal is being sent to the transducer and the pressure under the compensation land is pushing the pilot-valve plunger back to its closed position. At the same time, the pressure is equalizing across the compensation land through the needle valve. The buffer piston returns to center and the signal from the control has integrated back to the null voltage to hold the new fuel setting.

This actuator must also be calibrated on a test stand. The permanent magnet must be centered in the similar manner as the proportional actuator.

The null screw must be set to give the proper null voltage. NOTE: the polarity of the null voltage is important when setting the null screw. The null screw in the actuator is adjusted to either push up or pull down on the spring that suspends the permanent magnet. If it is set to pull up on the spring, the electronic control must send a positive null voltage signal to the transducer that will cause the transducer to push down on the permanent magnet an equal amount to keep the pilot valve centered. Should the signal from the electronic control be removed the pilot-valve plunger would move up (due to the null screw pulling up on the pilot valve) and move the fuel to minimum. If the null screw is set to push down on the spring, the electronic control sends a negative null voltage to the transducer to push up on the permanent magnet an equal amount to keep the pilot valve centered. Should the signal from the electronic control be removed the actuator would move towards maximum fuel. With a negative null voltage it is best to use an EGB type actuator do to the fact that loss of electrical signal causes maximum fuel and can cause overspeed. An EGB actuator, if properly adjusted, would prevent overspeed on loss of electronic signal from the control.

EGB (Ballhead Backup) Actuator/Governors
EGB 2, EGB 10,13, 22, , 29, 35, 58, 200, 300, and 500

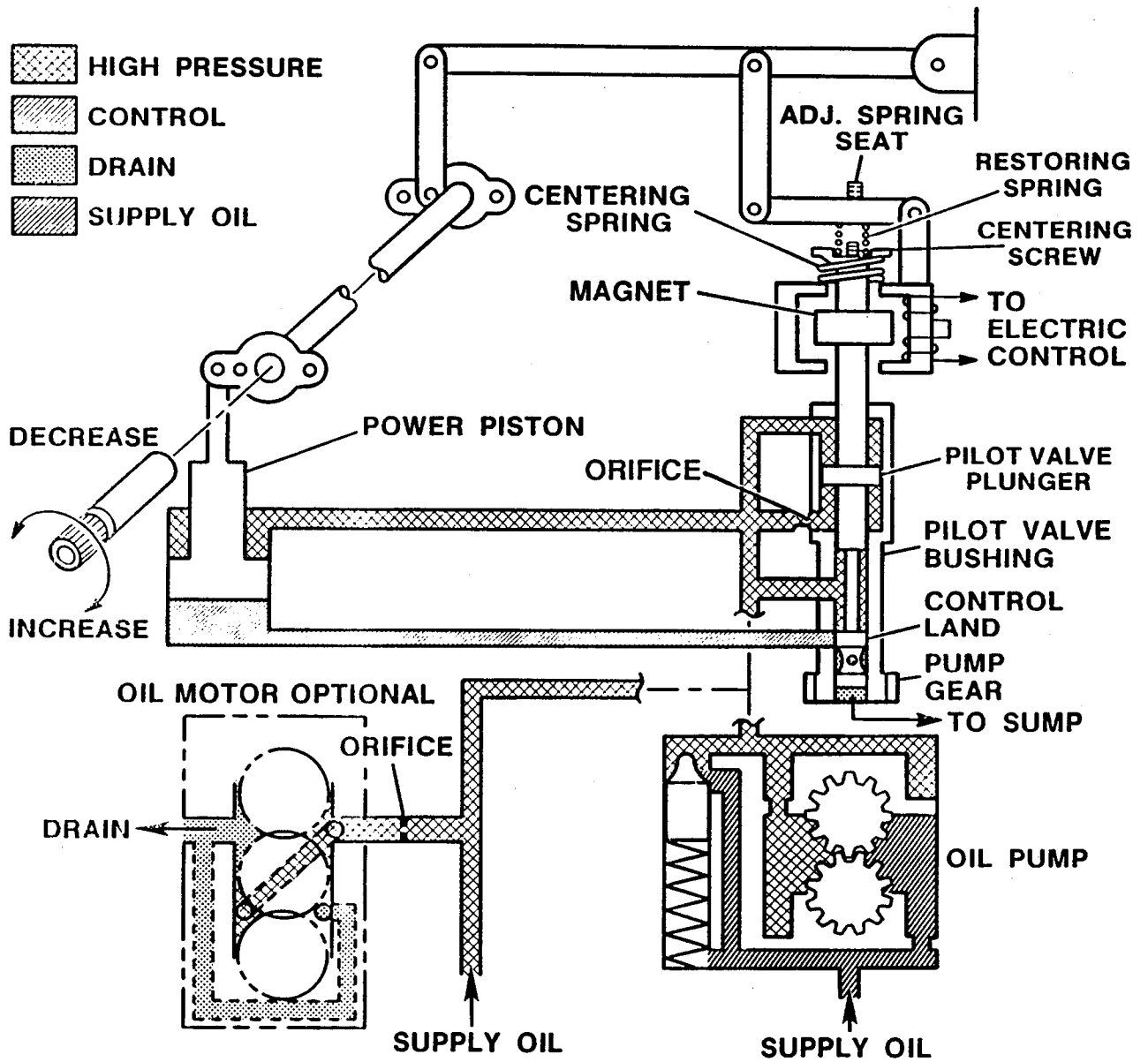
EGB actuators (Electric Governor with Ballhead Backup) provide a combination of a ballhead governor and hydraulic actuator in the same unit, using the same engine drive. The output of these devices takes the least fuel position required by either the electronic control or the ballhead speed sensing.

The ballhead portion of the EGB includes droop and compensation, allowing for either droop operation or isochronous operation. In operation the ballhead speed setting is normally set for a few RPM faster than the actual control speed. The electronic control then controls speed or load through the hydraulic actuator section. Should the loss of electronic control be set to fail toward increased speed or load; the engine will then continue to run (at a higher speed or greater load) under the control of the ballhead portion of the control. It should be noted that fuel to the engine could be increased to maximum under certain applications.

All of the EGB actuators are based on the functions of the EGB 2. An EGB 2 is included in all of the larger work output EGB units, with the rest of the unit serving primarily as a hydraulic amplifier to provide the muscle needed to move the fuel system. It is important to note that if the ballhead governor speed setting is not set properly above the speed setting of the electronic control, it can interfere with the operation of the electronic control. This can result in unstable operation and limiting of load carrying capability.

Electrically Powered Governors

The actuators of some electronic governor do not need a source of mechanical or hydraulic power. These actuators use electric power to move their output shafts. These actuators require a special matching electronic control to drive them; the combination of control and actuator is called an Electrically Powered Governor.



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Figure 8-4. EG-10P Schematic.

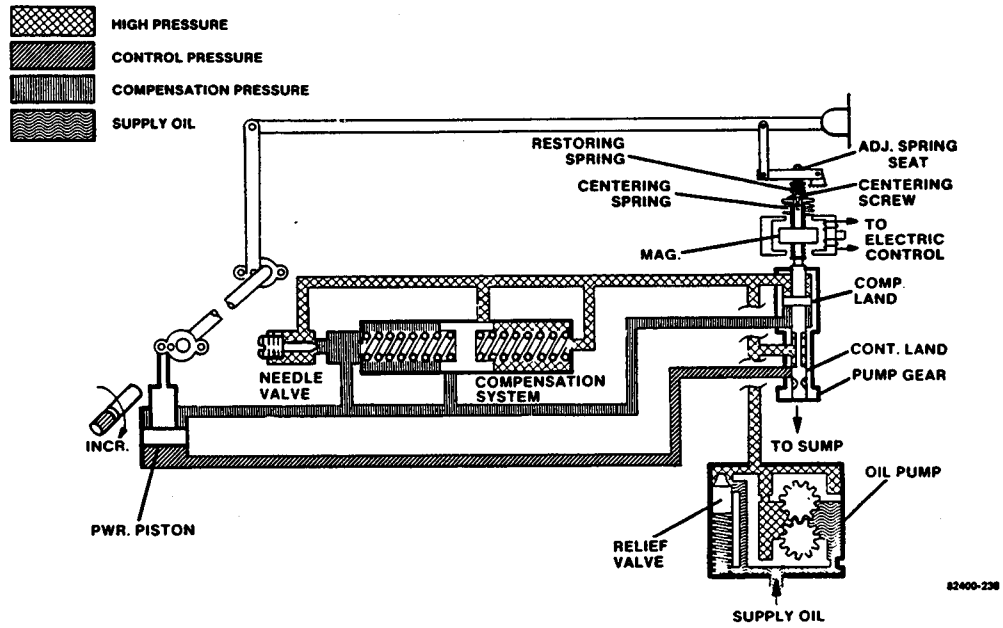


Figure 8-5. EG-10P Compensation System Schematic

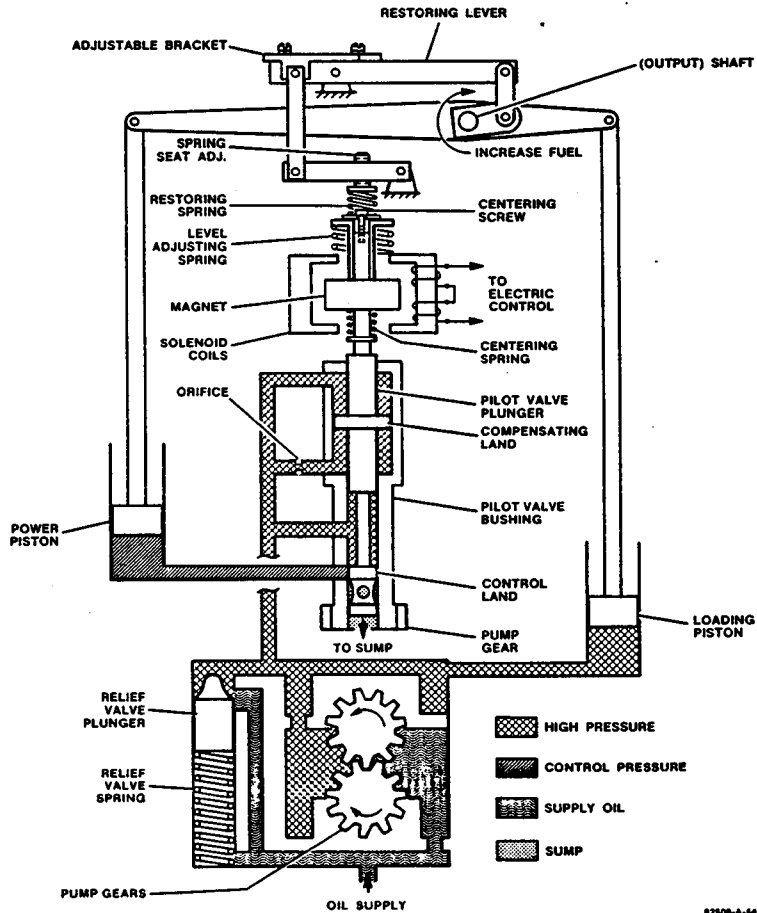


Figure 8-6. EG-3 Schematic

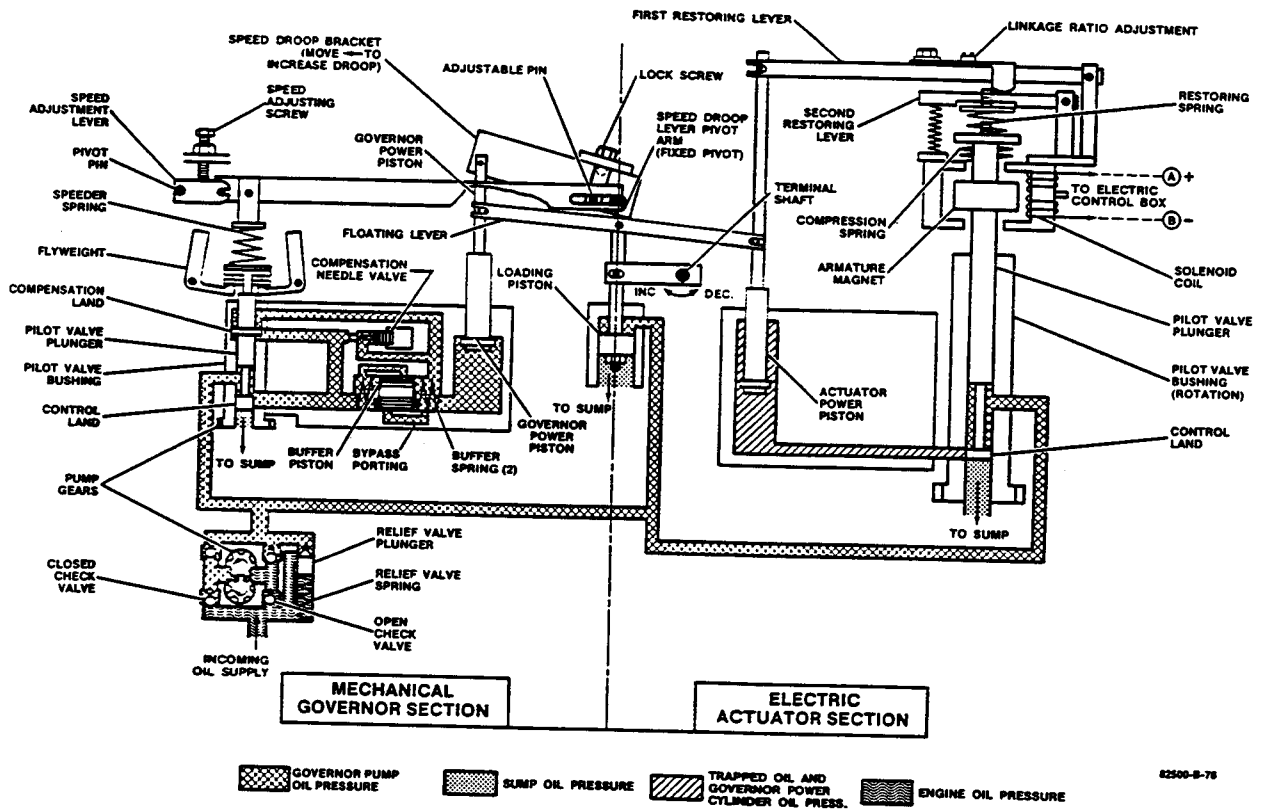


Figure 8-7. EGB-2 Schematic

FOLLOWER TYPE PILOT VALVE ACTUATORS

A number of actuators are available which use a "follower Type" pilot valve. This system does not use a rotating bushing to reduce friction, instead depending upon the operating pressures in the governor to move the pilot valve in much the same way that the differential power piston (servo) is moved.

The electronic transducer in these actuators is a torque motor working against a position feedback spring.

These actuators have been designed to provide direct replacements for UG and PG governors.

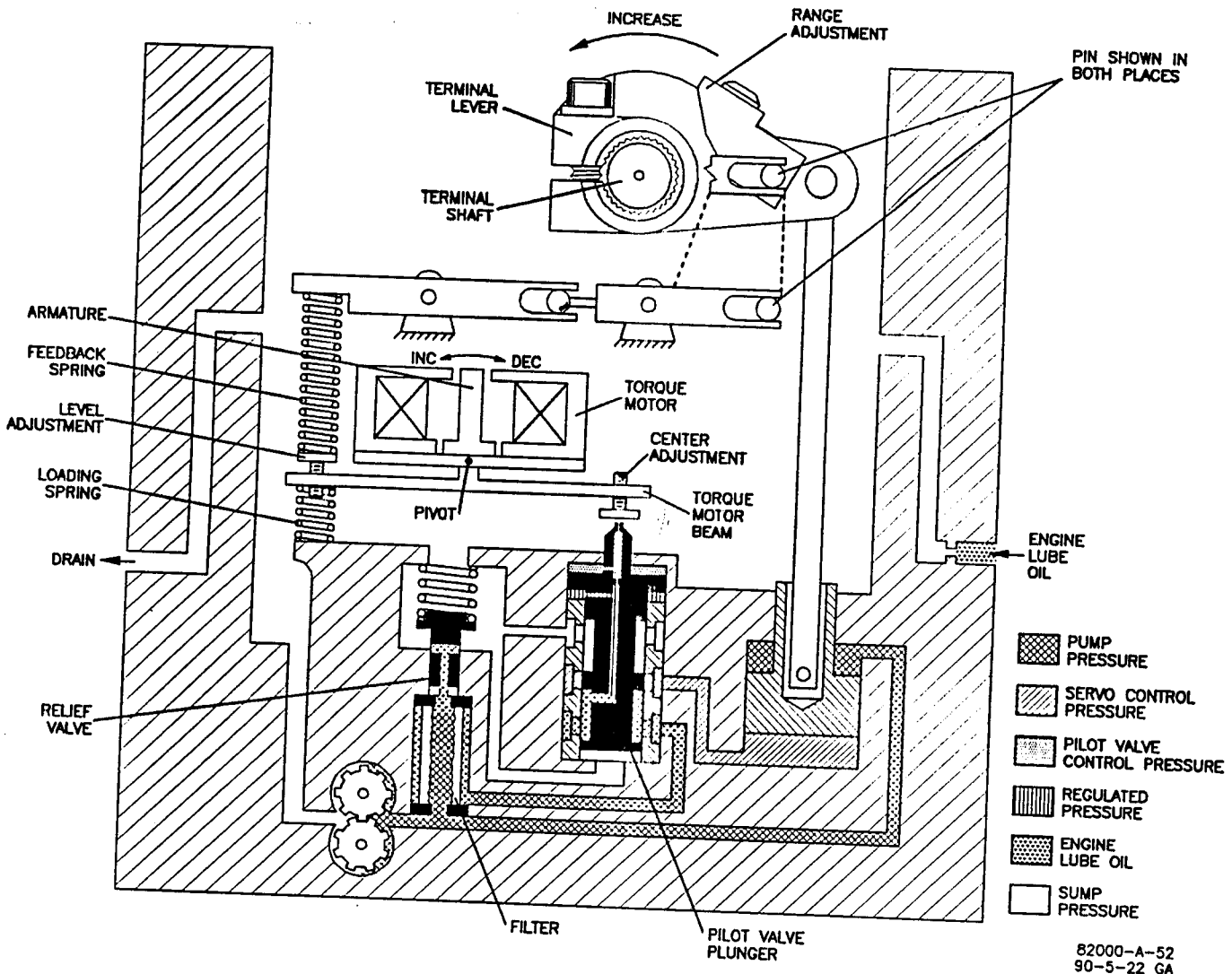


Figure 8-8. UA Actuator Schematic

PG-EG Ballhead Backup Actuator/Governor

A special type of actuator provides many of the PG features with a ballhead backup to a follower-type electric actuator. These controllers have an advantage over the EGB actuator/governor as the ballhead speed setting can "follow" the electronic speed allowing a more versatile backup should the electronic governing system fail.

BALLHEAD OPERATION

● ELECTRIC PORTION ISOLATED BY OPTIONAL MODE SELECT VALVE

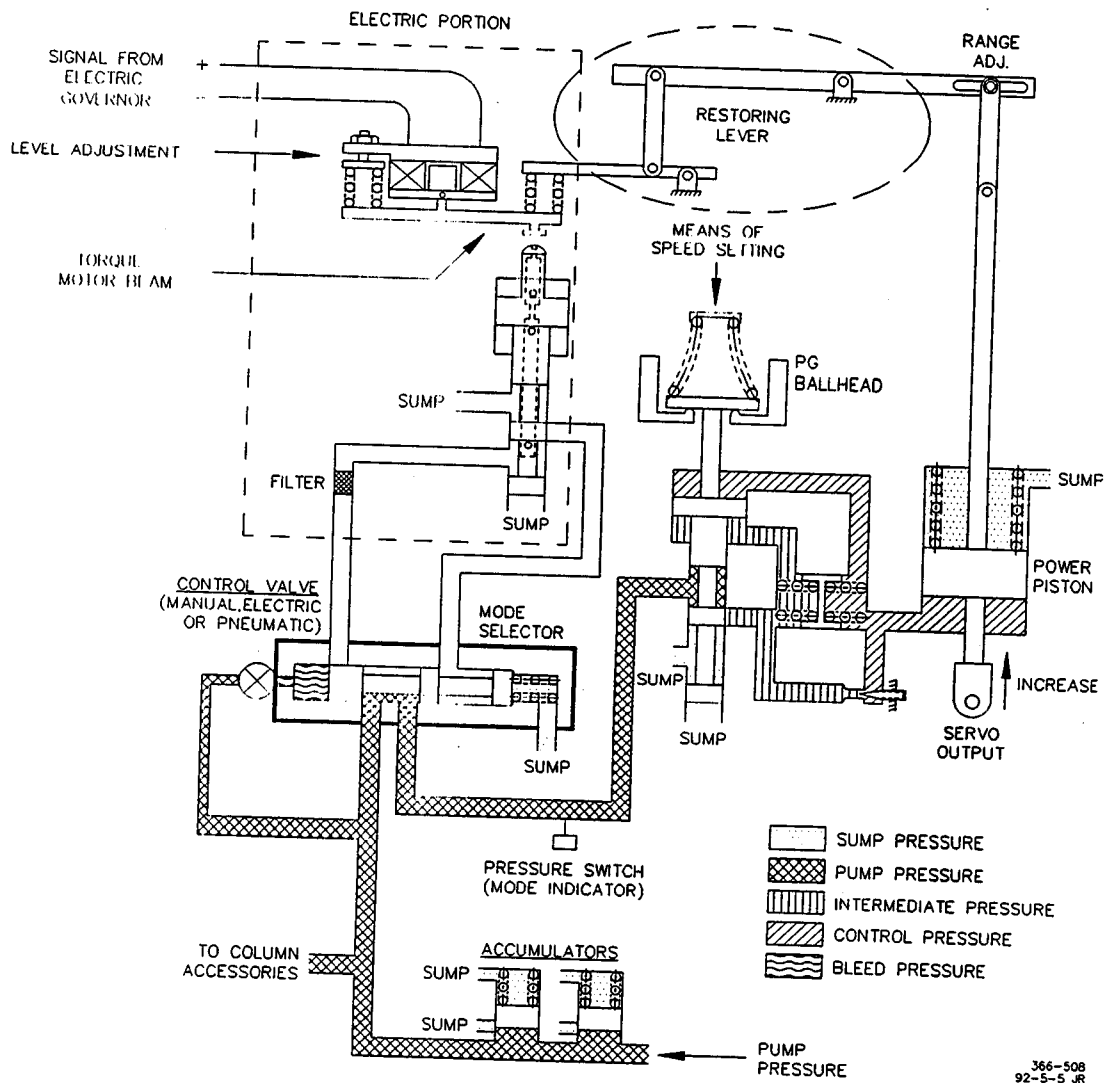


Figure 8-9. PGA-EG Actuator/Governor

Chapter 9 ELECTRONIC GOVERNING

INTRODUCTION

Woodward has been building electronic controls for more than 40 years. The need for isochronous load sharing of multiple generator sets and better ways of controlling parameters through current sensor lead to the development of electronic controls.

Over the years, electronic controls have been developed to keep up with the changing demands of modern systems. Their adaptability and reliability has led to widespread use of electronic controls in all types of applications. From simple speed controls, to load sharing and speed controls, to power management, to compressors and pipelines, to ignition and timing, to torque limiting, to complete locomotive controls, to sequencing, monitoring, and archiving of complete complex systems and much more, electronic controls have been proven and accepted in all phases of the engine and turbine control endeavor.

To understand how these electronic controls work it is necessary to learn some basic concepts. From the basic concepts it becomes easier to build an understanding of the more complex electronic controls.

The five fundamental components of a governor, as discussed in Chapter 1, still apply to electronic controls. Electronic controls have basically the same fundamental functions as do the hydraulic/mechanical governors. What the hydraulic/mechanical governor does the electronic controls do, and more. A comparison of hydraulic/mechanical governors to electronic controls will be discussed after a basic knowledge of electronic controls has been learned.

The key to understanding electronic controls is the summing point. This is where all signals (electrical forces) in a control loop add up and must equal zero to allow the electronic control to be controlling the engine at a steady condition. The summing point is electronically the same as the thrust bearing in a hydraulic/mechanical control where all the forces have to balance to equal zero. The advantage of a summing point is that many parameters in addition to speed can be sensed and sent to a summing point and controlled at a desired set point.

Just a few examples are speed, pressure, temperature, import and export of power, fuel limiting, and many more. In more complex controls several summing points may be used and the control can look at many parameters at the same time to ensure safe and proper operation of a complex engine or turbine system.

Chapter 10

Review of the Basic Operation of a Simple Speed Control and Summing Point

SIMPLE SPEED CONTROL AND SUMMING POINT

The basic speed control senses the speed of the prime mover by means of a magnetic pickup or in some cases by sensing the generator frequency. These are both AC signals with frequencies that are directly related to the speed of the prime mover.

The signal sensed is converted in the speed control to a DC voltage that is proportional to the speed of the prime mover. In other words, the faster the prime mover goes the greater the magnitude of the DC voltage developed. This voltage is referred to as the actual-speed voltage of the prime mover. This can be compared to the flyweights' force of a hydraulic/mechanical governor.

The speed reference or rated speed pot is connected across a regulated DC voltage source developed inside the control. By adjusting the rated speed pot, the desired speed voltage can be set (at the speed you want the prime mover to run). The speed reference can also be supplied from an external source such as a digital reference unit or a computer. This can be compared to the speeder spring in a hydraulic/mechanical governor.

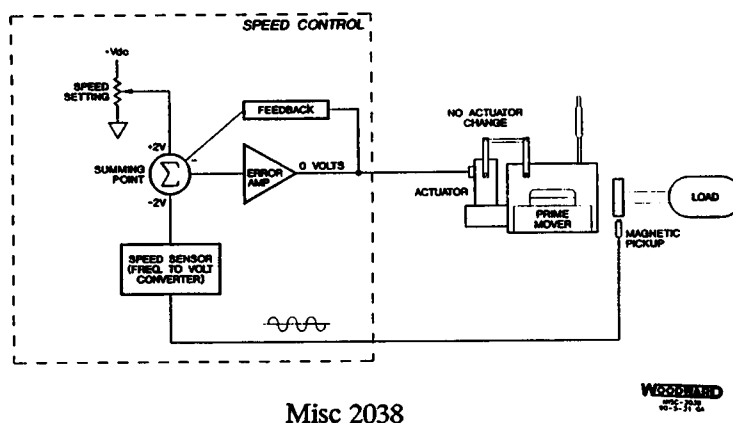
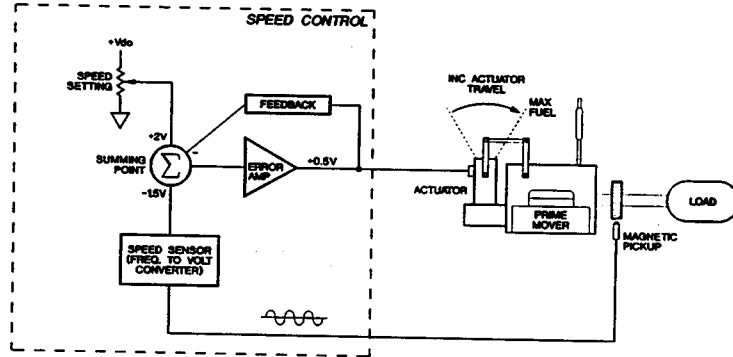


Figure 10-1. Block Diagram of Speed=Speed Reference Electronic Control

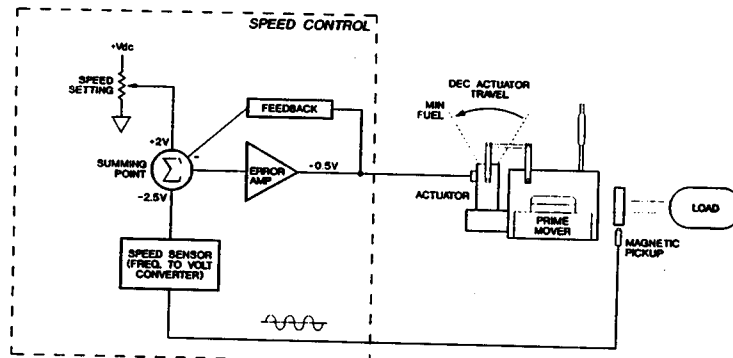
The desired speed voltage and the actual speed voltage are added algebraically at the summing point. The desired speed voltage is a positive voltage and the actual speed voltage is a negative voltage with respect to the control's signal common. When a positive voltage and negative voltage are summed together at the summing point, and they both have equal values but opposite polarity, the net result will equal "0" volts and the summing point is balanced. When these voltages sum up to zero volts, the prime mover is running at a constant and steady speed. This can be compared to the thrust bearing in the hydraulic/mechanical governor.



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Figure 10-2. Block Diagram of Speed is Less Than Speed Reference

If the net result at the summing point is positive, the prime mover is not running as fast as the desired speed is set for. A signal is sent from the amplifier to the actuator to increase the fuel in order to speed up the engine and increase the negative speed voltage. When the speed increases enough to balance out the summing point to "0" volts, the prime mover is again running at constant and steady speed.



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Figure 10-3. Speed is Greater Than Speed Reference

If the net result at the summing point is a negative voltage, the prime mover is running faster than the desired speed set. A signal is sent from the amplifier to the actuator to reduce fuel in order to slow down the prime mover and decrease the negative voltage to balance out the summing point to "0" volts. This process is a continuous action and causes the actuator to "feel alive" to the touch as the control makes minor adjustments.

Figure 10-4 shows a simple speed control with only two signals applied to the summing point, the desired speed set voltage and the actual speed voltage. Any change in speed, caused by a change in load or other disturbance, will cause a change in the summing point voltage. This change will reflect the increase or decrease in speed. Since the desired speed set voltage is fixed, the summing point amplifier output will be integrated up or down correcting the amount of fuel flow to bring the speed back to where the actual speed voltage again equals the desired speed set voltage and the summing point voltage returns to zero. This is basic isochronous- governor control.

EXAMPLE: In Figure 10-4, if the desired voltage is set for (+)2 volts and the actual speed voltage is (-)2 volts, the prime mover is running at a constant speed.

+2.0 Volts
-2.0 Volts
+0.0 Volts

Figure 31

If a load were applied to the prime mover, it would slow down somewhat. When it slows down, the actual speed voltage becomes less than (-)2 volt; for example (-)1.8V, the desired speed voltage is still set for (+)2V.

+2.0 Volts
-1.8 Volts
+0.2 Volts

When these voltages are summed together, the net result is a (+)0.2V and the amplifier sends a signal to the actuator to increase fuel. As fuel is increased, the prime mover increases speed and the actual speed voltage is increased back to (-)2 volts. The voltages now sum up to "0" volts at the summing point. The opposite effect happens when a load is removed from the prime mover.

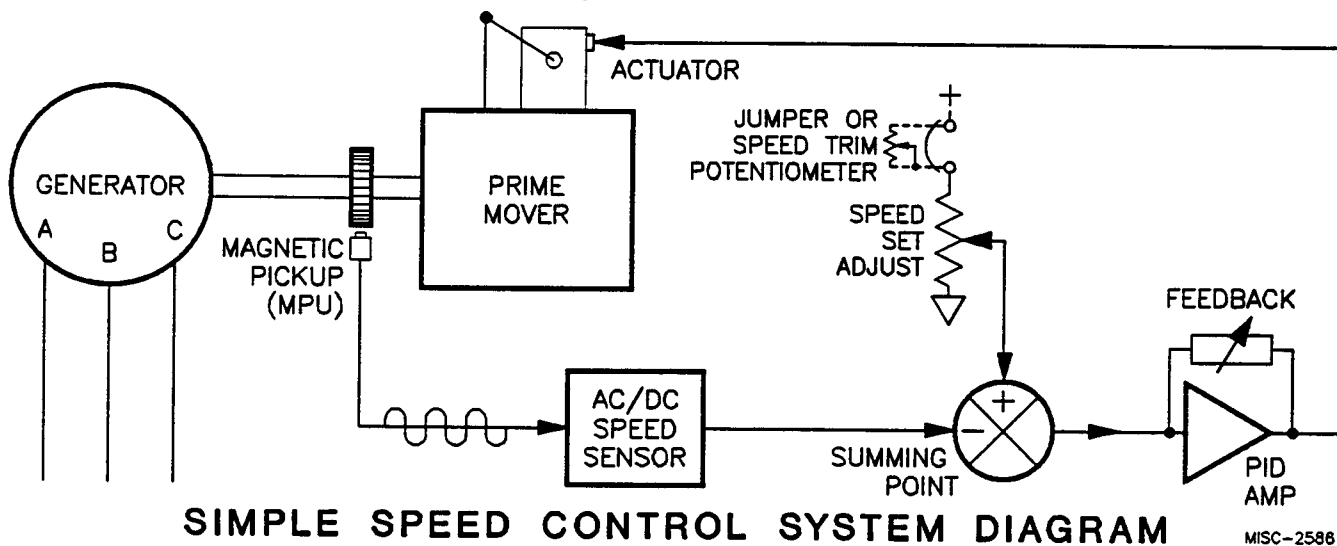


Figure 10-4. Simple Speed Control System Diagram

The summing point is the key to understanding the operation of all Woodward Governor Company analog controls. Digital electronic controls operate on basically the same principle, with the use of digital rather than analog circuits.

Keep in mind; a positive voltage sent to the summing point will increase fuel and a negative voltage will decrease fuel. The increase or decrease of fuel will effect speed or load on the engine depending on it's application and use at the time.

NOTE

The voltages used in the example are for explanation purposes only. No attempt should be made to read the voltage at the summing point.

If the above system were tied to an infinite bus or utility grid, the speed/frequency of the engine-generator would be fixed by the bus or grid. Thus both the speed set voltage and the actual speed voltage would be fixed.

Under this condition, if the set speed is different from that of the infinite bus or utility grid, the summing point would be unbalanced and the summing point amplifier output would integrate up or down trying to correct the offset. This would cause the engine-generator to either overload or motorize.

Obviously, there must be another signal fed to the summing point if we are to regain control of the engine-generator output. This signal comes from the Load Sensor. The Load Sensor will provide a signal to the summing point to allow a feed back similar to what the droop lever does in a hydraulic/mechanical governor. Signals from other controls such as the GLC, AGLC, Process-Import/Export or APTL can also be accessed through the load sensor.

Chapter 11

Load Sensing, Load Sharing, Base Loading

LOAD SENSING

The generator load sensor gets its name from the fact it senses the load on a generator. To sense this load, current transformers (CTs) are placed around the power output leads coming from the generator. As load is applied to the generator, alternating current flows through the generator lines and induces current into the CT's. The current in the CTs increases proportionally with the load on the generator (See Figure 11-1).

The induced current from the CTs is added vectorially and then is converted to a DC voltage in the load sensor.

However, since only real power is to be used in determining the load sensor output, potential transformers are also connected to the power output leads of the engine-generator. Only CT current which is in phase with the potential transformer voltage is used and converted to a DC voltage in the load sensor. This DC voltage is proportional to the percent of load on the generator. The generator load sensor DC voltage is applied across a "Load Gain Adjust" potentiometer. See Figure 11-2.

LOAD GAIN ADJUST POTENTIOMETER

This Load Gain Adjust potentiometer provides a means of setting a specific voltage, selected from the load sensor output, to represent the load on the engine-generator set. This load gain setting is normally at set 6 Vdc for 100 percent of the set's rated load. The output of the generator load sensor is linear so that voltages from zero to 6 Vdc represent loads from zero to 100 percent of the set's rated load. This load gain voltage is impressed across a balanced load bridge.

BALANCED LOAD BRIDGE

ISOCRONOUS

The balanced load bridge (see R1, R2, R3 and R4, Figure 11-2) is a device similar to a Wheatstone bridge. In this bridge $R1=R2$ and $R3=R4$. As long as the voltage developed across R1 equals the voltage developed across R3, which also means that the voltage developed across R2 equals that across R4, there is no voltage differential across capacitor C. The output of the load bridge to the summing point is zero. This is true regardless of the load gain voltage. The control is in isochronous. The load does not affect the speed or frequency.

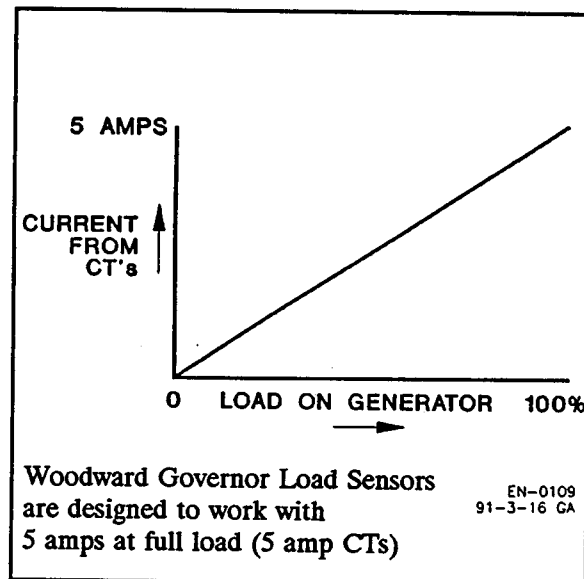


Figure 11-1. Generator Load Sensor

SIMPLE SYSTEM LOAD SENSING DIAGRAM

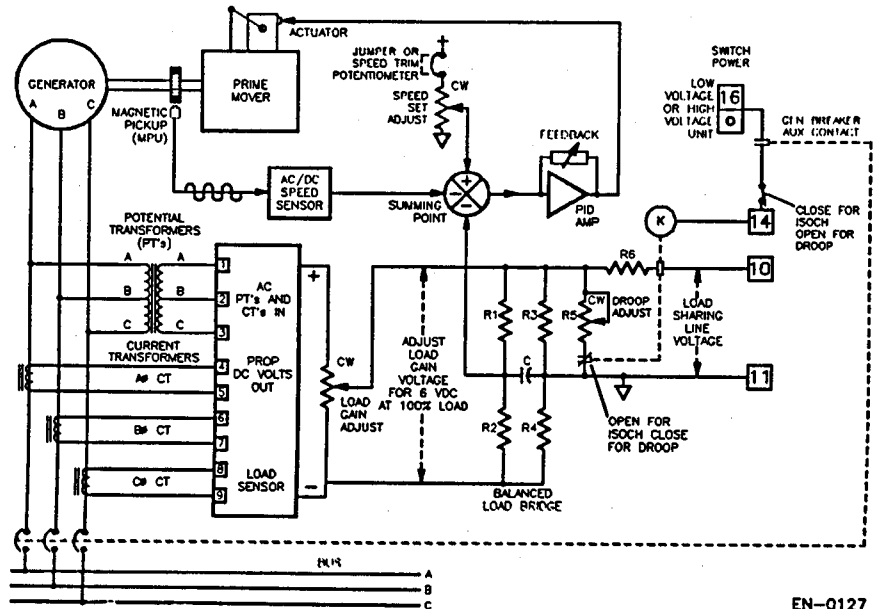


Figure 11-2 Balanced Load Bridge

DROOP

The load bridge may be unbalanced by either changing the value of a resistor in one leg of the bridge or by applying an unbalancing voltage across one leg of the load bridge. If you unbalance the load bridge by paralleling R5 with R3, the resulting resistance of (R3, R5) is less than R4. The voltage developed across (R3, R5) will be less than that developed across R4. The voltage developed across R1 and R2 are each still at 1/2 the load gain voltage. A voltage is now present across C with a value that will be determined by the load gain voltage and the amount of imbalance caused by R5 in parallel with R3. The voltage across C applied to the summing point will be negative with respect to circuit common. C is not required to make the bridge work. The time to charge and discharge the capacitor does slow down the load bridge action. This is necessary to ensure that the load bridge is not faster than the speed loop. If it is, oscillation will result.

At the summing point, the negative signal from the load bridge adds to the negative signal from the speed sensor. To obtain a summing point balance, the amplifier will act to reduce the speed until the sum of the two negative input signals equals the positive input signal from the speed set adjust. The control is in droop. The speed or frequency will decrease proportionally with addition of load.

To return the system to rated speed, it will be necessary to either increase the speed set adjust voltage or to re-balance the bridge and return the system to isochronous control.

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LOAD GAIN ADJUSTMENT

Start the engine and apply full load. Measure the LOAD SIGNAL voltage at the Load Gain test points on the control. Adjust the Load Gain potentiometer for six volts* If full load is not attainable, set the LOAD GAIN proportionally to the load. For example, at 50% load, adjust the LOAD GAIN to 3 volts (also see section on "Setting LOAD GAIN and droop when against utility").

When paralleled in the isochronous mode or on an isolated bus, generator speed and voltages must be the same. If they are not equal, load sharing will not remain proportional as the load varies. Any difference in loads between the units can be corrected by adjusting the Load Gain Potentiometer. Increasing the LOAD GAIN (turning the potentiometer clockwise) will cause that generator to carry less load. If stability problems occur when paralleled to another generator at a particular load-signal voltage, reduce the voltage by reducing the LOAD GAIN (turn the potentiometer counterclockwise), and reduce the load-signal voltage setting of all other generators in the system to the same voltage. When the load-signal voltages of all generators in a system are reduced, the load-sharing gain of the system will be reduced and this results in some loss of load-sharing sensitivity.

- * If six volts at full load (or lower voltage proportional to the load) cannot be attained, check the phasing of the potential and current transformer. If the phasing is correct, the current transformers could be the wrong size. The current-transformer output must be from 3 to 7 amps (5 amps nominal) at full load.

It may be necessary to reduce the load-signal voltage of each unit in the system to as low as three volts at full load in cases of extremely poor system dynamics. If your system requires a load-signal voltage as low as three volts, consult Woodward Governor Company for suggestions for possible remedies.

DROOP ADJUSTMENT FOR LOAD SENSORS

Proper percent of droop must be set when a generator set is to be operated in droop. The normal recommended droop is 3 to 5%. The percent of droop is dependent on the amount of LOAD GAIN voltage therefore, proper phasing and LOAD GAIN voltage setting must be done before setting droop. The generator set must be loaded to set the droop. An isolated load or a load bank is a simple way to set droop. If an isolated load or load bank is not available, LOAD GAIN and droop can be set using the utility as a load.

WARNING

Do not use this procedure for hydro-mechanical governors as their droop rate is not adjustable in this manner.

Determine or select the desired governor system droop percentage (normally between 3 and 5%).

Calculate the desired frequency change by multiplying the rated generator frequency (60.0 Hz) by the desired droop percentage. (Example: 60.0 Hz times

3% droop = 1.8 Hz.) This means that for an isolated load and 3% droop, from no load to full load, the speed would decrease or droop 1.8 Hz or from 60 Hz to 58.2 Hz.

When using the utility for a load and setting 3% droop, the no load speed would be 1.8 Hz above the full load speed or 60 Hz or 61.8 Hz no load and 60 Hz full load. Both will give 3% droop, no load to full load.

If you are unable to attain full load these same adjustment step values can be made in proportion to the load you have available. Examples reduce all adjustment step values by the percentage of load available. (The greatest accuracy is at full load.)

Example: 3% droop and 50% load available:

$$3\% \times 60 \text{ Hz} \times 50\% \text{ load}$$
$$.03 \times 60 = 1.8 \times .50 = .9 \text{ Hz.}$$

SETTING DROOP FOR AN ISOLATED LOAD

1. Calculate the desired droop from no load to full load.
 2. Place the unit in the droop mode of operation.
 3. Start the engine and adjust the RATED SPEED potentiometer for rated speed with no load.
 4. Apply full load*.
 5. Adjust the droop potentiometer to give the calculated speed decrease.
- * If full load is not available, calculate the percent of full load available. Multiply that percentage times the amount of Hz decrease for full load droop. Adjust the droop for the calculated value.

SETTING THE DROOP AND LOAD GAIN VOLTAGE USING THE UTILITY TO OBTAIN LOAD

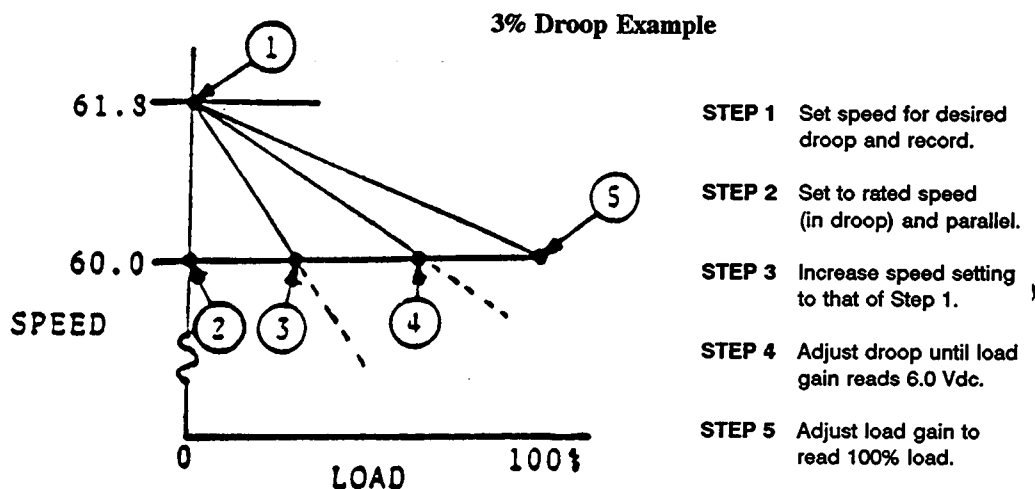
Refer to the 3% Droop Example that Follows These Instructions

NOTE 1: If your actuator is equipped with a ballhead backup governor, be sure the ballhead speed setting is set at least 0.5 Hz above the value chosen.

1. With engine running at rated speed and no load, (breaker open), increase the speed setting by the frequency change calculated with the desired percent droop (i.e. to 61.8 Hz, see example set 1). Record this speed setting position (i.e. by marking the manual potentiometer position or recording speed trim voltage or position.) Then return speed setting to 60 Hz (see example Step 2.
2. Pre-set both the droop and load gain potentiometers fully CW.

Note 2: For some systems, these settings may be too high. If your system becomes unstable when the breaker closes, open the breaker and reduce the setting from CW (10 position mark) to the 7 position mark and continue the procedure.

3. Select the droop mode of operation.
4. Properly synchronize and close the generator breaker to the utility. After assuring that everything is OK, slowly move the speed setting back up to the NO LOAD speed setting point recorded in Step 1. The unit should respond by picking up some load (see example).



For the above example when only 50% load is available:

- STEP 1** = 61.8 Hz x 50% load = 60.9 Hz.
STEP 4 = 6 Vdc x 50% load = 3 Vdc.
STEP 5 = Adjust for 50% load.

NOTE 3:

CAUTION

Settings 4 and 5 are non linear. Make small incremental movements to prevent overload.

5. Increase the load on the unit again, this time by turning the droop potentiometer CCW until the load gain voltage reads 6.0 Vdc*. The unit should not yet be at the 100% rated load level at this load gain voltage reading (see example).
- * 6.0 Vdc is usually the desired value for load sensors used at Woodward Governor Company (see example).
6. Increase the load to 100% rated level, this time by turning the Load Gain potentiometer CCW.
7. The droop and load gain adjustments are now complete. Unload the unit by reducing the speed-setting adjustments until near zero load and then open the breaker.

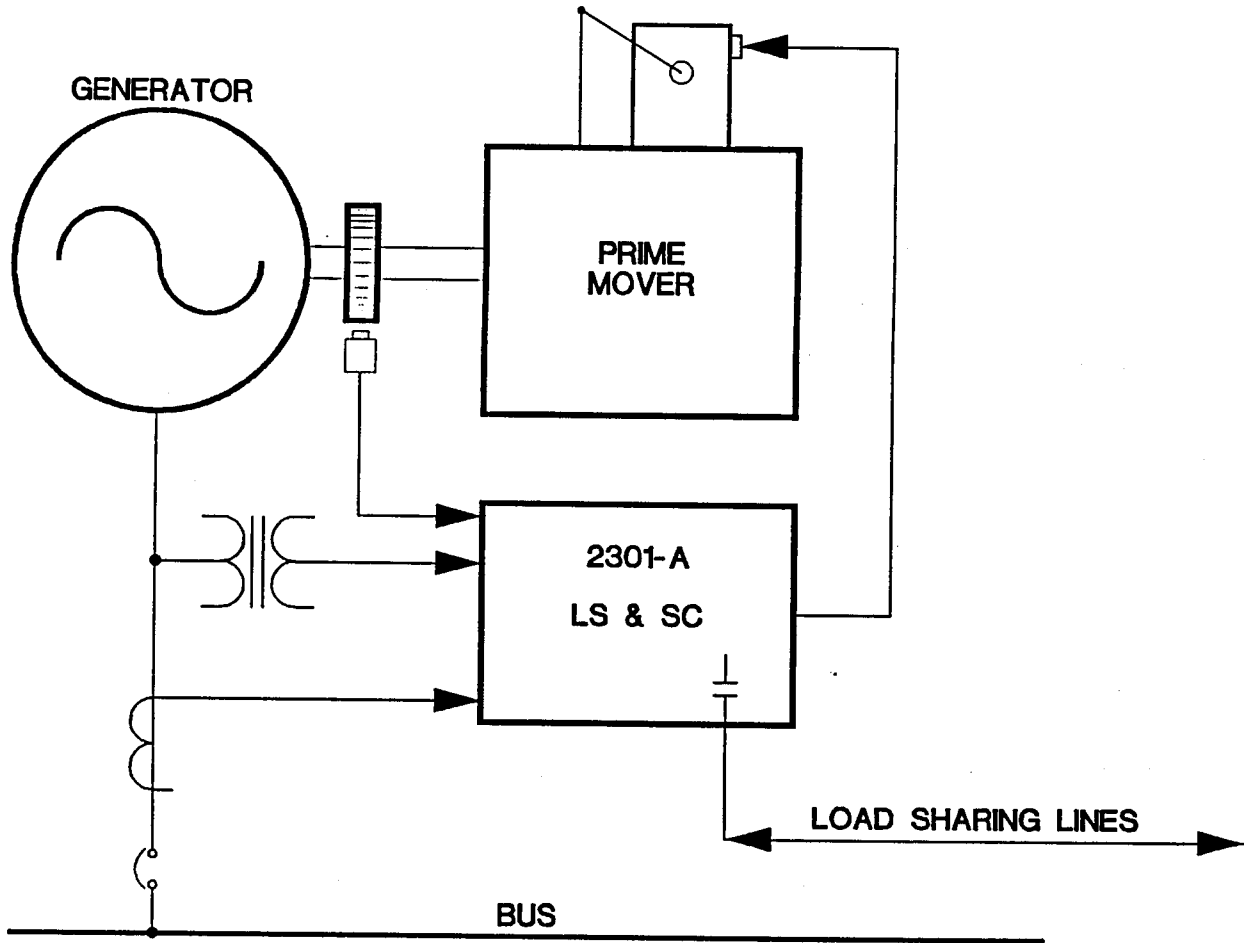


Figure 11-3. Basic Load Sensing Block Diagram

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LOAD SHARING

The action of the load bridge is also used to bring about isochronous load sharing. Instead of unbalancing the load bridge by changing the resistance of one leg of the bridge, parallel one leg of a bridge from the control on one engine-generator set with the corresponding bridge leg of the control of a second engine generator set. (See Figure 11-2.) As long as both sets are providing the same voltage across these connected lines there will be no imbalance to the load bridge. The summing point is then returned to zero when the speed set and speed sensor signals are equal.

Take two engine-generator sets and adjust each set's load gain for 6 Vdc at 100 percent of that set's rated output. The voltage developed across R3 of each balanced bridge will be 1/2 of that set's load gain voltage or 3 Vdc at 100 percent of rated load. Start one set and load it to 100 percent of rated load. Start the second set and bring it on line at zero load. Simultaneously, when paralleling the two sets, connect the R3 leg of the balanced bridges of the two sets together by means of the load sharing lines. (See Figure 11-2.)

The voltage across the two R3's are different at the time when set two is brought on line. The R3 of set one is at 3 Vdc indicating 100% load and that of set 2 is zero indicating no load. These differences will balance out through R6 and R3 to a voltage between zero and 3 volts. Both load bridges will be unbalanced, but in opposite sense. The voltage developed across C of the first unit will call for reduced fuel and that of the second for increased fuel. This imbalance will disappear as the two generator sets approach the same percentage of rated output.

Where both engine-generator sets are of the same output rating, the outputs of the two units will both come to 50 percent of their rated load. The load gains will both be at 3 Vdc and the voltages across the R1's and R3's will all be 1.5 Vdc. The bridges of both sets are balanced. The bridge outputs are zero and the sets are in isochronous load share at rated speed. Voltage across the load sharing lines would be 1.5 Vdc.

If the oncoming engine-generator set is rated at only one-half that of the first sets rating, say the first was rated at 100KW and the second at 50KW, balanced load would be achieved when each engine-generator set is carrying its proportional share based on its rated output.

$$\text{Rated share } X = \frac{100 \text{ KW Load}}{100 \text{ KW} + 50 \text{ KW}} \text{ or } X = 2/3 \text{ or } 66.67\text{percent}$$

Load gain outputs would match at 2/3 of 6 Vdc or 4 Vdc. Voltages across the R1's and R3's would be 2 Vdc. The load bridges would return to balance when the first machine was carrying 66.67 KW and the second would be carrying 33.33 KW. The sets are in isochronous load share rated speed. Voltage across the load sharing lines would be 2 Vdc. Each set would be carrying its proportional share of the load.

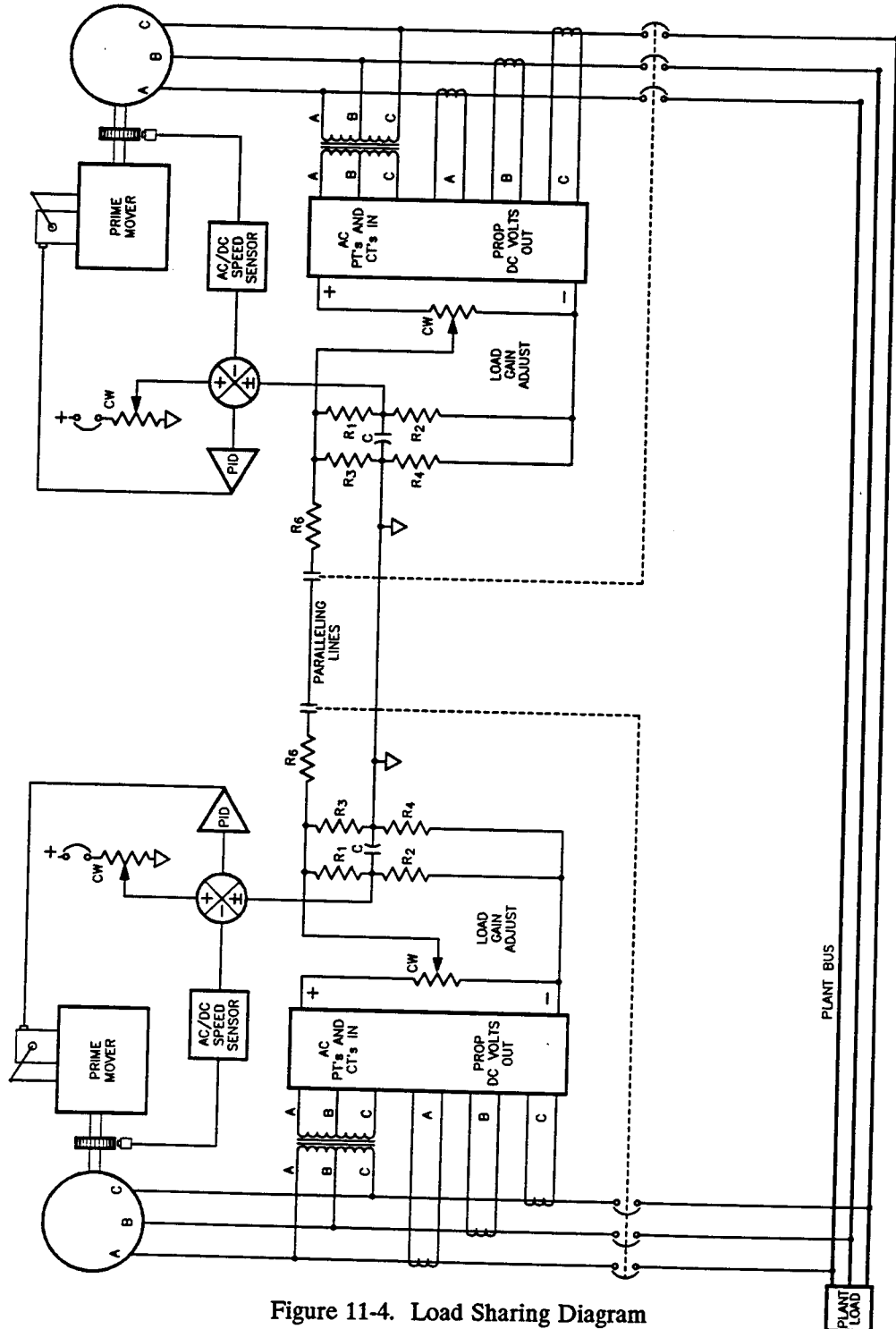
This method of connecting the load bridge between controls of multiple engine-generator sets, which are supplying the same load, can be used to obtain load sharing between a number of different sets. See Figure 11-3 and 11-4. The maximum number of sets which can be controlled in this manner has not been determined. One known installation has 21.

POWER OUTPUT SENSOR

The load sharing of mechanical loads or of mixed electrical and mechanical loads uses a different type of load sensing. The most desirable method of sensing load would be to measure the torque on the engines, but this is difficult and requires very special measuring devices. The more common method, based on the assumption that power output is relative to actuator position, is to use a signal developed from the control output (either current or voltage) to the actuator coil. Here, the current is the more desirable since force at the actuator is based on ampere turns. If the actuator coil resistance changes with temperature, the change does not affect the current load signal.

Another signal that can be used is one developed from the fuel valve position.

This method makes use of Hall effect devices or of either LVDTs or RVDTs (linear or rotary variable differential transformers). These devices require modulators/demodulators to supply an AC voltage to the position sensors and to rectify the return signal. A DC signal is developed representing fuel valve position. For load sharing these DC voltages relative to output load do not have to be exactly linearly proportional to the load to be useful for load sharing. They do need to be



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Figure 11-4. Load Sharing Diagram

equal from each engine in the load sharing system for any particular percent of each engine's load capability. Again the sensor output is impressed on a load gain adjustment potentiometer.

The above load sharing analysis can also be applied to a system using power output sensors to accomplish load sharing. The summing point amplifier in the control of each engine will integrate to a fuel position which brings the load bridges in each control to balance. This will set the fuel system of each engine to the same power output whether the load on a particular engine is electric, mechanical or a combination of electric and mechanical. The actual load sharing will depend on how closely the fuel systems of the different engines track for the same percentage of rated load.

ISOCHRONOUS BASE LOAD

If an engine-generator set is under the control of a load sharing and speed control or if it is in an isochronous load sharing system, connecting the system to a utility will fix the speed sensor input to the summing point. Since the speed set is also at a fixed set point and the system is in isochronous, one of two things will happen. Either the system will be motorized or it will go to overload. The summing point, having all inputs fixed, cannot correct what it sees as an imbalance. If the system was at a frequency slightly below that of the utility, the speed sensor will send a signal to the summing point in excess of the set point input. The amplifier will integrate in a decreased fuel direction, cutting fuel to the engine. The utility then ends up driving the system. If the system frequency was slightly higher than the utility, the speed signal to the summing point would be below the set point, resulting in increased fuel until the mechanical stops are reached.

To prevent these two conditions and to set the desired load, an auxiliary bias signal can be applied to the system load sharing lines. This will set a demand on the generating system to generate a given portion of each engine-generator's rated output. The action is the same as when load sharing units unbalance the balanced load bridges. The load bridge outputs to the individual set summing points will be either positive or negative based on whether the engines are to pick up load or to shed load. Again, when the output of the engine-generators balance the voltages on the load bridge, the system will be at the desired load. The summing point can now function to correct imbalances and the system is under isochronous base load control.

If we now connect such an isochronous load sharing system to a utility, where the speed/frequency is fixed by the utility, and we place a fixed bias signal on that system's load sharing lines, all units in that system will be forced by load bridge imbalance to carry the load demanded by the bias signal. This control method opens many possibilities for load management through Isochronous base loading.

Refer to manual 01740 for more information on Power Management.

Simplified Unloading Scheme for Electronic Governors

It is practical to unload an engine from a parallel-lines load-sharing system before opening the circuit breaker. This will protect the circuit breaker from excessive arcing and allow the engines remaining on the system to avoid excessive frequency/voltage swings as the additional load is accepted.

AUTOMATED EQUIPMENT

Woodward can provide a wide range of generator control equipment to permit controlled loading and unloading procedures on preestablished scales, and the use of this equipment is recommended for optimal generator efficiency, switch life, and frequency/voltage control. A listing of this equipment and related publications is included at the end of this application note.

INEXPENSIVE UNLOADING SYSTEM

Multiple engine installations which do not include any of the sophisticated electronic equipment, but which use isochronous load sharing may avoid damage to contacts and system disruption by switching the engine from isochronous load sharing to droop operation before opening the breaker. Since the remainder of the system will still be in isochronous-load-sharing operation, the engine in droop will shed almost all load in a controlled manner. The engine may then be removed from the system without damage to the circuit breaker and without the jump in speed which may occur if the generator is dropped from the system while the engine is loaded.

The generator could be damaged by reverse current if the breaker is not opened as no load is approached.

To prevent a possible reverse current condition, the operator should open the breaker manually as the engine approaches no load on the KW meter. The engine being unloaded may go out on reverse current if the speed setting is lower than the system speed. The KW meter or real power meter should be carefully monitored as the engine load decreases to prevent possible damage from reverse current.

Refer to Manual 50500.

Chapter 12 Magnetic Pickups

MAGNETIC PICKUPS

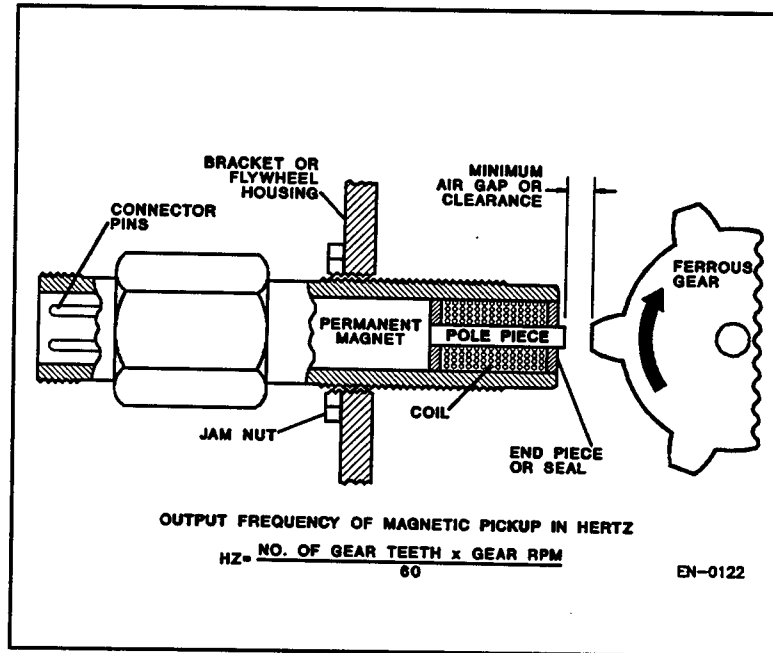


Figure 12-1. Magnetic Pickup

A magnetic pickup (see Figure 12-1) is the device most often used to sense the speed of a prime mover. It is basically a single pole, alternating current, electric generator, consisting of a single magnet with a multiple layer coil of copper wire wrapped around one pole piece. The field or flux lines of the magnet exit the north pole piece of the magnet, travel through the pole piece and air path to surround the coil, returning to the south pole of the magnet. When a ferrous material, such as a gear tooth, covers the pole piece (see Figure 12-2) the reluctance path is de-

creased and the flux lines increase. When the ferrous metal no longer covers the pole piece (see Figure 12-3), the original air path is reestablished. The flux lines will decrease to the original number. This increase and decrease of flux induces an alternating voltage into the coil around the magnet.

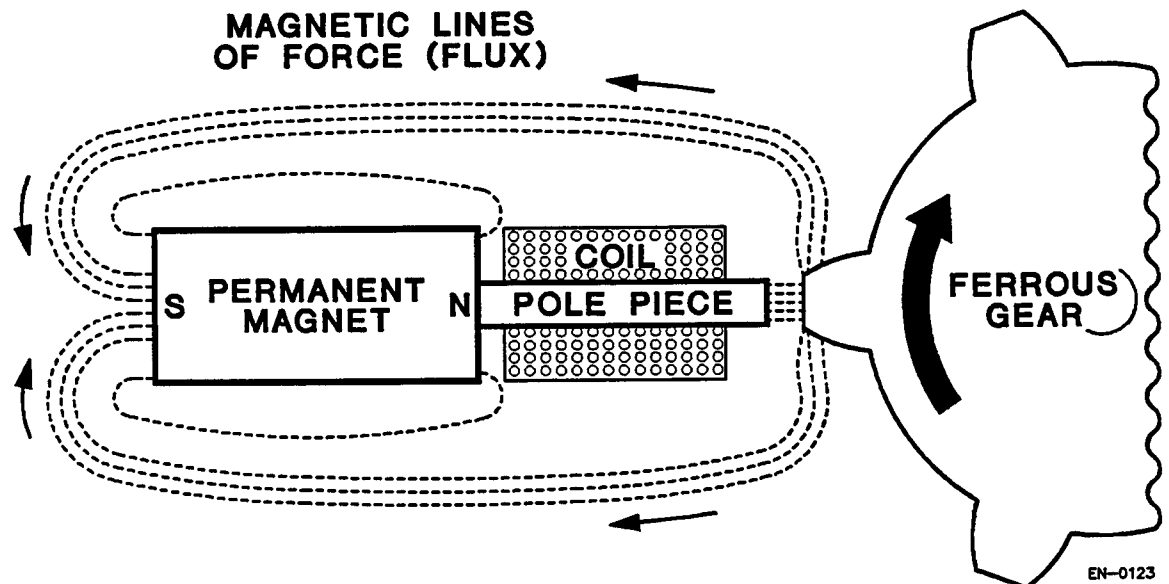


Figure 12-2. Low Reluctance Gear Position

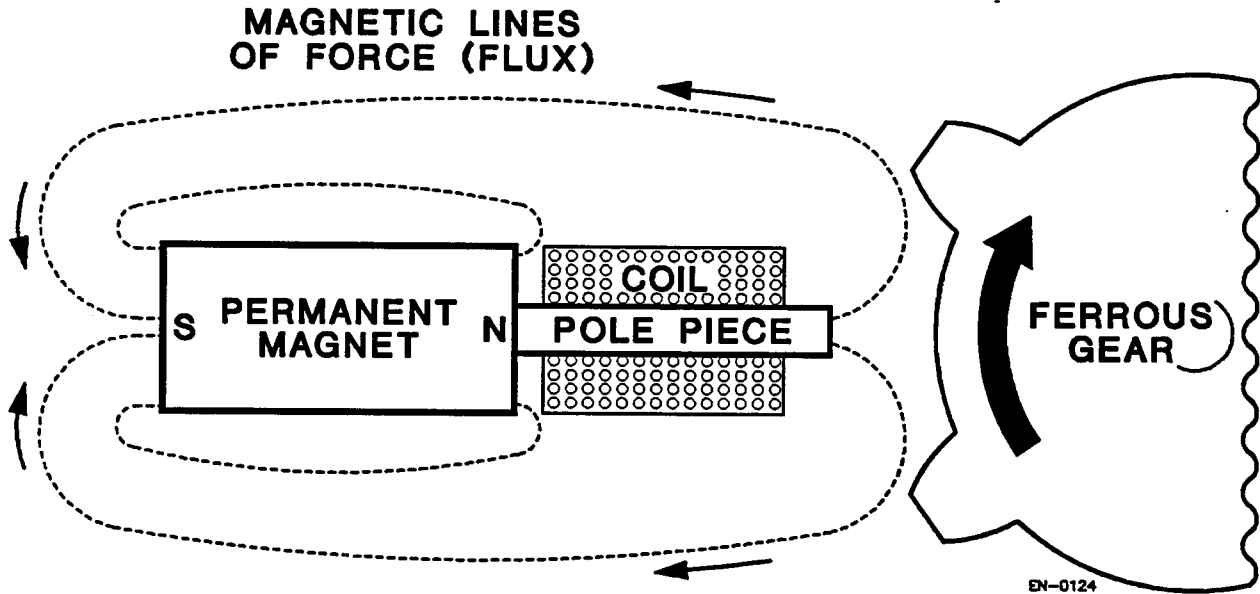
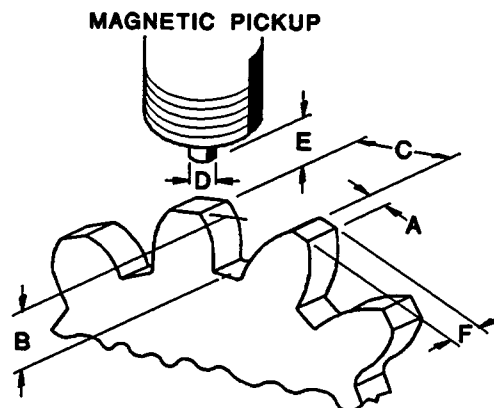


Figure 12-3. High Reluctance Gear Position

The output of this single pole generator, known as a magnetic pickup, depends on the surface speed of the gear being monitored, the gap or clearance between the pole piece and the gear teeth, the dimensions of the magnetic pickup and those of the gear (see Figure 12-4), and the impedance connected across the output coil of the magnetic pickup. The voltage wave form of the output will depend on the shape and size of the gear teeth relative to the shape and size of the end of the pole piece (see Figure 12-5). Any change in the reluctance of the flux path, external to the magnetic pickup, caused by the addition or removal of ferrous material will cause an output voltage to be developed. Gear teeth, projections or holes, can be used to change the reluctance. Spacing between the gear teeth, projections or holes, must be uniform. Differences in spacing will be seen as changes in frequency or speed.

- A = DIMENSION OF TOP OF TOOTH
- B = HEIGHT OF TOOTH
- C = SPACE BETWEEN TEETH
- D = DIAMETER OF POLE PIECE
- E = CLEARANCE (GAP)
- F = GEAR THICKNESS

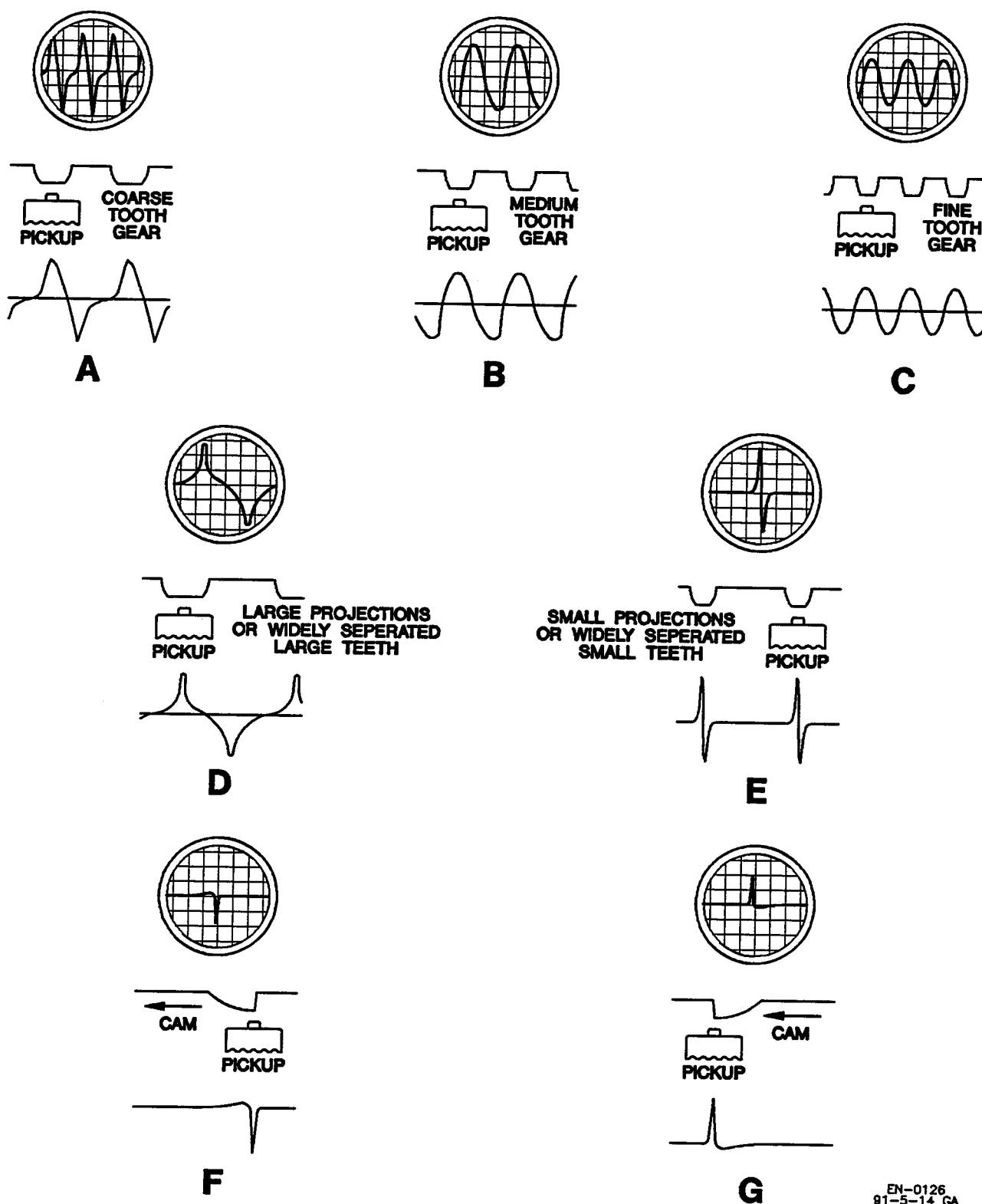


THE OPTIMUM RELATIONSHIP FOR MAXIMUM OUTPUT IS AS FOLLOWS:

- (A) EQUAL TO OR GREATER THAN (D)
- (B) EQUAL TO OR GREATER THAN (C)
- (C) EQUAL TO OR GREATER THAN THREE TIMES (D)
- (F) EQUAL TO OR GREATER THAN (D)

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Figure 12-4. Magnetic Pickup and Gear Dimensions



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Figure 12-5 Generated Waveforms

Chapter 13

Comparing Electronic and Mechanical Controls

Electronic

Mechanical

Speed Sensing:

MPU counts the gear teeth and creates an AC sine wave. The frequency of the AC sine wave is proportional to speed. In the electronic control a frequency to voltage converter changes the sine wave to D.C. voltage which is also proportional to speed.

The D.C. voltage is sent to the summing point providing an electrical force that is proportional to speed.

Fly Weights

Flyweights sense the speed of the engine and provide a mechanical force to the thrust bearing that is proportional to speed.

Speed Setting

Rated speed potentiometer is connected to an internal regulated D.C. voltage supply. The electronic signal (force) at the potentiometer is sent to the summing point representing the desired speed setting.

Speeder Spring

The speeder spring pushes down on the thrust bearing, providing a mechanical force to the thrust bearing for the desired speed setting.

Summing Point

Electrical force from the speed sensor and the speed setting sum together. The sum equals 0 for steady state control. The electrical output of the summing point reflects any difference between the desired speed and the actual speed.

Thrust Bearing

Mechanical force from the flyweights and the speeder spring sum together. 0 force equals steady state control.

The movement of the pilot-valve plunger reflects any differences between the desired speed and the actual speed.

Stability

Stability (reset) is adjusted to stabilize the engine. The adjustment sets the time the feedback circuit is reduced to zero at the summing point (at the rate the engine accelerates.)

Needle Valve

Set the time to equalize the differential pressure across the compensation land (at the rate the engine accelerates). The needle valve is set to match the dynamics of the engine and maintains stable operation.

Amplifier

Electronic amplifiers are designed differently for different types of prime movers. The amplifier controls the signal that sets the amount of terminal shaft movement of the actuator in relation to the amount of off speed detected at the summing point.

Pilot Valve Porting

Pilot valve bushings are designed with different sized ports for different governors. The porting controls the amount of oil flow to move the terminal shaft for a given amount of off speed.

Gain

A portion of the amplifier output is fed back through the gain adjustment and stability adjustment to the summing point. The gain adjustment controls response time of the electronics to an off speed and allows the control to be tuned to the dynamics of the engine.

Buffer Springs

A portion of the oil from the pilot valve bushing and buffer piston pushes on the compensation land. The "push" is a feedback to the thrust bearing, adding to the force of the flyweights and speeder spring. Buffer springs set the gain of the hydraulic circuits.

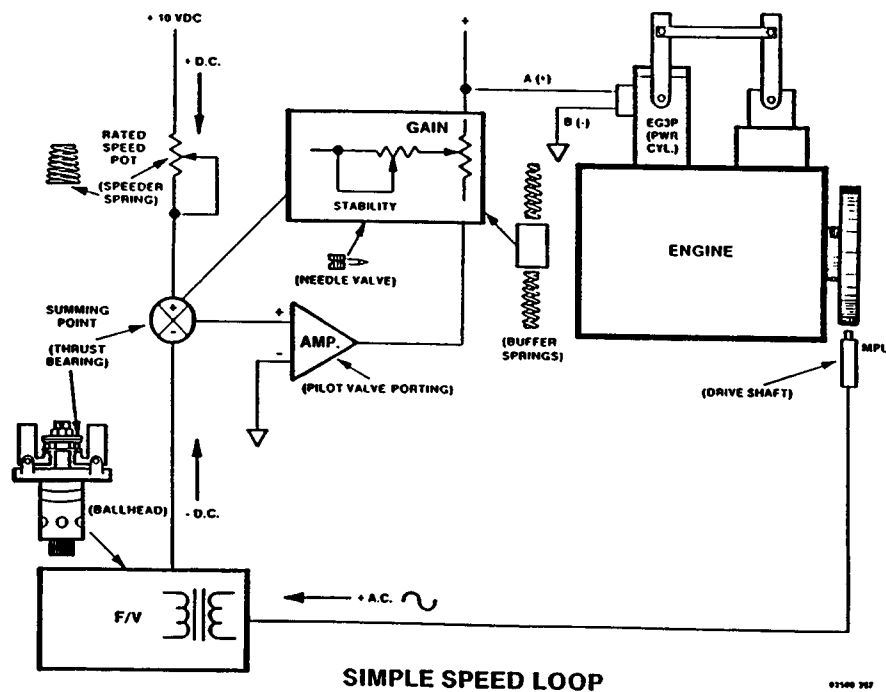
Magnetic Pickup (MPU)

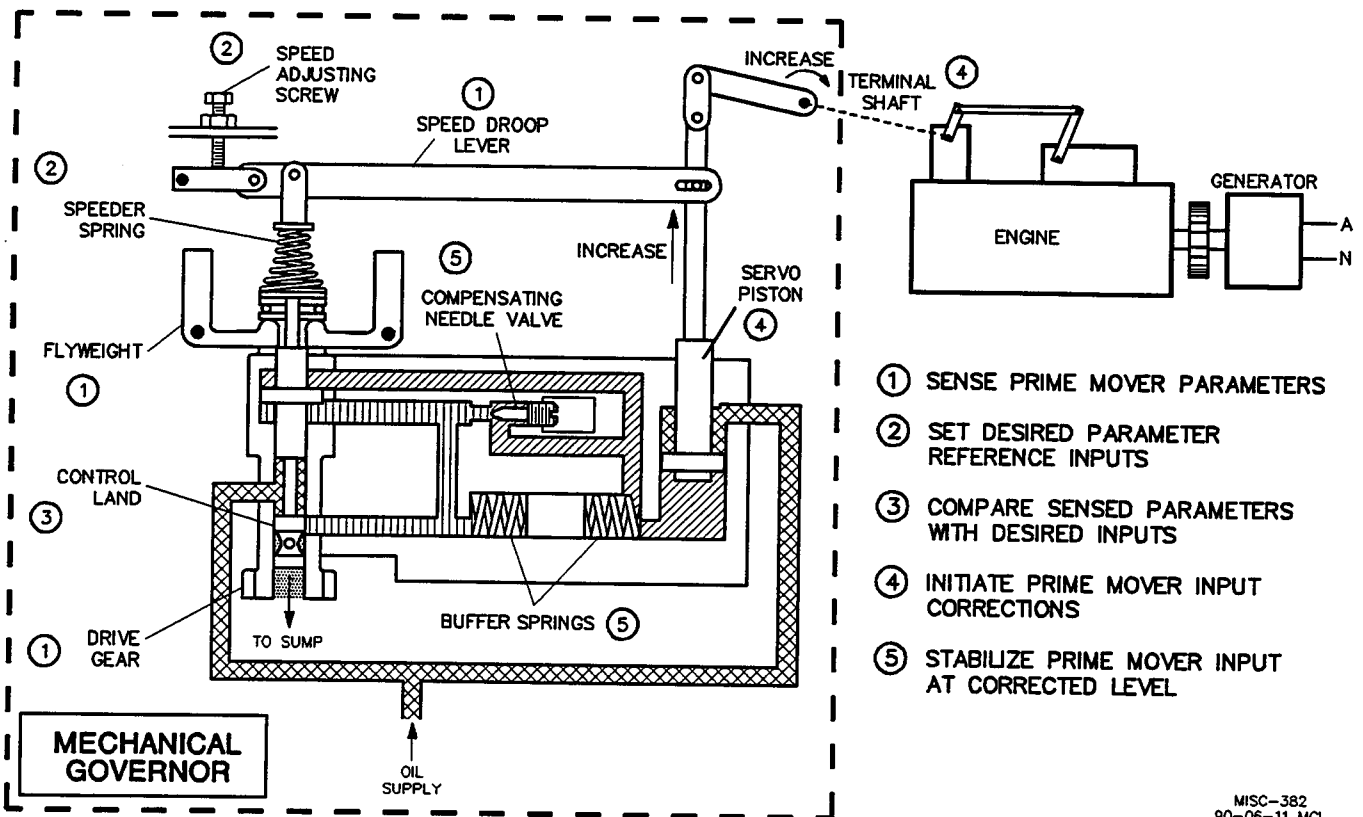
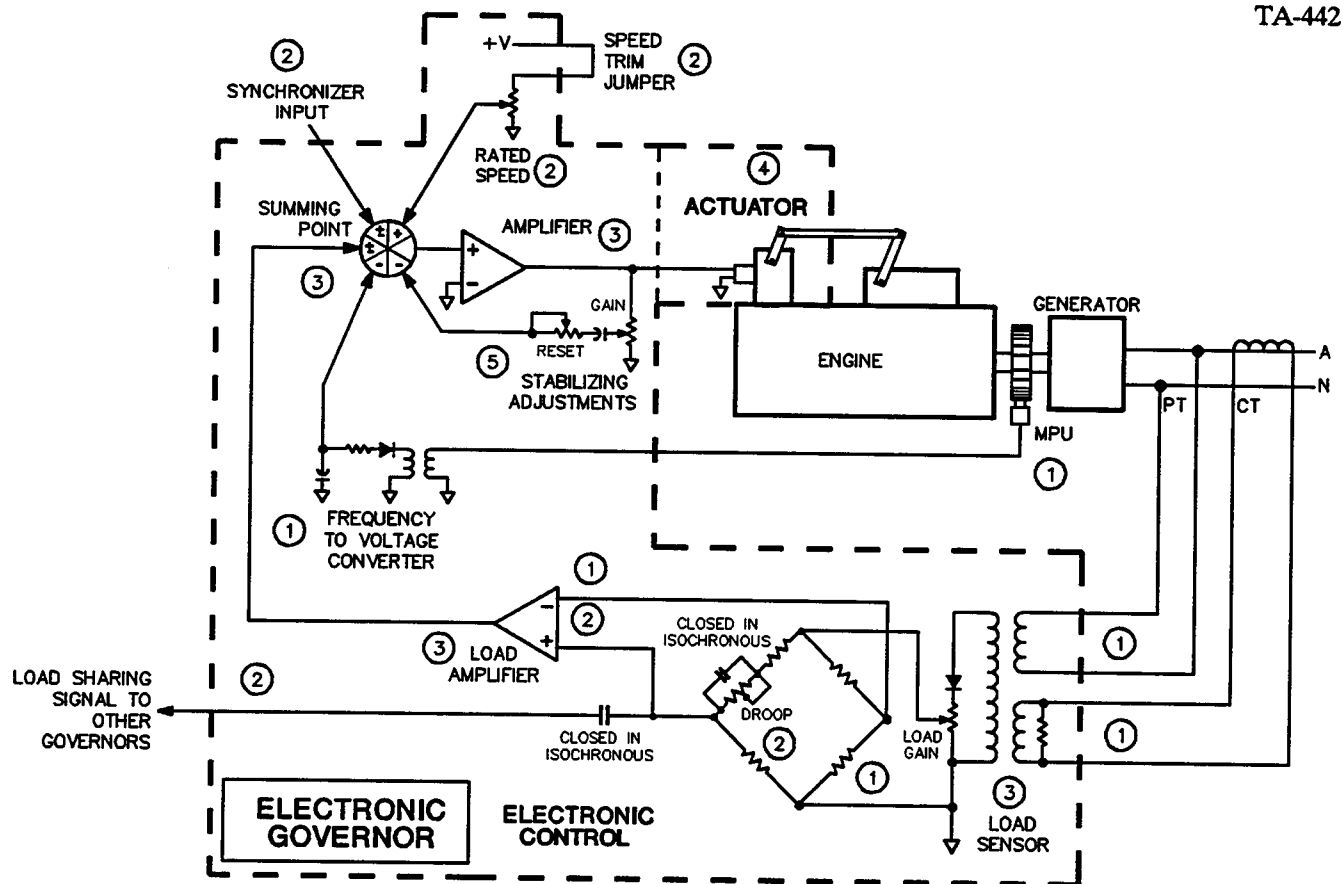
The magnetic pickup is the connection to the engine that provides an input for speed sensing.

Drive Shaft

The drive shaft is the connection to the engine that provides an input for speed sensing.

This listing is provided to help illustrate the relationship between parts of the electronic governor and parts of a hydraulic/mechanical governor.





- ① SENSE PRIME MOVER PARAMETERS
- ② SET DESIRED PARAMETER REFERENCE INPUTS
- ③ COMPARE SENSED PARAMETERS WITH DESIRED INPUTS
- ④ INITIATE PRIME MOVER INPUT CORRECTIONS
- ⑤ STABILIZE PRIME MOVER INPUT AT CORRECTED LEVEL

Figure 13-1. Simple Speed Governor. Comparison Between Electronic and Hydraulic-Mechanical

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Chapter 14

Engine Overspeed and Start Up

OVERSPEED SHUTDOWN

Governors are designed and installed to control the speed of an engine and should prevent overspeed and damage to the engine from overspeed. Failures can occur and it is recommended that no diesel engine or turbine should ever be started unless an overspeed trip device that is completely separate from the governor system is in place and is operative.

The overspeed device is insurance against catastrophic overspeed when the consequences of engine destruction and possible personal injury and even death is considered.

Causes of Overspeed

It is impossible to list all of the conditions which could occur and cause an overspeed which the governor will not control. However, imagination can produce a number of scenarios. As a governor company Woodward has seen most of these scenarios actually occur. For this reason it is firmly recommended that any engine or turbine with a Woodward governor must also have a separate overspeed trip device which is completely separate from the governor system.

Overspeed protection must not depend on the governor servo or governor linkage to accomplish a shutdown since these are among the parts of the governor which could fail and in themselves be responsible for the overspeed.

Prudent operation procedure also requires that these overspeed devices be tested on a regular basis to be sure they are operative and available should they be needed. (Some turbine overspeed devices cannot be tested since they are destructive to themselves when used. These devices must be regularly inspected to be sure they have not been rendered inoperative due to paint or corrosion.)

EMERGENCY START UP PROCEDURES

Any time that a governor has been replaced, modified, or worked on it is important that those involved in the first start up be prepared to either manually control engine fuel and speed or manually shutdown the engine. the operator must predetermine what action will be taken should the governor fail to control speed.

Historically, most catastrophic overspeeds have occurred on the first start up of a new or repaired governor. For this reason it is extremely important that the operator know emergency procedures and be prepared to institute these procedures during start up with an unproven governor system.

The possible results of overspeed are too dangerous to ever overlook the emergency control procedures before first start up.

Governors are designed for dependable control of speed. Governor failure is extremely rare. The costs of uncontrolled overspeed are so high that no prudent installation operates without separate and independent shutdown equipment.

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