Westinghouse Technology Systems Manual

Section 8.1

Rod Control System

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8.1 ROD CONTROL SYSTEM

Learning Objectives:

1. State the purposes of the rod control system.

2. List the inputs to the automatic rod control system and explain why each is used.

3. Explain why the rate of change of difference between the turbine and nuclear powers is used in the power mismatch circuit.

4. Deleted.

5. Given a list, arrange in proper order the stepping sequence of the Control Rod Drive Mechanism (CRDM).

6. List the rod withdrawal stops that occur in both automatic and manual rod control.

7. Describe the effects of an "urgent failure" in the logic cabinet and in a power cabinet.

8. Explain how individual rod motion is achieved.

9. Briefly describe the functions of the Bank Overlap Unit (BOU).

10. Briefly describe the rod speed program and explain the purposes of "deadband" and "lock-up".

8.1.1 Introduction

The purpose of the rod control system is to control the motion of the neutron absorbing full length rods (rods). This control system moves the rods, in response to demand signals from either the reactor operator (for start-up, shutdown, and power operations), or from the automatic rod control system (power operations) to maintain a programmed reactor coolant system average temperature (T_{avg}). It also releases the rods in response to manual or automatic reactor trip signals, allowing the rods to fall into the core, shutting down the reactor.

The rod control system is used to compensate for fast short term reactivity changes, such as those resulting from power changes and xenon transients. Compensation for slower long term effects, such as fuel depletion, gradual xenon and samarium changes, is accomplished by adjusting the boron concentration in the reactor coolant. Refer to Section 4.1 (chemical and volume control system).

Between 15% and 100% power, the automatic rod control system maintains the average temperature of the primary coolant at a programmed value by adjusting the reactivity in the core. Automatic rod control below 15% turbine power is not provided.

By design, this system is capable of handling the following transients: a 10% step load increase or decrease, a 5% per minute ramp load increase or decrease, or a 50% step load decrease with the aid of the steam dump system (Section 11.2) and without actuating the pressurizer relief valves or generating a reactor trip.

The first two transients (a ±10% step, or a ±5% per minute ramp change in power), can occur during power operation and design transients. During these design transients, the rod control system provides adequate reactivity addition rates so that the average temperature of the reactor coolant remains within ±5°F of the temperature program. As long as T_{avg} is within its program the steam dump system will not actuate. However, the rod control system reactivity addition rates are insufficient to reduce power quickly enough to prevent a significant temperature mismatch from developing during a 50% step loss of load. In this case, the steam dump system removes the excess heat generated by the reactor until the rod control system reduces the temperature of the reactor coolant to the new program value.

As previously stated, one of the purposes of the rod control system is to maintain a programmed average temperature in the reactor coolant system by regulating the reactivity in the core. Deviation of the average temperature from the program temperature by more than a preselected amount results in automatic rod movement to return T_{avg} to program. The rod speed varies with the size of the temperature deviation. The direction of rod movement is dependent upon whether the average temperature of the reactor coolant is higher or lower than the program temperature.

The rods are separated into two functional categories: shutdown rods and control rods. Each category consists of a number of individual rods which are arranged in banks. Each bank contains between four and nine rods which are moved together. The shutdown banks are always in the fully withdrawn position during power operations and are moved into this position at a fixed speed in manual bank control prior to criticality. The shutdown banks provide a large negative reactivity insertion upon a reactor trip to ensure the reactor achieves and maintains subcriticality.

The control banks are the only rods that can be manipulated under automatic rod control. The control banks are used: to change the reactivity in the core, to take the reactor critical, and during automatic control of this system, to maintain the average temperature of the reactor coolant at the programmed temperature. In addition, the control banks also fall into the core following a reactor trip signal, to aid the shutdown banks in placing the reactor in a subcritical condition.

8.1.2 System Description

In the automatic mode of control as shown in Figure 8.1-1, the rod control system uses three input signals to control the positioning of the control rods; auctioneered high T_{avg}, auctioneered high nuclear power, and turbine first stage pressure (P_{imp}). These three inputs are used in two comparison circuits to develop a total error signal which is processed by the reactor control unit.

The power mismatch circuit compares auctioneered high nuclear power with P_{imp}. If a rate of change of the difference between the two signals (P_{imp} and auctioneered high nuclear power) exists, the power mismatch circuit generates an error signal. As the rate of change of the difference increases, so does the magnitude of the error signal.

The summing unit compares T_{ref} (generated from P_{imp}) and auctioneered high T_{avg}. Any difference between these two signals (T_{ref} - T_{avg}) produces a temperature error signal. This error signal is algebraically summed with the error signal produced by the power mismatch circuit. The result is a total error signal which is sent to the reactor control unit.

The reactor control unit generates an analog signal. The polarity and magnitude of this signal determines the speed and the direction of rod motion. When the bank selector switch is placed in automatic, the output from the reactor control unit is sent to the logic cabinet.

Analog signals generated in the reactor control unit are converted into digital signals by the pulser located within the logic cabinet. After the signal is converted into a digital output, the digitized pulses are transmitted to the power cabinets. Within the logic cabinet, signals are developed that determine rod speed, rod direction, the control bank to be moved, and the group of rods within a control bank to be moved. The rod stop interlocks, also located within the logic cabinet, prevent outward rod motion during predefined conditions.

Each power cabinet receives electrical power from the rod drive motor-generator (MG) sets through two series reactor trip breakers and/or their associated bypass breakers. Each power cabinet distributes electrical power to the proper coils within the control rod drive mechanisms. Signals from the logic cabinet activate and deactivate components within the power cabinets that initiate the stepping sequence of rod drive mechanisms. Each power cabinet is capable of supplying up to three groups of rods.

Manual control of the rods is accomplished by placing the bank selector switch in the manual position. This action switches the logic cabinet input from the reactor control unit to the bank selector switch. Rod motion is achieved by using the IN-HOLD-OUT switch.

8.1.3 Control Rod Drive Mechanism

The control rod drive mechanism is used to withdraw or insert the full length rods. The complete drive mechanism, shown in Figure 8.1-2, consists of the internal latching assemblies (grippers), the rod drive shaft assembly, the pressure housing, and the magnetic coil stack. Every single rod has its own drive mechanism. The control rod drive mechanism is an electromagnetic jack and is sometimes referred to as a magnetic jack assembly or a "mag jack."

The movable and stationary gripper latches engage the rod drive shaft when their respective coils are energized. The movable grippers are used to raise or lower the control rod drive shaft when the lift coil is energized or de-energized. The stationary grippers are used to hold the drive shaft in position whenever rod motion is not required. A reactor trip is achieved by simply removing the electrical power from the coils, which allows springs to disengage the grippers from the rod drive shaft, and the rod falls by gravity into the core.

Three magnetic coils induce a magnetic flux through the pressure housing to operate the internal latching mechanisms. Energizing and de-energizing the magnetic coils in a fixed sequence causes the internal mechanisms to either engage or disengage from the grooved drive shaft. This, in turn, moves the rod one step into or one step out of the core in discrete 5/8-in. steps.

During steady-state plant operation, the control rod drive mechanism's stationary grippers hold the control rod withdrawn from the core in a static position. When rod movement is required, a signal is sent from the rod control system to withdraw (section 8.1.3.1) or insert (section 8.1.3.2) the control rod in a prescribed sequence, which is described in the following sections.

8.1.3.1 Control Rod Withdrawal

1. Movable Gripper Coil - ON - The movable gripper armature raises and swings the movable gripper latches into one of the grooves on the rod drive shaft.

2. Stationary Gripper Coil - OFF - Gravity causes the stationary gripper latches and armature to move downward until the load of the drive shaft is transferred to the movable gripper latches. Simultaneously, the stationary gripper latches swing out of the drive shaft groove.

3. Lift Coil - ON - Once energized, the magnetic force from this coil pulls up the movable gripper latch assembly. Since the movable grippers are coupled to the rod drive shaft, the rod is raised 5/8 in.

4. Stationary Gripper Coil - ON - The stationary gripper armature raises, swinging the stationary gripper latches into a drive shaft groove. The latches contact the shaft and lift it 1/16 in. The load is transferred from the movable to the stationary gripper latches.

5. Movable Gripper Coil - OFF - The movable gripper armature separates from the lift armature under the force of the spring and gravity. Three links, pinned to the movable gripper armature, swing the three movable gripper latches out of the drive shaft groove.

6. Lift Coil - OFF - The lift armature and the movable gripper latches drop 5/8 in. to a position adjacent to the next groove.

8.1.3.2 Control Rod Insertion

1. Lift Coil - ON - The movable gripper latches are raised 5/8 in. to a position adjacent to a shaft groove.

2. Movable Gripper Coil - ON -The movable gripper armature raises and swings the movable gripper latches into a groove.

3. Stationary Gripper Coil - OFF - The stationary gripper armature moves downward and swings the stationary gripper latches out of the groove.

4. Lift Coil - OFF - Gravity and spring force separates the lift armature from the lift magnet poles, and the control rod drops down 5/8 in.

5. Stationary Gripper Coil - ON - The stationary gripper armature raises, swinging the stationary gripper latches into a drive shaft groove. The latches contact the shaft and lift it 1/16 in. The load is transferred from the movable to the stationary gripper latches.

6. Movable Gripper Coil - OFF - The movable gripper armature separates from the lift armature under the force of the spring and gravity. Three links, pinned to the movable gripper armature, swing the three movable gripper latches out of the drive shaft groove.

Each sequence (withdrawal or insertion) is called a step or a cycle, and the result is that the rod moves 5/8 in. for each demanded step. This sequence can be repeated at a rate of up to 72 times per minute. The control rods can, therefore, be withdrawn or inserted at a rate up to 45 in./min.

8.1.4 Rod Control System Signal Processing

The mode of operation of the rod control system is selected by the reactor operator via the bank selector switch located on the main control board. This switch allows for either manual, automatic, or individual bank select operation. All positions of this switch are explained in section 8.1.4.1.

8.1.4.1 Bank Selector Switch

The bank selector switch is a ten (eleven in some plants) position switch that permits selection of individual banks, manual control, or automatic control. A description of each position is given below.

MANUAL

In this position, the control rods are withdrawn or inserted by the use of the IN-HOLD-OUT switch. The bank sequence and overlap program (section 8.1.5) is maintained with the rods in manual rod control. The rod speed is adjustable between 8 and 72 steps/min. with a potentiometer located within the rod control cabinet. The speed normally selected for manual operation is 48 steps/min.

AUTOMATIC

Placing the bank selector switch in automatic electrically disconnects the IN-HOLD-OUT switch. Rod motion (direction and speed) is determined by the reactor control unit (section 8.1.4.5). The control bank sequence and the overlap program is maintained by the bank overlap unit located inside the logic cabinet. Inputs for the reactor control unit come from the power mismatch and the temperature mismatch circuits. These circuits are explained in sections 8.1.4.2 and 8.1.4.3, respectively.

CONTROL BANK A

Control bank A rods can be moved manually using the IN-HOLD-OUT switch. The rod sequence and overlap is not maintained; that is, the bank overlap unit (section 8.1.5.4) program is overridden. The rod speed signal in this position is the same as that for manual operation (48 steps/min).

CONTROL BANK B, C, D

Same as Control Bank A.

SHUTDOWN BANK A

In this position, shutdown bank A rods are moved using the IN-HOLD-OUT switch. Rod speed is preset by an adjustable stepping rate potentiometer located in the rod control cabinet. The normal preselected speed is 64 steps/min.

SHUTDOWN BANKS B, C, D

Same as shutdown bank A.

8.1.4.2 Power Mismatch Circuit

The power mismatch circuit provides a fast, stable response to a change in load. Its purpose is to anticipate a change in the average temperature of the reactor coolant due to turbine load changes. If nuclear and turbine power are changing at different rates, the resulting power mismatch will change T_{avg}. This circuit provides an error signal to the summing unit which increases rod speed at the beginning of a transient. Moving the rods faster, earlier in a transient, helps reduce the magnitude of error between T_{avg} and T_{ref}.

The inputs into this circuit (Figure 8.1-3) are nuclear (primary) power and turbine (secondary) power. The nuclear power input signal for automatic rod control is obtained from the highest of the four power range excore nuclear instruments. All four power range signals are sent to an auctioneering unit which allows the highest signal to pass through, and is referred to as auctioneered high nuclear power. The turbine power signal is generated from the first stage impulse chamber pressure of the high pressure turbine. This signal is referred to as $P_{impulse}$ or P_{imp}.

The rate comparator of the power mismatch circuit monitors the two power inputs and provides an output if, and only if, there is a rate of change of the difference between the inputs. This rate comparator prevents the power mismatch circuit from responding to steady state calibration differences between nuclear and turbine power. The larger the rate of change of power mismatch, the larger the output from the rate comparator.

A nonlinear gain unit is placed at the output of the rate comparator. Its function is to convert the power mismatch signal to an equivalent temperature signal. In addition, this signal is amplified as a function of the magnitude of the input. That is, for power mismatches of less than 1% the unit operates on low gain (0.3°F signal per percent power deviation). For larger mismatches (> 1%), the unit operates on high gain (1.5°F signal per percent power deviation).

A variable gain unit is located directly after the nonlinear gain unit. This component provides a higher gain to the power mismatch error signal at low power levels and a lower gain at high power levels. The lower gain at higher power levels limits the likelihood that rapid rod motion (and the associated rate of reactivity change) could cause a significant overshoot during a power change. Moreover, minimizing rapid overshoots with reactor power near 100% helps to avoid violating the plant's licensed power limit. The variable gain unit ensures that the power mismatch circuit provides adequate control at low power levels and stable operation at higher power levels. Since the output from this unit is inversely proportional to turbine load, a P_{imp} signal is provided for the reference power input. Between 0% and 50% power this unit provides a gain of two. Between 50% and 100% turbine load, it provides a gain inversely proportional to turbine power, i.e., 1/(% power). At turbine loads equal to or greater than 100% this unit provides a gain of one.

The output from the power mismatch circuit is combined at the summer with the temperature mismatch error as described below.

8.1.4.3 Temperature Mismatch Circuit

This circuit provides fine control during steady-state operation and returns T_{avg} to T_{ref} after a transient. The inputs into this circuit (Figure 8.1-3) are auctioneered high T_{avg} and reference temperature (T_{ref}). The T_{avg} input is obtained from an auctioneering unit which monitors the four T_{avg} channels and allows the highest T_{avg} to pass through to the input of the temperature mismatch circuit. The reference temperature (the desired or programmed temperature) is generated from P_{imp} (turbine power). The temperature mismatch circuit compares T_{avg} (the actual temperature) to T_{ref} (the desired temperature) and generates an error signal if there is a mismatch between these two inputs. Any resultant error signal is sent to the summing unit.

8.1.4.4 Summing Unit

The summing unit algebraically sums the signals from the power mismatch circuit and the temperature mismatch circuit. Its output represents a total temperature error, and this signal is sent to the reactor control unit.

8.1.4.5 Reactor Control Unit

The reactor control unit generates the rod speed program as shown in Figure 8.1-4. The reactor control unit receives an input from the summing unit and converts this signal into a rod speed and direction signal. The speed and direction signal is sent to the pulser (section 8.1.5.1) located within the logic cabinet.

A deadband of ±1.5°F, which includes a 0.5°F lock-up, is employed to eliminate continuous rod stepping and bistable chattering. The lock-up can be explained by referring to Figure 8.1-4 and examining a signal for rod withdrawal. When the total error signal reaches +1.5°F, the output from the reactor control unit demands the minimum rod speed to return T_{avg} to program. As the rods step out, T_{avg} increases, reducing the total error signal. When the total error signal reaches +1°F, the unit turns off, stopping rod motion. This 0.5°F difference between starting and stopping rod motion prevents the bistable from chattering (turning on and off continuously).

Rod speed is determined by the total error signal. For small error signals, ±1.5°F to ±3°F, the reactor control unit produces an output demanding a minimum speed of eight steps per minute. This minimum rod speed is based upon a minimum response of the rod control system for small errors generated by this system. A slow speed prevents excessive movement of the rods which could cause a temperature overshoot. Temperature overshoots could cause hunting by the rods, i.e., excessive rod movement. As the temperature error signal increases from ±3°F to ±5°F, the rod speed program enters a proportional speed region. This region calls for 32 steps/min/°F. This gain is selected to be consistent with the need for increased rod motion to limit transient temperature overshoot while, at the same time, preventing overcompensation and temperature oscillations. With an error of 5°F or greater, the rod speed programmer of the reactor control unit generates a maximum rod speed of 72 steps/min. The maximum rod speed is based upon a maximum response to a large error signal and upon the physical limitations of the rod drive mechanism, with the latter being the limiting factor.

8.1.5 Logic Cabinet

The logic cabinet contains the following components: the pulser, the master cycler, the bank overlap unit, and the slave cyclers. The function of the logic cabinet is to generate the necessary signals to step the rods into or out of the core. The logic cabinet receives command signals from either the IN-HOLD-OUT switch (when in manual), or from the reactor control unit (when in automatic). In response to these signals, the logic cabinet selects the appropriate bank of rods to maintain the proper sequence and overlap. It then supplies the proper stepping sequence to the power cabinets (section 8.1.6) to move the selected bank(s) of rods.

The withdrawal sequence for the control banks is A, B, C, D. The overlap between banks (the time when two separate banks move together) is such that as control bank A passes the center of the core, control bank B begins moving. This sequencing and overlap is chosen to produce relatively even reactivity additions per step of rod movement and to minimize the effect of rod motion on core peaking factors.

The rods in the four control banks (and the rods in shutdown banks A and B) are subdivided into groups of rods. Shutdown banks C, and D, (which contain only four rods each) are not divided into groups.

Upon receipt of a command signal for "IN" or "OUT" rod motion, the rods move at a predetermined speed with staggered stepping of groups within the banks. Upon removal of the command signal, all rod motion stops. However, a group of rods still in sequential motion completes its entire step before halting. Reversal of direction is programmed so that the last group that ceased motion is the first group to move in the new direction. Staggered stepping of the groups within banks is controlled by the master cycler (section 8.1.5.2).

Proper rod sequencing and overlap are controlled by the bank overlap unit (section 8.1.5.4). A summary of the bank overlap and sequencing is given below.

1. Two groups within the same bank are stepped so that the relative position of each group within a bank will not differ by more than one step.

2. Control bank withdrawals are programmed; so that when the first bank reaches a preset position, the second bank begins to move out simultaneously with the first bank. When the first bank reaches the top of the core, it stops, while the second bank continues to move toward its fully withdrawn position. When the second bank reaches a preset position, the third bank begins to move out, and so on. The control bank insertion sequence is the opposite of the withdrawal sequence (i.e., the last bank withdrawn is the first bank to be inserted).

3. The overlap between successive control banks is adjustable with an accuracy of ±1 step. Normally the overlap is set at 100 steps. As an example, once control bank A has reached 131 steps, control bank B starts to withdraw. Control bank B steps out simultaneously with control bank A during control bank A’s last 100 steps, hence the 100-step overlap.

A programmed signal is also sent to the slave cyclers (section 8.1.5.3). The slave cyclers cause the rods to sequence through one step by signaling the power cabinets to operate the coils of the magnetic jack as described in section 8.1.4.

8.1.5.1 Pulser

The function of the pulser is to convert the analog output from the reactor control unit into a digital signal. The pulser generates pulses at a rate proportional to the speed signal, which corresponds to a control rod bank stepping rate of 8 to 72 steps/min. The pulser multiplies the speed signal by a factor of six and, therefore, pulses at 48 to 432 pulses/min. When the reactor control unit output exceeds 1.5°F the pulser begins to pulse at 48 pulses/min. Each pulse advances or reverses the master cycler by one step.

8.1.5.2 Master Cycler

The master cycler receives rod speed and direction signals from the pulser and converts these signals into “Go” pulses. This device also directs these Go pulses to the proper slave cyclers (section 8.1.5.3). The master cycler accomplishes this function by using a reversible clock/counter which operates over a range of zero to five counts. It counts once for each pulse from the pulser circuit and, therefore, goes through one complete cycle after receiving six pulses.

An out-motion pulse signal increases the master cycler's count, while an inward-motion pulse decreases the count. The master cycler sends an output to the slave cyclers, in the form of GO pulses, every time it passes the zero or the three on the clock. At count zero, a GO pulse is sent to the slave cyclers controlling group one rods (1AC and 1BD), and at count three a GO pulse is sent to the slave cyclers controlling group two rods (2AC and 2BD). The master cycler divides the pulser's pulse rate by six and produces two evenly spaced pulses for the slave cyclers.

The bank overlap unit determines whether the group one or the group two slave cyclers actually receive a pulse. Since the pulser multiplies by six and the master cycler divides by six, the rod speed is processed correctly. The multiplication by six is designed to allow the flexibility of having two groups of rods per bank. This arrangement allows sequencing of groups within banks. A bank has taken a complete step when both groups within that bank have taken a step in the same direction. Because of the reversible feature of the counter, the last rod group that moved is the first group to move if a different direction is called for. For example, if the last demanded rod motion was outward and the master cycler happened to stop at count four, group two would have been the last to step (passing through three increasing: 0,1,2,3,4). If the next demand signal is for inward motion, the master cycler would count back toward zero and move group two into the core first (i.e., counting from 4,3,2,1, etc.). The clock reversal feature insures the proper sequencing of the groups. The bank overlap unit is notified each time the master cycler counts a zero or a three, so that the BOU can track the total number of steps.

Before the master cycler can properly distribute the GO pulses, it must know which bank to move and in what direction to move the rods. This is accomplished by information received from either the bank selector switch (section 8.1.4.1) or the bank selector switch through the bank overlap unit (section 8.1.5.4).

8.1.5.3 Slave Cycler

The function of the slave cycler is to generate current orders to its associated power cabinet. These orders move the rod drive mechanisms through one cycle of insertion or withdrawal. Each slave cycler provides signals to only one power cabinet.

A "GO" pulse from the master cycler starts the operation of the slave cycler (Figure 8.1-5). The slave cycler is a seven-bit binary counter that counts from 0 to 127, and performs this operation in 780 milliseconds. Once the counter reaches 127, it resets to zero and awaits another GO pulse from the master cycler.

The stationary gripper, movable gripper, and lift coils of the control rod drive mechanism receive current orders from different count points generated by the slave cycler. These orders correspond to:

- Magnitude - the amount of current (full, reduced, or zero) that is applied to a coil,
- Duration - the length of time the signal is supplied to a coil, and
- Time - when the current is applied to or removed from a particular coil.

The rod group has taken one step into or out of the core after the counting sequence is complete.

Since the rod drive mechanism coils require different actuation sequences for either an IN cycle or an OUT cycle (section 8.1.4), the slave cycler must know which sequence to use. The sequence is determined by the master cycler.

8.1.5.4 Bank Overlap Unit

The bank overlap unit (BOU) determines the sequence and overlap of the control banks. It also provides multiplexing signals (section 8.1.6.3) to the power cabinets.

The bank overlap unit receives counts from the master cycler and records one IN or one OUT count for the insertion or withdrawal of the two groups of rods within a bank of rods. The BOU provides an input into the master cycler for each count it registers. This feedback directs the “GO” pulses from the master cycler to the proper slave cyclers.

The BOU maintains the control rod sequence and overlap by counting all steps taken by the control rods. It records these steps as counts on a reversible counter that counts from 0 to 999. Thumbwheel switches located on the bank overlap unit preset the range of the overlap. During withdrawal of the control banks, control bank A withdraws first until it reaches a preselected setpoint, for example 131 steps on the control bank A step counters or 131 counts on the BOU. When control bank A takes its 132nd step, control bank B takes its first step. Control banks A and B move in unison until control bank A reaches the top of the core (231 steps on control bank A or 231 counts on the BOU), and control bank A then stops moving. Control bank B continues to withdraw, until it reaches the next preselected overlap point (131 steps on bank B or 262 counts on the BOU). As control bank B takes its 132nd step, control bank C takes its first step. This sequence and overlap continues until all control banks are withdrawn from the core.

When two banks are in an overlap region, groups are withdrawn simultaneously. For instance if control bank A and B are moving in the overlap region, group 1 of both banks move simultaneously. Similarly, the group 2 rods of the overlapped banks move simultaneously.

8.1.6 Power Cabinet

The circuitry layout for a typical power cabinet is shown on Figure 8.1-6. The function of this cabinet is to convert a three-phase ac power input into an amplitude-controlled dc voltage. It then directs this dc voltage to the rod drive mechanism coils.

Each power cabinet is designed to accommodate three groups of drive mechanisms, and each group contains four individual drive mechanisms. A fifth mechanism may be connected to one of the three groups as required by the rod grouping on some four-loop plants. The design of the power cabinets allows the motion of only one group of rods, with the remaining two groups of rods held in a stationary position. The method used to operate one group of rods and hold the other rod groups stationary is explained in sections 8.1.6.1 - 8.1.6.4.

Electrical power to the power cabinets is supplied via two parallel motor-generator sets operating from two separate, nonvital, 480-Vac, three-phase buses. Each generator is driven by a 150-hp induction motor and supplies 260 volts line to line through two, redundant, series-connected reactor trip breakers. Removing electrical power to the power cabinets (opening either of the reactor trip breakers), de-energizes all mechanism coils, and the rods drop into the core. Reactor trip bypass breakers can be connected in parallel with the reactor trip breakers to facilitate on-line testing of the reactor protection system (Chapter 12). The use of these bypass breakers is under administrative control.

8.1.6.1 Thyristors

A thyristor is a generic title referring to a class of electronic devices, one of which is the silicon-controlled rectifier (SCR). This device functions as a current controlled switch. The outstanding features of the SCR are the speed of switching (turning on and off) and the ability to control high currents. Load currents of tens to hundreds of amperes may be turned on in as little as three microseconds and turned off in about 30 microseconds. The thyristor is an essential part of the power cabinet, which supplies high, reduced, or zero current to the stationary, movable, and lift coils. These devices are show on Figure 8.1-6.

8.1.6.2 Half-Wave Bridge

If rectifiers, instead of thyristors, were installed in the power cabinet in each phase of the ac power supply, a fixed dc current would flow to the various coils. The purposes of the power cabinet, however, are: to supply three accurate current levels (full, reduced, or zero), to provide these currents for a fixed period of time, and to arrive at these fixed points in the fastest possible time. This is accomplished by gating (turning on) the half-wave bridge network at different phase angles (time intervals). This converts the ac supply to a variable dc supply. The variable dc output from this network allows the profiling (changing) of the current as needed for the stepping sequence.

8.1.6.3 Multiplexing Circuit

Figure 8.1-6 is an illustration of power cabinet 1BD. This cabinet contains the electronics for moving the group one rods of control bank B, control bank D, and shutdown bank B. The circuitry is arranged, through multiplexing, to allow rod motion of only one of the three groups at any time. For example, assume that the mechanisms for group one, control bank B have been selected for movement. The movable grippers multiplexing thyristor for control bank B is turned on, and the movable grippers' thyristors for control bank D and shutdown bank B are turned off.

In the lift coil circuit, the four multiplexing thyristors for control bank B are turned on, and the multiplexing thyristors (four each) for control bank D and shutdown bank B are turned off. The stationary gripper circuit for control bank D and shutdown bank B receive a constant hold current signal, which is explained in section 8.1.6.4. The power cabinet is aligned to move group 1, control bank B mechanisms. The multiplexing signals come from the bank overlap unit.

8.1.6.4 Firing Circuit

The firing circuits located within the power cabinet receive signals sent from a slave cycler. Their purpose is to gate the bridge thyristors to the proper current commands as dictated by the slave cycler. The power cabinet contains a total of five firing circuits. Each firing circuit supplies signals to its associated bridge thyristor. The arrangement of these circuits is as follows: the stationary gripper circuits (three firing circuits), movable gripper circuit (one firing circuit), and lift coil circuit (one firing circuit).

A simplified block diagram of the firing circuit (representative of any of the five provided) is shown in Figure 8.1-6. When a firing circuit receives an input from the slave cycler, it gates (turns on) its associated bridge thyristor. The thyristors adjust the current signal (either full, reduced, or zero) to the magnetic coils. The current, from the coils, is sampled to provide a feedback signal into the firing circuit. If the current being sampled is not the same as demanded by the slave cycler, the firing angle of the bridge thyristor is varied to obtain the exact current demanded by the slave cycler.

As explained in the multiplexing section (section 8.1.6.3), the stationary gripper circuits for the banks that are not to be moved receive a hold current signal. This is accomplished by an inhibit signal input into the firing circuits. The inhibit signal is generated by the bank overlap unit and overrides any signals entering the firing circuit from the slave cycler.

When an inhibit signal is present, the firing circuit gates the bridge thyristor for the non-moving rods at a reduced current. This signal remains in the circuit until the moving rods have sequenced through one step. The slave cycler inhibit signal is only supplied to the three firing circuits associated with the stationary gripper circuits. This circuit is provided to keep the gripper coils energized for the banks not being stepped, thereby holding these rods in a static position.

8.1.6.5 DC Hold Cabinet

A failure within a power cabinet may require the replacement of a printed circuit card, a fuse, or another electronic component. To prevent dropping rods during maintenance, and to avoid the need for a separate external power source, each power cabinet contains three switches, which may be used to energize any one of the three groups of stationary gripper coils. The maintenance power source (125 Vdc for latching and 70 Vdc for holding) is taken from the load side of the reactor trip breakers and is distributed to the power cabinets via the dc hold cabinet. Therefore, if a group of rods were on the hold cabinet and a reactor trip signal opened the reactor trip breakers, these rods would de-energize and trip into the core along with all the other rods.

This power supply is designed so that it can latch or hold a maximum of six mechanisms. Therefore, placing more than one group of rods on the hold cabinet could result in overloading the power supply. To apply hold voltage, the switch is rotated from the OFF position to the LATCH position and held in that position for at least one second. It, is then rotated to the HOLD position. The 125 Vdc supply is used to assure latching of the stationary grippers, while the 70 Vdc supply is used to hold the grippers without overheating the coils.

8.1.6.6 Lift Coil Disconnect Switches

A lift coil disconnect switch is furnished for each rod drive mechanism. These switches are located in the rod disconnect switch panel located in the control room or the auxiliary building in close proximity to the control room. These switches are used to move an individual rod (e.g., to retrieve a dropped rod). By disconnecting the lift coils of all the rods in the bank containing the dropped rod, except the lift coil of the dropped rod, the dropped rod may be returned to its original position.

8.1.7 System Interrelations

8.1.7.1 Control and Indications

All controls used for normal system operation are located on the main control board. The major components are:

- Bank selector switch (section 8.1.4.1),
- IN-HOLD-OUT switch,
- Rod speed indication and the IN-OUT lights (section 8.1.7.2),
- Group and bank position indication (Section 8.2), and
- Individual rod position indication (Section 8.2).

In addition to these controls and indications, there are various annunciators and rod stop interlocks, which are explained in this section.

8.1.7.2 In-Out Lights

In-and-out lamps on the control board indicate that rod motion has been requested by either the IN-HOLD-OUT switch or the reactor control unit.

8.1.7.3 Interlocks and Rod Stops

Commands for manual and automatic rod motion must pass through various permissive circuits in the rod control system prior to generating the actual call for rod motion. The following interlocks are provided by the full length rod control system:

Manual Rod Withdrawal Stops

1. Power range high flux rod stop, 1/4, power range power > 103%,
2. Intermediate range high flux rod stop, 1/2, intermediate range power > 20%,
3. Overtemperature ΔT (OTΔT) rod stop and runback, 2/4, loop ΔT > (OTΔT reactor trip setpoint - 3%), and

4. Overpower ΔT (OPΔT) rod stop and runback, 2/4, loop ΔT > (OPΔT reactor trip setpoint - 3%).

Automatic Rod Withdrawal Stops

1. Power range high flux rod stop, 1/4, power range power > 103%,
2. Intermediate range high flux rod stop, 1/2, intermediate range power > 20%,
3. Overtemperature ΔT (OTΔT) rod stop and runback, 2/4, loop ΔT > (OTΔT reactor trip setpoint - 3%),
4. Overpower ΔT (OPΔT) rod stop and runback, 2/4, loop ΔT > (OPΔT reactor trip setpoint - 3%),
5. Low power interlock, 1/1, turbine power (impulse pressure) < 15%, and
6. Control bank D withdrawal interlock, demanded bank D position > 223 steps.

These interlocks or rod stops only prevent outward rod motion. The rods can always be inserted into the core using either manual or automatic rod control.

8.1.7.4 Non-Urgent Failure Alarms

The rod control system has two non-urgent failure alarms, one for the logic cabinet and one for the power cabinets. In either case, the probability of dropping a rod is very remote since this alarm is generated by a loss of one of the redundant power supplies. Actuation of this alarm does not affect the ability to move rods.

One annunciator window (ROD CONTROL NON-URGENT FAILURE) is used for an alarm in either a logic cabinet or a power cabinet. The annunciator is actuated whenever any one of the three redundant power supplies is lost inside the logic cabinet, or if a power cabinet loses one of its two power supplies.

8.1.7.5 Urgent Failure Alarms

An urgent failure is a failure which could affect rod motion and includes the possibility of dropping a rod. The urgent failure alarm can be generated from either the logic or power cabinets. Depending upon the source of the urgent failure, rod motion is inhibited as described below.

The ROD CONTROL URGENT FAILURE annunciator is actuated when any one of the following conditions occurs inside the logic cabinet:

- Slave cycler failure,
- Pulser failure, or
- Removal of any printed circuit board.

If any of these conditions exist, the rod control system inhibits all automatic and manual rod motion. Rods may be moved only by selecting an individual bank on the bank selector switch. Rods affected by a slave cycler failure will not move even if the individual bank is selected.

The ROD CONTROL URGENT FAILURE annunciator is also actuated when any one of the following conditions occurs inside a power cabinet:

- Blown fuse in an ac supply line,
- Bridge thyristor fault,
- Current signal at the coils doesn't match the demand current,
- Loss of current signal to both the stationary and movable gripper coils at the same time, or
- Loss of multiplexing signal.

If any of these conditions exist, the rod control system inhibits all automatic and manual rod motion. In addition to stopping all rod motion, the following occurs inside the affected power cabinet:

a. All power is removed from the lift coils, and
b. Low current is applied to engage both the stationary and the movable gripper coils.

This action is initiated to prevent dropping a rod. During an urgent failure in a power cabinet, rods can only be moved in individual bank select with the exception of those rods in the affected cabinet.

After an urgent failure, rods cannot be moved in manual or automatic until the problem is corrected. In addition, the alarm must be reset at the both the affected power cabinet and the main control board before rod motion can be restored.

8.1.8 Shutdown Bank C & D Control

Shutdown banks C and D are selected individually by the bank selector switch and are manually controlled by the IN-HOLD-OUT switch. Since there are no control banks in this power cabinet, the control circuit consists of only a pulser and slave cycler. The pulser and slave cycler units are identical to the units previously described. Multiplexing for this cabinet comes from the bank selector switch. A potentiometer is located in the pulser unit and is used to adjust the rod speed (normally set at 72 steps per minute), for these groups of rods.

8.1.9 Summary

The rod control system provides reactivity control to compensate for rapid short term variations in the reactivity of the core. The rods are divided into two functional categories; shutdown rods and control rods. The shutdown rods are fully withdrawn prior to criticality and serve only to provide a large amount of negative reactivity upon a reactor trip. The control rods provide not only shutdown reactivity upon a trip, but also provide the reactivity control needed for startup and power operation.

Overlapping the control rods helps maintain a relatively constant reactivity addition rate to the core. The overlap occurs near the middle of the core. After the first control bank reaches the mid-plane of the core the second control banks begins to withdraw. During the overlap period, two separate control banks step together. The rods are also moved in a preselected sequence; i.e., control bank A is the first bank of control rods to be moved, followed by control bank B, etc. The bank overlap unit determines this sequence and overlap. This sequence and overlap is maintained as long as the bank selector switch is selected to manual or automatic.

System operation is determined by the bank selector switch. It may be positioned to select an individual shutdown bank or an individual control bank or positioned to operate in either manual or automatic. In the manual mode, the reactor operator controls the reactivity addition to the core by manually adjusting the height of the control banks. The bank selector switch is placed in manual when conducting a reactor start-up. After the secondary load exceeds 15% power the bank selector switch is usually placed into the automatic position. Based on signals supplied to the reactor control unit, rod speed and direction are determined. Due to the output of the reactor control unit the control rods step at a programmed speed and in the proper direction to return T_{avg} to the desired temperature.

The control inputs for this system (in automatic) are provided by two deviation or mismatch signals as described below:

1. The temperature mismatch circuit, which compares T_{avg} (actual temperature) to T_{ref} (desired temperature), and
2. The power mismatch circuit, which compares auctioneered high nuclear power to P_{imp} (turbine power).

The temperature mismatch circuit provides fine control which maintains T_{avg} within 1.5°F of T_{ref}, while the power mismatch circuit starts or stops rod motion in an anticipation of a change in T_{avg}. These circuits acting together provide good system response and control stability.

The power cabinets receive input signals from the logic cabinet. In response to these signals the drive mechanisms sequence the rods into or out of the core. Two motor-generator sets provide power to the rod drive mechanisms via two series reactor trip breakers. Opening either of the two reactor trip breakers de-energizes the rod drive mechanisms, allowing the rods to fall, by gravity, into the core.

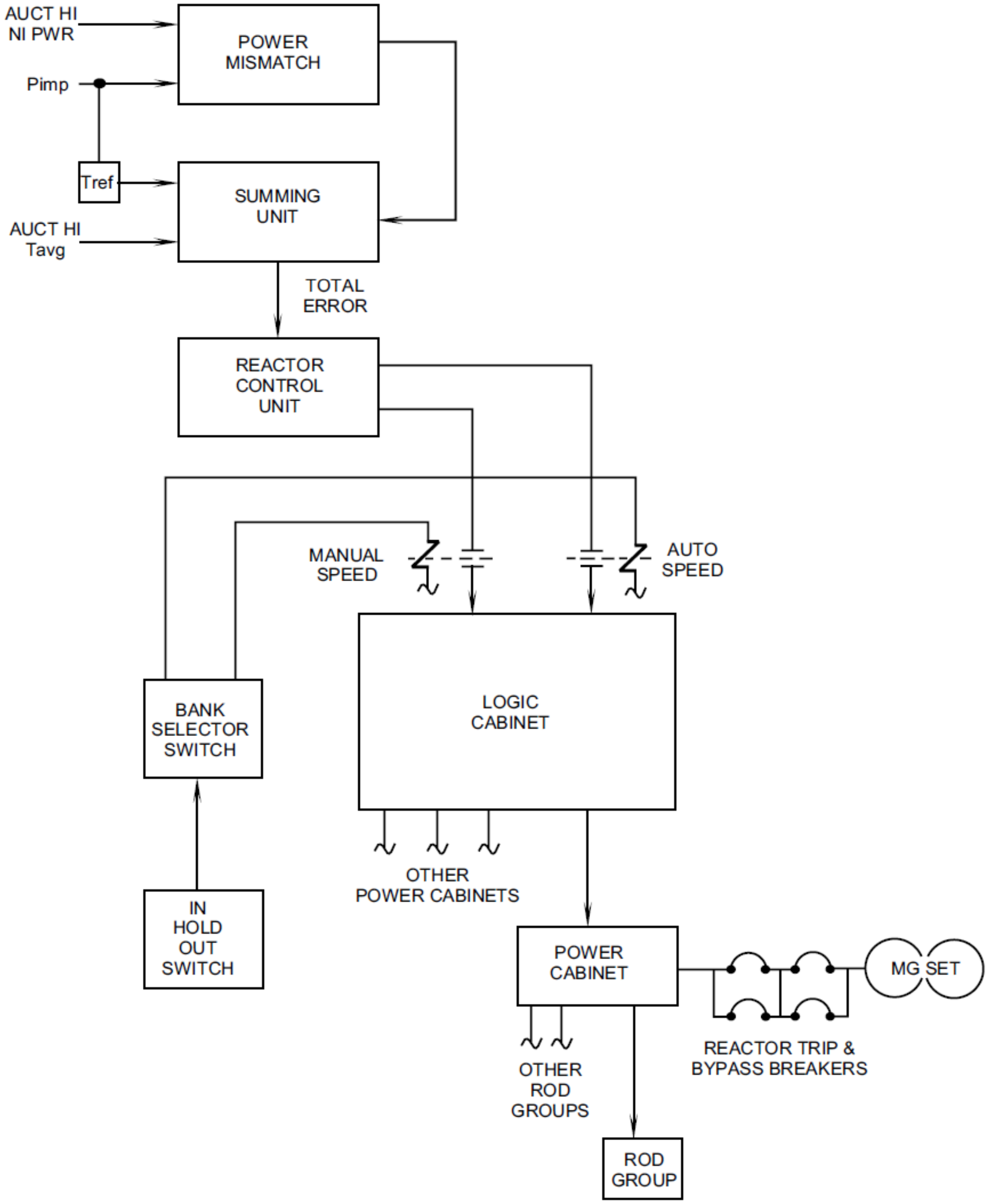


Figure 8.1-1 Rod Control System Block Diagram

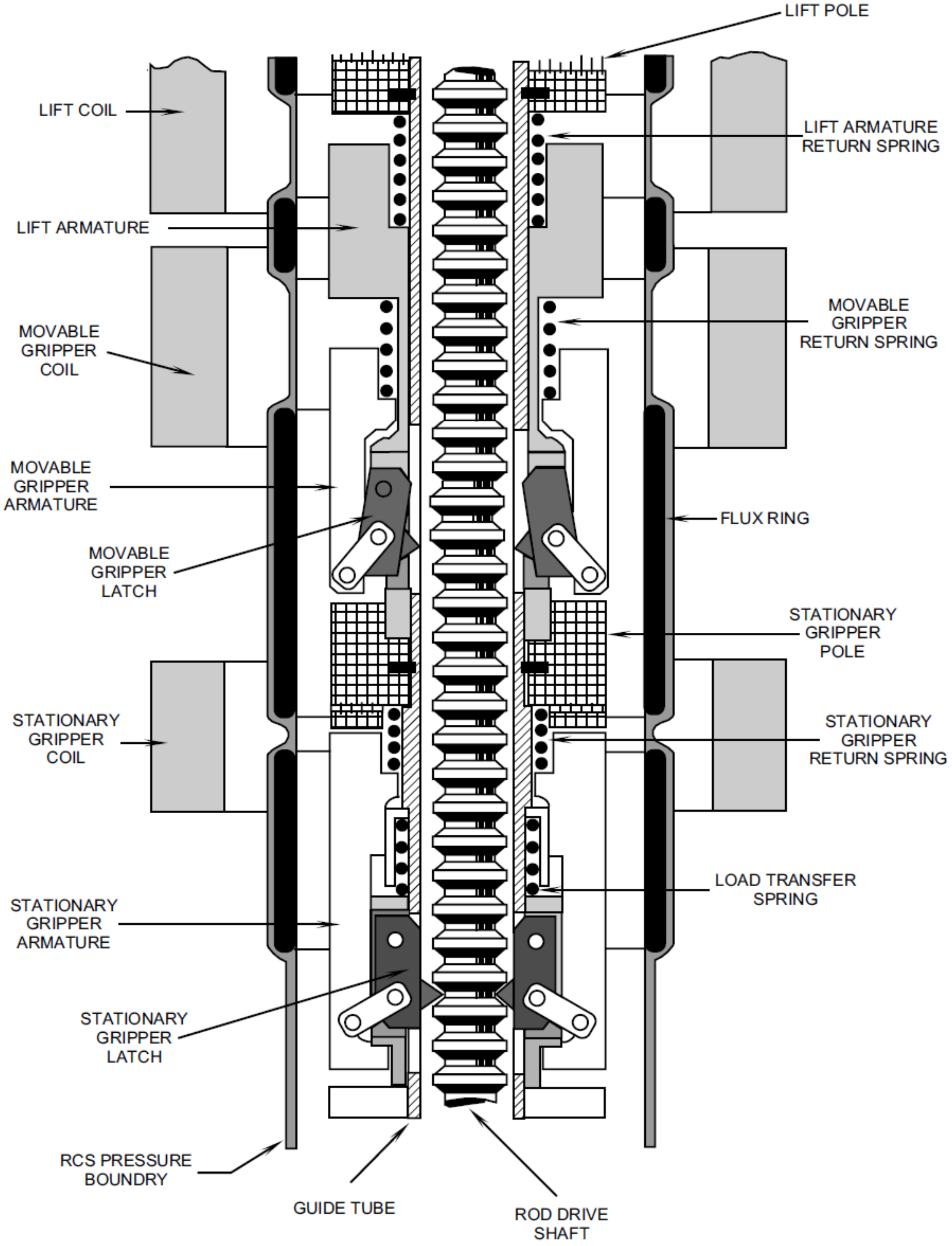


Figure 8.1-2 Magnetic Jack Assembly

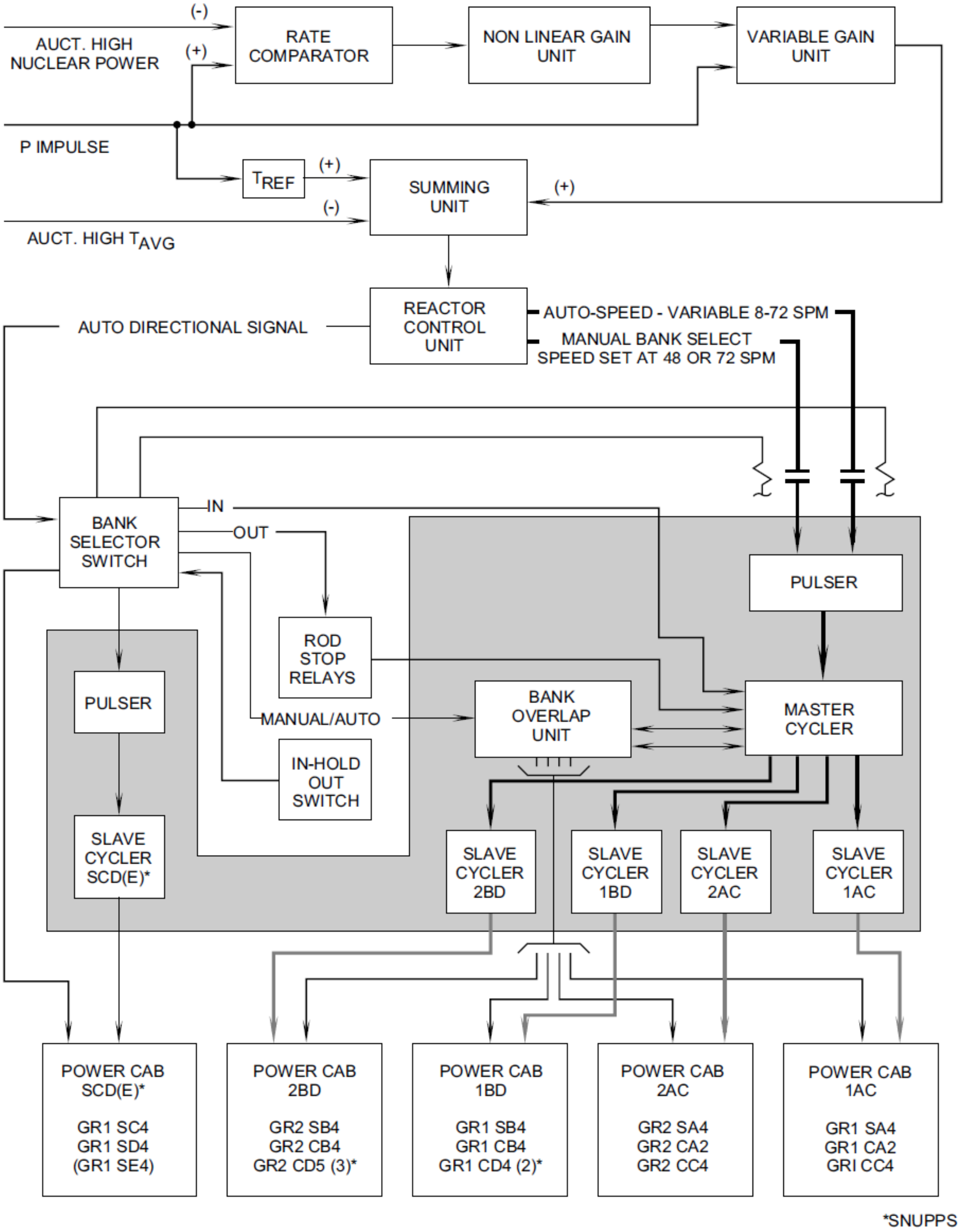


Figure 8.1-3 Full Length Rod Control

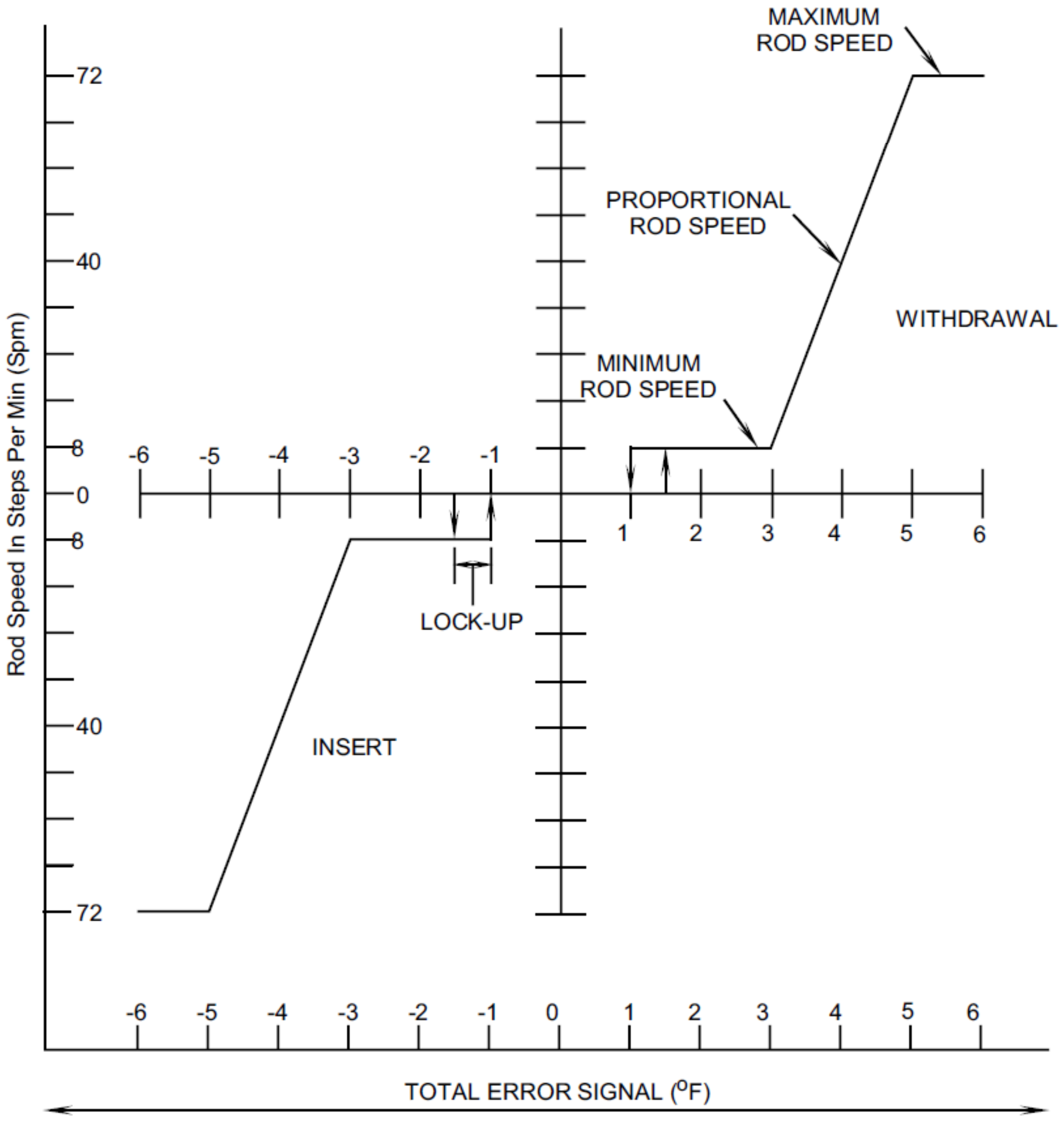
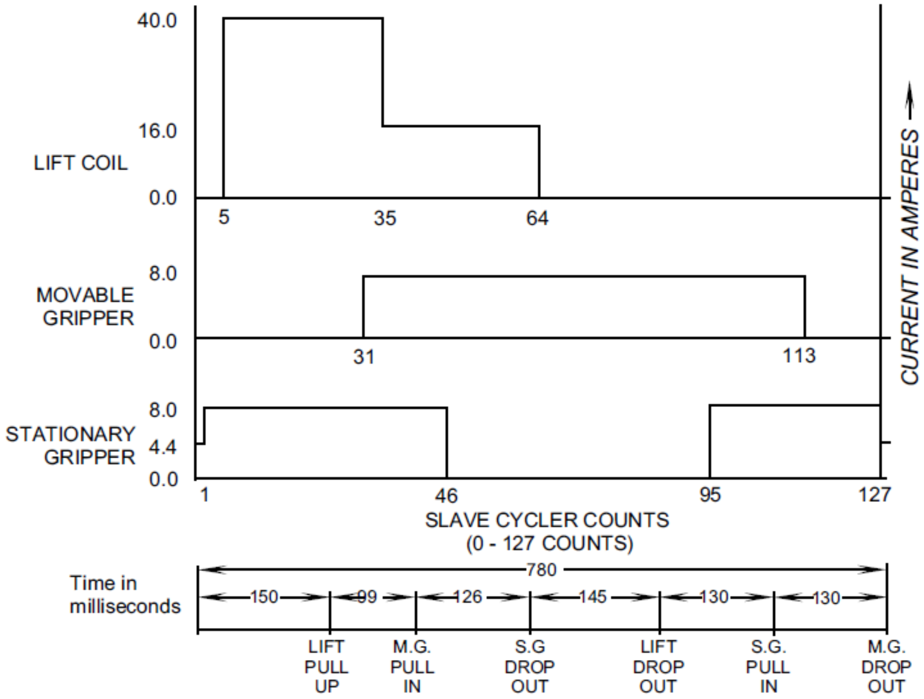
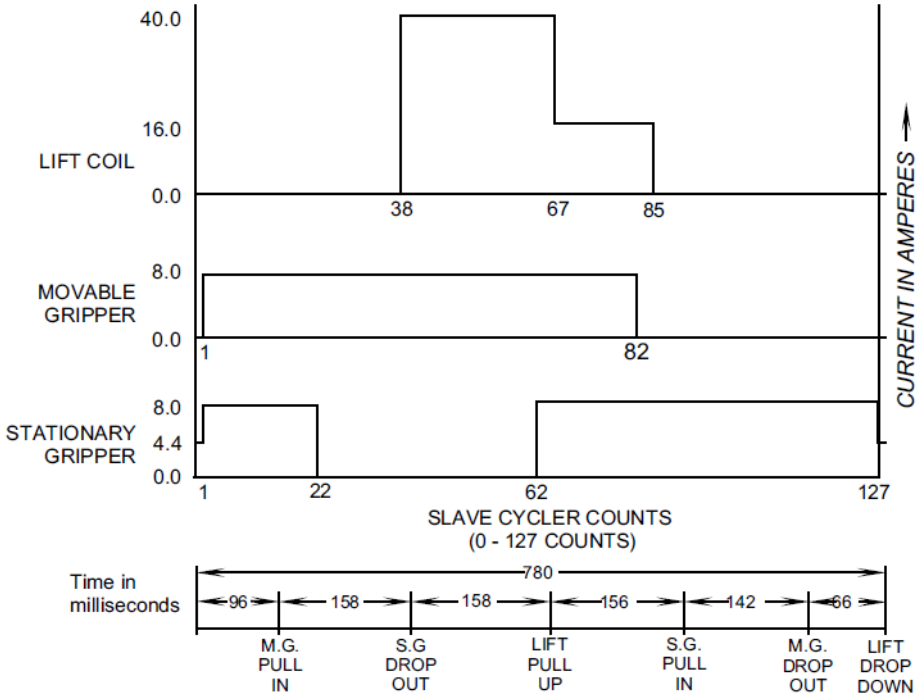


Figure 8.1-4 Rod Speed Program



IN CYCLE



OUT CYCLE

Figure 8.1-5 Slave Cycler Timing Diagram

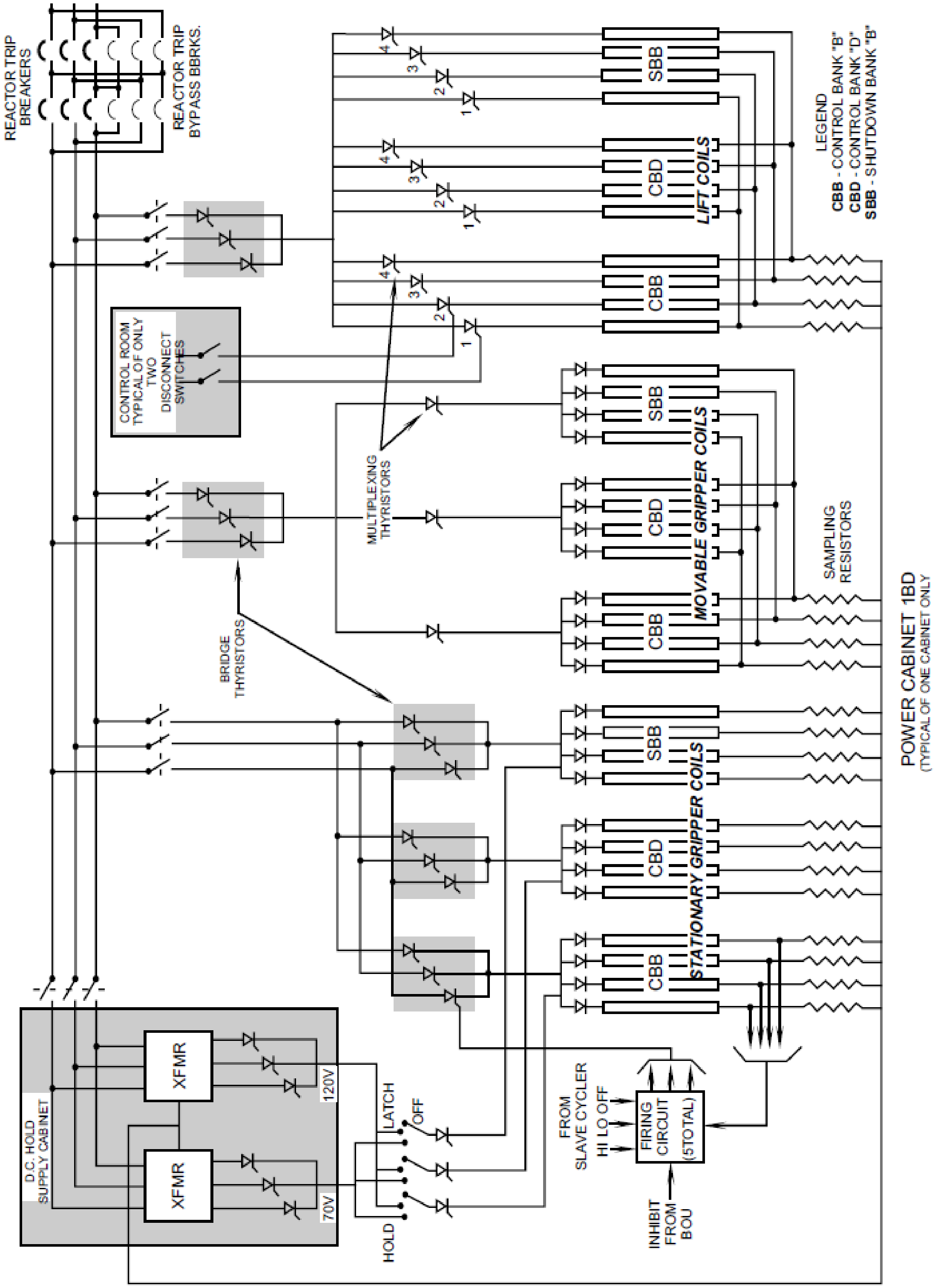


Figure 8.1-6 Solid State Power Cabinet