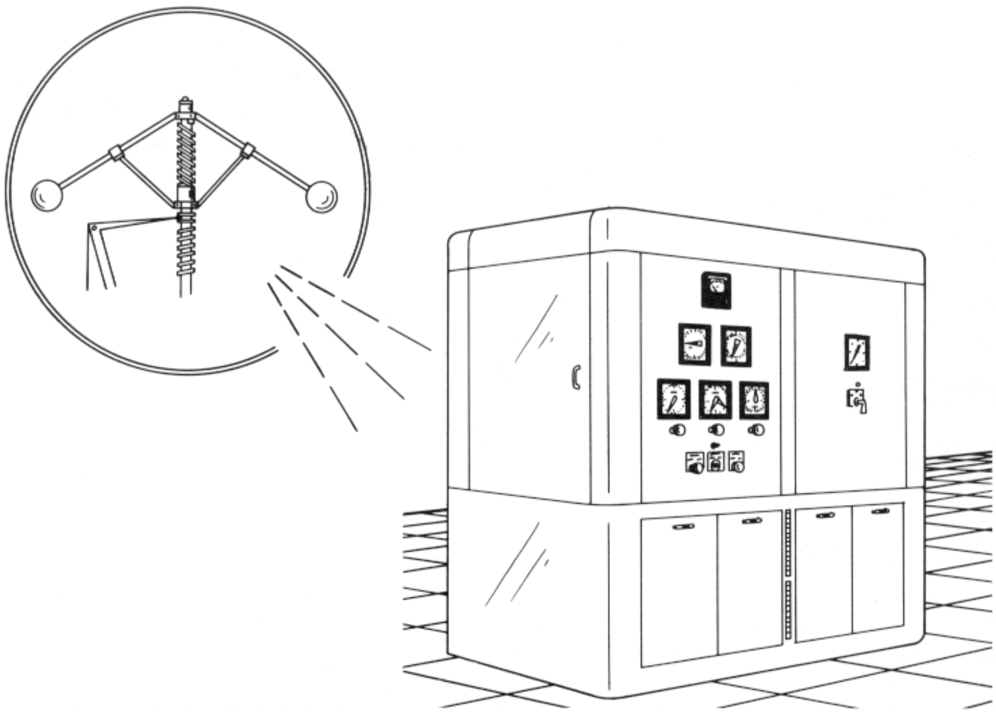
# MECHANICAL GOVERNORS FOR HYDROELECTRIC UNITS



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William Duncan, Jr. and Roger Cline

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The Bureau of Reclamation has prepared this document to provide guidelines for the maintenance and adjustment of mechanical governors for hydroelectric units. This document describes the operation of mechanical governors and provides detailed procedures for adjusting and maintaining the most common mechanical governors found in Reclamation powerplants.

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# MECHANICAL GOVERNORS FOR HYDROELECTRIC UNITS

Revised 1990
William Duncan Jr.

Revised 2002
Roger Cline

HYDROELECTRIC RESEARCH AND
TECHNICAL SERVICES GROUP

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER, COLORADO

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# MECHANICAL GOVERNORS FOR HYDROELECTRIC UNITS

## 1. INTRODUCTION

The primary purpose of a governor for a hydroelectric unit is to control the speed and loading of the unit. It accomplishes this by controlling the flow of water through the turbine. To understand how a hydroelectric governor operates, a basic understanding of governor fundamentals is helpful.

## 2. GOVERNOR FUNDAMENTALS

### 2.1. Speed Sensing Governor

Speed control is one of the primary functions of a governor. A speed sensing governor in its simplest form is shown in figure 1. A set of rotating flyballs, opposed by a spring, controls the position of a valve. The valve controls the flow of oil to a servomotor that controls the throttle or, in the case of a hydro unit, the wicket gates. Any change in speed will cause the valve to be moved off its centered position, making the gates open or close, and changing the unit's speed.

### 2.2. Speed Droop Governor

The speed sensing governor is inherently unstable and is not suitable for speed regulation. The undamped movement of the valve will allow the servomotor to move too far before the speed actually changes and the flyballs can react. This lag between the servomotor movement and the flyball response will lead to a severe "hunting" condition where the servomotor will continue to oscillate back and forth. Since there is no feedback of servomotor position, the valve doesn't know when to stop moving. To provide stability in the governor, feedback in the form of speed droop can be introduced. Figure 2 shows a simple speed droop governor. In the speed droop

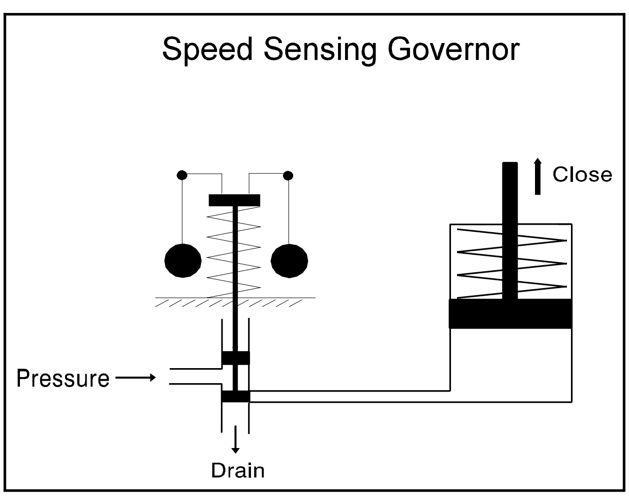



*Figure 1.—Speed sensing governor.*

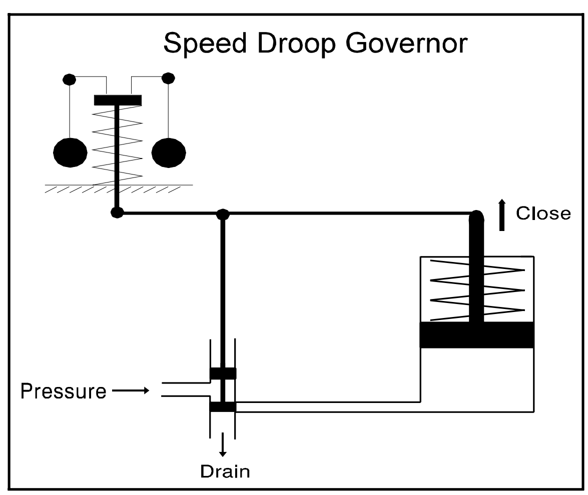



*Figure 2.—Speed droop governor.*

governor, a decrease in speed will cause the valve to move upward, allowing the servomotor to drain and move in the opening direction. As the servomotor moves open, the valve is moved down by the speed droop lever, centering it over the port and stopping the servomotor. The unit is now operating at a slightly slower speed, but the servomotor will not overshoot because for a given speed the servomotor must move to a specific position.

Speed droop by definition is the governor characteristic that requires a decrease in speed to produce an increase in gate opening. The graph in figure 3 shows the relationship between speed and gate position of a speed droop governor. A governor with speed droop set at 5 percent will require a decrease in speed of 5 percent in order to achieve full gate. A decrease in speed of 2.5 percent will cause the gates to open to 50 percent. The speed droop is equal to the percent change in speed divided by the change in gate position.

When the generator is part of a large system, no single unit is capable of changing the system frequency, and therefore, the unit must operate at the system frequency. This large system is referred to as an infinite bus. This is how most plants are operated. When a unit is connected to an infinite bus, the speed droop controls the loading of the unit through adjustments of the speed changer. With a unit connected to an infinite bus, an increase in speed changer setting has the same effect as a decrease in speed of a unit operating off-line. Figure 4 shows speed changer versus gate position of a speed droop governor connected to an large power system. The speed is fixed at 100 percent. In this example, the governor is adjusted so that the unit is at speed-no-load with a 0 speed changer setting. With a speed changer setting of 2.5 percent, the load will be 50 percent. A 5 percent speed changer setting would result in 100 percent load.

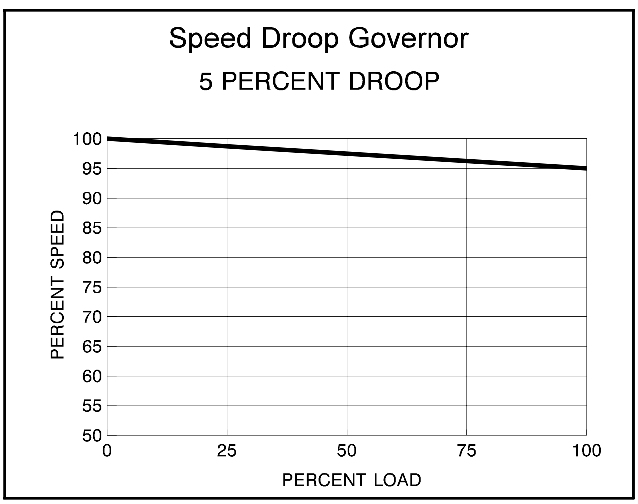



***Figure 3.—Speed droop governor - speed vs. gate position.***

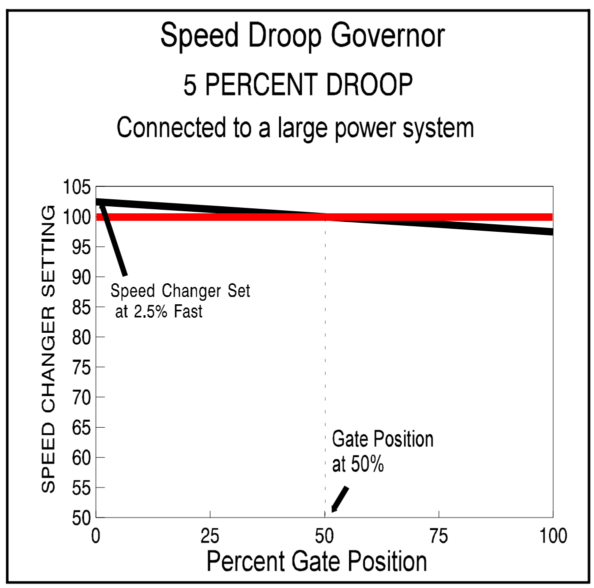



***Figure 4.—Speed droop governor - large power system.***

## 2.3. Compensating Dashpot

Speed droop alone usually does not provide adequate stability for an isolated power system or for a unit operating off-line. Figure 5 shows a speed droop governor with the addition of a compensating dashpot. The large plunger of the dashpot is connected to the servomotor so that its movement is proportional to the servomotor movement. Movement of the large plunger is hydraulically transmitted to the small plunger so that it moves a proportional amount in the opposite direction. The small plunger moves the valve to slow the response of the servomotor. A spring on the small plunger attempts to hold the plunger in its centered position. When the small plunger is moved off center, the spring will eventually recenter it. The rate at which the plunger moves to center is controlled by the setting of the needle valve. The needle valve provides an adjustable leak in the hydraulic system between the two plungers.

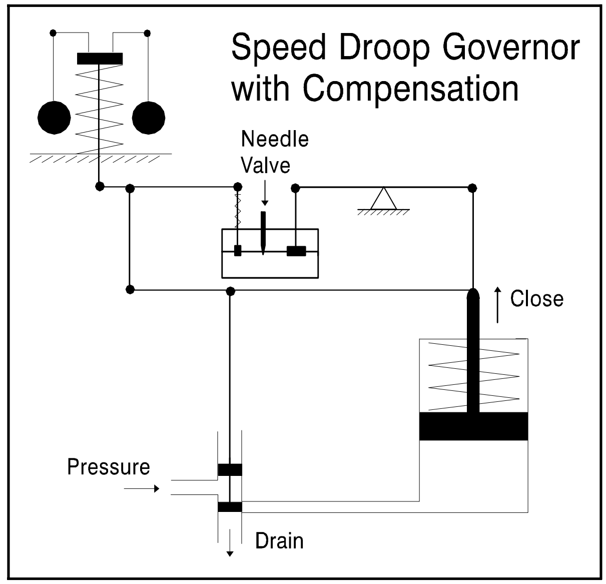



*Figure 5.—Speed droop governor with compensation.*

The dashpot adds temporary droop to the governor system and provides compensation for the effects of inertia of the unit and the water column. Through the adjustment of the dashpot needle and the compensating crank, the governor response can be set to match the inertia and water flow characteristics of a specific unit. The needle adjustment allows the time required for the small plunger to recenter to be adjusted to match the time required for the unit speed to return to normal. The dashpot can provide stability in cases where servomotor movement is not great enough to provide sufficient feedback through the normal speed droop mechanism, such as operating off line at speed-no-load.

When a unit is connected to a large power system, speed stability is usually not a concern and the damping from a dashpot is no longer required. The damping from the dashpot will cause a slower response to changes in speed changer adjustment. To provide a quicker response and allow the unit loading to be changed rapidly, most dashpots are equipped with a dashpot bypass. The bypass may be solenoid operated or operated through mechanical linkage and provides an addition leakage path to allow the small dashpot to recenter rapidly. The bypass is used only when the unit is operating on line and connected to a large power system. If the unit becomes part of a small island, the bypass should not be used.

# 3. GENERAL DESCRIPTION OF MECHANICAL GOVERNORS

There are numerous designs and configurations of mechanical governors, but generally, they have many of the same components. The main parts are a speed sensing device, usually a ball head, an oil pressure system, hydraulic valves to control oil flow, and one or more hydraulic servomotors to move the wicket gates.

## 3.1. Ball Head

The ball head is the component that responds to speed changes of the unit. There are various designs of ball heads, but generally, they consist of two flyweights attached to arms that pivot near the axis of rotation. The arms are attached to a collar on a shaft. As the ball head rotational speed increases, the flyballs move out because of centrifugal force pushing a rod down. The rod, usually termed the speeder rod, acts on the pilot valve to route oil to the main valve and the servomotors. On a Pelton governor, the flyweights are attached to two leaf springs that are attached to the ball head motor at one end and the pilot valve plunger at the other. As the weights move out, the plunger is pulled down. The ball head is usually turned by a three-phase motor that is powered by a permanent magnet generator (PMG) that is driven by the unit being governed. The speed of the ball head motor is always directly proportional to the speed of the PMG and the unit.

## 3.2. Hydraulic System

The hydraulic system consists of an oil sump, one or two oil pumps, an air over oil accumulator tank, and piping to the servomotors. Typically, there are two pumps with lead and lag controls so that there is always a backup pump. Some systems will share two pumps between two units so that in an emergency one pump could be used for both units. The accumulator tank is usually sized so that in the event the pumps fail, the gates can still be closed.

The size of the valve required to control the large amount of oil flowing to the servomotors is too large to be controlled by the ball head. Therefore, a hydraulic amplifier system is used. Oil is routed to a servo on the larger valve by a small pilot valve. The pilot valve is very small so that it is sensitive to the small forces that result from small changes in speed. The larger valve may be called the main valve, regulating valve, control valve, relay valve, or distributing valve. The pilot valve usually is designed with a moveable bushing. The plunger of the pilot valve is connected, through a floating lever, to the ball head, and the bushing is connected to main valve. Whenever the pilot valve moves off center, oil is routed to the main valve servo, causing the main valve to move. The pilot valve bushing is moved off center by the main valve movement, blocking the port of the pilot valve, stopping further main valve movement. The restoring lever between the main valve and the pilot valve bushing is usually adjustable so that the ratio of pilot valve movement to main valve movement is adjustable.

## 3.3. Speed Adjustment

The speed adjustment allows adjustment of the speed of the unit when it is off line, and it also allows adjustment of the loading when the unit is on line. The mechanism by which it accomplishes its purpose depends on the design of the governor, but in all cases, adjusting the speed changer moves the pilot valve off center, which causes the gates to move (figure 6). If the unit is off line the gates will continue to move until the change in unit speed causes the flyballs to move enough to recenter the pilot valve. When the unit is on line and the flyballs are essentially in a fixed position, the gates will continue to move until the feed back from gate position through the speed droop mechanism recenters the pilot valve. The speed changer is usually calibrated from 85 to 105 percent of synchronous speed.

### 3.4. Gate Limit

The gate limit physically limits the travel of the servomotors and wicket gates to the position indicated by the gate limit indicator hand. On Woodward governors, lowering the gate limit setting below the current gate position lowers a stop that acts on the top of the pilot valve plunger, forcing it down to route oil to close the gates. As the gates close, the restoring mechanism raises the stop so that when the gate position matches the gate limit setting the pilot valve is recentered, halting further motion.

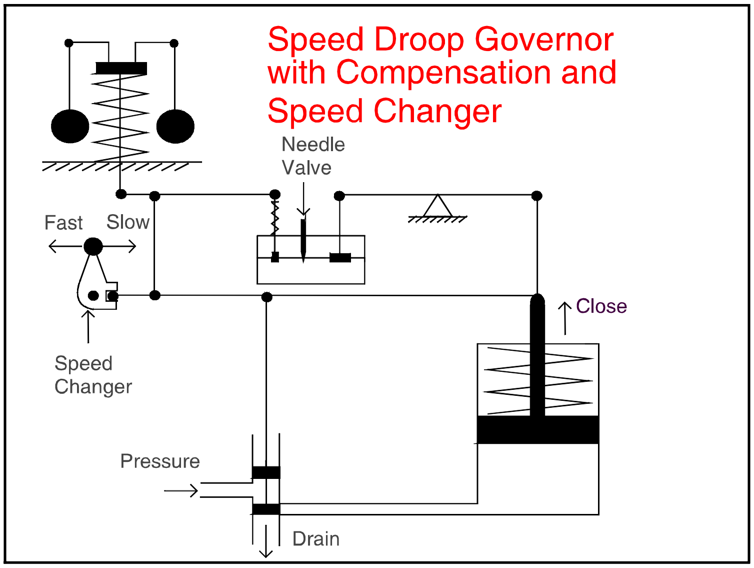



***Figure 6.—Speed droop governor with compensation and speed changer.***

On Pelton governors, the gate limit is provided by a separate gate limit valve. When the gate limit setting is above the gate position, the gate limit valve allows unobstructed flow between the pilot valve and the main valve. When the gate position matches the gate limit setting, the gate limit valves blocks all oil flow from the pilot valve. If the gate limit is moved below the gate position, the gate limit valve over-rides the pilot valve and routes oil to close the gates.

With any governor, raising the gate limit setting will not have any effect on the gate position unless the speed of the unit is below the speed setting when the unit is off line or the gate position is below the position called for by the speed changer setting when the unit is on line. In some cases, it may be desirable to set the gate limit at the desired load and increase the speed changer setting above what would be required to achieve that setting. When this is done, the pilot valve is trying to call for an increase in gate opening but is blocked by the gate limit. This is called a blocked load.

### 3.5. Auxiliary Control

Most cabinet actuator type governors also have a smaller auxiliary valve to control the gate position. Because of the relatively small ports of the auxiliary valve, the gates are moved slowly and can be positioned precisely. The auxiliary valve has no connection to the ball head, and therefore, no speed control. There is also no protection from the shutdown solenoids when on auxiliary control. A unit should never be left unattended when operating with the auxiliary valve. When operating with the auxiliary valve, the gates are moved by moving the gate limit. The gate position will follow the gate limit where ever it is set. There isn't an auxiliary valve on gate shaft governors, but in some cases, there may be a hand wheel that can be used to close the gates in the event the governor fails.

### 3.6. Shutdown Solenoid

All governors have some sort of safety shutdown mechanism to operate automatically or manually to close the wicket gates in case of emergency. The device is usually controlled by a solenoid. In most cases, a weighted arm that is connected to the gate limit mechanism is held in place by the solenoid. If the trip is initiated, either automatically or manually, the solenoid is de-energized, dropping the weight, causing the gate limit to go to zero. A few installations have shutdown solenoids that are designed so that they must be energized to trip. Typically, there is a manual emergency shutdown switch in the control room and at the governor cabinet. The solenoid is usually tripped automatically under any of the following conditions: generator or transformer differential relay operation, hot generator windings, overspeed, overcurrent, reverse current, ground fault current, low generator voltage, low governor oil pressure, or high bearing temperature. Depending on the plant, other conditions may also trip the shutdown solenoid. When the emergency shutdown solenoid is tripped, it must be reset manually.

Many units also have a second solenoid operated shutdown device that is usually identical to the emergency shutdown solenoid. It may be used as a normal shutdown solenoid or a speed no load solenoid. If it is used as a normal shutdown device, its operation will still close the wicket gates, but unlike the emergency shutdown solenoid, it does not need to be reset manually. A speed no load solenoid typically moves the gate limit to some value just above the speed no load gate position. The speed no load solenoid is usually tripped during startup and shutdown while the breaker is open. This prevents unit overspeed if governor control is lost.

### 3.7. Transfer Valve

The transfer valve is a three-way hydraulic valve that (1) permits the selection of the main distributing valve or the auxiliary valve for operating the wicket gates or (2) closes both valves. The main valve and the auxiliary valve each have plungers that can close off the pressure, opening, and closing ports of the valves. The bottom of the plungers have a smaller diameter than the top so that if oil is routed to the top of the plungers they will be forced closed. The transfer valve routes oil to the top of the plungers of the valve to be closed, forcing the three plungers in the valve ports down, sealing the valve shut. The top of the valve that is open is routed to drain, allowing the valve plungers to open. The block position routes oil to both the main and auxiliary valves closing both valves.

**Note: The block position is not adequate protection for working on or around the wicket gates or wicket gate linkage.**

## 4. SERVOMOTOR, WICKET GATE, AND GOVERNOR HAND ALIGNMENT

### 4.1. Servomotor Alignment or Squeeze Adjustment

During full closure of the wicket gates, the servomotor will continue to move a small distance past the zero gate position. This movement is referred to as the “squeeze” on the wicket gates. The squeeze acts to take up any slack in the wicket gate mechanism and applies force to hold the wicket gates closed against water pressure.

The working pressure for governor systems vary, but generally the pressure required to apply the necessary squeeze is half of the working pressure. The servomotor stops usually must be adjusted to absorb part of the excess force of the full working pressure. Also the servomotor stops must be adjusted so that each servomotor applies the same amount of squeeze at the end of the stroke to prevent distortion of the operating ring and headcover. In extreme cases, unequal servomotor squeeze can distort the turbine bearing housing, causing a bearing wipe or causing the turbine runner to contact the seal rings.

Unless otherwise specified by the turbine manufacturer, the following procedure can be used to adjust the servomotors to establish optimum gate squeeze.

(a) Remove pressure from the spiral case by closing the guard gate or valve and draining the penstock or spiral case.

(b) Use full governor pressure to close the wicket gates.

(c) Install and zero dial indicators on each servomotor to measure servomotor movement.

(d) Bleed the air from the governor accumulator tank to 50 percent of the normal working pressure. If properly adjusted, the dial indicators will still read zero when the pressure reaches 50 percent.

(e) Continue bleeding air from the accumulator and reading the dial indicators until zero pressure is reached. If properly adjusted, the dial indicators will begin to change as the pressure drops below 50 percent. The final indicator readings on each servomotor will be within 10 percent of each other. If the differential is greater than 10 percent, adjustment is required. Continue with the next step.

(f) Restore governor pressure to 50 percent of working pressure.

(g) If stopnuts are provided on each servomotor for closing travel, move the stopnuts snug against their seats.

    If no stopnuts are provided on either servomotor, adjust the turnbuckle in the servomotor arms to bottom out the piston in the cylinder of each servomotor to prevent further travel.

    If a stopnut is provided only on one servomotor, move the stopnut snug against its seat and use the turnbuckle to bottom the piston in the cylinder in the other servomotor.

(h) Repeat steps (a) through (g) until the dial indicators on the servomotors begin to change at approximately 50 percent of the normal governor working pressure and the final readings on the dial indicators are within 10 percent of each other.

## 4.2. Wicket Gate Alignment

The wicket gate heel to toe clearances must be uniform and tight to prevent excessive leakage when the gates are closed and to evenly distribute the servomotor force around the wicket gate linkage when the gates are in full squeeze. A procedure for adjusting wicket gates can be found in appendix D of FIST Volume 2-7, Mechanical Overhaul Procedures for Hydroelectric Units.

## 4.3. Gate Position/Gate Limit Hand Alignment of Woodward Mechanical Actuator

(a) Close guard gate or valve and drain spiral case.

(b) Verify zero gate on servomotor scale. (This is required only if you are unsure of zero gate calibration.)

1. Set gate limit below zero gate to insure full squeeze on gate.

2. Bleed air from actuator tank until pressure is 0 psi.

3. The pointer at the servomotor should now read 0. If it does not, adjust the scale as necessary.

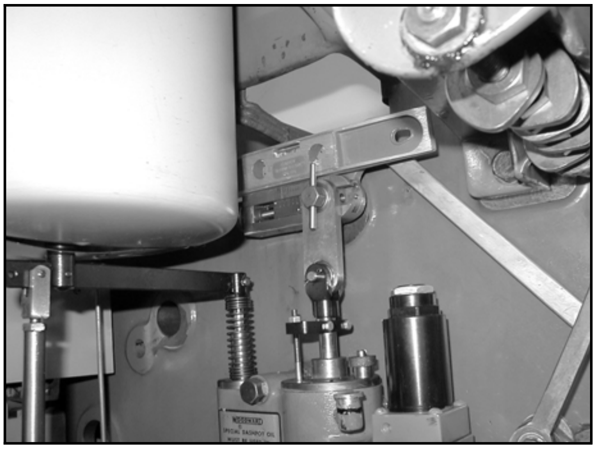
4. Recharge the governor tank to normal working pressure.

(c) Set speed adjustment and speed droop adjustment to “0" on governor panel.

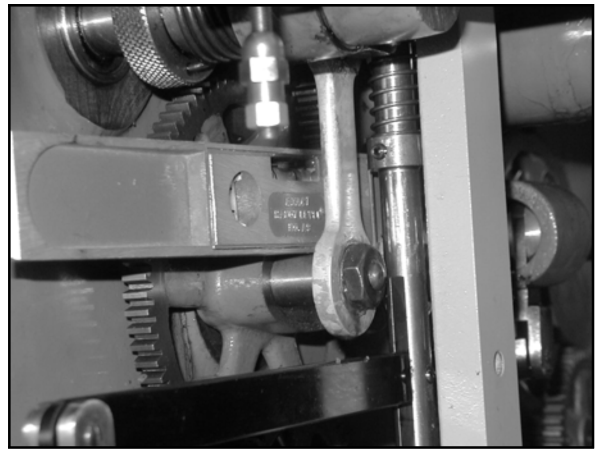
(d) Set transfer valve to Auxiliary Valve Open and move gates to exactly 50 percent, as measured at the servomotor. Depending on the placement of the governor, it may be helpful to station someone in the turbine pit with a radio. Always make sure that anyone in the turbine pit is clear of moving components before moving the gates.

(e) Place a small level on top of the compensating crank (photograph 1). Make sure that it is resting on a flat portion of the crank. If the compensating crank is not level, adjust the length of the restoring cable to make it level. After each adjustment, operate the gates back and forth several times to seat the restoring cable and then bring the gates back to exactly 50 percent. When the compensating crank is level with the gates at 50 percent, the black gate position needle should be at 50 percent. If it isn’t, carefully remove it and move it to 50 percent. Do not push the black needle on tightly at this time as it may need to removed again to position the gate limit needle.

(f) Adjust the gate limit using the gate limit control knob until the studs on the bottom end of the distributing valve gate limit link and the auxiliary valve gate limit link are level. This can be measured by placing a small level on the studs (photograph 2). When level, the red gate limit needle should be at 50 percent. If it is not, carefully remove the gate position needle (noting its exact position) and the gate limit needle and place the gate limit needle exactly on 50 percent. Place the gate position needle back in its original position and press firmly into place.



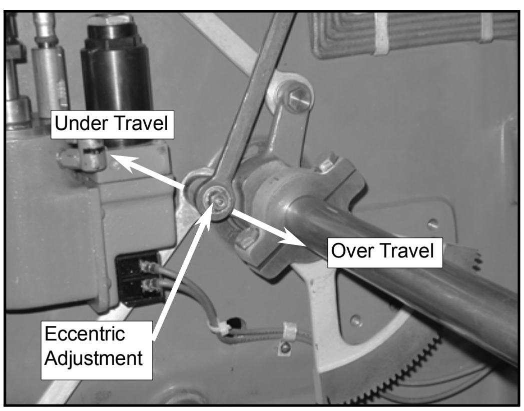
***Photograph 1.—Leveling compensating crank.***



***Photograph 2.—Leveling studs on gate limit links.***

(g) Set transfer valve to Main Valve Open.

(h) Move gates to 10 percent open as measured at the scale on the servomotors and check to see if the gate position needle indicates 10 percent. If the gate position needle does not indicate 10 percent, move the eccentric adjustment in the restoring shaft bell crank to position it correctly (photograph 3). Move it toward the restoring shaft if there is over travel and away from the restoring shaft if there is under travel (figure 7). Move the gates to 90 percent, as measured at the servomotor scale, and check the gate position indicator needle. It may be necessary to elongate the slot in the restoring shaft bell crank to obtain sufficient travel.




***Photograph 3.—Restoring shaft bellcrank.***

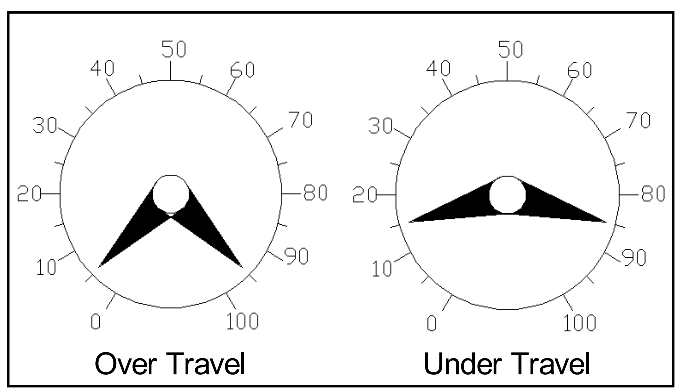



***Figure 7.—Over and under travel of gate position indicator.***

(i) Recheck the gate position at 50 percent to make sure nothing has changed.

(j) Move the gate limit to 50 percent and check to see if the gate position indicator needle is at 50 percent. If it isn't, adjust the limit stop arm adjustment at the pilot valve until the gate position needle reads 50 percent.

(k) Move the gate limit to 10 percent and 90 percent, noting the position of the gate position indicating needle to check for over/under travel between the gate limit and gate position. With the gate limit at 10 and 90 percent, under travel is when the gates travel to 15 and 85 respectively, and over travel is when the gate travels to 5 and 95 (figure 8). To correct over travel of under travel, adjust the position of the distributing valve limit link in the slot of the gate limit operating lever (photograph 4). If the gates under travel, move the limit link away from the gate limit shaft. If the gates over travel, move the limit link towards the gate limit shaft.

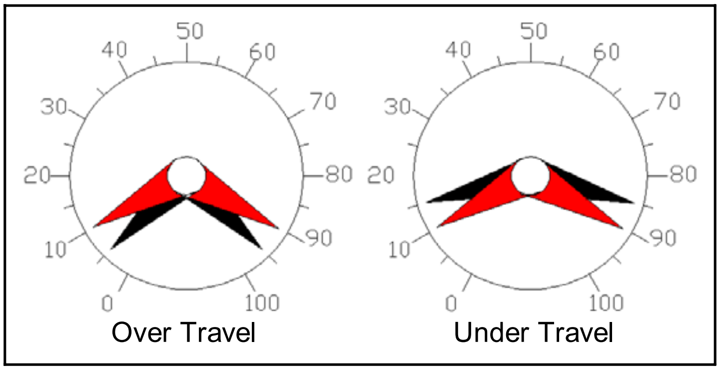
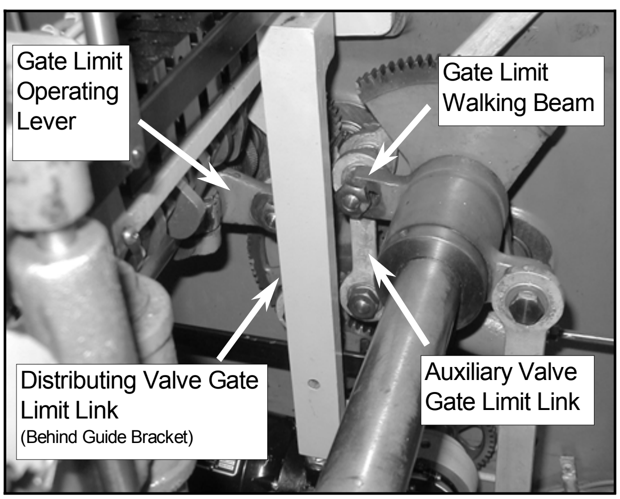
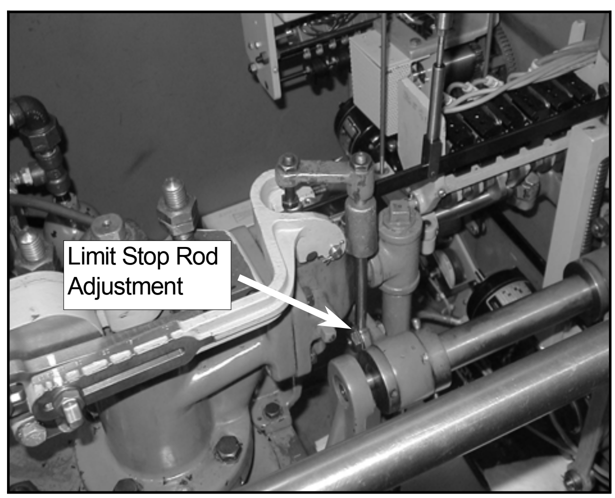



***Figure 8.—Over and under travel with respect to gate limit.***

(l) Move the gate limit to 10 and 90 percent and check for lead or lag. A lead or lag problem is when the differences between gate limit and gate position are not equal. The gates are leading the gate limit if the gate position matches the gate limit at 10 percent and moves to 95 percent with the gate limit set at 90 percent. The gates are lagging the gate limit if the gate position matches the gate limit at 10 percent and moves to 85 percent when the gate limit is set at 90 percent. If there is a lead/lag problem, adjust the lower end of the limit stop rod in the slider (photograph 5). After any adjustment here, move the gate limit back to 50 percent to see if the gate position is also at 50 percent. If it is not, readjust the limit stop arm screw and repeat steps 11 and 12.



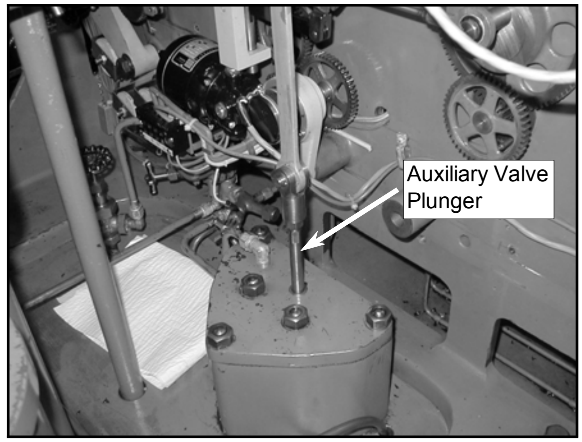

***Photograph 4.—Gate limit links.***




***Photograph 5.—Gate limit stop rod.***

(m) Move the transfer valve to Auxiliary valve open. Move the gate limit to 50 percent and check to see if the gate position is also at 50 percent. If it is not, adjust the auxiliary valve plunger until the gate position reads 50 percent (photograph 6).

(n) Move the gate limit to 10 percent and 90 percent, noting the position of the gate position indicating needle to check for over or under travel between the gate limit and the gate position. To correct over or under travel, adjust the position of the auxiliary valve limit link in the slot of the gate limit walking beam (photograph 4). If the gates under travel, move the limit link away from the gate limit eccentric shaft. If the gates over travel, move the limit link towards the gate limit shaft.




***Photograph 6.—Auxiliary valve.***

### 4.4. Gate Position and Gate Limit Hand Alignment of Pelton Mechanical Actuator

(a) Close the guard gate or valve and drain the spiral case.

(b) Verify zero gate on servomotor scale. (This is required only if you are unsure of zero gate calibration.)

1. Set the gate limit below zero gate to insure full squeeze on gate.

2. Bleed air from actuator tank until pressure is at 0.

3. The pointer at the servomotor should now read 0. If it does not, adjust the scale as necessary.

4. Recharge the governor tank to normal working pressure.

(c) Set speed adjustment and speed droop adjustment to 0 on the governor panel.

(d) Set the transfer valve to Auxiliary Valve Open and move the gates to exactly 50 percent, as measured at the servomotor. Depending on the placement of the governor, it may be helpful to station someone in the turbine pit with a 2-way radio. Always make sure that anyone in the turbine pit is clear before moving the gates.

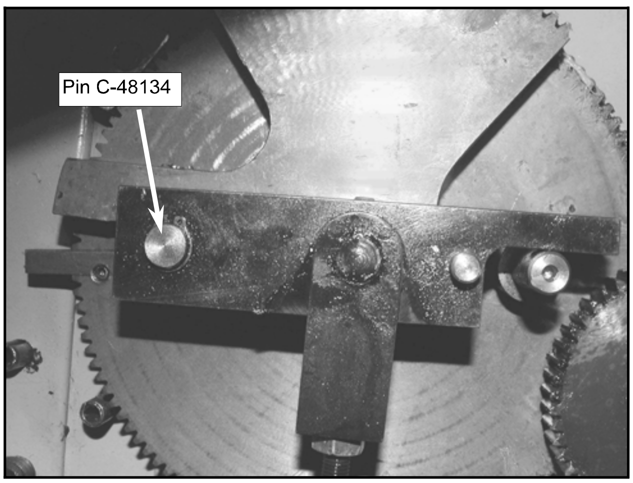
(e) Check to see that the restoring cable quadrant is approximately in its mid-position. It is important for it to be close to mid-position at 50 percent gate so that it doesn't run out of travel at 0 or 100 percent. If it is not at mid-position, adjust the restoring cable.

(f) Starting at the restoring quadrant end, adjust the length of all connecting rods so that all levers make a 90 degree angle to their connecting rods. Move gates back and forth several times to reseat the restoring cable and reset the gates to exactly 50 percent as measured at the servomotor.

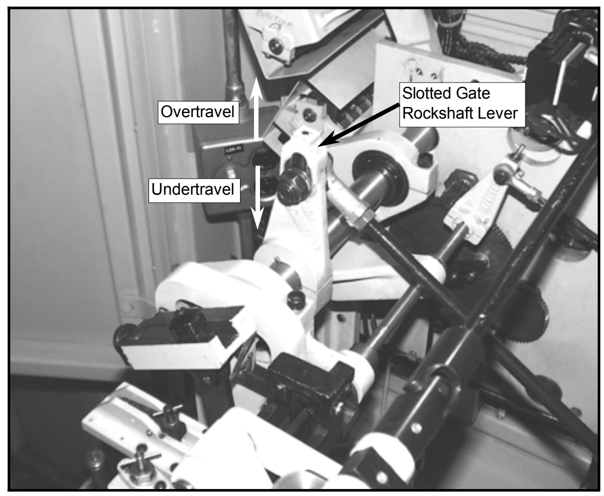
(g) Check that pin C-48134 (photograph 7) on the gate position gear is at the 9 o'clock position. If it isn't, adjust the restoring cable and the connecting rods as in step 6, so that the pin is in the 9 o'clock position. If the restoring cable adjustment required to move the pin to the 9 o'clock position moves the restoring quadrant significantly out of its mid-position, it may be necessary to shorten the restoring cable. Continue with steps 8, 9, and 10 to determine if shortening the cable will be necessary.

(h) Recheck that the gates are exactly at 50 percent, as measured at the servomotor, and move the black gate position hand on the governor cabinet to 50 percent.

(i) Move the gates to 10 and 90 percent, as measured at the scale on the servomotors and check to see if the gate position hand indicates 10 and 90 percent. If the gate position hand doesn't match the servomotor position, move the connecting rod end on the slotted gate rockshaft lever to position it correctly (photograph 8). If the gate position hand under travels, that is, it indicates 15 and 85 percent, move the connecting rod end towards the rockshaft. If the gate position hand over travels, move the connecting rod end away from the rockshaft (figure 7).




***Photograph 7.—Pin C-48135 on gate position gear.***




***Photograph 8.—Slotted gate rockshaft lever.***

(j) Move the gates to 0 and 100 percent to make sure the gate position hand indicates 0 and 100. If the restoring cable goes slack before reaching 0 or 100, it must be shortened. After the cable is shortened, repeat steps 5 through 10.

(k) Set transfer valve to Main Valve Open.

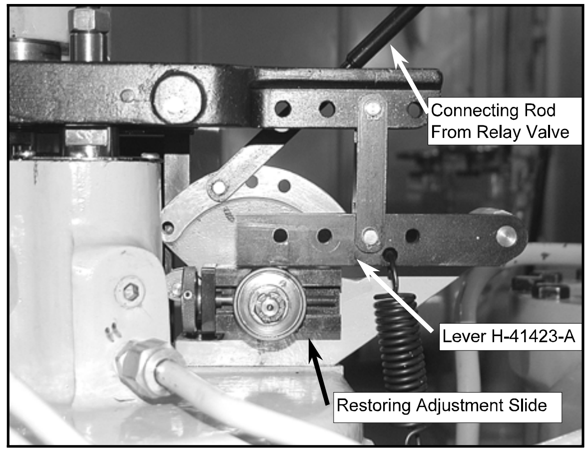
(l) Move the wicket gates to 50 percent and adjust the length of the connecting rod between the relay valve and governor head so that the restoring adjustment slide is parallel to lever H-41423-A (photograph 9).

(m) Adjust the length of the connecting rod between the gate limit rockshaft and the governor head (H-41524-A) (photograph 10) to make the levers on the rockshaft parallel to the base. Adjusting the connecting rod will move the gates. After each adjustment, move the gates back to 50 percent. Continue to make adjustments until the levers are parallel to the base when the gates are at 50 percent.

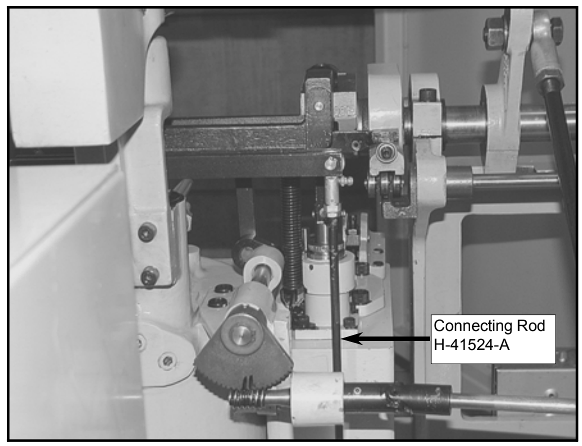
(n) Adjust the gate limit using the normal gate limit adjustment when the gates are at 50 percent. Adjust the length of the C-48709 until the three pins in the floating lever line up horizontally with the position bar C-48133. When this is accomplished, move the red gate limit hand to 50 percent (photograph 11).

(o) Set the transfer valve to Auxiliary Valve Open.

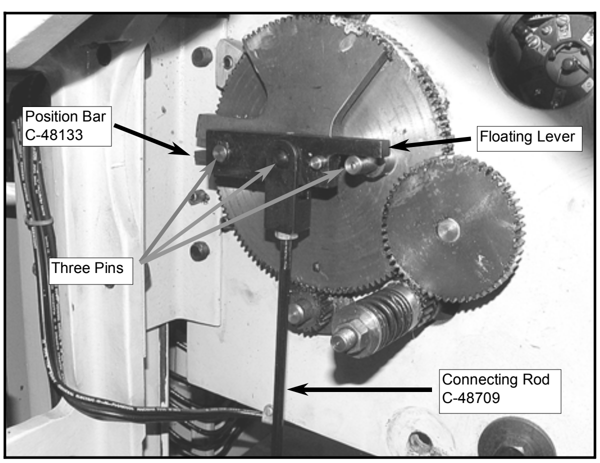
(p) Adjust the length of the connecting rod from the auxiliary valve to the gate limit rockshaft until the gate position hand matches the gate limit hand (photograph 12).



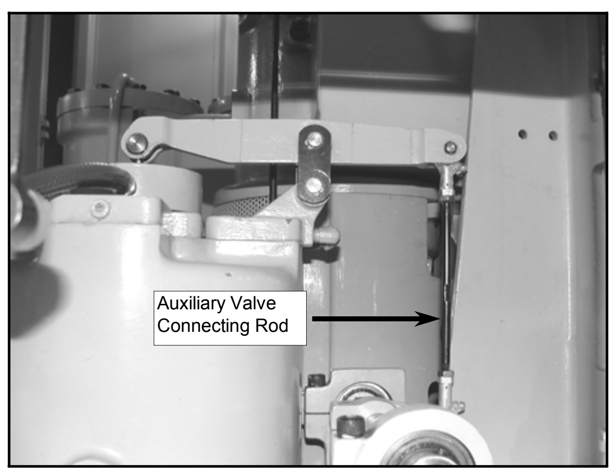

***Photograph 9.—Adjustment of relay valve restoring mechanism.***




***Photograph 10.—Connecting rod H-42524-A.***




***Photograph 11.—Location of floating lever and pins.***




***Photograph 12.—Auxiliary valve connecting rod.***

## 5. REMAGNETIZING THE ROTOR OF A WOODWARD PERMANENT MAGNET GENERATOR

The rotor of a Woodward Permanent Magnet Generator (PMG) can become demagnitized over time, or it can be partially or completely demagnitized if its leads are short circuited during operation. If the measured voltage is less than 80 percent of rated voltage, the field should be remagnetized. Remagnitizing the rotor is accomplished using three-phase alternating current at 2,300 volts. The power source can be obtained from three distribution transformers with at least 10 kva capacity each.

Procedure:

(a) Remove all the speed switch assemblies driven by the drive gear.

(b) If the 2,300 volt power source can be safely connected to the PMG with the PMG in place, the rotor should be disconnected from the drive shaft by removing the upper coupling drive pins and the four cap screws that secure the upper drive plate to the rotor bushing. If it is necessary to remove the PMG from the generator, it must be securely mounted to a sturdy bench.

(c) Disconnect the three PMG stator leads from the terminal block and connect them directly to the 2,300 volt leads from the transformers. Connect a three-pole circuit breaker to the low side leads of the transformer (figure 9). Verify all connections are electrically sound, and observe safety precautions.

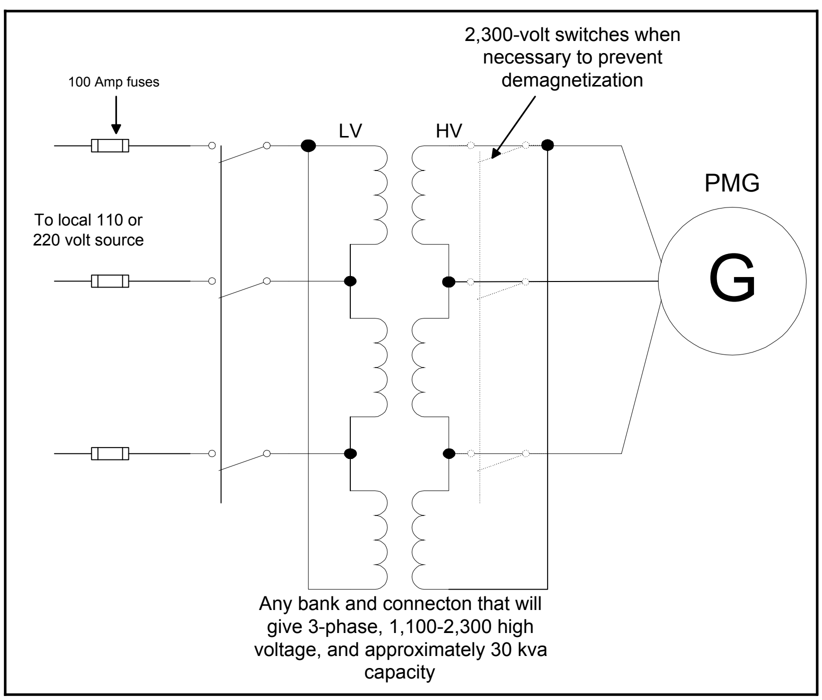



***Figure 9.—Schematic for remagnetizing PMG.***

(d) Close the switch for a period not to exceed 2 seconds. The rotor will reach maximum speed instantly when the switch is closed and will stop abruptly when the switch is opened because of the high magnetic saturation.

If the capacity of the supply transformers exceeds 30 kva by a large margin, it is possible that the above procedure will not produce the desired remagnetization. This can occur if the transformer magnetizing current supplied by the PMG after the low voltage switch is opened is sufficiently large because the current required to magnetize the core of the transformer exerts a strong demagnetizing influence on the rotor of the PMG. If this is found to be a problem, a three-phase, 2,300 volt switch should be provided for de-energizing the PMG in addition to the low voltage switch. All phases of the 2,300 volt circuit should be opened at the same time to avoid demagnetizing effects of single-phase operation.

(e) Disconnect the transformer and reinstall the PMG in the reverse order that it was removed from the generator. Reconnect the PMG leads. Reinstall the cap screws and drive pins. Reinstall the speed switch assemblies.

(f) Bring the unit to the rated speed and measure the voltage. If the measured voltage is higher than 110 percent of the rated voltage, it should be demagnitized down to the rated voltage.

(g) If demagnitizing is required, place a resistance in series with a switch across two of the three phases. A voltmeter should be connected to these phases to monitor voltage (figure 10). Start with approximately 200 ohms resistance and close the switch momentarily with the unit running at rated speed. The measured voltage will drop when the switch is closed and then return to a value less than the original when the switch is opened. If the voltage is still higher than the rated voltage, close the switch again. If the voltage is dropping in very small increments, the rheostat resistance can be decreased or the time the switch is closed can be increased. Either will result in larger demagnetizing steps and speed up the process. The voltage should be monitored closely during the demagnetizing process. If it falls below 80 percent of rated voltage, it will have to be remagnetized.

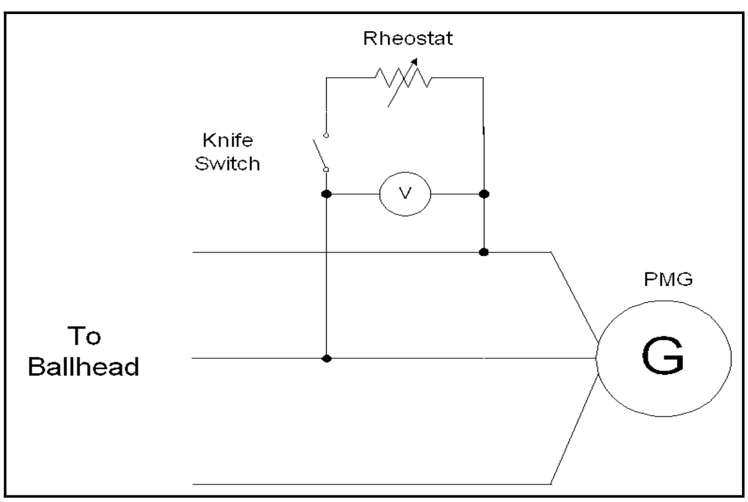



***Figure 10.—Schematic for demagnetizing PMG.***

## 6. TESTING AND ADJUSTMENT OF MECHANICAL GOVERNORS

Reclamation's Governor Adjustment Program was initiated for the purpose of adjusting governors to provide safe and stable operation. Safe closure rates and data for setting the governor for optimum performance have been developed for most Reclamation plants. These data are available on the Reclamation intranet at <http://intra.do.usbr.gov/mechdata/>.

### 6.1. Wicket Gate Timing

The first adjustment to the governor is the full rate gate timing. The stop nuts on the governor main valve are adjusted to limit the amount of travel of the main valve. By changing the maximum movement of the main valve, the amount of oil flowing to the servomotors is changed, and, therefore, the maximum speed at which the wicket gates travel is changed. The rate at which the wicket gates close determines the magnitude of penstock pressure transients or water hammer and the maximum speed of the unit following a load rejection. Faster wicket gate timing results in a lower maximum over speed, but the penstock pressure transients will be higher. Slowing the wicket gate timing down results in a lower transient penstock pressure rise, but the maximum over speed will increase. The final setting of the wicket gate timing is a compromise. Since the rotating components are designed to withstand terminal over speed, provided the balance of the unit is acceptable, the critical factor to consider is the transient pressure. The wicket timing should be as fast as possible while keeping the maximum transient penstock pressure below the design pressure. It should be noted that the safe closure rate is based on the allowable design pressure of the scroll case or the penstock, whichever is the lowest. While plants with short penstocks or low head will, in most cases, have lower magnitudes of water hammer, penstock or scroll case failure can occur if the safe closure rate is exceeded.

When an unit is uprated, the hydraulic characteristics can change and the safe closure rate must be reevaluated. A hydraulic transient study should be performed to determine a theoretical safe closure time, and load rejection tests should be performed to verify results of the study.

### 6.2. Optimizing Governor Performance

The second objective of governor adjustment is twofold: to adjust the governor to optimize performance within the power system and to optimize the governor's ability to carry an isolated load. Most governor manufacturer's literature provides a procedure for adjusting the governor. These procedures usually require making adjustments to minimize visible "hunting" by the governor. While this may provide a governor response that is adequate for synchronizing, it will probably not provide an optimum response on line or may not allow the governor to adequately maintain frequency if disconnected from the grid. The governor should respond to frequency changes quickly without becoming unstable. The optimal governor response will match the response of the governor to the rotating inertia of the unit and the inertia of the water in the penstock.

The magnitude of wicket gate response to a change in frequency or speed changer setting will be determined by the speed droop on units connected to the system. The speed droop setting on units operating isolated is important because the speed droop setting controls how the loads are split between units and how well frequency is maintained. Speed droop can be thought of as the inverse of the gain between the change in speed changer setting and the change in wicket gate position. For a speed droop setting of 5 percent, a 1 percent change in speed changer setting would cause a change in gate position of 20 percent. Likewise, with a speed droop setting of 10 percent, a 1 percent change in the speed changer setting would produce a 10 percent movement of the wicket gates. In most cases, it is sufficient to calibrate the speed droop at 5 percent, the normal setting for most units. If operation with zero droop is ever required, it may also be desirable to check the calibration at zero droop.

There is an adjustable feedback from the main valve to the pilot valve to adjust the ratio of main valve to pilot valve movement. By changing the amount the main valve moves for a given movement of the pilot valve, the relative speed of the servomotors is changed. This is independent of the setting for wicket gate travel rate. The main valve normally doesn't move far enough to contact the stop nuts during a load change. The feedback acts on the pilot valve bushing to close off the pilot valve ports to stop the flow of oil to the main valve servo, and therefore, stop the movement of the main valve. The farther the main valve is allowed to move, the faster the servomotors will travel. The feedback is adjusted to provide a fast, stable response with no overshoot. On Woodward governors, the feedback adjustment is the restoring ratio pivot pin. The restoring lever is usually numbered from 10 to 60. The number indicates the ratio of main valve movement to pilot valve movement. With the restoring ratio set at 60, the main valve will move 60 times the amount the pilot valve moves. The Pelton governor uses a non-calibrated adjustable thumb screw to adjust the feedback.

The dashpot adds temporary speed droop to the governor. Permanent speed droop alone does not provide adequate stability for units that operate is isolation or off line. Droop through the dashpot is added temporarily to match the response of the governor to that of the unit. The dashpot consists of a large dashpot plunger and a small dashpot plunger connected hydraulically through an oil reservoir. The large dashpot plunger is connected rigidly to the servomotor through the restoring cable and linkage. The small dashpot plunger is connected to the pilot valve through a floating lever and is held in a centered position by a spring. The compensating crank is an adjustable lever in the feedback linkage between the servomotor and the large plunger of the dashpot. Adjusting the compensating crank adjusts the amount the large dashpot plunger moves for a given movement of the servomotor. If there is no leakage in the oil reservoir, the small dashpot plunger will move rigidly with the large plunger and there will be additional permanent speed droop. To provide temporary droop, an adjustable needle valve is provided on the dashpot to provide a leakage path that allows the small dashpot plunger to return to its original position at a rate that matches the inertia of the unit. On Woodward governors, the compensating crank is usually calibrated from 1 to 10; 10 provides the most compensation or movement of the large dashpot. On Pelton governors, the compensating crank is not calibrated, but moving the slide away from the thumb wheel will increase the compensation. The dashpot needle adjustment is not calibrated on either governor.

The dashpot may also be equipped with either a mechanical or solenoid operated bypass. When the unit is operating on line and is connected to a large system, the system controls unit frequency and the compensation provided by the dashpot is not needed. The dashpot only makes the response much slower. To allow load changes to be accomplished much faster, the bypass provides another leakage path in the dashpot to allow the small plunger to recenter faster and greatly reduce the amount of temporary droop.

The mechanical bypass uses a slotted rod that is actuated by a lever on the large dashpot plunger shaft to provide another leakage path in the dashpot. The lever is positioned so that the bypass opens at a gate position above speed no load, when the unit is normally on line. If it is necessary to operate isolated, the bypass arm is moved out of the way and the unit dashpot will function normally.

The solenoid operated dashpot bypass provides a leakage path in the dashpot when the solenoid is energized. The rate of leakage is adjustable through a needle valve. Reclamation's standard operation of the solenoid operated bypass calls for the bypass to be energized when a load change is initiated and held energized for 40 seconds to allow the load change to occur. An override is provided to prevent the solenoid from operating when a unit is carrying an isolated load.

A computer program was developed to model the response of a unit to a change in speed or speed changer adjustment. The data input into the program are the particular parameters referencing speed, power, rotational inertia, penstock length, water velocity, and head for a given unit. The output is graph of gate position versus time for the optimum response of the governor. The governor time constant, or $T_{gate}$, is used to define the governor response to a speed change. $T_{gate}$ is defined as the time required for the unit to complete 63 percent of its total response to a sudden change in speed or speed changer adjustment.

If we look at the response curve we can get a better understanding of the governor response (figure 11). In phase one, the governor has reacted to the speed change. The pilot valve and the main valve have opened, and the gates are moving at a constant rate indicated by the straight line. In phase two, the gates have moved enough to activate the dashpot, moving the large dashpot plunger. The movement of the large dashpot plunger causes the small dashpot plunger to move the pilot valve, through the floating levers, in the opposite direction. This causes the gates to momentarily slow or even reverse direction, causing a dip in the response curve. In phase three, the small dashpot plunger is gradually recentering as the oil discharges through the needle valve, which allows the wicket gates to travel to their final position at a rate that matches the stability requirements of the machine.

# 7. GOVERNOR ADJUSTMENT PROCEDURE

## 7.1. Equipment

The tests can be completed with the unit watered up and operational or can be completed unwatered with a PMG Simulator. A PMG simulator provides an alternating current to the ball head that matches the output of the PMG in frequency and voltage. It simulates on-line conditions for the governor. As a minimum, the following equipment is required: a strip chart recorder with two or more channels, a frequency transducer with a 55 to 65 hertz range, and a position transducer with sufficient range to measure gate travel. If a PMG simulator is used, a digital multimeter capable of reading the PMG voltage and frequency is required.

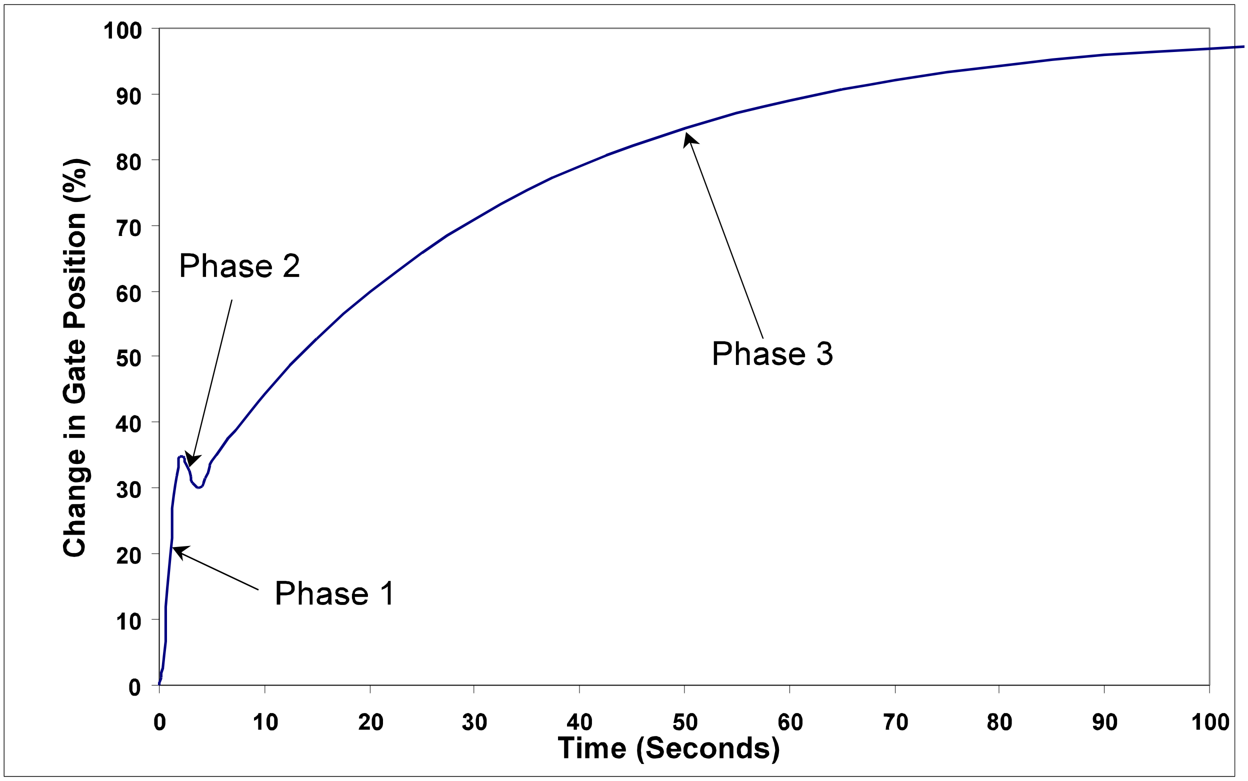



***Figure 11.—Governor response curve.***

## 7.2. Wicket Gate Timing

**CAUTION:** Proper full rate wicket gate opening and closing time is vital to the safe operation of the powerplant. The gate timing should be checked during annual maintenance.

To check the wicket gate timing:

(a) Depressurize the unit by closing the guard gate or guard valve and draining the spiral case or penstock. There should be no need to drain the draft tube.

(b) Place the governor in Main Valve Mode.

(c) Install the position transducer to record the servomotor stroke. Calibrate the strip chart recorder for full gate travel.

(d) Latch or block up shutdown solenoid weights to allow operation of wicket gates. Note: On units that have shutdown solenoids that energize to trip, the solenoid weights can be left down.

(e) With the strip chart recorder running at 10 mm/sec, move the gate limit on the governor cabinet rapidly from 0 percent to 100 percent. Allow the gates to stabilize at 100 percent. Move the gate limit rapidly from 100 percent to 0 percent.

Calculate the dry wicket gate timing:

opening = (25 percent to 75 percent) x 2
closing = (75 percent to 25 percent) x 2

The gate timing is measured from 25 to 75 percent gate and 75 to 25 percent gate to eliminate any errors that would be introduced by the slower rate during the cushion at the end of the closing stroke.

**Note:** If a strip chart recorder is not available, the time from 25 to 75 percent gate and from 75 to 25 percent gate can be measured with a stop watch (figure 12).

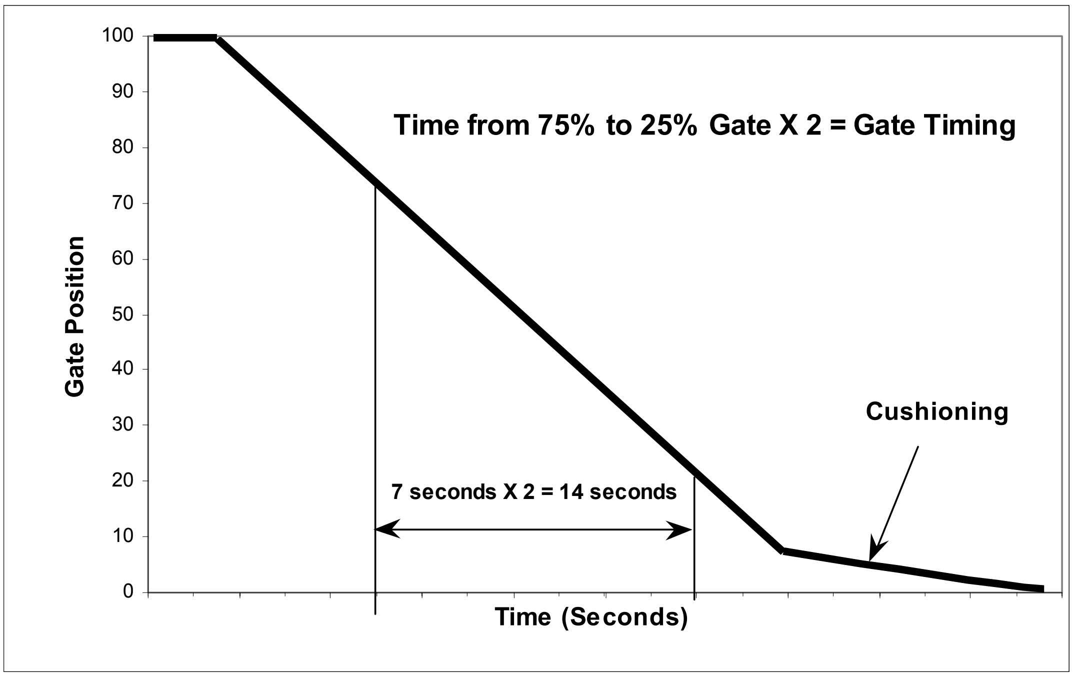
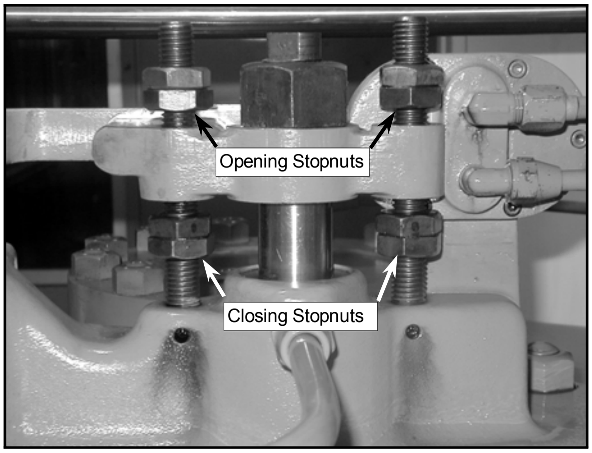



***Figure 12.—Wicket gate timing: closing.***

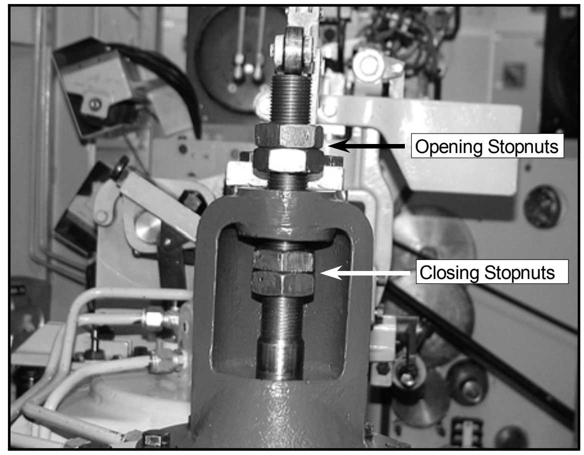
(f) Also note the effect of cushion on the closing stroke. If possible, adjust each servomotor cushion as necessary to achieve at least a 5 second closure time from 10 to 0 percent gate to prevent slamming the gates. Depending on the design of the servomotor, the cushion may not be adjustable.

(g) To allow for hydraulic effects, adjust the upper and lower stop nuts on the main valve to obtain a dry wicket gate timing approximately 10 percent longer than the value required for safe operation (photographs 13 and 14).

The upper stop nuts generally control the opening rate, and the lower stop nuts generally control the closing rate. Opening and closing gate timing should usually be the same.




*Photograph 13.—Stopnuts on a woodward governor.*




*Photograph 14.—Stopnuts on a Pelton governor.*

**CAUTION**: Units with pressure regulators may require special procedures because the regulators have been known to drastically affect full flow gate timing. Contact Mechanical Engineer, D-8450, to discuss special precautions for adjusting these units.

### 7.3. Setting up the PMG Simulator (if Used)

Before shutting the unit down, measure and record the PMG voltage and frequency with the unit on line.

(a) Disconnect the PMG leads from the ball head motor at the governor cabinet terminal block. Caution: Tape the leads to be sure they do not touch. If the leads contact each other, the PMG may be demagnetized. Make sure wires are labeled.

(b) Connect the PMG simulator output leads to the terminal block to connect it to the ball head motor. Use number 12-14 wire.

(c) Set the PMG simulator for the proper ball head voltage and frequency.

(d) Plug the PMG simulator into a 20-ampere, 120-VAC outlet. If an extension cord is used, make sure it is rated for 20 amperes.

(e) Before turning on power to the PMG simulator, confirm the position of the following:

1. The "MASTER/SLAVE" switch on the rear of the enclosure should be in the "MASTER" position.

2. The "OUTPUT ENABLE/DISABLE" switch on the front of the unit should be in the "DISABLE" position.

3. The switch labeled "RAMP UP - RAMPING - RAMP DOWN" should be in the "RAMP DOWN" position.

4. The switch labeled "INTERNAL/EXTERNAL" should be in the "INTERNAL" position.

5. The "VOLTAGE SETPOINT" and the "FREQUENCY SETPOINT" should be set to match the output of the PMG. The "% DEVIATION FROM SETPOINTS" should be set to 00.00.

(f) Apply power to the simulator by turning on the master power switch, if so equipped, or by turning on the sine-wave generator and then the amplifiers.

(g) Check ball head rotation by placing the "OUTPUT ENABLE/DISABLE" switch in the "ENABLE" position and momentarily moving the "RAMP UP - RAMPING - RAMP DOWN" switch to the "RAMP UP" position. If the ball head rotation is correct, move the "RAMP UP - RAMPING - RAMP DOWN" switch to the "RAMP UP" position and wait for the "LOCKED UP" lamp to light. This indicates the ball head is at full speed. If the rotation is incorrect, follow the power-down sequence in the next paragraph and switch any two of the output wires from the sine-wave generator.

(h) Power-Down Sequence

1. Place the "RAMP UP - RAMPING - RAMP DOWN" switch in the "RAMP DOWN" position. Wait until the "LOCKED DOWN" lamp is lit.

2. Place the "OUTPUT ENABLE/DISABLE" switch in the "DISABLE" position.

3. Turn off the amplifiers first and then the sine-wave generator or the main power switch.

*Note*: The voltage and frequency output of the PMG simulator can vary slightly as the amplifiers warm up. If possible, the simulator should be left on, running the ball head for approximately ½ hour to let the amplifiers reach their operating temperature. The voltage and frequency should be monitored throughout the testing and periodically adjusted, if required, to maintain the desired output. The voltage and frequency setpoints may vary slightly from the actual output. Note the actual settings required to obtain the desired output. Care should be taken when adjusting the setpoints so as not to hit the wrong button and make a large change in voltage or frequency.

## 7.4. Check and Adjust Permanent Droop

Open the dashpot needle two turns to effectively take the dashpot out of service and increase the speed of the gate response during this test.

(a) Set up the strip chart recorder scale on the gate position so that full scale equals full travel.

(b) Change the speed in 1 percent steps

(c) Unwatered Method (PMG Simulator): Set the speed changer to its speed-no load (SNL) setting and the speed droop to 5 percent. With the PMG simulator driving the ball head at nominal frequency, adjust the "% DEVIATION FROM SETPOINTS" on the PMG simulator to decrease the ball head motor frequency in 1 percent increments, four times, recording the gate position after each change. Increase the ball head frequency in 1 percent increments four times to bring the frequency back to it nominal setting, recording the gate position after each change.

(d) Operational Method: With the unit operating on-line at SNL, make 1 percent increases in the speed changer setting four times, recording the gate position after each change. Make 1 percent decreases in the speed changer setting four times to bring the unit back to the SNL setting, recording the gate position after each change.

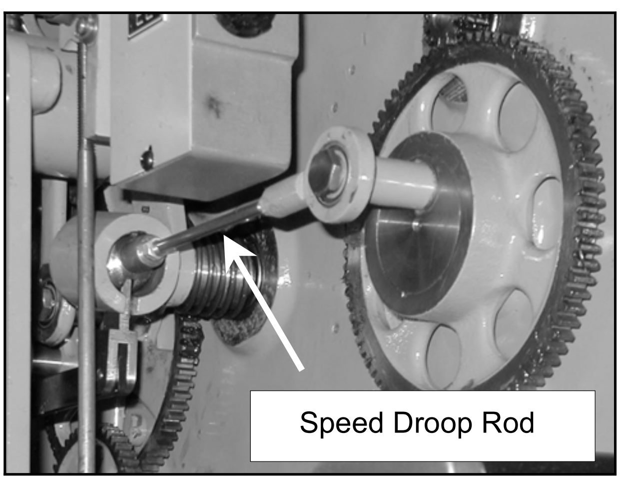
(e) Calculate droop. For a 1 percent change in frequency:

Droop = 1/change in gate position

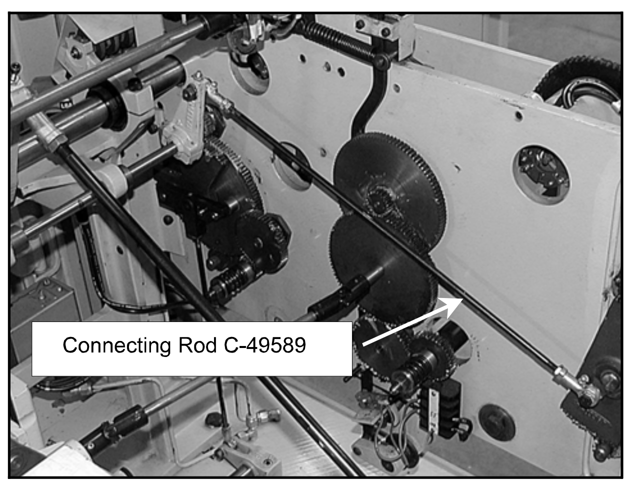
The calculated speed droop should be 4.5 to 5.5 percent, or there should be a change in gate position of 18 to 22 percent gate for every 1 percent change in frequency.

On Woodward cabinet actuators, adjust the droop rod turnbuckle to obtain approximately 5 percent droop (photograph 15) (4.5 percent to 5.5 percent is usually obtainable). A half turn on the turnbuckle usually makes a change of approximately 0.5 percent droop. The rod is shortened to increase droop and lengthened to decrease droop.

On Pelton cabinet actuators, adjust the connecting rod C-49589 to obtain approximately 5 percent droop (photograph 16).




***Photograph 15.—Woodward speed droop calibration.***




***Photograph 16.—Pelton speed droop calibration.***

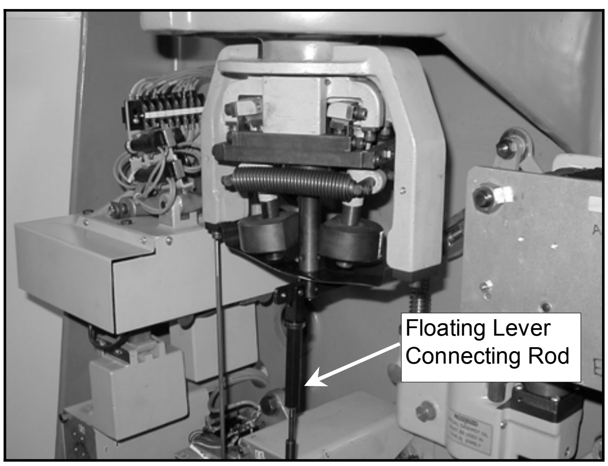
## 7.5. Adjust Speed Changer

(a) Unwatered Method: With the PMG simulator driving the ball head at 100 percent speed ("% DEVIATION FROM SETPOINTS" set at 00.00), set the speed droop to 5 percent and the speed changer to the normal speed no load (SNL) position. The standard adjustment of the speed changer is 60 Hz at 0 on the speed changer dial and 0 on the droop dial. This will result in an SNL gate position of about -2 percent on the speed changer dial with droop at a 5 percent setting. Depending on plant philosophy, the SNL setting may be different. If adjustments are made with the ball head operating at a constant speed and the speed droop at 0 percent, the gates will tend to go completely open or completely closed and adjustment will be impossible. To perform the unwatered method it is necessary to know the normal speed no load wicket gate position.

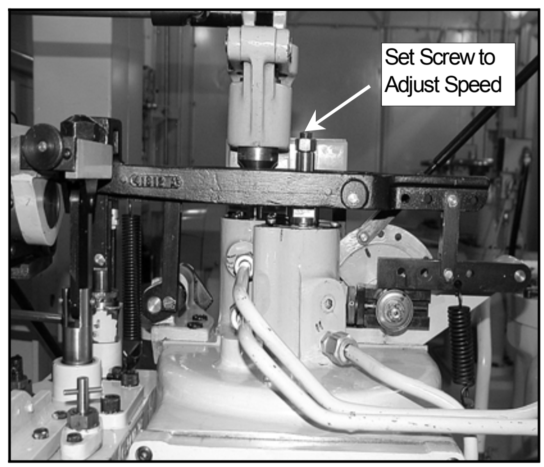
Verify with a frequency meter that the ball head is turning at nominal frequency. Observe the gate position and adjust it to SNL gate position.

1. On Woodward governors, adjust the length of the floating lever connecting rod, which is usually called the speeder rod (photograph 17).

2. On Pelton governors, adjust the setscrew on the pilot valve (photograph 18).




***Photograph 17.—Woodward ball head and floating lever connecting rod.***




***Photograph 18.—Pelton speed adjustment.***

(b) Operational Method: With the unit operating off-line and on governor control, set the speed droop to 0 percent and the speed changer to 0 percent. At some plants, the preferred setting is at 5 percent droop and the 0 percent on the speed changer. This is not the standard setup, but it shouldn't cause any operational problems.

Observe the unit frequency and adjust it to nominal frequency.

1. On Woodward governors, adjust the length of the floating lever connecting rod.

2. On Pelton governors, adjust the setscrew on the pilot valve.

### 7.6. Adjust Dashpot

(a) Tests with inactive dashpot

1. Change the scale on the strip chart recorder so that full scale equals 20 percent gate. This will make the trace easier to read.

   Unwatered: Run the ball head motor at rated speed and voltage with the PMG simulator. Adjust the speed changer to bring the wicket gates above 20 percent to avoid the cushion on the servomotors.

   Operational: With the unit on line, adjust the speed changer to bring the wicket gates to approximately 20 percent to avoid the cushion of the servomotors.

2. Open the main dashpot needle at least two full turns to remove the dashpot from service.

   Unwatered: Decrease the ball head speed by 0.5 percent. Wait until the gate position stabilizes and increase the ball head speed by 0.5 percent.

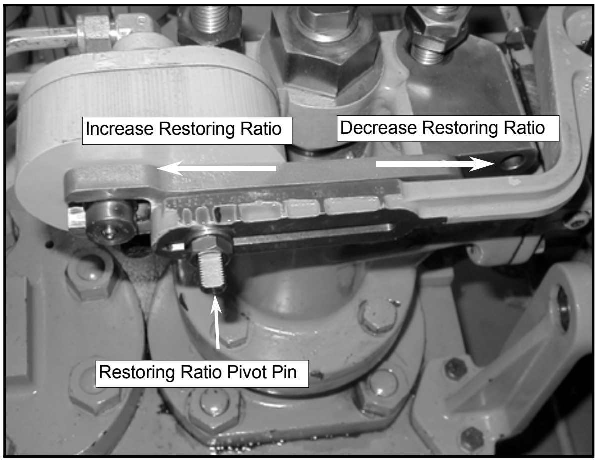
   Operational: Rapidly raise the speed changer by 0.5 percent (½ turn). Wait until the gate position stabilizes, then rapidly lower the speed changer to the original setting.

3. Adjust the restoring ratio on the pilot valve restoring lever on Woodward governors or the relay valve feedback sensitivity thumbscrew on Pelton governors to obtain a fast, stable response with no overshoot (photographs 19 and 20). Look at the curve of gate position in both directions (figure 13). The restoring ratio is the ratio of main valve movement to pilot valve movement. Increasing the restoring ratio allows the main valve to travel farther and increases the over-shoot. Label the strip chart with the restoring ratio setting during each test.

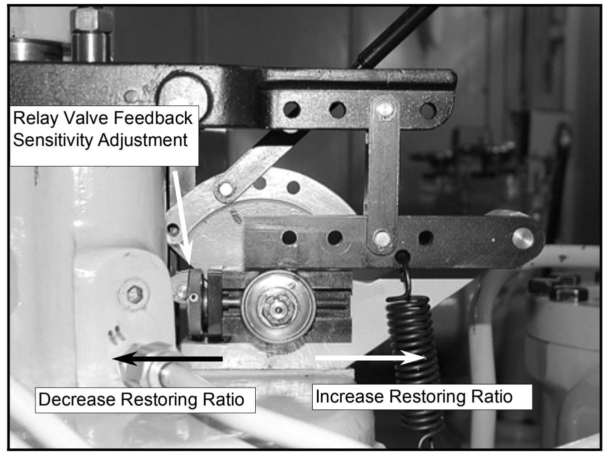
(b) Tests with active dashpot active (small signal governor response)

1. Close dashpot needle to approximately 1/4 turn open.

2. Verify that the dashpot solenoid bypass is not energized. Connect a DC voltmeter across the terminals. If the voltmeter reads 125 VDC, the solenoid is energized.




***Photograph 19.—Woodward restoring ratio adjustment.***




***Photograph 20.—Pelton restoring ratio adjustment.***

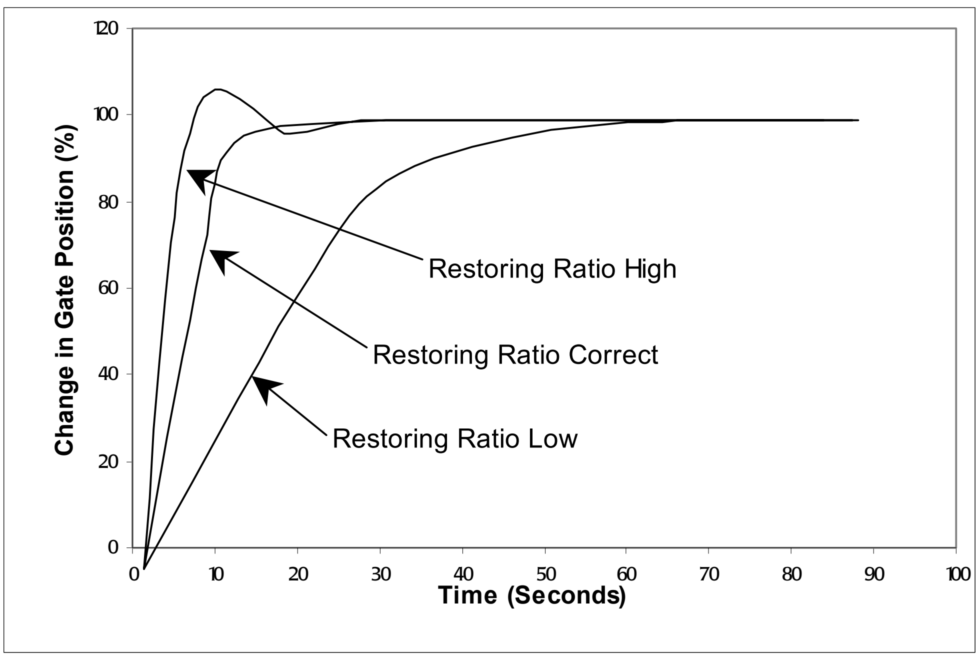



***Figure 13.—Governor response with dashpot disabled.***

Unwatered: Decrease the ball head speed by 0.5 percent. Wait until the gate position stabilizes and increase the ball head speed by 0.5 percent.

Operational: Rapidly raise the speed changer by 0.5 percent (½ turn). Wait until the gate position stabilizes, then rapidly lower the speed changer to the original setting.

3. Adjust the compensating crank and dashpot needle to match the simulated response curve (figure 14) (photographs 21 and 22). Label the strip chart with each compensating crank setting and the corresponding changes in the dashpot needle settings. The following are general guidelines for adjusting the settings:

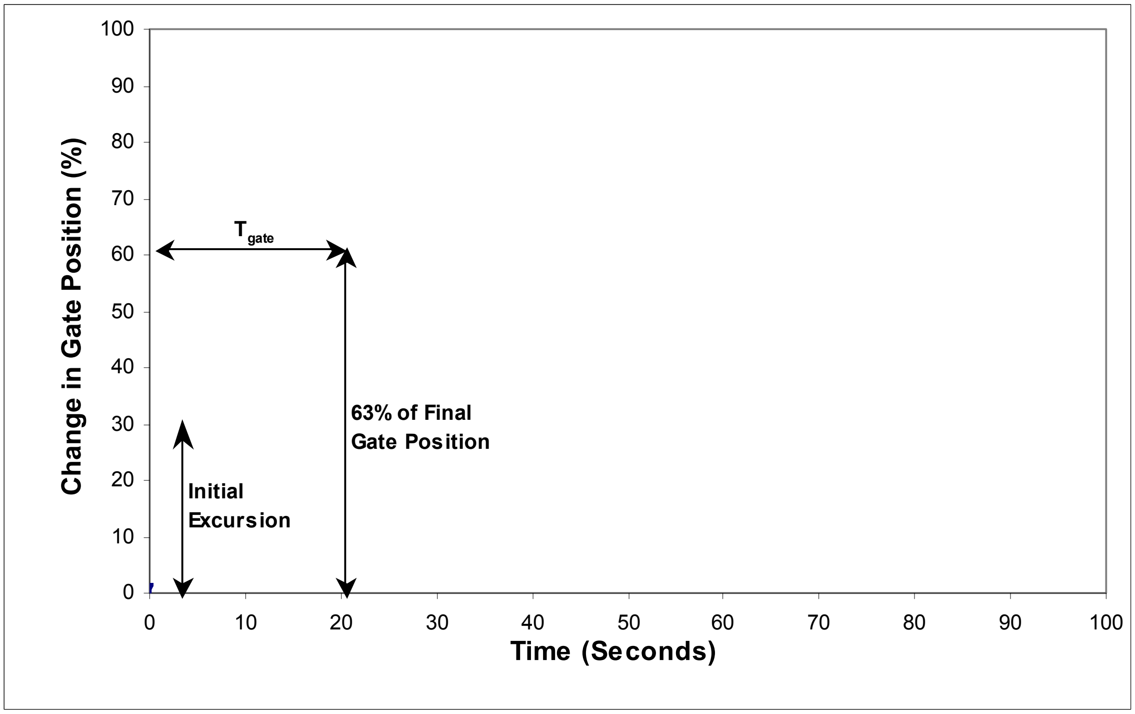
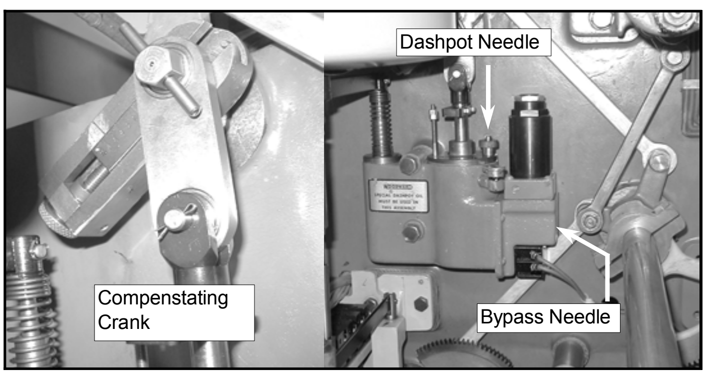
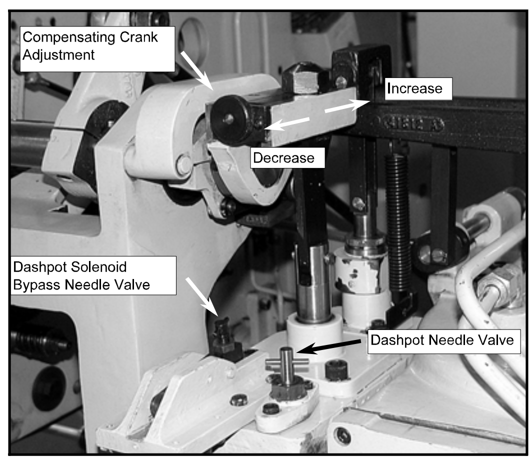



***Figure 14.—Simulated governor response curve.***




***Photograph 21.—Woodward dashpot and compensating crank.***




***Photograph 22.—Pelton dashpot and compensating crank.***

- First adjust the compensating crank. Increasing the setting on the crank increases the movement of the large dashpot plunger and decreases the magnitude of the initial excursion of the gate position, and increases $T_{gate}$.

- Increasing the opening of the dashpot needle valve increases the slope of the gate position versus time curve, decreasing the gate time constant, $T_{gate}$.

**Note**: The dashpot needle is not calibrated. If the needle is moved for maintenance or for any other reason, $T_{gate}$ will be changed and this test will have to be redone.

(c) Test with dashpot bypassed (if equipped)

1. Instruct the operator to energize the dashpot bypass solenoid through the control room. A voltmeter across the dashpot bypass solenoid terminals should indicate 125 VDC.

   Unwatered: Decrease the ball head speed by 0.5 percent. Wait until the gate position stabilizes and then increase the ball head speed by 0.5 percent.

   Operational: Rapidly raise the speed changer by 0.5 percent (½ turn). Wait until the gate position stabilizes, then rapidly lower the speed changer to the original setting.

2. Adjust the dashpot bypass solenoid needle until a time constant ($T_{gate\ 2}$) of 20 seconds in both directions is obtained. Record the relative turn changes of the needle on the strip chart. If the time constant is very fast initially, the needle may be gently seated and backed out 1/4 turn as a starting point.

## 7.7. Check and Adjust Dither

(a) Install LVDT, proximity probe, or dial indicator to observe the main valve motion. Use a tachometer to measure oil motor speed.

(b) Procedures for units with oil motor vibrator units:

1. Adjust the eccentric bushing (reference 07079-570) to obtain 0.006 to 0.009 inch of movement of the main valve.

2. Adjust the regulator adjusting screw (reference 07079-596) to obtain a 7 to 10 Hz frequency (420 to 600 RPM).

(c) Procedures for units with vibrator disks: If no motion can be felt with a finger between the main valve and the base, the vibrator disks (references 07079-391 and -394) should be replaced.

(d) Procedures for units with Pelton governors: If no motion can be felt with a finger between the main valve and base, the pilot valve should be disassembled and the dither port checked.

### 7.8. Normal Operations Check

With the PMG simulator completely shut down, remove the PMG simulator leads from the terminals and reconnect the PMG leads. Return the unit to service.

(a) Off-line governor tests

1. Set up strip chart recorder.

   Channel 1 - gate position, adjust so that 10 percent gate equals full scale on the chart.

   Channel 2 - frequency transducer, adjust so that 1 Hz equals full scale on the chart.

2. With the unit running off line near 60 Hz and the field breaker closed, make a rapid increase of one turn (1 percent) in the speed changer adjustment.

3. Wait until the speed settles and then make the same rapid change one turn (1 percent) back to original setting.

4. Repeat parts 2 and 3 two more times each.

5. Calculate and record the speed stability index (SSI) from channel 2 frequency measurements.

   SSI% = ((Max.Freq in Hz - Min Freq in Hz) x 100%)/60Hz

   A mechanical governor in good condition should have an SSI of less than 0.3 percent (a frequency wander of 0.2 Hz).

(b) Observation of synchroscope

1. Synchronize the unit using normal procedures.

2. Load the unit.

3. Consult with operations personnel to verify adequate synchronizing and loading performance.

4. Check the governor and the servosystem to determine if servicing is required if difficulty in synchronizing the unit or excessive frequency wander (above 0.4 Hz) are detected. The dashpot needle can temporarily be turned down to help increase unit stability until the source of the problem can be located and corrected.

# 8. GOVERNOR MAINTENANCE

## 8.1. Governor Tests and Adjustments

Annual adjustments: Check wicket gate timing and speed droop calibration as described in Section 7. Check the mechanical alignment of the governor as described in Section 4. If the dashpot, pilot valve, or any of the governor linkage is disassembled, adjust dashpot and compensating crank as described in Section 7.

Five-year adjustments: Perform all the tests outlined in Section 7.

## 8.2. Governor Ball Head (Woodward Vibrator Type)

Weekly adjustments: Oil the ball head by applying a few drops of light machine oil to the top of the ball head motor shaft. Check to see if motion can be felt with a finger between the main valve and base. If no motion can be felt, replace the vibrator and balls.

Annual adjustments: After shutdown, remove the ball head and disassemble. Clean and inspect the slide blocks, flyball rod, and flyball rod bushings. Replace vibrators and vibrator balls if no motion of the main valve was felt before shutdown or if there is any noticeable wear on the vibrators. If sliding surfaces of slide blocks are worn, rotate both blocks to a new surface. Scribe an "X" or other mark on the worn slide block surfaces so they are not reused. Check flyball rod for wear and for straightness and replace as required. Check ball bearings in ball head motor and flyball arms and replace as required. Replace flyball rod bushings if they are worn or scored. Cover vibrator balls with a light grease and reassemble. Do not fill vibrator cup with grease because this can dampen the vibration. Check operation of pressure type oilers if so equipped.

## 8.3. Governor Ball Head (Woodward Strap Suspended Type)

Quarterly adjustments: Add dashpot oil to the top of the ball head motor to fill the internal dashpot. Do not use lubricating oil.

Annual adjustments: Observe the operation of the ball head and check for any unusual vibration. If any abnormal vibration is noted, disassemble the ball head and the check condition of the thrust bearing, ball head shaft bearings, and ball head motor bearings. Follow the manufacturer's alignment and reassembly procedure.

## 8.4. Governor Ball Head (Pelton)

Annual adjustments: Observe the ball head and the ball head motor for any unusual vibration or noise. Replace the ball head motor bearings if any abnormal vibration or noise is noted. Follow the manufacturer's instructions for disassembly and reassembly.

## 8.5. Woodward Oil Motor Vibrator

Annual adjustments: Check that the oil motor vibrator is providing a 0.006 to 0.007 inch oscillation of the main valve and that the motor is turning in the range of 400 to 600 RPM (7 to 10 Hertz). Adjust the eccentric bushing in the pivot lever to change the magnitude of oscillation. Adjust the oil flow regulator to change the motor speed.

## 8.6. Pilot Valve

Annual adjustments: Disassemble the pilot valve and remove all rust spots and oil varnish with a fine grade emery cloth (320 to 500) and crocus cloth. Any nicks or scratches should be removed by stoning with a very fine flat stone. Care must be taken not to round or break the edges of the valve lands. If wear is excessive or the plunger does not move freely in the bushing, replace with a new matched plunger-bushing set.

## 8.7. Main and Auxiliary Distributing Valves

Annual adjustments: Check that the main valve plunger is free. Shut off the oil supply to the pilot and main valves and disconnect the pressure supply to the pilot valve. With the oil pressure relieved, lift the main valve plunger until it hits the opening stop nuts and then drop it so it hits closing stop nuts. If the plunger drops freely, it is acceptable, but if there is any binding or if the plunger drops sluggishly, disassemble the valve to determine the problem. Check the operation of the transfer valve and the auxiliary valve.

Biannual adjustments: Remove the main and auxiliary valve plunger and remove all rust spots and oil varnish with a fine grade emery cloth (320 to 500) and crocus cloth. Any nicks or scratches should be removed by stoning with a very fine flat stone. Care must be taken not to round or break the edges of the valve lands. Check the ports in the valve bushings for dirt or sludge and clean as required. Check that the main valve plunger is free and can fall of its own weight after reassembly.

Unscheduled adjustments: Completely disassemble the main and auxiliary valves. Remove opening, closing, and pressure plungers and remove all rust spots and oil varnish with a fine grade emery cloth (320 to 500) and crocus cloth. Check the condition of the main distributing valve plunger's piston rings, and replace as required.

## 8.8. Miscellaneous Valves

Biannual adjustments: There may be other hydraulic valves in the governor such as gate limit valves and solenoid valves. These valves should be disassembled, and all rust spots and oil varnish should be removed with a fine grade emery cloth (320 to 500) and crocus cloth. Any nicks or scratches should be removed by stoning with a very fine flat stone. Care must be taken not to round or break the edges of the valve lands. Check the ports in the valve bushings for dirt or sludge, and clean as required.

## 8.9. Dashpot

Annual adjustments: Check the dashpot oil level and add oil if necessary. Do not use lubricating oil. Check the operation of the solenoid operated bypass. If tests of section 7 indicate a problem with the dashpot, disassemble and clean the plungers. Before reassembly, check the setting of the small dashpot plunger. On Woodward governors, the distance from the center of the pivot pin to the top of the bonnet should be 2-7/8 inches. Turn the small plunger spring to adjust this distance. On other governors, check the manufacturer's instruction book for the adjustment procedures. To refill the dashpot, reassemble, except for the small dashpot plunger. Tip the dashpot so that the opening for the small plunger is higher than the large plunger and fill the dashpot through the small plunger opening. Move the large plunger occasionally during filling to allow air to escape. To check for trapped air once the dashpot is filled, install the small plunger, close the dashpot needle, and operate the large plunger while holding the small plunger. The small plunger should react instantly to any movement of the large plunger. Any lag in small plunger movement indicates there is air in the dashpot or a leak past the needle, solenoid bypass, or the plungers. To purge the air, open the needle, hold the small plunger in place, and operate the large plunger.

To check the condition of the dashpot, close the bypass and the needle completely, push the small plunger down as far as it will go, and time how long it takes to recenter. It should take more than 50 seconds to travel 0.125". A shorter time indicates excessive leakage past the needle or plungers and the dashpot should be repaired or replaced.

After any maintenance on the dashpot, it is important to perform the governor adjustment tests of section 7 to bring the governor back to optimum performance.

## 8.10. Links and Pins

Monthly adjustments: Lubricate links and pivot pins with a light machine oil.

Annual adjustments: Check links and pins for wear or binding. Use a new pin to check holes in links for wear, and use a new link with the proper sized mating hole to check the condition of the pins. Replace pins and links as required. Check bearings in the linkage, on the shafts, and in the control panel for any roughness and replace as required. Lubricate bearings as required. Check gears for wear and proper meshing.

## 8.11. Restoring Cable

Annual adjustments: Lubricate restoring cable sheaves and rod ends at the servomotor connection.

Unscheduled adjustments: Disassemble sheaves and inspect sheaves and cable. Replace sheaves if the pulley is worn or if the bearings are rough.

## 8.12. Hydraulic System

Daily adjustments: Check the level of oil in the sump and the actuator tank and add oil or charge the pressure tank with air as required.

Weekly adjustments: Switch the lead pump to lag and vice versa.

Monthly adjustments: Switch the strainers and clean or replace the filter element. If the pumps are equipped with hour meters, note the run time. Compare the run time to the previous month's readings and investigate any large deviation.

Annual adjustments: Before scheduled maintenance, send a sample of the governor oil to the laboratory for analysis. If analysis shows filtration is required, drain and filter the oil.

When the oil is drained, clean the oil sump and actuator tank with lint free rags and squeegee, inspect, and repaint as required. Check the condition of the float valve disk, seat, float, and float arm for any damage or wear. Check the condition of the float, the cable, and the sheaves of level switches for wear and free operation.

After the system is refilled, check the operation of the pump unloader valve. Check the operation of the pressure relief valves on the pumps and actuator tank. Relief valves on the actuator tank should be set to operate at a pressure no higher than the maximum allowable working pressure for the tank. The pump relief valves should be set to operate at a slightly lower pressure than the actuator tank relief valve. This is to prevent the pumps from continuing to fill the actuator tank if high pressure occurs in the system.

Check the calibration and operation of the pressure and level switches and reset as required. Check annunciation where applicable.

With wicket gates blocked, time the pumping cycle for each pump, noting the length of time the pump is on, the rise of the oil level in the actuator tank, and the length of time between pumping cycles. Compare the time to previous readings. If the pump is taking longer to reach operating pressure or is pumping more frequently, check for leaks in the system.

## 8.13. Generator Air Brake Valve

Annual adjustments: Check the manual and solenoid operation of the valve. Lubricate pivot points with light machine oil. Clean the airline filter.

Biannual adjustments: Disassemble and remove all rust spots with a fine grade emery cloth (320 to 500) and crocus cloth. Lap the valve seats if required.

### 8.14. Permanent Magnet Generator (PMG) or Speed Signal Generator (SSG)

Annual adjustments: Inspect the speed switches and drive gears for wear. Lubricate pivot pins and check speed switch bearings. Check the setting and operation of the speed switches. Check the insulation between PMG or SSG housing and the supporting frame by measuring the resistance from the housing to ground with a meggar. Replace or repair the insulating gasket as required. Check the voltage output of the PMG.

Unscheduled adjustments: Replace the main drive bearings of the PMG or SSG. If necessary, remagnetize the PMG field following the procedure in section 5.

### 8.15. Position and Limit Switches

Annual adjustments: Check the operation and settings of the gate limit, the speed changer position, and the gate position switches and adjust as required. Clean the contacts as required. Check the drive gears for wear and proper meshing. Check annunciation where applicable.

### 8.16. Shutdown Solenoids

Annual adjustments: Check the operation of the solenoids for binding or sticking when tripped and reset. Check the settings to ensure that the complete shutdown solenoid closes the wicket gates completely and the partial shutdown solenoid brings the gates to the speed no load setting. When the solenoids are reset, make sure that the linkage does not prevent the gates from going to 100 percent. Inspect the solenoid for any signs of overheating or other damage. Check the condition of electrical connections and auxiliary contacts.

### 8.17. Speed Changer, Gate Limit Motors, and Remote Position Indicators

Annual adjustments: Operate motors and check for excessive vibration or noise. Replace bearings as required. Check electrical connections and motor brushes. Check the operation of the position indicators for any sticking or binding and check the correlation between the transmitter and receiver. Check gears for wear and proper meshing. Check the clutch adjustment.

## 9. TROUBLESHOOTING

A well-maintained mechanical governor will provide years or trouble free service, but eventually there will be problems. Friction and misadjustment are the biggest cause of problems. It would be impossible to address every possible problem. Some of the more common problems and the most likely causes are discussed below.

## 9.1. Hunting

Hunting is an unstable condition in which the governor can't maintain frequency at an acceptable level when operating off line. Some movement of the wicket gates and frequency wander is normal for a mechanical governor, but if the frequency wander exceeds 0.2 hertz peak to peak or if the automatic synchronizer can't put the unit on line, it is considered excessive. On-line hunting (the wicket gates move back and forth) can occur, but is fairly uncommon.

Off-line hunting is usually the first and possibly the only sign of a problem with a governor. Off-line hunting is a symptom of a variety of problems. The most common cause of off-line hunting is misadjustment of the dashpot. If the dashpot needle is too far open, there is not enough compensation and the governor will hunt. Ideally, the best solution is to perform the governor tests as outlined in section 7. If that is not possible, the dashpot needle should be slowly closed until the hunting stops. This will allow the unit to be put on line but probably won't be an optimum adjustment for the dashpot. The tests of section 7 should be scheduled to readjust the governor.

If the dashpot needle is completely closed and the unit is still hunting, there is probably a problem with the dashpot. If the dashpot had been removed and refilled with dashpot oil, there may be air in the lower chamber of the dashpot. Remove the dashpot and work the air out as described in paragraph 8.9. If air in the dashpot has been ruled out, the dashpot should be checked for excessive leakage by the test described in paragraph 8.9. If the leakage is excessive with the dashpot needle closed, also close the bypass needle completely to check for leakage past the solenoid valve. If the leakage is still excessive, the dashpot must be replaced or rebuilt.

Excessive friction can also cause hunting. It is often possible to reduce the hunting caused by friction by closing the dashpot needle. This may allow the unit to be put on line, but the governor response will be slow and irregular. The governor response tests of section 7 can help show friction by an irregular response instead of the normal smooth curve. While the test may show that there is friction in the system, finding the source of friction can be difficult. If the irregular response is seen only in one direction, the friction is probably in the restoring mechanism. Because the restoring cable is rigidly attached to the servomotor, movement in the direction that the servomotor pulls the cable may be smooth. Movement in the other direction may be affected by friction because the cable is pulled by only a large hanging weight. The friction may be in the cable sheaves or in any of the linkage attached to the restoring cable in the cabinet. Other sources of friction may be the pilot valve, dashpot, pivot pins, ball head, main valve, and the wicket gate operating mechanism.

On-line hunting is not very common. Once a unit is on line, the actual speed of the unit can't change. Any hunting on line is the result of a bad signal from the PMG (the most common cause) or a hydraulic problem. The most likely cause of on-line hunting is a broken or damaged drive pin. If a drive pin is broken or damaged, the speed of the PMG will change slightly every revolution, causing the wicket gates to move. An example of a hydraulic problem causing on-line hunting is a restoring ratio setting that is too large. If the main valve is allowed to move to far before the pilot valve bushing resets, the hydraulic system can become unstable. This is very uncommon, and on most mechanical governors, it is not possible to set the restoring ratio high enough for this to occur on line.

## 9.2. Inability to Reach Full Speed

The inability of a unit to reach 100 percent speed usually happens after major maintenance on the governor. This problem is usually the result of a misadjusted speeder rod on a Woodward governor or the speed setting screw on a Pelton governor. If adjusting the speed rod or the set screw doesn't bring the unit to normal speed, the problem may be in the ball head or the gate limit. Damage to the ball head, such as a broken spring, may cause the pilot valve to center at a lower or higher speed than normal. If the gate limit is out of adjustment, the gate may be restricted from opening to the speed no load position. The alignment procedure in section 4 should be used to realign the gate limit.

## 9.3. Inability to Reach Full Load

The most common cause of a unit not being able to reach full load is the gate limit being out of adjustment. The procedure in section 4 should be followed to align the gate limit.

Another cause of a unit not being able to reach full load is misadjustment of the shutdown solenoid. On a Woodward governor, the shutdown rods that act on the gate limit shaft are adjusted with acorn nuts to determine how far the gate limit is driven on a shutdown. If these nuts are too high, they will prevent the gates from opening.

## 9.4. Wicket Gates Sticking Midrange

Wicket gates sticking when the governor is calling for a change is usually not a function of the governor. This is usually the result of friction in the wicket linkage or in the wicket gates themselves, or may be the result of marginally sized servomotors.

**MISSION STATEMENTS**

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.