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Mechanical Maintenance of Mechanical and Digital Governors for Hydroelectric Units

U.S. Department of the Interior

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14. ABSTRACT
The Bureau of Reclamation operates and maintains 53 hydroelectric powerplants and many switchyards, pumping plants, dams, canals, and associated facilities that are important to electric power and water delivery systems This volume includes standards, practices, procedures, and advice on day-to-day operation, maintenance, and testing of mechanical and digital speed governors. Following the procedures described in this FIST for mechanical maintenance and testing of speed governors and their associated equipment will meet FIST 4-1A and NERC standards.

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Bureau of Reclamation
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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.

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POM: https://teamssp.bor.doi.net/printanddup/forms/POM%20Forms/Forms/AllItems.aspx
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Acronyms and Abbreviations

DC	direct current
FAC	Project Planning and Facility Operations, Maintenance, and Rehabilitation (of Reclamation Manual)
FIST	Facilities Instructions, Standards, and Techniques
Hz	hertz
ISO	International Standards Organization
kVA	kilovolt ampere
LVDT	linear variable differential transformer
MLDT	magnetostrictive linear displacement transducer
NERC	North American Electric Reliability Corporation
NFPA	National Fire Protection Association
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
PLC	programmable logic controller
PMG	permanent magnet generator
PO&M	Power Operations and Maintenance
ppm	parts per million
PRO	Power Resources Office
psi	pounds per square inch
RCD	Records Management (of Reclamation Manual)
RM D&S	Reclamation Manual Directive and Standard
RPM	revolutions per minute
RPVOT	Rotating Pressure Vessel Oxidation Test
Reclamation	Bureau of Reclamation
SNL	speed-no-load
SSG	speed signal generator
SSI	speed stability index
TAN	total acid number
TSC	Technical Service Center
VDC	volts direct current
WECC	Western Electricity Coordinating Council

Symbols

%	percent

1.0 Introduction

The Bureau of Reclamation operates and maintains hydroelectric powerplants, switchyards, pumping plants, water delivery equipment and associated facilities in the 17 western United States. These facilities house complex electrical and mechanical equipment that must be kept operational because they are critical to the electric power and water delivery systems relied on by many. FIST are technical documents that provide criteria and procedures that should be utilized by the offices involved in managing Reclamation facilities and assets.

This document establishes standard technical practices to ensure the, safe, reliable, economic and efficient O&M of Federal facilities by keeping related assets in good condition and ultimately protecting Federal investments. These technical practices provide a sufficient level of detail to ensure consistent application while providing flexibility for the use of innovative techniques and approaches. This document was developed with input from staff in Reclamation's Denver, regional, and area offices.

1.1 Purpose and Scope

This document is intended to promote uniformity in the manner that assets are managed, documented, and coordinated, and may be utilized by transferred facilities and other entities as appropriate. It establishes consistent procedures, minimum standards and O&M criteria for hydroelectric equipment and systems owned and operated by Reclamation. Other technical documents may provide additional electrical and mechanical maintenance information for the equipment or systems discussed in this document.

O&M requirements are based on industry standards and experience. Maintenance requirements vary based on equipment condition and past performance, and sound engineering practices and maintenance management should be employed for special circumstances. Manufacturer recommendations and instructions should be consulted for additional maintenance that may be required beyond what is stated in this manual.

This volume includes standards, practices, procedures, and advice on day-to-day operation, maintenance, and testing of mechanical and digital speed governors. Following the procedures described in this FIST for mechanical maintenance and testing of speed governors and their associated equipment will meet FIST 4-1A and NERC standards.

1.2 Reclamation Standard Practices

FIST manuals are designed to provide guidance for maintenance and testing on equipment in Reclamation's facilities. There may be multiple ways to accomplish tasks outlined in this document. Facilities may exercise discretion as to how to accomplish certain tasks based on equipment configurations and available resources.

Reclamation's regions, PRO, and TSC agree that certain practices are required to be consistent across all Reclamation facilities. Mandatory FIST procedures, practices, and schedules that appear in **{Red, bold, and bracketed}** or **[Black, bold, and bracketed]** text are considered Reclamation requirements for the O&M of equipment in power facilities. RM D&S FAC 04-14, *Power Facilities Technical Documents*, describes the responsibilities required by text designations: **{Red, bold, and bracketed}**, **[Black, bold, and bracketed]**, and plain text, within this technical document. Refer to RM D&S FAC 04-14 for more details concerning technical documents.

1.3 Maintenance Tables

Maintenance tables for tasks described in this document are included in FIST 4-1A, *Maintenance Scheduling for Mechanical Equipment*, and FIST 4-1B, *Maintenance Scheduling for Electrical Equipment*.

1.4 Manufacturer Recommendations

The information in this document is based on governor manufacturers' documentation and historic Reclamation practices. Due to the differences in equipment designs, owner's manuals and manufacturer's recommended maintenance should be consulted when developing job plans. Not following the manufacturer's guidance may void the warranty of new equipment. If there is a discrepancy between the FIST and the manufacturer's recommendations, the job plan must use the more stringent practice unless there is a reason that a less restrictive maintenance practice is warranted. Use of a less restrictive maintenance practice must be approved as outlined in RM D&S FAC 04-14 by either a deviation or a variance. A deviation maybe granted in accordance with RCD 03-03 and variance through POM Form 300.

1.5 FIST Revision Requests

The FIST Revision Request Form (POM-226) is used to request changes to a FIST document. The request will include a summary of the recommended changes and a basis for the revision or new FIST. These forms will be submitted to the Manager, PRO. The PRO Manager will keep a list of Revision Requests for each FIST and include these in the next scheduled revision unless the change is prioritized sooner.

1.6 Mechanical Database

The TSC Mechanical Equipment Group created and maintains a Mechanical Equipment Database. All Reclamation employees have access to the database, which contains test data, operating data, and general information about the following:

1) Turbines
2) Governors
3) Gates and valves
4) Pressure vessels
5) Penstocks

6) Elevators
7) Hoists
8) Cranes

The database:

1) Provides visibility of other Reclamation facilities with similar equipment; i.e., find all Reclamation facilities with Obermeyer Gates.
2) Is a critical tool for facility reviewers, i.e., reviewers can obtain printable forms from the database website for each asset being reviewed. The form can be taken to the site and used to compare and update information.
3) Tracks equipment testing frequencies and critical data comparison. For example, governor alignment results can be compared to the previous governor alignment results. An increase in operating pressures or opening/closing times can indicate gate repairs are required.
4) Provides updated testing and inspection dates for gates, valves, pressure vessels, and penstocks for mechanical inspectors/reviewers to use during Power Reviews (RM D&S FAC 04-01), Associated Facilities Reviews (RM D&S FAC 01-04) and High and Significant Hazard Dam Reviews (RM D&S FAC 01-07).

When tests and alignments, as outlined in FIST 4-1A or the database, are completed, facilities or region personnel should submit the recorded data to the Mechanical Equipment Group (bordromechequipdb@usbr.gov). A service agreement is established with TSC to update the database and keep it accurate. The PRO&M review programs use this database to ensure tests and alignment are up to date and are being tracked.

The link to the Mechanical Equipment Database is: https://mechdb.usbr.gov/MechDB/.

2.0 Mechanical Governor Fundamentals

2.1 Governor Purpose

The primary purpose of a governor for a hydroelectric unit is to control the speed and loading of the unit. The governor accomplishes this by controlling the flow of water through the turbine. The following sections describe how hydroelectric governors operate.

2.2 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 move off its centered position and make the gates open or close, which changes the unit's speed.

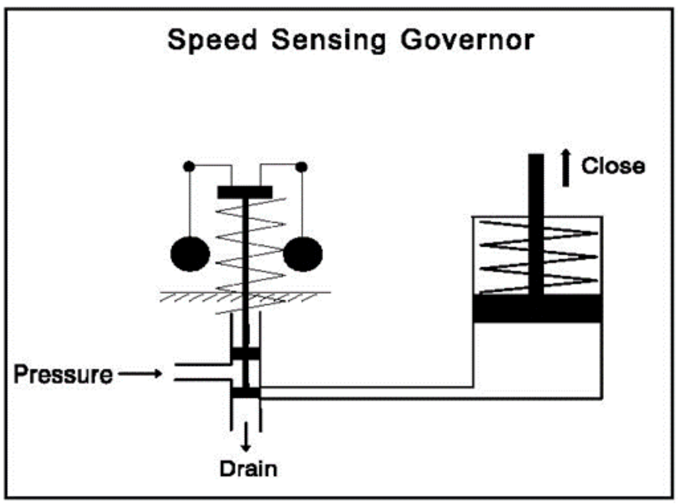


Figure 1. Speed sensing governor schematic

2.3 Speed Droop Governor

A speed-sensing governor is inherently unstable and is not suitable for speed regulation. The undamped movement of the valve allows the servomotor to move too far before the speed actually changes and the flyballs react. This lag between the servomotor movement and the flyball response leads to a severe "hunting" condition in which the servomotor continues to oscillate because there is no feedback of servomotor position and the valve does not know when to stop moving.

To provide stability in the governor, feedback in the form of speed droop can be introduced. Speed droop by definition is the governor characteristic that requires a decrease in speed to produce an increase in gate opening. Figure 2 shows a simple speed-droop governor. In the speed-droop governor, a decrease in speed causes the valve to move upward, allowing the servomotor to drain and move in the opening direction. As the servomotor moves to the open position, the speed-droop lever moves the valve down, centering it over the port and stopping the servomotor. The unit then operates at a slightly slower speed, but the servomotor does not overshoot because, for a given speed, the servomotor must move to a specific position.

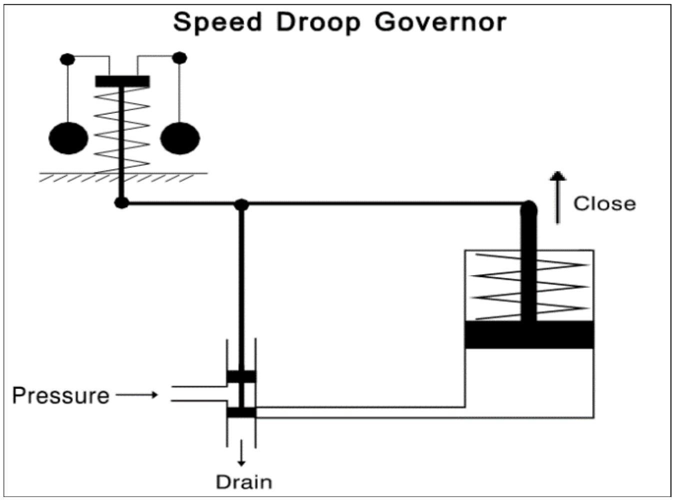


Figure 2. Speed droop governor schematic

Figure 3 shows the relationship between speed and gate position of a speed droop governor. A governor with speed droop set at 5% requires a decrease in speed of 5% in order to achieve full gate opening. A decrease in speed of 2.5% will cause the gates to open 50%. Speed droop is equal to the percent change in speed divided by the change in gate position.

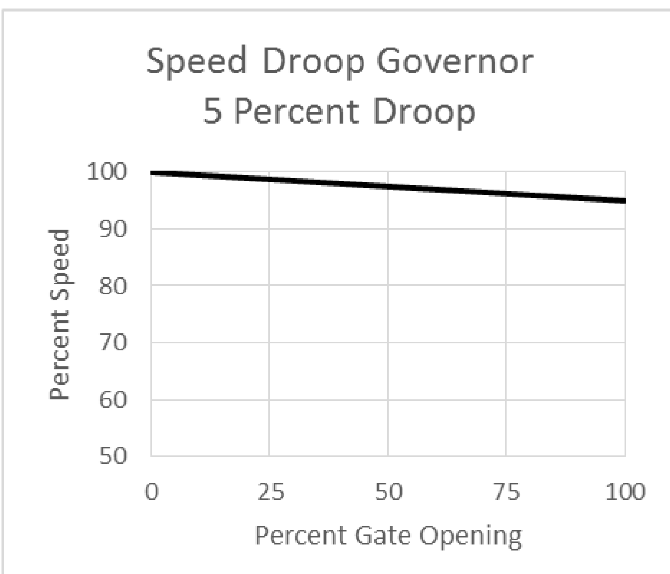


Figure 3. Relationship between speed and gate position for a 5% speed-droop governor

When the generator is part of a large system, no single unit is capable of changing the system frequency; therefore, the unit must operate at the system frequency. This large system is referred to as an infinite bus, and most hydroelectric power plants are operated this way most of the time. When a generator is connected to an infinite bus, the governor controls the loading of the unit by adjusting the speed changer according to the slope of the speed-droop setting. With a unit connected to an infinite bus, an increase in the 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, set at 5% droop, connected to a large power system. For this example, it is assumed that zero gate equals zero load and 100% gate is 100% load. The speed is fixed at 100%. In this example, the governor is adjusted so that the unit is at SNL with a zero speed-changer setting. With a speed changer setting of 2.5%, the load will be 50%. A 5% speed-changer setting would result in 100% load.

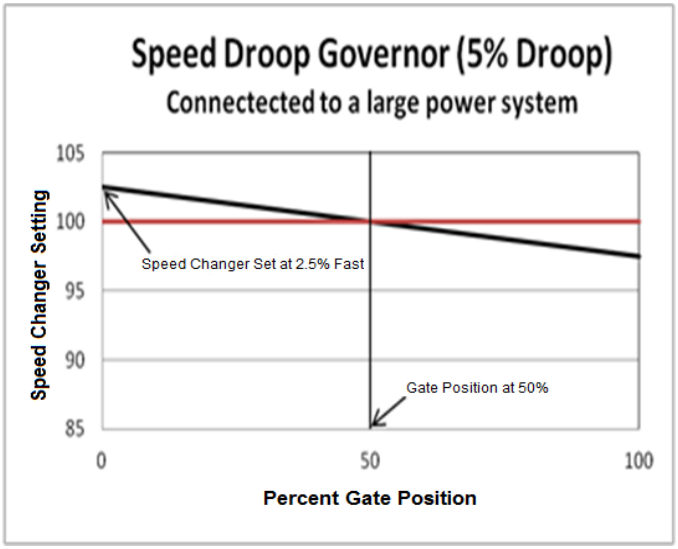


Figure 4. Speed-changer setting versus gate position for a speed-droop governor connected to a large power system

2.4 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 is set to move the plunger toward its centered position. When the small plunger is moved off-center, the spring will eventually re-center it. The rate at which the plunger moves to center is controlled by the needle valve setting, which provides an adjustable leak in the hydraulic system between the two plungers.

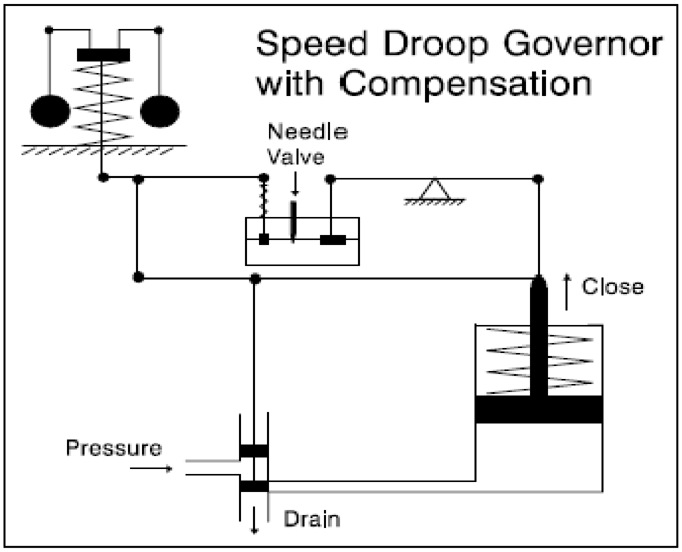


Figure 5. Speed-droop governor with compensation schematic

As shown in Figure 5, the dashpot acts in parallel with the speed droop and adds more speed droop to the governor. Because of the re-centering of the small dashpot plunger, the speed droop provided by the dashpot is temporary. This temporary droop compensates unit inertia and the water column. A compensating crank adjusts the amount the large dashpot plunger moves for a given wicket gate movement. The governor response can be set to match the inertia and water flow characteristics of a specific unit by adjusting the dashpot needle and compensating crank. The needle adjustment allows time for the small plunger to re-center and time for the unit speed to return to normal. The dashpot can provide stability when servomotor movement is not great enough to provide sufficient feedback through the normal speed-droop mechanism, such as when operating off-line at SNL.

When a unit is connected to a large power system, the damping from the dashpot causes a slower response to changes in the 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 provides an additional leakage path to allow the small dashpot to re-center rapidly. It may be operated by solenoid or mechanical linkage. The bypass is used when the unit is operating on-line and connected to a large power system. If a powerplant is separated from the main system and is required to carry the load and maintain frequency for a small system, the bypass should not be used.

3.0 General Description of Mechanical Governors

Mechanical governors have numerous designs and configurations. Regardless of the manufacturer or design, all governors 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.

The two basic designs used in Reclamation powerplants are cabinet actuators and gate shaft governors. Cabinet actuator governors typically have the ball head, valves, and pumps located in a cabinet outside the turbine pit with oil piping supplying oil to servomotors located in the turbine pit. The servomotors drive the shift ring to move the wicket gates. Gate shaft governors provide oil to a single servomotor located outside of the turbine pit. The servomotor drives a "gate shaft" which, through mechanical linkages, drives the shift ring in the turbine pit 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. At design synchronous speed, the flyweights are in a neutral position. The ball head is usually turned by a three-phase motor that is powered by a 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. As the unit rotational speed increases, the flyballs swing outward because of centrifugal force, which pushes 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.

3.2 Hydraulic System

The hydraulic system consists of an oil sump, one or two oil pumps, an oil actuator 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 share two pumps between two units so that, in an emergency, one pump could be used for both units. The actuator 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 by the larger main valve (also called the regulating valve control valve, relay valve, or distributing valve), which is controlled by a small pilot valve. The pilot valve is very small so that it is sensitive to the minimal forces that result from minor changes in speed.

The pilot valve usually is designed with a movable bushing. The plunger of the pilot valve is connected through a floating lever to the ball head, and the bushing is connected to the main valve. Whenever the pilot valve moves off-center, oil is routed to the main valve servo, causing the main valve to move. The main valve movement moves the pilot valve bushing, which blocks the port of the pilot valve and stops 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 also adjustable.

3.3 Speed Adjustment

Speed adjustment provides the speed setpoint (or desired speed) when the unit is off-line and the load setpoint (or desired load) when the unit is on-line connected to large power system. The design of the governor determines the mechanism by which it accomplishes its purpose, but in all cases, adjusting the speed changer moves the pilot valve off center, which causes the gates to move as shown in 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 re-center the pilot valve. When the unit is on-line the unit speed is fixed and the flyballs are essentially in a neutral position. The gates will continue to move until the feedback from gate position through the speed droop mechanism re-centers the pilot valve. The speed changer is usually calibrated from 85% to 105% of synchronous speed.

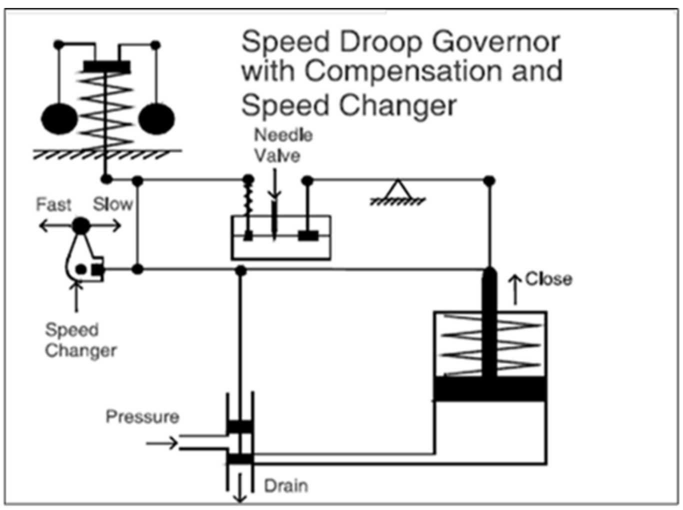


Figure 6. Speed-droop governor with compensation and speed changer schematic

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 re-centered, halting further motion.

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 valve blocks all oil flow from the pilot valve. If the gate limit is moved below the gate position, the gate limit valve overrides the pilot valve and routes oil to close the gates.

With any governor, raising the gate limit setting will not affect 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 in position 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. When operating with the auxiliary valve, the gates are moved by moving the gate limit. The gate position will follow the gate limit wherever it is set. Auxiliary valves are not used with gate-shaft governors, but in some cases, there may be a handwheel that can be used to move the gates for testing or to close the gates in the event the governor fails. [Employees shall never leave a unit unattended when operating with the auxiliary valve.]

3.6 Shutdown Solenoid

All governors have some type of safety shutdown mechanism to operate automatically or manually to close the wicket gates in case of an emergency. The solenoid is usually tripped automatically under any of the following conditions: generator or transformer differential relay operation, hot generator windings, over-speed, 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 can only be reset manually. Typically, there is a manual emergency shutdown switch in the control room and at the governor cabinet.

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 and 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. Facilities should carefully review systems with this type of shutdown solenoid to ensure that there are means to safely shut down the unit in all types of emergencies, specifically those involving loss of station service.

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 SNL 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. An SNL solenoid typically moves the gate limit to some value just above the SNL gate position. The SNL solenoid is usually tripped during startup and shutdown while the breaker is open, which prevents unit over-speed 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 valve or the auxiliary valve 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 bottoms of the plungers have smaller diameters than the tops so that, if oil is routed to the tops of the plungers, they will be forced closed. The transfer valve routes oil to the tops 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.

4.0 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 linkage and applies force to hold the wicket gates closed against water pressure.

The procedure for adjusting the squeeze depends on the design of the servomotor. The manufacturer's procedure should be followed if available. If there is no procedure available, review the servomotor drawings. From the drawings, determine how the servomotor piston position is adjusted, whether the servomotors have stops for the pistons, and where they are located. Once this information is obtained, develop an adjustment procedure.

Wicket gate servomotors are normally provided with some type of cushioning device. This device slows down the travel rate of the servomotor piston at the end of the closure stroke so that the gates do not slam shut. This is typically accomplished by the pistons covering the main drain ports on the cylinder and the oil being routed through a small cushioning valve. It is important that the cushioning does not come into effect until the gates are below SNL gate position. If the cushioning comes into effect close to the SNL gate position when the unit is off-line, there will be excessive "hunting" (see Section 11.1) due to slow gate movement in the closing direction. The governor will not be able to react quickly enough, and the resulting hunting can be severe. If the cushioning is coming into effect too early, adjust the piston rods or connecting rods between the servomotor and the shift ring so that the pistons cover the drain ports at a lower gate opening. As the SNL gate position will be lower at full reservoir, the adjustment should take into account the lowest SNL gate position encountered. This should be done prior to any adjustment of squeeze.

There are servomotor designs that have no physical stops. In this design, when the unit is on squeeze, the servomotors will provide the force developed by full governor pressure to close the wicket gates. The gates will continue to move as far as full governor pressure can push them. If one piston bottoms out while the other is still trying to travel, the shift ring can distort and potentially move the bearing housing. If this condition is found, adjust the piston rods or connecting rods between the servomotor and the shift ring to equalize the movement of both pistons.

Most servomotors are provided with some type of physical stop to allow the squeeze to be adjusted and balanced between servomotors. The servomotor piston stops may be internal or external to the cylinder. The adjustment of the squeeze is accomplished by adjusting the piston rod, connecting the rod between the servo and shift ring, or adjusting the stops themselves. The servomotor stops usually must be adjusted to absorb part of the excess force of the full working pressure. Also, the servomotor stops should be adjusted so that each servomotor applies the same amount of squeeze at the end of the stroke to prevent distortion of the shift ring and headcover. In extreme cases, unequal servomotor squeeze can distort the turbine bearing housing, causing a bearing wipe or the turbine runner to contact the seal rings.

The procedure below utilizes one-half of the governor's working pressure for setting the squeeze. Generally, this has proven effective, but the optimum squeeze is the least amount that will still close the gates tight enough to allow the unit to stop. Too little squeeze can lead to excessive leakage and difficulty shutting a unit down. Too much squeeze can overstress the wicket gate linkage and lead to broken shear pins. If the servomotors have stops and there is no manufacturer's procedure, the following procedure can be used to adjust the squeeze:

1) Remove pressure from the spiral case by closing the guard gate or valve and draining the penstock or spiral case.
2) Use full governor pressure to close the wicket gates.
3) Install and zero dial indicators on each servomotor to measure servomotor movement.
4) Bleed the air from the governor actuator tank to 50% of the normal working pressure. If properly adjusted, the dial indicators will still read zero when the pressure reaches 50%.
5) Continue bleeding air from the actuator 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%. The final indicator readings on each servomotor will be within 10% of each other. If the differential is greater than 10%, adjustment is required. For example, if the reading on one indicator is 0.250 inch, the reading on the other indicator should be between 0.275 and 0.225 inch or ± 0.025 inch. Continue with the next step.
6) Restore governor pressure to 50% of working pressure.
7) 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 out the piston in the cylinder in the other servomotor.
8) Repeat steps 1-7 until the dial indicators on the servomotors begin to change at approximately 50% of the normal governor working pressure and the final readings on the dial indicators are within 10% of each other.
9) Water up the unit and verify that it does not creep while on squeeze.
10) Start up the unit and initiate a shutdown to verify that the shutdown time is reasonable.

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 2-7, Mechanical Overhaul Procedures for Hydroelectric Units.

4.3 Gate Position/Gate Limit Hand Alignment

There are several reasons to perform the hand alignment procedures listed below. Matching the gate position indicator to the actual wicket gate position will eliminate confusion when setting gate position switches at the governor cabinet. With the gate limit adjusted properly, the gate position will track the gate limit and cannot exceed it. On block-loaded units, the gates will come all the way to the intended setting. With the linkages adjusted properly, the wicket gates can travel from squeeze to 100% gate with no chance of running out of travel.

4.3.1 Woodward Mechanical Actuator Hand Alignment

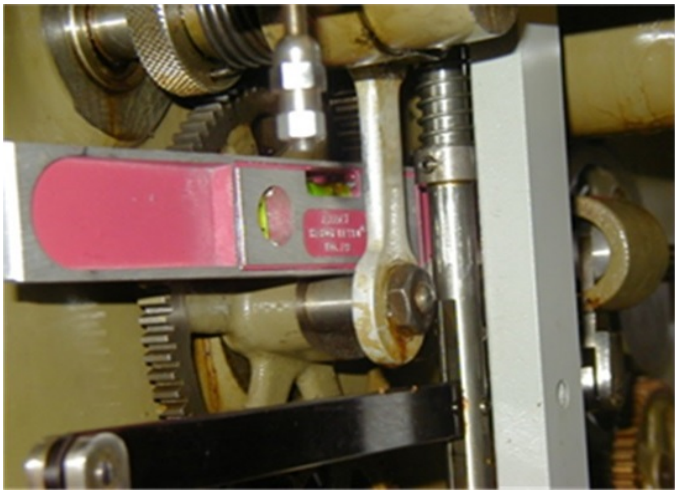
The following is a procedure to perform a Woodward mechanical actuator hand alignment:

1) Close the guard gate or valve and drain the spiral case.
2) Verify zero gate on the servomotor scale. (This is recommended only if you are unsure of zero gate calibration.)
    a) Set the gate limit below zero gate to ensure full squeeze on the gate.
    b) Bleed air from the governor actuator tank until the pressure is zero psi.
    c) The pointer at the servomotor should now read "0". If it does not, adjust the scale as necessary to make it read "0".
    d) Recharge the governor actuator tank to normal working pressure.
3) Set the speed adjustment and speed-droop adjustment to zero on the governor panel.
4) Set the transfer valve to Auxiliary Valve Open and move the gates to exactly 50% 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 two-way radio. Always make sure that anyone in the turbine pit is clear of moving components before moving the gates.
5) Place a small level on top of the compensating crank (Photograph 1). A highly accurate level is not required. 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%. When the compensating crank is level with the gates at 50%, the black gate-position needle should be at 50%. If it is not, carefully remove it and move it to 50%. Do not push the black needle on tightly at this time because it may need to be removed again to position the gate-limit needle.

Photograph 1. Leveling compensating crank

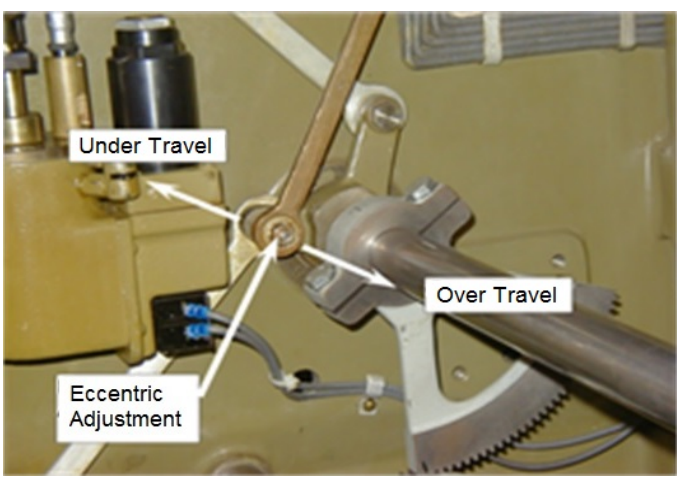
6) Adjust the gate limit using the gate limit control knob until the studs on the bottom end of the distributing valve gate limit link and the auxiliary valve gate limit link are level. This can

be measured by placing a small level on the studs (Photograph 2). When level, the red gate limit needle should be at 50%. 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%. Place the gate position needle back in its original position and press it firmly into place.



Photograph 2. Leveling studs on gate limit links

7) Set the transfer valve to Main Valve Open.
8) Move the gates to 10% open as measured at the scale on the servomotors and check to see if the gate position needle indicates 10%. If the gate position needle does not indicate 10%, 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 shown in Figure 7. Move the gates to 90%, 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. If it is necessary to complete the eccentric adjustment in the restoring shaft bell crank, the position cam switch settings might be affected by this adjustment and may need to be recalibrated.



Photograph 3. Restoring shaft bellcrank

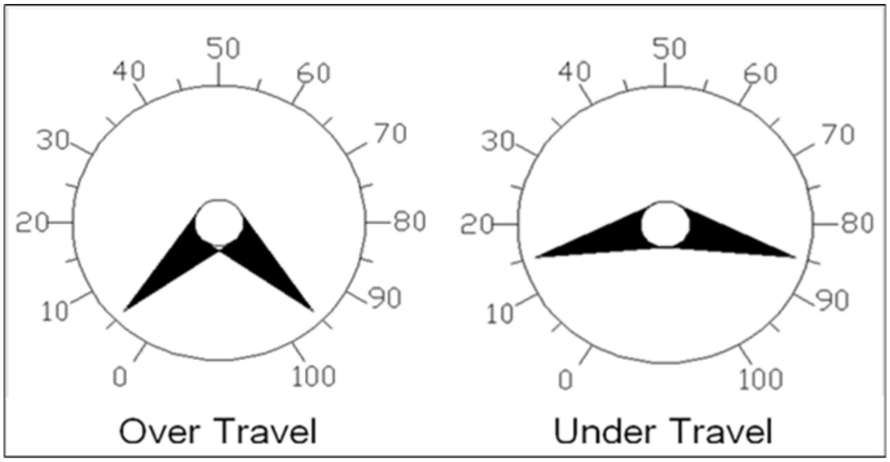
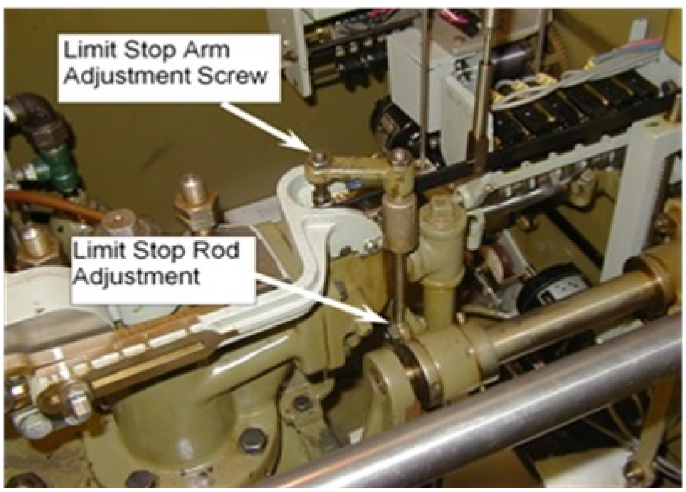


Figure 7. Representations of gate-position indicator showing over travel and under travel

9) Recheck the gate position at 50% to make sure nothing has changed.
10) Move the gate limit to 50% and check to see if the gate position indicator needle is at 50%. If it is not, adjust the limit stop-arm adjustment screw at the pilot valve (Photograph 4) until the gate position needle reads 50%.



Photograph 4. Gate limit stop-arm adjustment screw and stop rod

11) Move the gate limit to 10% and 90%, noting the position of the gate position indicating needle in each case to check for over- or under- travel between the gate limit and gate position. With the gate limit at 10% and 90%, under-travel is when the gates travel to 15% and 85%, respectively, and over-travel is when the gate travels to 5% and 95% shown in Figure 8. To correct over- or under-travel, adjust the position of the distributing valve limit link in the slot of the gate limit operating lever (Photograph 5). If the gates under-travel, move the limit link away from the gate limit shaft. If the gates over-travel, move the limit link toward the gate limit shaft.

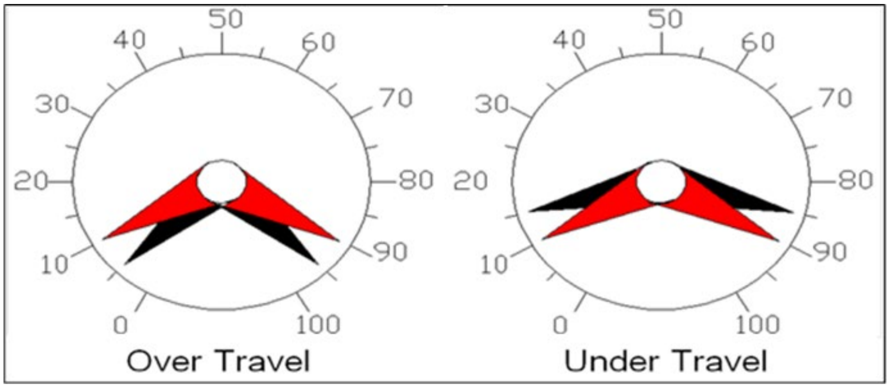
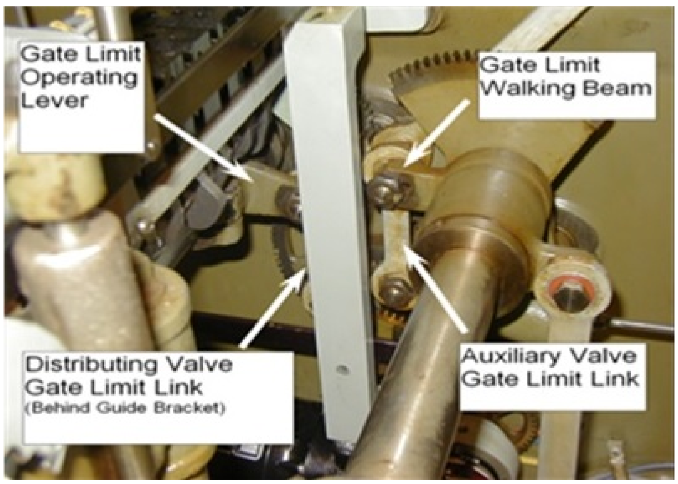
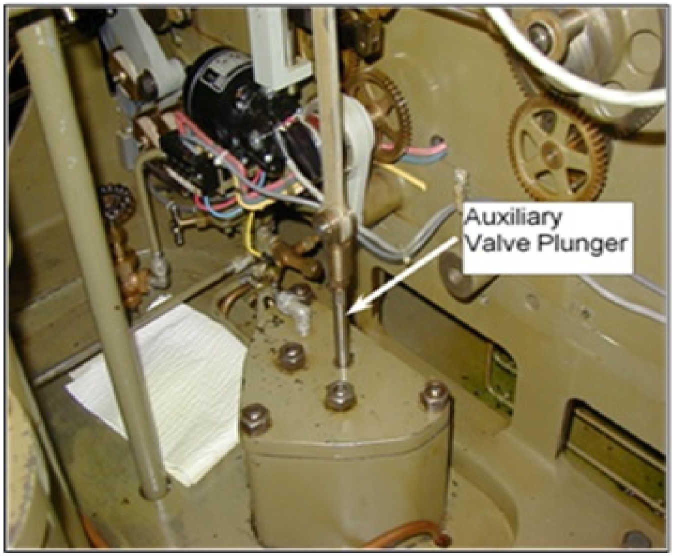


Figure 8. Representations of gate-position indicator showing over- and under-travel with respect to gate limit



Photograph 5. Gate limit links

12) Move the gate limit to 10% and 90% and check for lead or lag. This refers to a situation in which the differences between the gate limit and the gate position are not equal. The gates are leading the gate limit if the gate position matches the gate limit at 10% and moves to 95% with the gate limit set at 90%. The gates are lagging the gate limit if the gate position matches the gate limit at 10% and moves to 85% when the gate limit is set at 90%. If there is a lead or lag problem, adjust the lower end of the limit stop rod in the slider (Photograph 4). After any adjustment here, move the gate limit back to 50% to see if the gate position is also at 50%. If it is not, readjust the limit stop-arm screw and repeat steps 11 and 12.
13) Move the transfer valve to Auxiliary Valve Open. Move the gate limit to 50% and check to see if the gate position is also at 50%. If it is not, adjust the auxiliary valve plunger until the gate position reads 50% (Photograph 6).



Photograph 6. Auxiliary valve

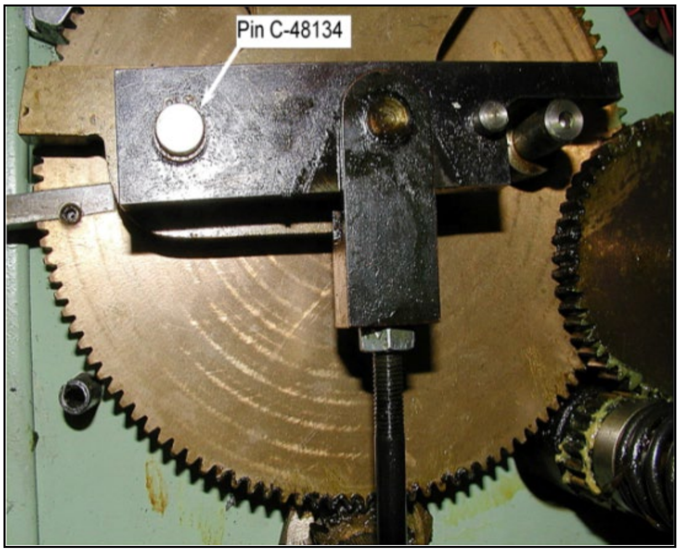
14) Move the gate limit to 10% and 90%, noting the position of the gate position indicating needle in each case to check for over- or under-travel between the gate limit and the gate position. To correct over- or under-travel, adjust the position of the auxiliary valve limit link in the slot of the gate limit walking beam (Photograph 5). 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 toward the gate limit shaft.

4.3.2 Pelton Mechanical Actuator Hand Alignment

The following is a procedure to perform hand alignment of a Pelton mechanical actuator:

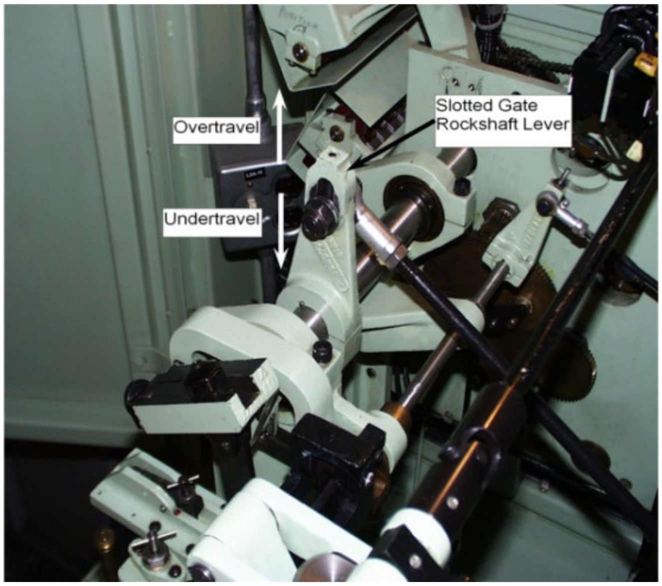
1) Close the guard gate or valve and drain the spiral case.
2) Verify zero gate on the servomotor scale. (This is required only if you are unsure of zero gate calibration.)
   a) Set the gate limit below zero gate to ensure full squeeze on the gate.
   b) Bleed air from governor actuator tank until pressure is at zero.
   c) The pointer at the servomotor should now read "0". If it does not, adjust the scale as necessary to make it read "0".
   d) Recharge the governor actuator tank to normal working pressure.
3) Set the speed adjustment and the speed-droop adjustment to zero on the governor panel.
4) Set the transfer valve to Auxiliary Valve Open and move the gates to exactly 50% 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 two-way radio. Always make sure that anyone in the turbine pit is clear before moving the gates.
5) 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% gate so that it does not run out of travel at 0 or 100%. If it is not at mid-position, adjust the restoring cable.
6) 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% as measured at the servomotor.

7) Check that pin C-48134 (Photograph 7) on the gate position gear is at the 9 o'clock position. If it is not, 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 amount of 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.



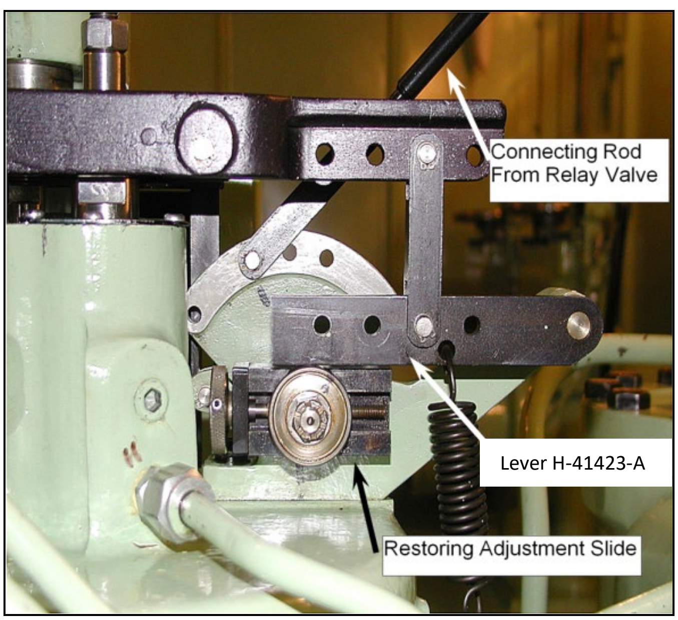
Photograph 7. Pin C-48134 on gate position gear

8) Recheck that the gates are exactly at 50%, as measured at the servomotor, and move the black gate-position hand on the governor cabinet to 50%.
9) Move the gates to 10% and 90%, as measured at the scale on the servomotors, and check to see if the gate-position hand indicates 10% and 90%. If the gate-position hand does not 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 (i.e., it indicates 15% and 85%), move the connecting rod end toward the rockshaft. If the gate-position hand over-travels, move the connecting rod end away from the rockshaft as shown in Figure 7.



Photograph 8. Slotted gate rockshaft lever

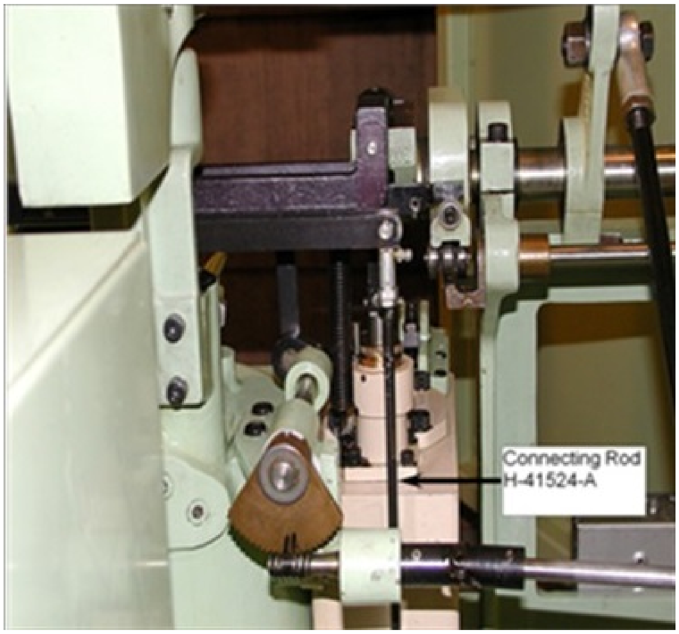
10) Move the gates to 0% and 100% to make sure the gate-position hand indicates 0 and 100. If the restoring cable goes slack before reaching 0 or 100, it will have to be shortened. After the cable is shortened repeat steps 5 through 9.
11) Set transfer valve to Main Valve Open.
12) Move the wicket gates to 50% and adjust the length of the connecting rod between the relay valve and the governor head so that the restoring adjustment slide is parallel to lever H-41423-A (Photograph 9).



Photograph 9. Adjustment of relay valve restoring mechanism

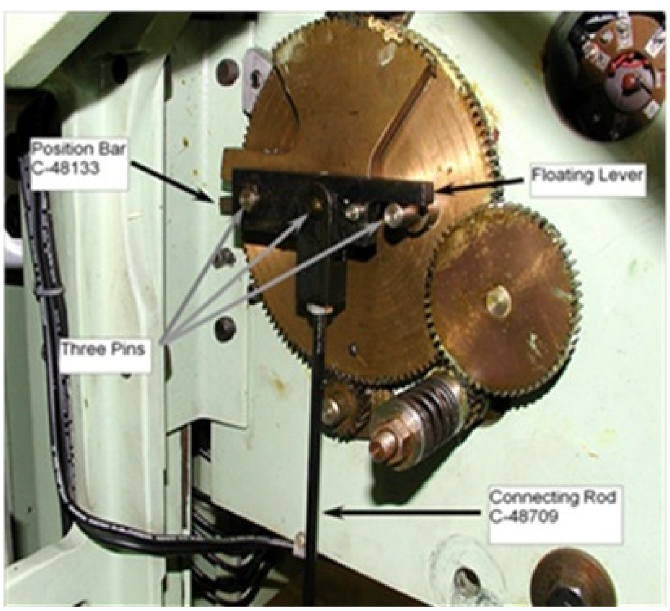
13) Adjust the length of the connecting rod between the gate-limit rockshaft and the governor head (H-41524-A) (Photograph 10) to make the levers on the rockshaft parallel to the base.

Adjusting the connecting rod will move the gates. After each adjustment, move the gates back to 50%. Continue to make adjustments until the levers are parallel to the base when the gates are at 50%.



Photograph 10. Connecting rod H-42524-A

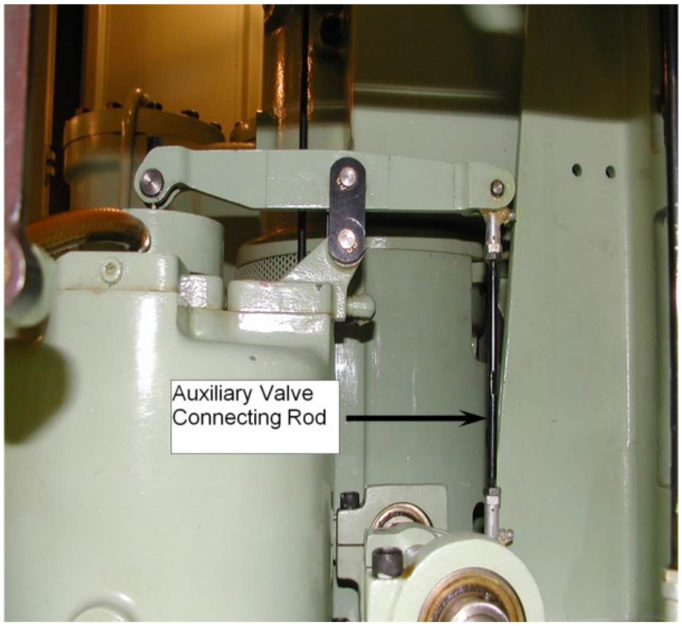
14) Adjust the gate limit using the normal gate limit adjustment when the gates are at 50%. Adjust the length of connecting rod C-48709 until the three pins in the floating lever line-up horizontally with the position bar C-48133. When this is accomplished, move the red gate-limit hand to 50% (Photograph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



Photograph 11. Location of floating lever and pins

15) Set the transfer valve to Auxiliary Valve Open.

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



Photograph 12. Auxiliary valve connecting rod

5.0 Remagnetizing the Rotor of a Woodward Permanent Magnet Generator

PMG maintenance can be facilitated by the installation of quick disconnect leads. The PMG is removed for maintenance activities such as the setting of speed switches, replacement of main bearings, and remagnetization. Removal of the PMG requires disconnecting all of the leads from the terminal block, which includes the output from the PMG, and all of the outputs from the speed switches. The voltage and current rating should be considered when choosing the plugs. Installing the female receptacle on the PMG side will eliminate the need to tape the PMG leads to prevent grounding or phase-to-phase contact of the leads.

The rotor of a Woodward PMG can become demagnetized over time, or it can be partially or completely demagnetized if its leads are short-circuited during operation. [If the measured voltage is less than 80% of rated voltage, the field must be remagnetized.] Remagnetizing 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:

1) Remove all the speed switch assemblies driven by the drive gear.
2) If the 2,300-volt power source can be safely connected to the PMG with the PMG in place, the rotor must 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.
3) 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 as shown in Figure 9. Verify that all connections are electrically sound and observe safety precautions.

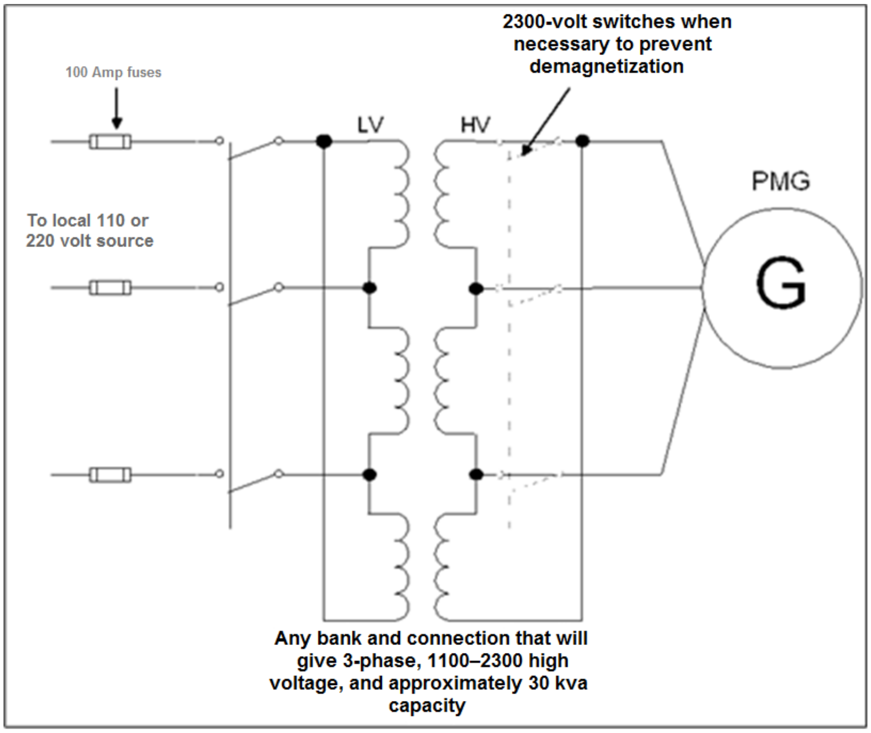


Figure 9. Schematic of the setup needed for remagnetizing a PMG

4) 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. The remagnetization may fail 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 the demagnetizing effects of single-phase operation.
5) 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.
6) Bring the unit to the rated speed and measure the voltage. [If the measured voltage is higher than 110% of the rated voltage, it shall be demagnetized down to the rated voltage.]
7) If demagnetizing is required, place a resistor in series with a switch across two of the three phases. A voltmeter should be connected to these phases to monitor voltage as shown in 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% of rated voltage, it should be remagnetized.

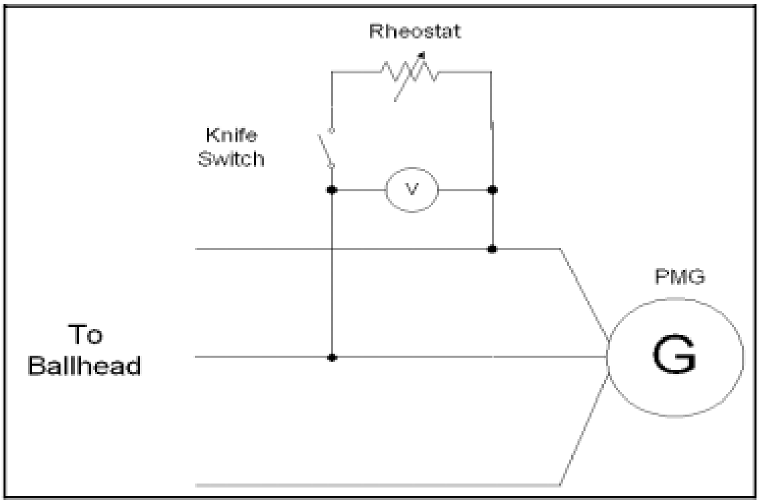


Figure 10. Schematic of the setup for demagnetizing a PMG

6.0 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 mechanical governors for optimum performance have been developed for all Reclamation plants with mechanical governors.

6.1 Wicket Gate Timing

The first objective of Reclamation's Governor Adjustment Program is to ensure safe operation through the testing and adjustment of the wicket gate timing. The adjustment of wicket gate timing is critical to ensure the safety of personnel and equipment. The stopnuts on the governor main valve are adjusted to limit the amount of travel of the main valve. Changing the maximum movement of the main valve also changes the amount of oil flowing to the servomotors and, therefore, the maximum speed at which the wicket gates travel. 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 overspeed, but the penstock pressure transients will be higher. Slowing down the wicket gate timing results in a lower transient penstock pressure rise, but the maximum overspeed will increase. The final setting of the wicket gate timing is a compromise. Since the rotating components are designed to withstand terminal overspeed, 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, penstocks or scroll cases can fail if the safe closure rate is exceeded.

[When a 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: (1) to adjust the governor to optimize performance within the power system, and (2) to optimize the governor's ability to maintain frequency while carrying an isolated load. Most governor manufacturers' literature provides a procedure for adjusting the governor. These procedures usually require making adjustments to minimize obvious "hunting" by the governor. While such procedures may provide a governor response that is adequate for synchronizing, they will probably not provide an optimum response on-line, or they 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 a change in the speed-changer setting is 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%, a 1% change in the speed-changer setting would cause a change in gate position of 20%. Likewise, with a speed-droop setting of 10%, a 1% change in the speed-changer setting would produce a 10% movement of the wicket gates. In most cases, it is sufficient to calibrate the speed droop at 5%, which is the most common speed-droop setting in Reclamation plants.

There is an adjustable feedback from the main valve to the pilot valve to adjust the ratio of main valve to pilot valve movement. Changing the amount the main valve moves for a given movement of the pilot valve in turn changes the relative speed of the servomotors. This is independent of the wicket gate-timing setting. The main valve normally does not move far enough to contact the stopnuts during a load change. The restoring linkage 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 in isolation or off-line. The dashpot adds droop 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 on the dashpot controls 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, with 10 providing the most compensation or movement of the large dashpot plunger. 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 re-center 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 its leakage path in the dashpot. The lever is positioned so that the bypass opens at a gate position above SNL 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 mechanical bypass should only be used in a manned plant, as the bypass arm can only be moved out of the way manually.

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 be completed. 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 in the speed-changer adjustment. The program is based on a model developed to replicate the behavior of the linkage and valves in a governor. 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 specific inputs to the program are the permanent speed-droop setting (σ), the transient or temporary speed droop (δ), the dashpot recovery time (*Tr*), the servosystem secondary time constant (*Tp*), and the main servo integration time (*Tg*).

The transient speed droop and dashpot recovery time can be determined by first calculating the machine starting time (*Tm*) and the water starting time (*Tw*). These two parameters provide a measure of the inertia of the unit and can be calculated for each unit according to the equations below:

$$Tm = 0.462(N^2 \times WR^2)/Pr$$

$$Tw = \sum(LV)/gH$$

Where:

N =	Rotational speed (RPM)
WR^2=	Rotational inertia (pounds-square foot)
Pr =	Rated power (megawatts)
L =	Penstock length (feet)
V =	Water velocity (feet per second)
g =	Gravitational constant (32.2 feet/second^2)
H =	Head (feet)

Based on Reclamation-sponsored research by Mr. Ferber Schleif, the transient speed droop and dashpot recovery time can then be approximated by the following equations:

$$\delta = 2.5Tw/Tm$$

$$Tr = 5Tw$$

The servomotor secondary time constant and the main servo integration time are both associated with the specific configuration of the hydraulic system for the individual governor. These constants are determined by matching the governor response with the dashpot disabled to a set of computer-generated curves for various valves of Tp and Tg.

The output of the computer program is a graph of gate position versus time for the optimum response of the governor based on these parameters. 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% of its total response to a sudden change in speed or speed-changer adjustment. T_{gate} has been calculated using this program for every mechanical governor in Reclamation powerplants, and the value for each unit and copies of the optimized response curve are available from the Mechanical Equipment Group (86-68410) in Reclamation's TSC.

Looking at the response curve can provide a better understanding of the governor response as shown in 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, with the restoring cable 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 re-centering 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.

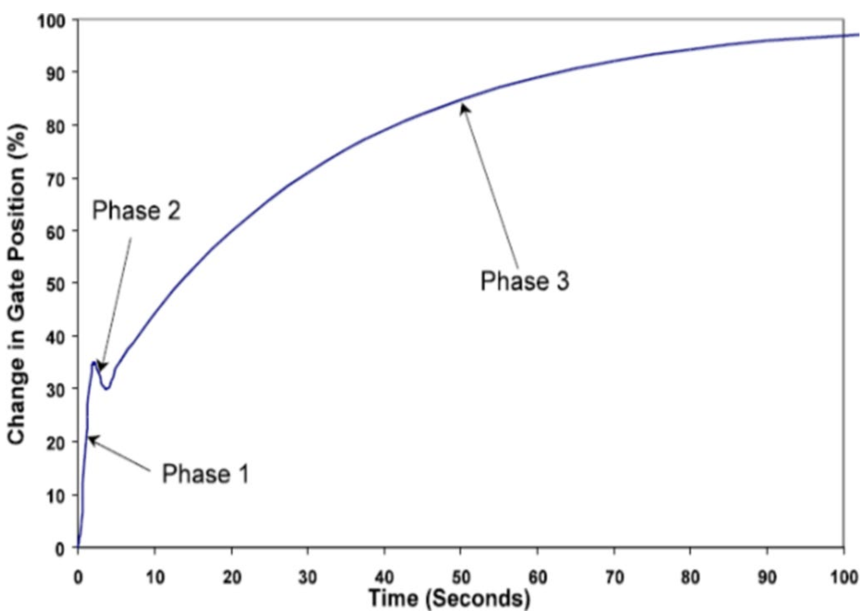


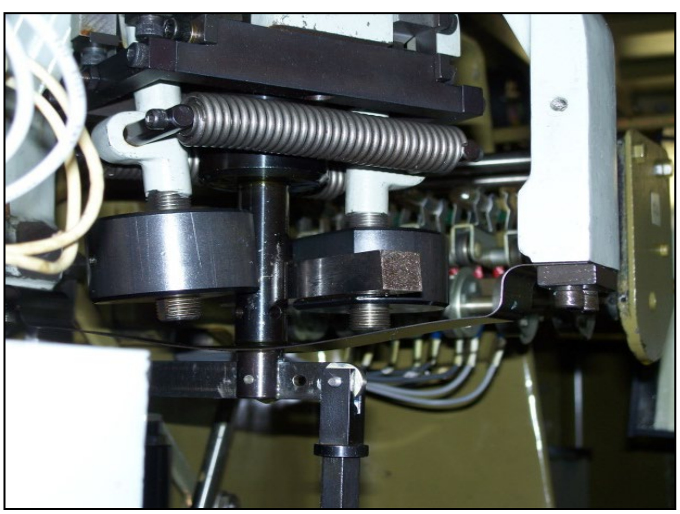
Figure 11. Governor response curve

7.0 Governor Adjustment Procedure

7.1 Equipment

The tests for governor adjustment can be completed either with the unit watered-up and operational or with the unit un-watered if some means of simulating on-line conditions is provided. When a unit is operating on-line, the governor ball head is operating at constant speed. On Woodward governors, this means that the connection to the upper floating lever and the ball head becomes a rigid pivot point. On Pelton governors, the pilot valve plunger becomes immovable. Simulating on-line conditions can be accomplished either with some type of power supply that can be adjusted to match the normal frequency and voltage output of the PMG (PMG simulator) or by simply blocking the fly balls on the ball head from their operating position. Ball-head motor drives, which utilize a variable-frequency, variable-voltage motor drive to allow operating the motor at its normal speed, are available. It is also possible to drive the ball-head motor with a relay test system that has an adjustable three-phase output. In either case, the normal operating frequency and voltage should be measured prior to shutdown so that simulated voltage can be adjusted to match. It should be noted that the nameplates on PMGs are not always correct; it is always a good idea to measure the actual voltage and frequency output.

Block the flyballs of a Woodward governor (Photograph 13). The design of the Pelton ball head does not lend itself to blocking the flyballs. The blocks only have to be on one flyball and should be thick enough to force the pilot valve down far enough that the gate just starts to move. An adjustable parallel works well for this purpose. While blocking the flyballs may allow completion of the on-line tests, it should only be done if a PMG simulator is not available and the tests cannot be done with the unit actually operating on-line. The spinning of the flyballs creates a more realistic simulation of on-line conditions. On units with vibrator disk ball heads that rely on rotation of the ball heads to impart dither to the hydraulic system, blocking the flyballs may lead to some sticking of the main and pilot valves.



Photograph 13. Installing block in ball head

To perform the tests, the following equipment is required: a strip chart recorder or data acquisition system and a computer with two or more channels, a frequency transducer with a 55- to 65-Hz range, and a position transducer with sufficient range to measure wicket gate travel. If a PMG simulator is used, a digital multimeter is required to measure the voltage and frequency from the PMG prior to shutdown. A stopwatch can be used for the required annual check of wicket gate timing.

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 shall be checked during annual maintenance.]** *The timing can be checked with a strip-chart recorder or with a stopwatch. Below is a procedure to check the wicket gate timing of a governor and to adjust the wicket gate timing.*

To check the wicket gate timing:

1) 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.
2) Place the governor in main valve mode.
3) Install the position transducer to record the servomotor stroke. If using a strip chart recorder, calibrate for full gate travel.
4) Latch or block up the shutdown solenoid weights to allow operation of the wicket gates. Note: On units that have shutdown solenoids that energize to trip, the solenoid weights can be left down.
5) If using a strip chart recorder, set the chart speed to 10 millimeters per second or faster. Move the gate limit on the governor cabinet rapidly from 0% to 100%. If using a stopwatch, time the gate travel from 25% to 75%. Allow the gates to stabilize at 100%. Move the gate limit rapidly from 100% to 0%. If using a stopwatch, time the travel from 75% to 25%. Prior to rapidly swinging the gates, ensure the governor actuator tank is fully charged.

Calculate the dry wicket gate timing:

Opening time = (time from 25% to 75% gate) × 2
Closing time = (time from 75% to 25% gate) × 2

The gate timing is measured from 25% to 75% gate and 75% to 25% gate to eliminate any errors that would be introduced by the slower rate during the cushion at the end of the closing stroke as shown in Figure 12.

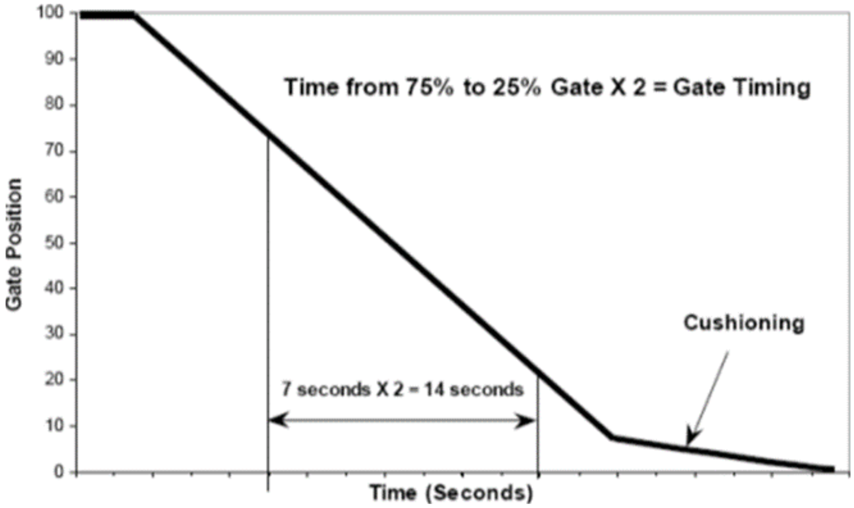
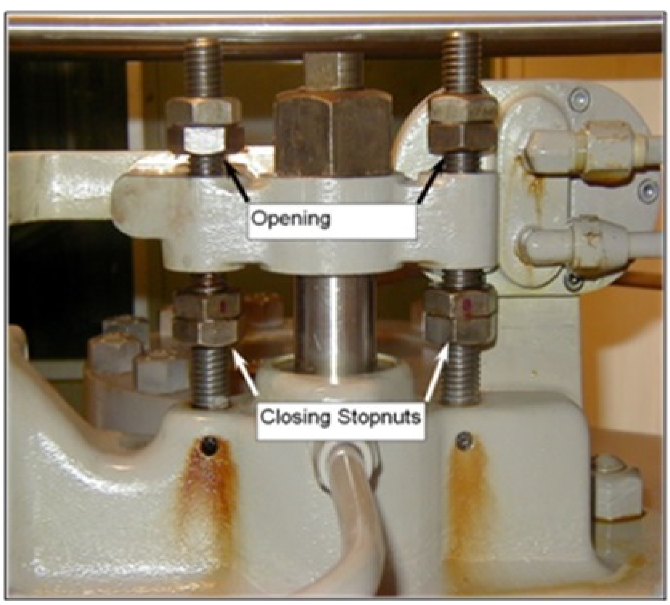
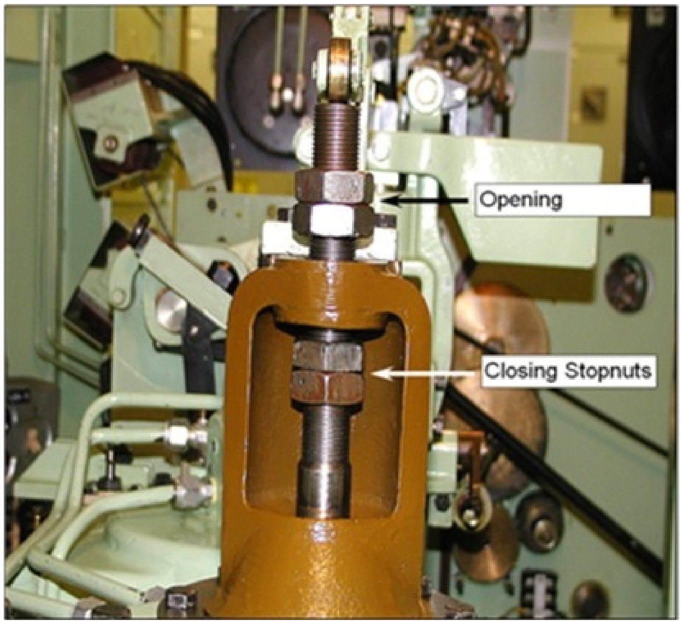


Figure 12. Wicket gate timing, closing direction

6) 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 some point below SNL gate position to 0% gate to prevent slamming the gates. See Section 4.1 if the cushioning starts above SNL gate position. Depending on the design of the servomotor, the cushion may not be adjustable.
7) To allow for hydraulic effects, adjust the upper and lower stopnuts on the main valve to obtain a dry (un-watered) wicket gate time approximately 10% longer than the value that would be measured during an actual load rejection. The wicket gate time shown in the mechanical equipment database is for un-watered conditions (Photographs 14 and 15). The upper stopnuts generally control the opening rate, and the lower stopnuts generally control the closing rate. Opening and closing gate time should usually be the same.



Photograph 14. Stopnuts on a Woodward governor



Photograph 15. 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 the Mechanical Equipment Group, 86-68410, to discuss special precautions for adjusting these units.

7.3 Setting up the Governor for Simulated On-line Testing (PMG Simulator or Flyball Blocks)

7.3.1 PMG Simulator Setup

This is a procedure to set up the PMG simulator or to use the flyball blocks while completing a governor alignment.

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

1) Shut down and un-water the unit.
2) Disconnect the PMG leads from the ball-head motor at the governor cabinet terminal block. Make sure wires are labeled. It is best to disconnect any other devices, such as speed switches and tachometers, which may be driven by the PMG.
3) Connect the PMG simulator leads to the terminal block to connect it to the ball-head motor. Verify that the leads are only connected to the ball head. The PMG can be demagnetized if the simulator is mistakenly hooked up to the PMG and not the ball head.
4) Set the PMG simulator for the proper ball-head voltage and frequency according to the manufacturer's instructions.
5) Start the simulator and verify direction of rotation. If it rotates in the wrong direction, turn off the simulator and either reverse two of the leads or push the reverse button if the simulator is so equipped.
6) Bring ball head up to full synchronous speed. Move the gate limit to above 100% to get it out of the way and verify that the gates respond to speed-changer movement.

7.3.2 Flyball Block Installation

This procedure is for Woodward governors. It should only be used if a PMG simulator is not available or the tests cannot be completed with the unit operational.

1) Move the gate limit to above 100% and adjust the speed changer to a position that corresponds to an on-line gate position of approximately 50%. The gates should go to 100%.
2) Remove the flyball covers to provide access to the flyballs.
3) Place a block between the flyball and the ball-head dashpot plunger on strap-suspended ball heads or between the flyball and the governor head case on vibrator-type ball heads (Photograph 13).
4) If using an adjustable block, such as an adjustable parallel, increase the thickness until the gates start to close, or, if the gates are all the way open, decrease the thickness until the gates start to close. If you are using nonadjustable blocks, put larger or smaller blocks in to get gate movement. Opening the dashpot needle two turns will allow the gate movement to stabilize more quickly while thickness adjustments are made.
5) Verify that the wicket gates respond to speed-changer movement.

7.4 Check and Adjust Permanent Droop

The speed droop will generally be calibrated at 5%. Units supplied by canals with float controls may have settings lower than 5%. Per WECC requirements, **{Governor droop for each generating unit shall be set to greater than or equal to 3% but less than or equal to 5%, unless a special circumstance exists.}** A droop setting below 3% is allowed for special circumstances such as the need to "island" a unit or if a unit is operated in conjunction with a canal. Note that coordination with the transmission authority is required for these circumstances. Also, a droop setting outside of the 3-5% range is allowed for those governors that do not have the adjustment capability to reach a droop of 3-5%. Verify and adjust permanent droop after performing governor alignment prior to putting the unit into service. Below is a procedure to check and adjust the permanent droop.

At 5% droop, a 1% change in speed should result in a 20% change in gate position. The procedure below requires the unit to be operating on-line or un-watered with a PMG simulator or flyball blocks to simulate on-line operation. This procedure assumes that the 1% change in the speed-changer setting actually would change the speed 1% when the unit is operating off-line. This is adequate in most cases. If a more precise measurement of speed droop is required or desired, the amount the gates move for a 1% change in speed changer setting with the unit on-line should be recorded. The unit should then be watered up, if it was un-watered, and the actual change in frequency recorded for the same change in speed changer setting. The actual speed droop would then be the change in frequency divided by the change in gate position. Use the procedure below unless there is some doubt about the calibration of the speed changer; this would only be a concern if the ball head has been modified.

If the dashpot is going to be adjusted as described in Section 7.6, the dashpot needle can be opened two turns to effectively take the dashpot out of service and increase the speed of the gate response during this test. If the speed droop is just being checked and adjusted, and no other adjustments are planned, the dashpot bypass can be energized, if so equipped, to speed up the step response. If there is no bypass and the dashpot itself will not be adjusted, the tests can be performed with the dashpot in its normal operating condition, but each step response can take several minutes to complete. The wicket gates must stop moving before another step is begun.

This test can be done by watching the gate position indicator on the cabinet if it is verified that the gate position indicator is calibrated.

1) If a strip chart recorder is being used, set up the strip chart recorder scale on the gate position so that full scale equals full travel.
2) Adjust the speed droop to 5% and the speed changer to bring the gate position to 10%.
3) Adjust the speed changer in 1% increments four times. Record the change in gate position with each adjustment.
4) Calculate droop.

$$Speed\ droop = \frac{Change\ in\ frequency}{Change\ in\ gate\ position}$$

For a 1% change in frequency or speed changer setting:

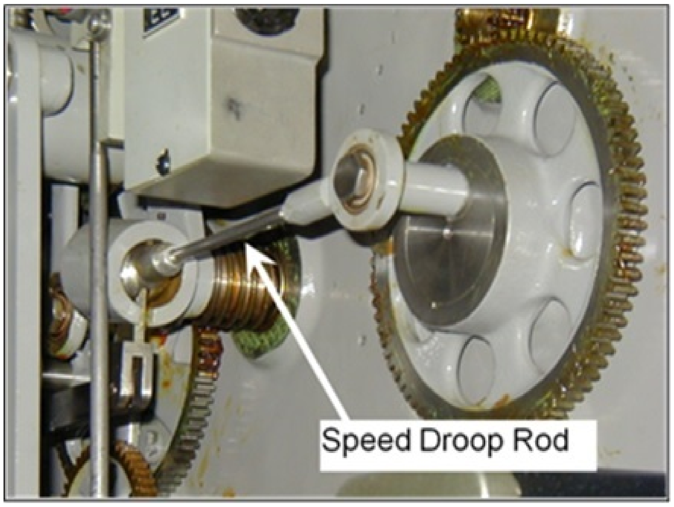
$$Speed\ droop = \frac{1}{Change\ in\ gate\ position}$$

For a 4% change in frequency or speed changer setting:

$$Speed\ droop = \frac{4}{Change\ in\ gate\ position}$$

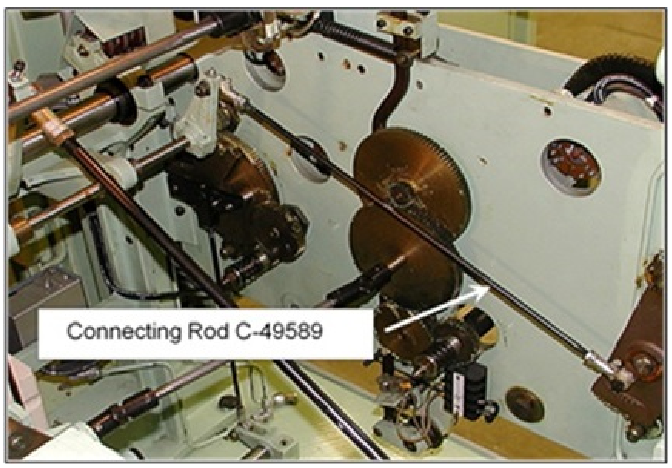
The calculated speed droop, when measured in 1% speed-changer steps, should be between 4.5% and 5.5%, or there should be a change in gate position of 18% to 22% gate for every 1% change in frequency. The speed droop is rarely linear through the entire gate range. To provide an average of 5% droop over most of the range, the gates should move 80% for a 4% change in the speed-changer setting. The droop should be adjusted so that the gates move from 10% to 90% or 90% to 10% for four turns on the speed changer.

On Woodward cabinet actuators, adjust the droop rod turnbuckle to obtain 5% droop (Photograph 16) over 80% gate travel. A half turn on the turnbuckle usually makes a change of approximately 0.5% droop. The rod is shortened to increase droop and lengthened to decrease droop.



Photograph 16. Turnbuckle used for speed droop calibration on Woodward actuator

On Pelton cabinet actuators, adjust the connecting rod C-49589 to obtain 5% droop (Photograph 17).



Photograph 17. Connecting rod C-49589 used for speed droop calibration on Pelton actuator

7.5 Speed-No-Load Calibration

Verify and adjust SNL calibration after performing governor alignment and prior to putting the unit into service. A procedure to verify and adjust SNL calibration is described below.

The preferred calibration setting for the SNL adjustment is with the speed droop and the speed changer are set to zero. Adjusting the governor to provide 60 Hz at this speed droop and speed changer-setting accomplishes two things. First, it provides a set point for a unit should it become necessary to run a plant isolated from the system. If the plant becomes separated from the system, one unit will need to be set at zero droop and set to maintain 60 Hz. This can easily and quickly be accomplished by moving both settings to zero. If the unit is adjusted to 60 Hz at zero on the speed changer and 5% droop when the speed droop is set to "0", the speed adjust will have to be manually adjusted until 60 Hz is achieved.

Second, adjusting SNL at zero droop and zero speed changer also ensures full travel of the gates. Mechanical governors typically only allow 5% adjustment on the positive side on the speed changer adjustment. When the SNL is adjusted with 5% droop and zero on the speed changer, it will require nearly the entire +5% speed changer adjustment to achieve full load. At 5% droop, it takes five turns on the speed changer to obtain 100% change in gate position. As the gates usually start at some gate position above 5% for SNL, this should not be a problem as long as the speed droop is calibrated. Unfortunately, speed droop does require recalibration periodically, and having it out of calibration by only a slight amount can cause the governor to run out of speed-changer adjustment before it reaches full load.

The procedures below provide the recommended setting for SNL.

7.5.1 Un-watered Method

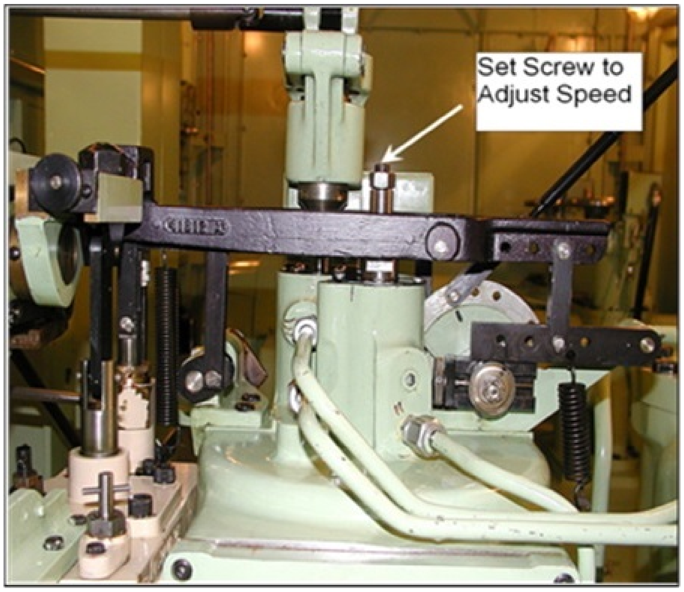
This procedure can only be accomplished with the ball head turning at synchronous speed and cannot be done with ball-head blocks. With the PMG simulator driving the ball head at 100% speed, set the speed droop to 5% and the speed changer to the normal SNL position. If adjustments are made with the ball head operating at a constant speed and the speed droop at 0%, the gates will tend to go completely open or completely closed, and adjustment will be impossible. To perform the un-watered method, it is necessary to know the normal SNL 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 18).

Photograph 18. Woodward ballhead and floating lever connecting rod

2) On Pelton governors, adjust the setscrew on the pilot valve (Photograph 19).



Photograph 19. Pelton speed adjustment setscrew

7.5.2 Operational Method

With the unit operating off-line and on governor control, set the speed droop to 0% and the speed changer to 0%. Observe the unit frequency and adjust it to nominal frequency.

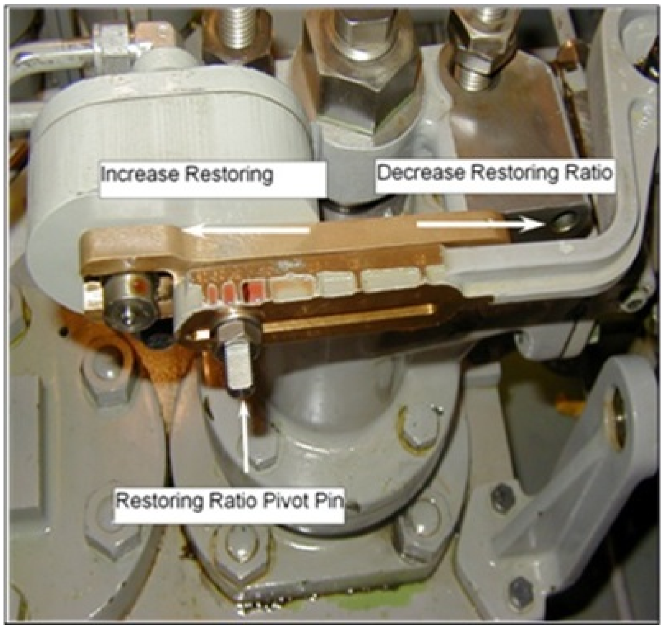
1) On Woodward governors, adjust the length of the floating lever connecting rod.
2) On Pelton governors, adjust the setscrew on the pilot valve.

7.6 Adjust Dashpot

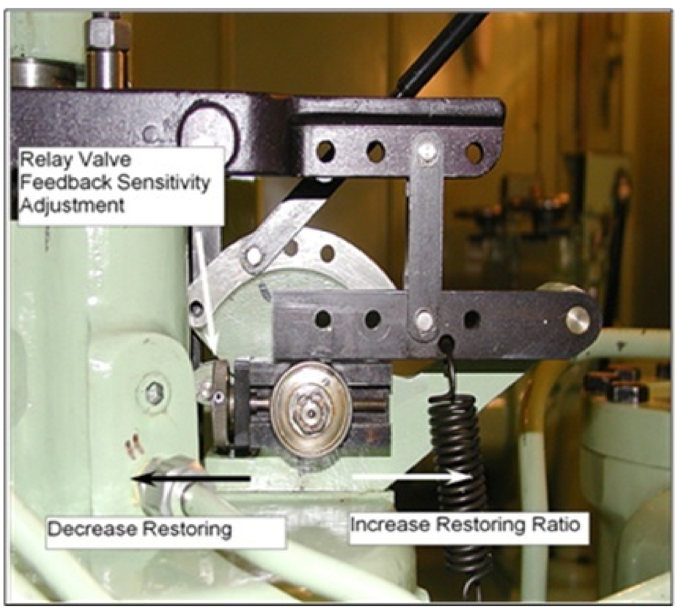
These tests require a position transducer on the servomotor and a recording device (strip chart recorder or data acquisition system). The tests can be performed with the governor operational and on-line or under simulated on-line conditions with a PMG simulator or flyball blocks. Verify and adjust the dashpot after aligning the governor and prior to putting the unit into service. A procedure to adjust the dashpot is described below.

1) Tests with inactive dashpot.
    a) Change the scale on the recording device so that full scale equals 20% gate. This will make the trace easier to read. With the unit on-line and with either the PMG simulator operating or the flyball blocks installed, adjust the speed changer to bring the wicket gates to approximately 20% to avoid the cushion of the servomotors.
    b) If not already done for the speed-droop tests, open the main dashpot needle at least two full turns to remove the dashpot from service. Rapidly raise the speed changer by 0.5% (one-half turn). Wait until the gate position stabilizes, then rapidly lower the speed changer to the original setting.
    c) Adjust the restoring ratio using either 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 20 and 21). Look at the curve of gate position in both directions as shown in 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 overshoot. Label the strip chart with the restoring ratio setting during each test.



Photograph 20. Pilot valve restoring lever on a Woodward generator



Photograph 21. Relay valve feedback sensitivity thumbscrew on a Pelton generator

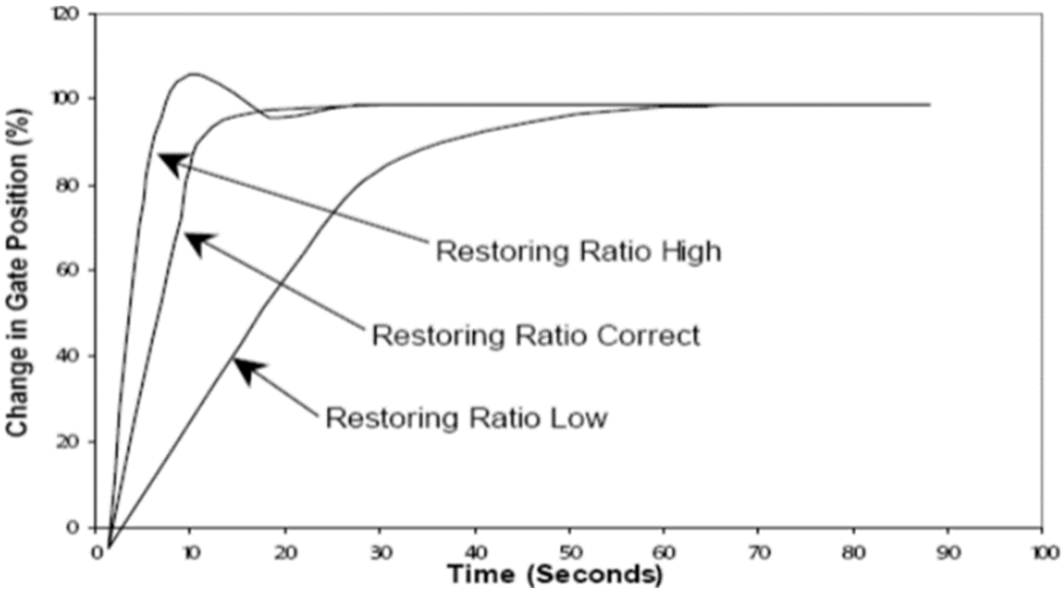
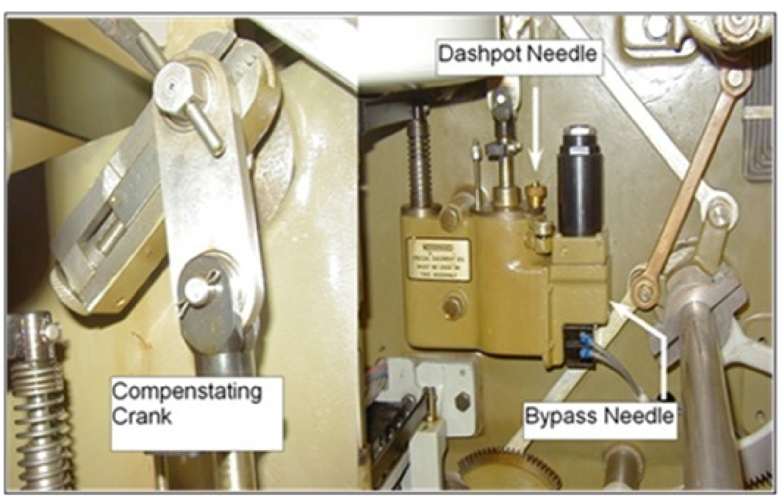
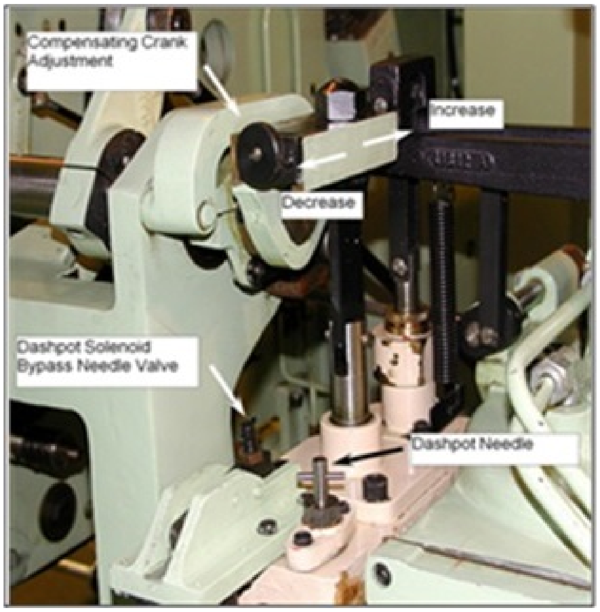


Figure 13. Governor response with the dashpot disabled

2) Tests with dashpot active (small signal governor response).
   a) Close dashpot needle to approximately one-quarter turn open.
   b) 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. Rapidly raise the speed changer by 0.5% (one-half turn). Wait until the gate position stabilizes, then rapidly lower the speed changer to the original setting.
   c) Adjust the compensating crank and dashpot needle (Photographs 22 and 23) to match the simulated response curve as shown in Figure 14. Label the strip chart with each compensating crank setting and the corresponding changes in the dashpot needle settings.



Photograph 22. Woodward dashpot and compensating crank



Photograph 23. Pelton dashpot and compensating crank

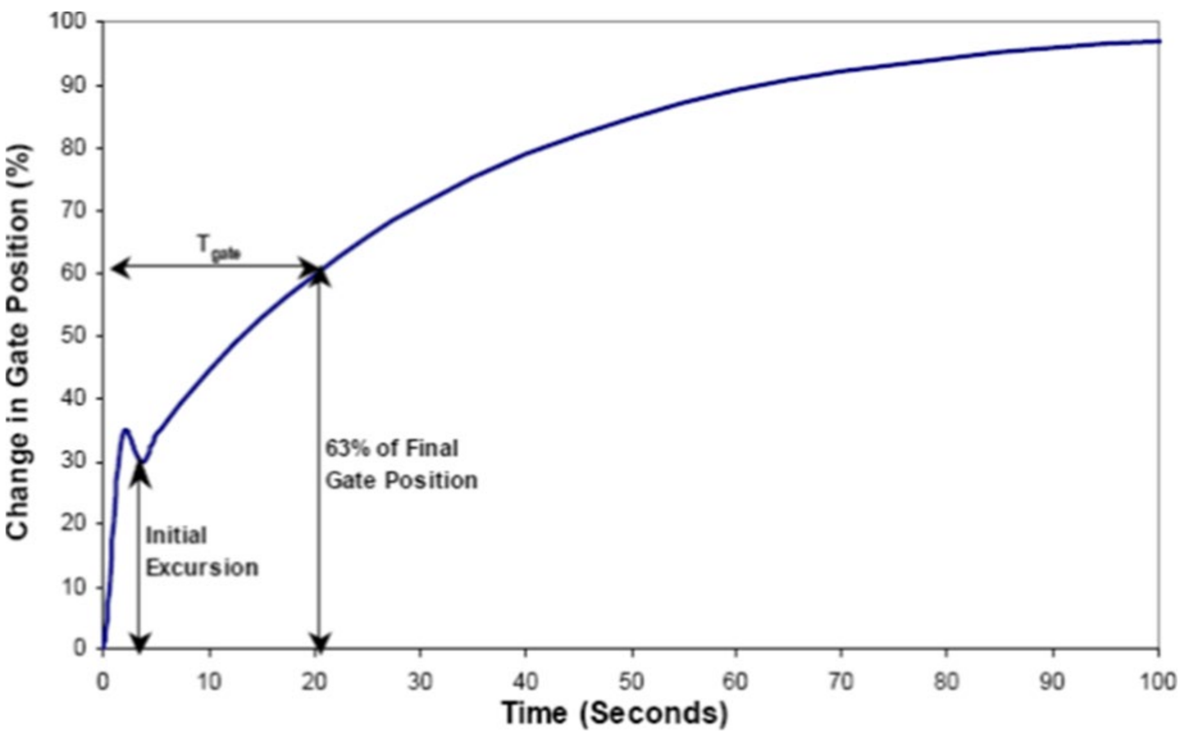


Figure 14. Simulated governor response curve

d) The following are general guidelines for adjusting the settings:
   i) First, adjust the compensating crank. Increasing the setting on the crank increases the movement of the large dashpot plunger, decreases the magnitude of the initial excursion of the gate position, and increases T_{gate}.
   ii) Increasing the opening of the dashpot needle value 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 change and this test will have to be redone.

3) Test with dashpot bypassed (if equipped).
   a) 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. Rapidly raise the speed changer by 0.5% (one-half turn). Wait until the gate position stabilizes, then rapidly lower the speed changer to the original setting.
   b) 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 one-quarter turn as a starting point.

7.7 Check and Adjust Dither

Verify and adjust the dither after aligning the governor and prior to putting the unit into service. The following is the procedure to check and adjust dither.

1) Install an LVDT, a proximity probe, or a dial indicator to observe the main valve motion. Use a tachometer to measure oil motor speed.
2) Procedure for units with oil motor vibrator units:
   a) Adjust the eccentric bushing (Woodward reference 07079 570) to obtain 0.006 to 0.009 inch of movement of the main valve.
   b) Adjust the regulator adjusting screw (Woodward reference 07079 596) to obtain a 7- to 10-Hz frequency (420 to 600 RPM).
3) Procedure for units with vibrator disks: If no motion can be felt with a finger between the main valve and the base, the vibrator disks (Woodward references 07079 391 and 394) should be replaced.
4) Procedure 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 for sticking or binding.

7.8 Normal Operations Check

Perform a normal operations check after aligning the governor and prior to putting the unit into service. The following is a procedure for normal operations check.

With the PMG simulator completely shut down, remove the PMG simulator leads from the terminals and reconnect the PMG leads. Remove flyball blocks if installed. Return the unit to service.

1) Off-line governor tests:
   a) Set up strip chart recorder or data acquisition system.

      Channel 1 – Gate position: adjust so that 10% gate equals full scale on the chart.

      Channel 2 – Frequency transducer: adjust so that 1 Hz equals full scale on the chart.

b) With the unit running off-line near 60 Hz and the field breaker closed, make a rapid increase of one turn (1%) in the speed changer adjustment.
c) Wait until the speed settles and then make another rapid change of one turn (1%) back to original setting.
d) Repeat steps 1(b) and 1(c) two more times each.
e) The frequency and gate position should overshoot slightly and settle into a steady wander. The change in frequency should be 0.6 Hz for a 1% change in the speed-changer adjustment.

The SSI is a measure of the ability of the governor to maintain frequency. The SSI can be determined from the channel 2 steady-state frequency measurements.

$$SSI\% = ((\,Max.Freq\ in\ Hz - Min.Freq.\ in\ Hz) \times 100\%)/60Hz$$

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

2) Observation of synchroscope:
a) Synchronize the unit using normal procedures.
b) Load the unit.
c) Consult with operations personnel to verify adequate synchronizing and loading performance.
d) Check the governor and the servosystem to determine if servicing is required; i.e., if there is difficulty in synchronizing the unit or if excessive frequency wander (above 0.4 Hz) is detected. The dashpot needle can be temporarily turned down to help increase unit stability until the source of the problem can be located and corrected.

8.0 Mechanical Governor Maintenance

The maintenance tasks described in this section shall be performed as indicated.

8.1 Inspection Checklist

Refer to FIST 4-1A for a detailed list for required maintenance and testing intervals.

8.2 Governor Tests and Adjustments

Verify and adjust wicket gate timing and speed-droop calibration as described in Section 7.0. Check the mechanical alignment of the governor as described in Section 4.0. If the dashpot is disassembled for any reason, adjust dashpot and compensating crank as described in Section 7.0.

After performing governor alignment and prior to putting the unit into service:

1) Verify and adjust wicket-gate timing and speed-droop calibration.
2) Verify and adjust SNL calibration.
3) Verify and adjust the dashpot.
4) Verify and adjust the dither.
5) Perform normal operations check.

8.3 Governor Ball Head (Woodward Vibrator Type)

Oil the ball-head motor, check for vibration, and overhaul if necessary. 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 the base. If no motion can be felt, replace the vibrator and balls.

Clean, inspect, and refurbish the governor ball head as applicable. 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 will not be reused. Check the flyball rod for wear and for straightness and replace as required. Check the ball bearings in the ball-head motor and flyball arms and replace as required. Replace the flyball rod bushings if they are worn or scored. Cover the vibrator balls with a light grease and reassemble. Do not fill the vibrator cup with grease because this can dampen the vibration. Check operation of pressure-type oilers if equipped.

8.4 Governor Ball Head (Woodward Strap-suspended Type)

Check the oil in the dashpot. Add dashpot oil to the top of the ball-head motor to fill the internal dashpot. Do not use lubricating oil. In the event that dashpot oil is not available, transformer oil can be used.

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 the condition of the thrust bearing, the ball-head shaft bearings, and the ball-head motor bearings. Follow the manufacturer's alignment and reassembly procedures.

8.5 Governor Ball Head (Pelton)

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.

8.6 Woodward Oil Motor Vibrator

Check that the oil motor vibrator is providing a 0.006- to 0.009-inch oscillation of the main valve and that the motor is turning in the range of 400 to 600 RPM (7 to 10 Hz). Adjust the eccentric bushing in the pivot lever to change the magnitude of oscillation. Adjust the oil flow regulator to change the motor speed.

8.7 Pilot Valve

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.

8.8 Main and Auxiliary Distributing Valves

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 stopnuts, then drop it so it hits the closing stopnuts. 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.

Remove the main 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 with its own weight after reassembly.

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 valve plunger's piston rings and replace as required.

8.9 Miscellaneous Valves

There may be other hydraulic valves in the governor, such as gate-limit valves and solenoid valves. Disassemble valves 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.

8.10 Dashpot

Check the dashpot oil level and add dashpot oil if necessary. Do not use any other oil except dashpot oil. Check the operation of the solenoid-operated bypass.

If the tests in Section 7.0 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 2⅞ 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, first reassemble it, except for the small dashpot plunger, then 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 that 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 re-center. It should take more than 50 seconds to travel 0.125 inch. 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 in Section 7.0 to bring the governor back to optimum performance.

8.11 Links and Pins

Lubricate links and pivot pins with a light machine oil.

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.

8.12 Restoring Cable

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

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

8.13 Hydraulic System

Check the level of oil in the sump and the governor actuator tank, add oil or charge the pressure tank with air as required. Switch the lead pump to lag and vice versa.

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.

Before scheduled maintenance, send a sample of the governor oil to the laboratory for analysis. If the analysis shows filtration is required, drain and filter the oil. If the analysis indicates that the oil should be replaced, make sure replacement oil is compatible with the old oil or thoroughly flush the entire hydraulic system.

When the oil is drained, clean the oil sump and governor 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**. [Remove the governor actuator float and inspect for any cracks near the threaded connection to the float arm. Inspect using either dye penetrant or magnetic particle non-destructive testing methods.]** Non-destructive inspection of the governor actuator float is required every 5 years due to a history of float failures at the connection to the float arm, which causes loss of governor control. If failure of the float occurs during unit operation, closing the head gate will typically be required to stop the unit.

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 governor actuator tank. Relief valves on the governor 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 governor actuator tank relief valve to prevent the pumps from continuing to fill the governor 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 governor 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.

8.14 Generator Air Brake Valve

Check the manual and solenoid operation of the valve. Lubricate pivot points with light machine oil. Clean the air-line filter.

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

8.15 Permanent Magnet Generator or Speed Signal Generator

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. Using an insulation resistance test (also commonly known as a megger test), check the insulation between the PMG or SSG housing and the supporting frame by measuring the resistance from the housing to ground. Replace or repair the insulating gasket as required. Check the voltage output of the PMG. If the voltage output is less than 80% or more that 110% of the rated voltage, perform the steps identified in Section 5.0.

Replace the main drive bearings of the PMG or SSG.

Remagnetize the PMG field following the procedure in Section 5.0. If the voltage output is less than 80% or more than 110% of the rated voltage, perform the steps identified in Section 5.0.

8.16 Position and Limit Switches

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.

8.17 Shutdown Solenoids

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 SNL setting. When the solenoids are reset, make sure that the linkage does not prevent the gates from going to 100%. Inspect the solenoid for any signs of overheating or other damage. Check the condition of electrical connections and auxiliary contacts.

8.18 Speed Changer, Gate Limit Motors, and Remote Position Indicators

Operate motors and check for excessive vibration or noise. Replace bearings as required. Check gears for wear and proper meshing. Check the clutch adjustment. 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.

8.19 Governor Actuator Tank

Inspect tank in accordance with FIST 2-9, *Inspection of Unfired Pressure Vessels*. While designs may vary, in general, actuator tanks are sized and the oil level and air cushion are adjusted to provide five full servomotor strokes when the system pressure is slightly below the minimum normal operating pressure (5 psi).

Verify low-pressure switch settings. Typically, at least two low-pressure switches are associated with the governor actuator tank. One switch is set to sound an alarm at a pressure slightly below the minimum normal operating pressure, and the other is set to operate the shutdown solenoid, shut off the governor pumps, and close the penstock or unit guard gate when the pressure drops to a point that corresponds to two complete servo strokes left in the tank.

Verify level switch settings. The low-level alarm should be set to close when the level falls to a level that corresponds to 5 psi less than normal low operating pressure. The low-level shutdown should close to shut down the unit and oil pumps and close the penstock gate at a level corresponding to two complete servomotor strokes.

8.20 Governor Inspection Report

An inspection report similar to PO&M Form 192 must be filled out annually to record data obtained during the annual inspection.

9.0 Mechanical Maintenance of Digital Governors

9.1 Introduction

Digital governors eliminate many of the mechanical components that require regular maintenance. The governor ball head, dashpot, and restoring linkage are eliminated, but there are still mechanical components that require attention. Some digital governor retrofits utilize the existing main valve assembly from the mechanical governor. The hydraulic system is not significantly different on a digital governor but typically requires closer attention to the oil cleanliness than would be required with a mechanical governor due to tighter clearances in the proportional valve.

The maintenance tasks described in this section shall be performed as indicated.

9.2 Inspection Checklist

Refer to FIST 4-1A for a detailed list for required maintenance and testing intervals.

9.3 Digital Governor Tests and Adjustments

Verify timing of wicket gates. Perform test as described in Section 7.2 or by using the manufacturer's specific procedure for the governor and record results. Some digital governors have a "gate timing test" programmed into the governor. Before making any adjustments to stopnuts or flow control valves, ensure the risks of this adjustment are understood. See Section 6.1 for more information. For Kaplan type turbines, test and record the servo blade timing in a similar manner.

Check permanent speed droop calibration. Perform test as described in Section 7.2 or by using the manufacturer's specific procedure for the governor and record results. If gate position readings are not as expected, re-calibrate the gate position transducer and repeat.

Perform an emergency shutdown test of the wicket gates. Digital governors should be designed for fail-safe operation that closes the unit wicket gates at the fastest allowed rate when the governor controller is no longer operational. Fail-safe operation is typically achieved with a solenoid-operated directional valve. This valve is spring-loaded so that the spool moves to supply closing pressure to the wicket gates on a loss of power to the solenoid. **[All facilities shall verify that the governor will close the wicket gates automatically in the event that both, AC power to the pumps, and DC control power is lost.]**

To test the emergency shutdown of the wicket gates, first open the wicket gates. If the turbine is un-watered, open the gates to approximately 50%. Otherwise, run the unit off-line at SNL. Remove power to the governor controller or to the directional control valve and verify that the wicket gates closed to the full squeeze position at a fast rate. Restore power.

Test governor protection, annunciation, and control circuits in accordance with FIST 4-1B, *Maintenance Scheduling for Electrical Equipment*.

9.4 Main and Auxiliary Distributing Valves

See Section 8.8 for governor systems where the original main distributing valve was retained. On digital governors with new distributing valves, follow the manufacturer's procedure for checking and maintaining the valve. Check the operation of the transfer valve and the auxiliary valve if equipped.

9.5 Miscellaneous Valves

As described in Section 8.9.

9.6 Links and Pins

As described in Section 8.11.

9.7 Feedback Transducers

Perform calibration checks on main distributing valve position transducer (typically type LVDT) and wicket gate position transducers (typically type MLDT). Generally, this involves adjusting the gain and offset so that the transducer provides the correct gate position reading from 0% to 100% gate. Follow the governor manufacturer's instructions for calibration.

Temporarily disconnect the connection plug to these devices and verify the loss of signal is properly sensed and indicated as an alarm at the governor controller.

Inspect moving parts for free movement and binding. Look for signs of uneven loading or wear. Replace as required.

9.8 Hydraulic System

As described in Section 8.13.

9.9 Generator Air Brake Valve

As described in Section 8.14.

9.10 Speed Signal Generator

Check the insulation SSG housing and the supporting frame by measuring the resistance from the housing to ground with an insulation resistance test. Replace or repair the insulating gasket as required.

Check the air gap distance between speed sensing transducer and toothed wheel to ensure it is within the manufacturer's specification. Remove and clean magnetic speed probes when metal shavings or filings can be seen on the probes.

9.11 Governor Actuator Tank

As described in Section 8.19.

Some governor hydraulic systems use accumulator bottles rather than an actuator tank. The bottles are charged by pistons or more commonly gas-filled bladders. Follow manufacturer's recommendations to verify charging pressures periodically and to recharge bladders when needed.

9.12 Electrical Cabinet

Visually inspect the governor electrical cabinet. The main concern for the lifespan of the electrical components is heat. Look for any discoloration of wires or evidence of high temperature. Change cabinet filters, if installed, as recommended. Verify louvers and vents are not blocked or clogged. Look for signs of dust buildup on components and signs of corrosion. Perform general housekeeping by removing dust or debris in the cabinet and verify all protective covers are in place. Verify temperature control devices such as heaters and fans are in good working order.

Check for loose connections of wires, loose mounting of devices, and any signs of physical damage. Reconnect and secure as recommended in manufacturer's equipment manual.

9.13 Controller (PLC)

Some PLC models have an internal replaceable lithium battery that preserves the controller memory when the device is powered down. Consult the manufacturer's product manual and replace as recommended.

10.0 Oil Maintenance

10.1 Oil Requirements

In most cases, the turbine oil used in the unit bearings can be used as governor oil. Reference FIST 2-4, *Lubrication of Powerplant Equipment*, for oil maintenance requirements for mechanical governors.

In rare cases in which the ambient temperatures are extremely high or low, an oil of higher or lower viscosity than is used in the bearings may be required. If the operating pressure of the governor is above 1,000 psi, it may be necessary to use a hydraulic oil that is formulated with anti-wear additives.

10.2 Oil Testing and Analysis

An oil testing and analysis program can be a very useful part of a preventive maintenance program. There are tests that tell the condition of the oil itself and its suitability for continued use. Testing can determine the level and makeup of contaminants to help determine if an abnormal condition is occurring and determine a schedule for filtering. Samples from the governor sump should be taken at least annually, prior to shutdown for annual maintenance. If the filtering schedule is based on the testing results, more frequent testing should be performed.

Laboratory tests should include viscosity, water content, TAN, particle count, and elemental analysis for wear metals, oil additives, and contaminants. A RPVOT, which provides an indication of the condition of the oxidation inhibitor in the oil, should be performed every 5 years or when other testing indicates the oil is oxidizing.

The measured viscosity should fall within the span for the specific ISO viscosity grade designation for the oil being tested. Any significant change in the viscosity from the previous test should be noted.

Water content should be below 500 ppm. If over 500 ppm, it should be noted.

The TAN is a measure of the acidity of the oil and an increase in the TAN is an indication that the oil is oxidizing. There is no limit for the TAN, but any increase would indicate that further testing, such as RPVOT, is necessary.

The ISO Cleanliness Code (ISO 4406:1999) is a universal standard for measuring particulate contamination levels in fluids. It assigns three numbers based on the number of particles per unit volume greater than 4, 6, and 14 microns. Target cleanliness codes should be selected for particular applications. When the oil tests show the particle count to higher than the target, filtering is required, or a better filter is required. A target cleanliness code of 17/15/12 is reasonable and achievable for the governor oil.

Elemental analysis can provide information on wear metals, contaminants, and the oil additive depletion. As many of the additives are proprietary, it may be necessary to involve the oil's manufacturer for a definitive analysis of additive elements. The primary wear metals will be iron and copper. Iron can come from any of the steel components such as valves and pumps, while copper will most likely come from worn bushings in the systems. Contaminants such as silicon can indicate that the oil system is not adequately sealed.

10.3 Filtering

Ideally, the filtering schedule should be based on the oil testing results. When the cleanliness code is above 20/18/15, or if the water content is above 1,000 ppm, the oil should be filtered. A cartridge-type 5-micron filter should be sufficient to bring the oil to a cleanliness code of 17/15/12.

Oils formulated with Group II base oils can be prone to varnish and sludge formation. If governor parts show signs of varnish formation that does not respond to normal filtering procedures, it may be necessary to use an electrostatic filtration system. Electrostatic filtration systems are very effective at removing very small contaminants as well as reducing varnish buildup on components.

10.4 Kidney Loop Filters

A kidney loop filtering system is an off-line system that consists of a pump, filter, and piping that takes oil from a bearing or governor sump, runs it through the filter, and returns it to the sump. This allows the oil to be purified while the equipment is operating. The system may be designed to run continuously or periodically. The system may be permanently mounted or made portable to be moved from unit to unit. One of the advantages of a kidney loop system is the ability to filter the oil in place rather than periodically draining the entire sump. The oil is maintained at a constant cleanliness level rather than allowing the contaminant levels to gradually increase until the oil is dumped and filtered. The use of a kidney loop system should increase the required intervals between draining the sump.

As a general rule, to ensure that all of the oil passes through the filter, the pump must move at least seven times the capacity of the sump being filtered. To clean the oil to the level determined by the filter media, all the oil should pass through the filter at least five times. As an example, a 200-gallon sump would require the kidney loop system to pump 7,000 gallons (200×7×5) to achieve the level of cleanliness indicated by the filter media rating. Permanently mounted systems can use a relatively small pump, as they can be run continuously or on a timer to achieve the desired oil movement. Portable systems that are attached for a shorter period must use larger pumps to achieve the same filtering results.

11.0 Troubleshooting

A well-maintained mechanical governor will provide years of trouble-free service, but due to wear, maladjustment, and friction, there can be problems. Some of the more common problems and the most likely causes are discussed below.

11.1 Hunting

Hunting is an unstable condition in which the governor cannot 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 Hz peak to peak or if the automatic synchronizer cannot put the unit on-line, it is considered excessive. On-line hunting in which the wicket gates move back and forth while the frequency is controlled by the system 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 maladjustment 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 7.0. 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 will not be an optimum adjustment for the dashpot. The tests of Section 7.0 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 Section 8.10. If air in the dashpot has been ruled out, the dashpot should be checked for excessive leakage by the test described in Section 8.10. 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 should 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 in Section 7.0 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, or the wicket gate operating mechanism. On-line hunting is not very common. Once a unit is on-line, the actual speed of the unit cannot 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 PMG 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 too 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.

11.2 Inability to Reach Full Speed

The inability of a unit to reach 100% 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 does not 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 SNL position. The alignment procedure in Section 4.0 should be used to realign the gate limit. If the governor employs an SNL solenoid, the rod from the solenoid should be checked for the correct adjustment.

11.3 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 4.0 should be followed to align the gate limit. It should also be noted that on Woodward governors at high gate openings, the gate position cannot match the gate limit. It will always be 1% or 2% lower than the gate limit. If 100% gate is desired, the gate limit must be set higher than 100%. The adjustment of the shutdown solenoid can prevent the unit from reaching full load. 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.

11.4 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 it may be the result of marginally sized servomotors or low governor pressure.