4.6 Functional Design of Reactivity Control System

The Reactivity Control System consists of (1) control rods and Control Rod Drive (CRD) System, (2) supplementary reactivity control in the form of a gadolinia-urania fuel rods (Section 4.3), and (3) the Standby Liquid Control System (Subsection 9.3.5).

Evaluations of the reactivity control systems against the applicable General Design Criteria (GDC) are contained in the following subsections:

GDC	Subsection
23	3.1.2.3.4
25	3.1.2.3.6
26	3.1.2.3.7
27	3.1.2.3.8
28	3.1.2.3.9
29	3.1.2.3.10

4.6.1 Information for Control Rod Drive System

4.6.1.1 Design Bases

4.6.1.1.1 Safety Design Bases

The CRD System shall meet the following safety design bases:

(1) The design shall provide for rapid control rod insertion (scram) so that no fuel damage results from any moderately frequent event (Chapter 15).

(2) The design shall include positioning devices, each of which individually supports and positions a control rod.

(3) Each positioning device shall be capable of holding the control rod in position and preventing it from inadvertently withdrawing outward during any non-accident, accident, post-accident and seismic condition.

(4) Each positioning device shall be capable of detecting the separation of the control rod from the drive mechanism to prevent a rod drop accident.

(5) Each positioning device shall provide a means to prevent or limit the rate of control rod ejection from the core due to a break in the drive mechanism pressure boundary. This is to prevent fuel damage resulting from rapid insertion of reactivity.

4.6.1.1.2 Power Generation Design Basis

The CRD System design shall meet the following power generation design bases:

(1) The design shall provide for controlling changes in core reactivity by positioning neutron-absorbing control rods within the core.

(2) The design shall provide for movement and positioning of control rods in increments to enable optimized power control and core power shaping.

4.6.1.2 Description

The CRD System is composed of three major elements:

(1) Electro-hydraulic fine motion control rod drive (FMCRD) mechanisms,

(2) Hydraulic control units (HCU), and

(3) Control rod drive hydraulic subsystem (CRDHS).

The FMCRDs provide electric-motor-driven positioning for normal insertion and withdrawal of the control rods and hydraulic-powered rapid insertion (scram) of control rods during abnormal operating conditions. There are a total of 205 FMCRDs mounted in housings welded into the reactor vessel bottom head.

The hydraulic power required for scram is provided by high pressure water stored in 103 individual HCUs. Each HCU contains a nitrogen-water accumulator charged to high pressure and the necessary valves and components to scram two FMCRDs. Additionally, during normal operation, the HCUs provide a flow path for purge water to the associated FMCRDs.

The CRDHS supplies clean, demineralized water which is regulated and distributed to provide charging of the HCU scram accumulators and purge water flow to the FMCRDs during normal operation. The CRDHS is also the source of pressurized water for purging the Reactor Internal Pumps (RIPs), the Reactor Water Cleanup(CUW) System pumps, and the Nuclear Boiler System (NBS) reference leg instrument lines.

The CRD System performs the following functions:

(1) Controls changes in core reactivity by positioning neutron-absorbing control rods within the core in response to control signals from the Rod Control and Information System (RCIS).

(2) Provides movement and positioning of control rods in increments to enable optimized power control and core power shape in response to control signals from the RCIS.

(3) Provides the ability to position large groups of rods simultaneously in response to control signals from the RCIS.

(4) Provides rapid control rod insertion (scram) in response to manual or automatic signals from the Reactor Protection System (RPS) so that no fuel damage results from any plant transient.

(5) In conjunction with the RCIS, provides automatic electric motor-driven insertion of the control rods simultaneously with hydraulic scram initiation. This provides an additional, diverse means of fully inserting a control rod.

(6) Supplies rod status and rod position data for rod pattern control, performance monitoring, operator display and scram time testing by the RCIS.

(7) In conjunction with the RCIS, prevents undesirable rod pattern or rod motions by imposing rod motion blocks in order to protect the fuel.

(8) In conjunction with the RCIS, prevents the rod drop accident by detecting rod separation and imposing rod motion block.

(9) Provides alternate rod insertion (ARI), an alternate means of actuating hydraulic scram, should an anticipated transient without scram (ATWS) occur.

(10) In conjunction with the RCIS, provides for selected control rod run-in (SCRRI) for core thermal-hydraulic stability control.

(11) Prevents rod ejection by means of a passive brake mechanism for the FMCRD motor and a scram line inlet check valve.

(12) Supplies purge water for the RIPs, CUW pumps, and NBS reference leg instrument lines.

The design bases and further discussion of both the RCIS and RPS, and their control interfaces with the CRD System, are presented in Chapter 7.

4.6.1.2.1 Fine Motion Control Rod Drive Mechanism

The FMCRD used for positioning the control rod in the reactor core is a mechanical/hydraulic actuated mechanism (Figures 4.6-1, 4.6-2 and 4.6-3). An electric motor-driven ball-nut and spindle assembly is capable of positioning the drive at a minimum of 18.3 mm increments. Hydraulic pressure is used for scrams. The FMCRD penetrates the bottom head of the reactor pressure vessel. The FMCRD does not interfere with refueling and is operative even when the head is removed from the reactor vessel.

The fine motion capability is achieved with a ball-nut and spindle arrangement driven by an electric motor. The ball-nut is keyed to the guide tube (roller key) to prevent its rotation and traverses axially as the spindle rotates. A hollow piston rests on the ball-nut and upward motion of the ball-nut drives this piston and the control rod into the core. The weight of the control rod keeps the hollow piston and ball-nut in contact during withdrawal.

A single HCU powers the scram action of two FMCRDs. Upon scram valve initiation, high pressure nitrogen from the HCU raises the piston within the accumulator, forcing water through the scram piping. This water is directed to each FMCRD connected to the HCU. Inside each FMCRD, high-pressure water lifts the hollow piston off the ball-nut and drives the control rod into the core. A spring washer buffer assembly stops the hollow piston at the end of its stroke. Departure from the ball-nut releases spring-loaded latches in the hollow piston that engage slots in the guide tube. These latches support the control rod in the inserted position. The control rod cannot be withdrawn until the ball-nut is driven up and engaged with the hollow piston. Stationary fingers on the ball-nut then cam the latches out of the slots and hold them in the retracted position. A scram action is complete when every FMCRD has reached their fully inserted position.

The use of the FMCRD mechanisms in the CRD System provides several features which enhance both the system reliability and plant operations. Some of these features are listed and discussed briefly as follows:

(1) Diverse Means of Rod Insertion

The FMCRDs can be inserted either hydraulically or electrically. In response to a scram signal, the FMCRD is inserted hydraulically via the stored energy in the scram accumulators. A signal is also given simultaneously to insert the FMCRD electrically via its motor drive. This diversity provides a high degree of assurance of rod insertion on demand.

(2) Absence of FMCRD Piston Seals

The FMCRD pistons have no seals that require periodic drive removal for maintenance; the FMCRD internals can remain in place for their full design life. Only a sample of two or three complete FMCRDs are planned to be removed for inspection each refueling outage to document drive condition. This is an order of magnitude reduction compared to previous BWR product lines in which 20 to 30 complete drives are removed for piston seal replacement each refueling outage.

(3) FMCRD Discharge

The water which scrams the control rod discharges into the reactor vessel and does not require a scram discharge volume, thus eliminating a potential source for common mode scram failure.

(4) Plant Maneuverability

The fine motion capability of the FMCRD allows rod pattern optimization in response to fuel burnup or load-following demands. Such a feature complements the ability to load follow with core flow rate adjustments. Combining this with Reactor Recirculation System flow control, further improves plant maneuverability.

(5) Plant Automation

The relatively simple logic of the FMCRD permits plant automation. This feature is utilized for automatic reactor startup and shutdown and for automatic load following.

(6) Reactor Startup Time

The FMCRDs can be moved in large groups. Movements of large groups of control rods (called gangs) are utilized to reduce the time for reactor startup.

(7) Rod Drop Accident Prevention

The control rod separation detection feature of the FMCRD virtually eliminates the possibility of a Rod Drop Accident (RDA) by preventing rod withdrawal when control rod separation is detected. Additionally, movement of rods in large groups during reactor startup greatly reduces the maximum relative rod worth to levels lower than current rod pattern controls. Rod pattern controls are retained in order to verify proper automatic rod movements and to mitigate the consequences of a rod withdrawal error

The drives are readily accessible for inspection and servicing. The bottom location makes maximum utilization of the water in the reactor as a neutron shield and gives the least possible neutron exposure to the drive components. Using water from the condensate treatment system and/or condensate storage tanks as the operating fluid eliminates the need for special hydraulic fluid.

4.6.1.2.2 FMCRD Components

Figure 4.6-1 provides a simplified schematic of the FMCRD operating principles. Figure 4.6-2 illustrates the drive in more detail.

The basic elements of the FMCRD are as follows:

(1) Components of the FMCRD required for electrical rod positioning or fine motion control (including the motor, brake release, associated connector, ball screw shaft, ball-nut and hollow piston).

(2) Components of the FMCRD required for hydraulic scram (including hollow piston and buffer).

(3) Components of the FMCRD required for pressure integrity (including the middle flange, installation bolts and spool piece).

(4) Rod position indication (position synchronizing signal generators).

(5) Reed position switches for scram surveillance.

(6) Control rod separation detection devices (dual Class 1E CRD separation switches).

(7) Bayonet coupling between the drive and control rod.

(8) Brake mechanism to prevent rod ejection in the event of a break in the FMCRD primary pressure boundary, and ball check valve to prevent rod ejection in the event of a failure of the scram insert line.

(9) Integral internal blowout support (to prevent CRD blowout).

(10) FMCRD seal leak detection system.

These features and functions of the FMCRD are described below.

4.6.1.2.2.1 Components for Fine Motion Control

The fine motion capability is achieved with a ball-nut and spindle arrangement driven by an electric stepping motor. The ball-nut is keyed to the guide tube (roller key) to prevent its rotation, and it traverses axially as the spindle rotates. A hollow piston rests on the ball-nut and upward motion of the ball-nut drives the control rod into the core. The weight of the control rod keeps the hollow piston and ball-nut in contact during withdrawal.

The drive motor, located outside the pressure boundary, is connected to the spindle by a drive shaft. The drive shaft penetrates the pressure boundary and is sealed by conventional packings. A splined coupling connects the drive shaft to the spindle. The lower half of the splined coupling is keyed to the drive shaft and the upper half keyed to the spindle. The tapered end of the drive shaft fits into a conical seat on the end of the spindle to keep the two axially aligned. The entire weight of the control rod and drive internals is carried by a drive shaft thrust bearing located outside the pressure boundary.

The axially moving parts are centered and guided by radial rollers. The ball-nut and bottom of the hollow piston include radial rollers bearing against the guide tube. Radially adjustable rollers at both ends of the labyrinth seal keep the hollow piston precisely centered in this region.

The top of the rotating spindle is supported against the inside of the hollow piston by a stationary guide. A hardened bushing provides the circumferential bearing between the rotating spindle and stationary guide. Rollers of the guide run in axial grooves in the hollow piston to prevent the guide from rotating with the spindle.

4.6.1.2.2.2 Components for Scram

The scram action is initiated by the HCU. High-pressure water lifts the hollow piston off the ball-nut and drives the control rod into the core. A spring washer buffer assembly stops the hollow piston at the end of its stroke. Departure from the ball-nut releases spring-loaded latches in the hollow piston that engage slots in the guide tube. These latches support the control rod in the inserted position.

The control rod cannot be withdrawn until the ball-nut is driven up and engaged with the hollow piston. Stationary fingers on the ball-nut cam the latches in the hollow piston out of the slots in the guide tube and hold them in the retracted position when the ball-nut and hollow piston are re-engaged.

Re-engagement of the ball-nut with the hollow piston following scram is automatic. Simultaneous with the initiation of the hydraulic scram, each FMCRD motor is signaled to start in order to cause movement of the ball-nut upward until it is in contact with the hollow piston. This action completes the rod full-in insertion and leaves the drives in a condition ready for restarting the reactor. With the latches in the hollow piston retracted, the permanent magnets in the stepping motor provide the holding torque to maintain the control rods fully inserted in the core. When the motor and brake are de-energized, the passive holding torque from the brake keeps the rods fully inserted.

The automatic run-in of the ball-nut, using the electric motor drive, following the hydraulic scram provides a diverse means of rod insertion as a backup to the accumulator scram.

The components for scram that are classified as safety-related within the drive are the hollow piston, latches, guide tube and brake.

4.6.1.2.2.3 FMCRD Pressure Boundary

The CRD housing (attached to the RPV) and the CRD middle flange and lower housing (spool piece) which enclose the lower part of the drive are a part of the reactor pressure boundary (Figure 4.6-1). The middle housing is attached to the CRD housing by four threaded bolts. The spool piece is, in turn, held to the middle housing and secured to the CRD housing by a separate set of eight main mounting bolts which become a part of the reactor pressure boundary. This arrangement permits removing the lower housing, drive shaft and seal assembly without disturbing the rest of the drive. Removing the lower housing transfers the weight of the driveline from the drive shaft to the seat in the middle housing. Both the spindle and drive shaft are locked to prevent rotation while the two are separated.

The part of the drive inserted into the CRD housing is contained within the outer tube. The outer tube is the drive hydraulic scram pressure boundary, eliminating the need for designing the CRD housing for the scram pressure. The outer tube is welded to the middle flange at the bottom and is attached at the top with the CRD blowout support, which bears against the CRD housing. The blowout support and outer tube are attached by slip-type connection that accounts for any slight variation in length between the drive and the drive housing.

Purge water continually flows through the drive. The water enters through the ball check valve in the middle housing and flows around the hollow piston into the reactor. Conventional packing seals the drive shaft and O-rings seal the lower housing. A labyrinth seal near the top of the drive restricts the flow into the reactor. During a scram, the labyrinth seals the high-pressure scram water from the reactor vessel without adversely affecting the movement of the hollow piston.

4.6.1.2.2.4 Rod Position Indication

Control rod position indication is provided by the FMCRDs to the control system by a position detection system, which consists of position detectors and position signal converters.

Each FMCRD provides two position detectors, one for each control system channel, in the form of synchronizing signal generators directly coupled to the stepping motor shaft through gearing. The output signals from these generators are analog. The analog signals are converted to digital signals by position signal converters. This configuration provides continuous detection of rod position during normal operation.

4.6.1.2.2.5 Scram Position Indication

Scram position indication is provided by a series of magnetic reed switches to allow for measurement of adequate drive performance during scram. The magnetic switches are located at intermediate intervals over 60% of the drive stroke. They are mounted in a probe exterior to the drive housing. A magnet in the hollow piston trips each reed switch in turn as it passes by.

As the bottom of the hollow piston contacts and enters the buffer, a magnet is lifted which operates a reed switch, indicating scram completion. This continuous full-in indicating switch is shown conceptually in Figure 4.6-3. It provides indication whenever the drive is at the full-in latched position or above.

4.6.1.2.2.6 Control Rod Separation Detection

Two redundant and separate Class 1E switches are provided to detect the separation of the hollow piston from the ball-nut. This means two sets of reed switches physically separated from one another with their cabling run through separate conduits. The separation switch is classified Class 1E, because its function detects a detached control rod and causes a rod block, thereby preventing a rod drop accident. Actuation of either switch also initiates an alarm in the control room

The principle of operation of the control rod separation mechanism is illustrated in Figure 4.6-4. During normal operation, the weight of the control rod and hollow piston resting on the ball-nut causes the spindle assembly to compress a spring on which the lower half of the splined coupling between the drive shaft and spindle assembly rests (the lower half of the splined coupling is also known as the “weighing table”). When the hollow piston separates from the ball-nut, or when the control rod separates from the hollow piston, the spring is unloaded and pushes the weighing table and spindle assembly upward. This action causes a magnet in the weighing table to operate the Class 1E reed switches located in a probe outside the lower housing.

4.6.1.2.2.7 Bayonet Couplings

There are two bayonet couplings associated with the FMCRD. The first is at the FMCRD/control rod guide tube/housing interface as illustrated in Figure 4.6-7. This bayonet locks the FMCRD and the base of the control rod guide tube to the CRD housing and functions to retain the control rod guide tube during normal operation and dynamic loading events. The bayonet also holds the FMCRD against ejection in the event of a hypothetical failure of the CRD housing weld. The locating pin on the core plate that engages the flange of the control rod guide tube and the bolt pattern on the FMCRD/housing flange assure proper orientation between the control rod guide tube and FMCRD to assure that the bayonet is properly engaged.

The second bayonet coupling is located between the control rod and FMCRD, as shown on Figure 4.6-5. The coupling spud at the top end of the FMCRD hollow piston engages and locks into a mating socket at the base of the control rod. The coupling requires a 45° rotation for engaging or disengaging. Once locked, the drive and rod form an integral unit that can only be unlocked manually by specific procedures before the components can be separated.

The FMCRD design allows the coupling integrity of this second bayonet to be checked by driving the ball-nut down into an overtravel-out position. After the weighing spring has raised the spindle to the limit of its travel, further rotation of the spindle in the withdraw direction will drive the ball-nut down away from the hollow piston (assuming the coupling is engaged). Piston movement, if any, can then be detected by a reed switch at the overtravel position. If the hollow piston and control rod are properly coupled the overtravel reed switch will not be activated, thus confirming the coupling integrity. If the hollow piston is uncoupled from the control rod the piston will follow the ball-nut to the overtravel position. The overtravel reed switch will be then be actuated by a magnet in the hollow piston, thereby indicating an uncoupled condition.

4.6.1.2.2.8 FMCRD Brake and Ball Check Valve

The FMCRD design incorporates an electromechanical brake (Figure 4.6-6) keyed to the motor shaft. The brake is normally engaged by spring force when the FMCRD is stationary. It is disengaged for normal rod movements by signals from the RCIS. Disengagement is caused by the energized magnetic force overcoming the spring load force. The braking torque of 49 N·m (minimum)between the motor shaft and the CRD spool piece is sufficient to prevent control rod ejection in the event of failure in the pressure-retaining parts of the drive mechanism. The brake is designed so that its failure will not prevent the control rod from rapid insertion (scram).

The electromechanical brake is located between the stepping motor and the synchronizing signal generators. The stationary spring-loaded disk and coil assembly are contained within the brake mounting bolted to the bottom of the stepping motor. The rotating disk is keyed to the stepping motor shaft and synchro shaft.

The brake is classified as passive safety-related because it performs its holding function when it is in its normally de-energized condition.

A ball check valve is located in the middle flange of the drive at the scram inlet port. The check valve is classified as safety-related because it actuates to close the scram inlet port under conditions of reverse flow caused by a break of the scram line. This prevents the loss of pressure to the underside of the hollow piston and the generation of loads on the drive that could cause a rod ejection.

4.6.1.2.2.9 Integral Internal Blowout Support

An internal CRD blowout support replaces the support structure of beams, hanger rods, grids and support bars used in BWR/6 and product lines before that. The internal support concept is illustrated schematically in Figure 4.6-7. This system utilizes the CRD outer tube integral with the internal support to provide the anti-ejection support. The outer tube is locked at top via the internal support to the control rod guide tube (CRGT) base by a bayonet coupling, which is described above. The outer tube is bolted to the CRD housing flange via the middle flange welded to it at the bottom, as described above in a discussion on FMCRD pressure boundary.

The CRD blowout support is designed to prevent ejection of the CRD and the attached control rod considering failures of two types at the weld (Point A in Figure 4.6-7) between the CRD housing and the stub tube penetration of the RPV bottom head: (1) a failure through the housing along the fusion line – just below the weld with the weld and the housing extension inside the vessel remaining intact, or (2) a failure of the weld itself with the entire housing remaining intact but without support at the penetration.

With a housing failure, the weight plus pressure load acting on the drive and housing would tend to eject the drive. In this event, the CRGT base remains supported by the intact housing extension inside the vessel; therefore, the CRD locked with the CRGT base remains supported, and thereby also restricts the coolant leakage through the small area of the annulus between the CRD outer tube and the inside of the CRD housing. In the event of total failure of the weld itself leaving the entire housing intact, the housing would tend to be driven downward by the total weight plus vessel pressure. However, after the interconnected assembly of the housing, CRD and CRGT moves down a short distance, the flange at the top of the CRGT contacts the core plate, stopping further movement of the assembly. Since the CRD is positively locked to the CRGT base, it cannot eject. In this case, the housing which bears on top of the blowout support, is also prevented from leaving the penetration, thereby restricting the coolant leak path to the small area of the annulus between the outside of CRD housing and the inside of the penetration stub tube.

An orderly shutdown would result if any of the two failures were to occur, since the restricted coolant leakage would be less than the supply from the normal make up systems. The safety-related components that provide the anti-ejection function are the (1) internal CRD blowout support, (2) CRD outer tube and middle flange, (3) entire CRD housing, (4) CRGT and (5) core plate. The materials of these components are specified to meet quality requirements consistent with that function.

If a total failure of all the flange bolts attaching the spool piece flange and also the middle flange with the CRD housing flange (Point B on Figure 4.6-7) were to occur, the drive would be prevented from moving downward by the middle flange seat provided for the spindle adapter as part of the anti-rotation gear (see Subsection 4.6.2.3.3.1.3).

4.6.1.2.2.10 FMCRD Seal Leak Detection

An FMCRD seal leak detection subsystem is located in the lower drywell underneath the drive mechanisms. It is provided to permit monitoring and collection of leakage flow past the drive shaft seal assemblies in the lower drive housings (spool pieces). By this means, seal performance can be observed during plant operation to facilitate maintenance planning for drive seal refurbishment during plant outages. The seal leak detection subsystem also functions to contain the drive leakage within a closed system where it can be routed to the drywell equipment drain sump as identified leakage.

The seal leak detection subsystem is composed of small diameter piping, flow sight glass boxes and leakage flow meters arranged into multiple leak detection groups. Each leak detection group consists of leak-off piping from multiple drives routed to a common flow sight glass box. The leak-off piping is connected to the flow sight glasses in such a way as to allow visual confirmation of leakage flow from the individual pipes and identification of the leaking FMCRD. Visual observation of leakage in this manner can only be made during plant outages when the lower drywell is accessible to plant personnel.

During plant operation, the leakage water is collected in the individual flow sight glass boxes and detected by the flow meters installed in the drain piping from each box. The flow meters are integral type meters which can sense very small quantities of leakage from each box. This method is used to monitor drive leakage during plant operation when the lower drywell is inaccessible to personnel. It allows identification of excessive leakage from any particular leak detection group.

The leakage water from all the leak detection groups is collected in a common drain header pipe and routed to the lower drywell equipment drain sump, where it contributes to containment identified leakage.

4.6.1.2.2.11 Materials of Construction

The materials of construction for the FMCRD are discussed in Subsection 4.5.1.

4.6.1.2.3 Hydraulic Control Units

Each hydraulic control unit (HCU) furnishes pressurized water for hydraulic scram, on signal from the RPS, to two drive units. Additionally, each HCU provides the capability to adjust purge flow to the two drives. A test port is provided on the HCU for connection of a portable test station to allow controlled venting of the scram insert line to test the FMCRD ball check valve during plant shutdown. Operation of the electrical system that supplies scram signals to the HCU is described in Chapter 7.

The basic components of each HCU are described in the following paragraphs. The HCU configuration is shown on the CRD System P&ID (Figure 4.6-8).

(1) Scram Pilot Valve Assembly

The scram pilot valve assembly is operated from the RPS. The scram pilot valve assembly, with two solenoids, controls the scram inlet valve. The scram pilot valve assembly is solenoid-operated and is normally energized. Upon loss of electrical signal to the solenoids (such as the loss of external AC power), the inlet port closes and the exhaust port opens. The pilot valve assembly (Figure 4.6-8) is designed so that the trip system signal must be removed from both solenoids before air pressure can be discharged from the scram valve operators. This prevents the inadvertent scram of both drives associated with a given HCU in the event of a failure of one of the pilot valve solenoids.

(2) Scram Inlet Valve

The scram inlet valve opens to supply pressurized water to the bottom of the drive piston. This quick-opening globe valve is operated by an internal spring and system pressure. It is closed by air pressure applied to the top of its diaphragm operator. A position indicator switch on this valve energizes a light in the control room as soon as the valve starts to open.

(3) Scram Accumulator

The scram accumulator stores sufficient energy to fully insert two control rods at any reactor pressure. The accumulator is a hydraulic cylinder with a free-floating piston. The piston separates the water on top from the nitrogen below. A check valve in the accumulator charging line, prevents loss of water pressure in the event that supply pressure is lost.

During normal plant operation, the accumulator piston is seated at the bottom of its cylinder. Loss of nitrogen decreases the nitrogen pressure, which actuates a pressure switch and sounds an alarm in the control room.

To ensure that the accumulator is always able to produce a scram, it is continuously monitored for water leakage. A float-type level switch actuates an alarm in the control room if water leaks past the piston barrier and collects in the accumulator instrumentation block.

(4) Purge Water Orifice and Makeup Valve

Each HCU has a restricting orifice in the purge water line to control the purge flow rate to the two associated FMCRDs. This orifice maintains the flow at a constant value while the drives are stationary. A bypass line containing a solenoid-operated valve is provided around this orifice. The valve is signaled to open and increase the purge water flow whenever either of the two associated FMCRDs is commanded to insert by the Rod Control and Information System (RCIS). During FMCRD insertion cycles, the hollow piston moves upward, leaving an increased volume for water within the drive. Opening of the purge water makeup valve increases the purge flow to offset this volumetric increase and precludes the backflow of reactor water into the drive, thereby preventing long-term drive contamination.

(5) Test Connection for FMCRD Ball Check Valve Testing and Friction Testing

Contained within the HCU is a test port to allow connection of temporary test equipment for the conduct of FMCRD ball check valve testing and drive friction testing. This test port, which has a quick-connect type coupling, is located downstream of the restricting orifice and check valve in the purge water line.

FMCRD ball check valve testing is performed by attaching the check valve test fixture to the HCU test port. The test fixture exercises the check valve by generating a controlled backflow through the check valve housing, causing the valve to backseat. The backflow is contained within a controlled volume inside the test fixture.

FMCRD friction testing also utilizes a special test fixture connected to the HCU test port. The test fixture contains hydraulic controls to pressurize the underside of the hollow piston. When the pressure under the hollow piston is high enough to overcome both the combined hollow piston and control rod weight and the drive line friction, the hollow piston will separate from the ball-nut and drift the control rod into the core. Instrumentation measures the pressure under the hollow piston as it is being inserted. The measured pressure is a direct indication of the drive line friction. Water for the test fixture is supplied from the CRD pump discharge line via piped connections to test ports located in the HCU rooms.

4.6.1.2.4 Control Rod Drive Hydraulic Subsystem

The Control Rod Drive Hydraulic Subsystem (CRDHS) supplies water under high pressure to charge the accumulators, to purge the FMCRDs, the Reactor Internal Pumps (RIPs), the Reactor

Water Cleanup (CUW) System pumps, and the NBS reference leg instrument lines. The CRDHS provides the required functions with the pumps, valves, filters, piping, instrumentation and controls shown on the CRD System P&ID (Figure 4.6-8). Duplicate components are included where necessary to assure continuous system operation if an inservice component should require maintenance. For system and component classification, see Section 3.2.

The CRDHS hydraulic requirements and components are described in the following paragraphs.

4.6.1.2.4.1 Hydraulic Requirements

The CRDHS process conditions are shown in Figure 4.6-9. The hydraulic requirements, identified by the function they perform, are:

(1) An accumulator hydraulic charging pressure of approximately 14.71 MPaG is required. Flow to the accumulators is required only during scram reset or system startup.

(2) Purge water to the drives is required at a flow rate of approximately 1.3 L/min per drive unit.

(3) Approximately 10 L/min purge flow is provided to the RIPs and 20 L/min to the CUW pumps. This flow is provided to both systems at approximately CRD pump discharge pressure. Each system provides its own pressure breakdown equipment to satisfy its individual hydraulic requirements.

(4) Approximately 0.03 L/min purge flow is provided to the NBS reference leg instrument lines. The purge flow maintains the RPV water level instrument reference lines filled to address the effect of non condensible gases in the instrument lines to prevent erroneous reference information after a rapid RPV depressurization event.

4.6.1.2.4.2 CRD Supply Pump

One supply pump pressurizes the CRD System with water from the condensate treatment system and/or condensate storage tanks. One spare pump is provided for standby. A discharge check valve prevents backflow through the nonoperating pump. A portion of the pump discharge flow is diverted through a minimum flow bypass line to the condensate storage tank. This flow is controlled by an orifice and is sufficient to prevent pump damage if the pump discharge is inadvertently closed.

Condensate water is processed by disposable element type pump suction filters with a 25-micrometer absolute rating. The drive water filter, downstream of the pump, is a cleanable element type with 50-micrometer absolute rating. A differential pressure indicator and control room alarm monitor each filter element as they collect foreign materials.

4.6.1.2.4.3 Accumulator Charging Water Header

Accumulator charging pressure is established by precharging the nitrogen accumulator to a precisely controlled pressure at known temperature. During scram, the scram valves open and permit the stored energy in the accumulators to discharge into the drives. The resulting pressure decrease in the charging water header allows the CRD supply pump to “run out” (i.e., flow rate to increase substantially) into the control rod drives via the charging water header. The flow element upstream of the charging water header senses high flow and provides a signal to the manual/auto flow control station which, in turn, closes the system flow control valve. This action effectively blocks the flow to the purge water header so that the runout flow is confined to the charging water header.

Safety-related pressure instrumentation is provided in the charging water header to monitor header performance. The pressure signal from this instrumentation is provided to both the RCIS and RPS. If charging water header pressure degrades, the RCIS will initiate a rod block and alarm at a predetermined low pressure setpoint. If pressure degrades even further, the RPS will initiate a scram at a predetermined low-low pressure setpoint. This assures the capability to scram and safely shut down the reactor before the HCU accumulator pressure can degrade to the level where scram performance is adversely affected following the loss of charging header pressure.

The charging water header contains a check valve and a bladder type accumulator. The accumulator is located downstream of the check valve in the vicinity of the low header pressure instrumentation. It is sized to maintain the header pressure downstream of the check valve above the scram setpoint until the standby CRD pump starts automatically, following a trip or failure of the operating CRD pump. Pressure instrumentation installed on the pump discharge header downstream of the CRD pump drive water filters monitors system pressure and generates the actuation signals for startup of the standby pump if the pressure drops below a predetermined value that indicates a failure of the operating pump.

4.6.1.2.4.4 Purge Water Header

The purge water header is located downstream from the flow control valve. The FCV adjusts automatically to maintain constant flow to the FMCRDs as reactor vessel pressure changes. Because flow is constant, the differential pressure between the reactor vessel and CRDHS is maintained constant independent of reactor vessel pressure. A flow indicator in the control room monitors purge water flow. A differential pressure indicator is provided in the control room to indicate the difference between reactor vessel pressure and purge water pressure.

4.6.1.2.5 Control Rod Drive System Operation

The operating modes of the CRD System are described in the following sections.

4.6.1.2.5.1 Normal Operation

Normal operation is defined as those periods of time when no control rod drives are in motion. Under this condition, the CRD System provides charging pressure to the HCUs and supplies purge water to the control rod drives, RIPs, CUW pumps, and the NBS reference leg instrument lines.

A multi-stage centrifugal pump (C001) supplies the system with water from the condensate and feedwater system and/or CST. A constant portion of the pump discharge is continuously bypassed back to the CST in order to maintain a minimum flow through the pump. This prevents overheating of the pump if the discharge line is blocked. The total pump flow during normal operation is the sum of the bypass flow, the FMCRD purge water flow through the flow control valve (F010), the RIP purge flow, the CUW pump purge flow, and the NBS reference leg instrument purge flow. The standby pump provides a full capacity backup capability to the operating pump. It will start automatically if failure of the operating pump is detected by pressure instrumentation located in the common discharge piping downstream of the drive water filters.

The system water is processed by redundant filters in both the pump suction and discharge lines. One suction filter (D001) and one drive water filter (D002) are normally in operation, while the backup filters are on standby and valved out of service. Differential pressure instrumentation and control room alarms monitor the filter elements as they collect foreign material.

The purge water for each drive is provided by the purge water header. The purge water flow control valve (F010) automatically regulates the purge water flow to the drive mechanisms. The purge water flow rate is indicated in the control room.

In order to maintain the ability to scram, the charging water header maintains the accumulators at a high pressure. The scram valves remain closed except during and after scram, so during normal operation no flow passes through the charging water header. Pressure in the charging water header is monitored continuously. A significant degradation in the charging header pressure causes a low pressure warning alarm and rod withdrawal block by the RCIS. Further degradation, if occurring, causes a reactor scram by the RPS.

Pressure in the pump discharge header downstream of the drive water filters is also monitored continuously. Low pressure in this line is used to indicate that the operating pump has failed or tripped. If it should occur, automatic startup of the standby pump is initiated and the system is quickly repressurized. This prevents the malfunctioning of the operating pump from causing a reactor scram on low charging water header pressure, an event which would otherwise be a direct consequence of the malfunction.

4.6.1.2.5.2 Control Rod Insertion and Withdrawal

The FMCRD design provides the capability to move a control rod up and down both in fine steps of 18.3 mm and continuously over its entire range at a speed of 30 mm/s ±10%. Normal control rod movement is under the control of the RCIS. The RCIS controls the input of actuation power to the FMCRD motor from the electrical power supply (via the stepping motor driver module) in order to complete a rod motion command. The FMCRD motor rotates a screw shaft which, in turn, causes the vertical translation of a ball-nut on the screw shaft. This motion is transferred to the control rod via a hollow piston which rests on the ball-nut. Thus, the piston with the control rod is raised or lowered, depending on the direction of rotation of the FMCRD motor and screw shaft.

During a drive insertion, the purge water flow to the drive is increased by opening the solenoid-operated purge water makeup valve within the associated HCU. The increased flow offsets the volumetric displacement within the drive as the hollow piston is inserted into the core and prevents reactor water from being drawn back into the drive.

4.6.1.2.5.3 Scram

Upon loss of electric power to both scram pilot valve solenoids, the scram valve in the associated HCU opens to apply the hydraulic insert forces to its respective FMCRDs using high pressure water stored within the precharged accumulator (the nitrogen-water accumulator having previously been pressurized with charging water from the CRDHS). Once the hydraulic force is applied, the hollow piston disengages from the ball-nut and inserts the control rod rapidly. The water displaced from the drive is discharged into the reactor vessel. Indication that the scram has been successfully completed (all rods full-in position) is displayed to the operator.

The CRD System provides the following scram performance with vessel pressure below 7.48 MPaG (as measured at the vessel bottom), in terms of the average maximum elapsed time to attain the listed scram position (percent insertion) after loss of signal to the scram solenoid pilot valves (time zero):

Percent Insertion	**Time (s)**
Start of Motion	≤ 0.20
10	≤ 0.42
40	≤ 1.00
60	≤ 1.44
100	≤ 2.80

The start of motion is the time delay between loss of signal to the scram solenoid pilot valve and actuation of the 0% reed switch.

Simultaneous with the hydraulic scram, each FMCRD motor is started in order to cause electric-driven run-in of the ball-nut until it reengages with the hollow piston at the full-in position. This action is known as the scram follow function. It completes the rod full-in insertion and prepares the drives for subsequent withdrawal to restart the reactor.

After reset of the RPS logic, each scram valve recloses and allows the CRDHS to recharge the accumulators.

4.6.1.2.5.4 Alternate Rod Insertion

The alternate rod insertion (ARI) function of the CRD System provides an alternate means for actuating hydraulic scram that is diverse and independent from the RPS. The signals to initiate the ARI are high reactor dome pressure or low reactor vessel water Level 2 or manual operator action. Following receipt of any of these signals, solenoid-operated valves (F043, F044, F047, F048 and F049) on the scram air header open to reduce pressure in the header, allowing the HCU scram valves to open. The FMCRDs then insert the control rods hydraulically in the same manner as the RPS initiated scram. The same signals that initiate ARI will simultaneously actuate the FMCRD motors to insert the control rods electrically.

4.6.1.2.6 Instrumentation

The instrumentation for the CRD System is defined on the system P&ID (Figure 4.6-8). Supervisory instrumentation and alarms such as accumulator trouble and low charging water header pressure are adequate and permit surveillance of the CRD System’s readiness.

The design bases and further discussion are covered in Chapter 7.

4.6.2 Evaluations of the CRD System

4.6.2.1 Failure Mode and Effects Analysis

This subject is covered in Appendix 15B.

4.6.2.2 Protection from Common Mode Failures

The position on this subject is covered in Appendix 15B.

4.6.2.3 Safety Evaluation

The safety evaluation of the control rod drives is given below.

4.6.2.3.1 Evaluation of Scram Time

The rod scram function of the CRD System provides the negative reactivity insertion required by Safety Design Basis 4.6.1.1.1(1). The scram time shown in the description is reflected in plant transient analyses (Chapter 15).

4.6.2.3.2 Scram Reliability

High scram reliability is the result of a number of features of the CRD System. For example:

(1) Each accumulator provides sufficient stored energy to scram two CRDs at any reactor pressure.

(2) Each pair of drive mechanisms has its own scram valve and dual solenoid scram pilot valve; therefore, only a single scram valve needs to open for scram to be initiated. Both pilot valve solenoids must be de-energized to initiate a scram.

(3) The RPS and the HCUs are designed so that the scram signal and mode of operation override all others.

(4) The FMCRD hollow piston and guide tube are designed so they will not restrain or prevent control rod insertion during scram.

(5) Each FMCRD mechanism initiates electric motor-driven insertion of its control rod simultaneous with the initiation of hydraulic scram. This provides a diverse means to assure control rod insertion.

4.6.2.3.3 Precluding Excessive Rate of Reactivity Addition

Excessive rates of reactivity addition are precluded in the design of the FMCRD. Prevention of rod ejection due to FMCRD pressure boundary failure and prevention of control rod drop are described below.

4.6.2.3.3.1 Control Rod Ejection Prevention

A failure of the CRD System pressure boundary will generate differential pressure forces across the drive, which will tend to eject the CRD and its attached control rod. The design of the FMCRD includes features that preclude rod ejection from occurring in these hypothetical circumstances. The following subsections describe how these features function for pressure boundary failures at various locations.

4.6.2.3.3.1.1 Failures at Drive Housing Weld

The bottom head of the reactor vessel has a penetration for each CRD location. A drive housing is raised into position inside each penetration and fastened by welding. The drive is raised into the drive housing and bolted to a flange at the bottom of the housing.

In the event of a failure of the housing just below the housing to penetration weld, or a failure of the weld itself with the housing remaining intact, ejection of the CRD and attached control rod is prevented by the integral internal CRD blowout support. The details of this internal blowout support structure are contained in Subsection 4.6.1.2.2.9.

4.6.2.3.3.1.2 Rupture of Hydraulic Line to Drive Housing Flange

For the case of a scram insert line break, a partial or complete circumferential opening is postulated at or near the point where the line enters the housing flange. This failure, if not mitigated by special design features, could result in rod ejection at speeds exceeding maximum allowable limits of 10 cm/s (assuming rod pattern control) or 15 cm maximum travel distance before full stop. Failure of the scram insert line would cause loss of pressure to the underside of the hollow piston. The force resulting from full reactor pressure acting on the cross-sectional area of the hollow piston, plus the weights of the control rod and hollow piston, is imposed on the ball-nut. The ball-nut, in turn, translates this resultant force into a torque acting on the spindle. When this torque exceeds the motor residual torque and seal friction, reverse rotation of the spindle will occur, permitting rod withdrawal. Analyses show that the forces generated during this postulated event can result in rod ejection speeds which exceed the maximum allowable limits.

The FMCRD design provides two diverse means of protection against the results of a postulated scram insert line failure. The first means of protection is a ball check valve located in the middle flange of the drive at the scram port. Reverse flow during a line break will cause the ball to move to the closed position. This will prevent loss of pressure to the underside of the hollow piston, which, in turn, will prevent the generation of loads on the drive which could cause rod ejection.

The second means of protection is the FMCRD brake described in Subsection 4.6.1.2.2.8. In the event of the failure of the check valve, the passive brake will prevent the ball spindle rotation and rod ejection.

4.6.2.3.3.1.3 Total Failure of All Drive Flange Bolts

The FMCRD design provides an anti-rotation device which engages when the lower housing (spool piece) is removed for maintenance. This device prevents rotation of the spindle and hence control rod motion when the spool piece is removed. The two components of the anti-rotation device are (1) the upper half of the coupling between the lower housing drive shaft and ball spindle, and (2) the back seat of the middle flange (Figure 4.6-1). The coupling of the lower housing drive shaft to the ball spindle is splined to permit removal of the lower housing. The underside of the upper coupling piece has a circumferentially splined surface which engages with a mating surface on the middle flange back seat when the spindle is lowered during spool piece removal. When engaged, spindle rotation is prevented. In addition to preventing rotation, this device also provides sealing of leakage from the drive while the spool piece is removed. In the unlikely event of the total failure of all the drive flange bolts attaching the spool piece flange and the middle flange of the drive to the housing flange, the anti-rotation device will be engaged when the spool piece falls and the middle flange/outer tube/CRD blowout support will be restrained by the control rod guide tube base bayonet coupling, thus preventing rod ejection.

4.6.2.3.3.2 Control Rod Drop Prevention

Control rod drop is prevented by the following features:

(1) Two redundant Class 1E switches in the FMCRD sense separation of the hollow piston, which positions the control rod, from the ball-nut. These switches sense either separation of the piston from the nut or separation of the control rod from the piston, and block further lowering of the nut, thereby preventing drop of either the control rod or the control rod and hollow piston as an assembly (See Subsection 4.6.1.2.2.6 for further details).

(2) Two redundant spring-loaded latches on the hollow piston open to engage in openings in the guide tube within the FMCRD to catch the hollow piston if separation from the ball-nut were to occur. These latches open to support the hollow piston (and control rod) following every scram until the ball-nut is run-in to provide the normal support for the hollow piston (and control rod).

(3) The control-rod to hollow-piston coupling is a bayonet type coupling. Coupling is verified by pull test for the control rod upon initial coupling at refueling and again each time an attempt is made to drive beyond the “full out” position during reactor operation. The control rod can only be uncoupled from the FMCRD by relative rotation, which is not possible during operation. The control rod cannot rotate, since it is always constrained between four fuel assemblies, and the hollow piston/CRD bayonet coupling cannot rotate, since the hollow piston has rollers which operate in a track within the FMCRD. Only structural failure would permit or result in control rod to FMCRD uncoupling, which, in turn, could only result in rod drop if the redundant switches failed to sense separation. In such failure scenarios, the rate of rod drop may exceed acceptable reactivity addition rates; however, the number of failures involved in the scenario are so numerous that the probability of occurrence for the event is low enough to be categorized as incredible.

4.6.2.3.4 CRD Maintenance

The procedure for removal of the FMCRD for maintenance or replacement is similar to previous BWR product lines. The control rod is first withdrawn until it backseats onto the control rod guide tube. This metal-to-metal contact provides the seal that prevents draining of reactor water when the FMCRD is subsequently lowered out of the CRD housing. The control rod normally remains in this backseated condition at all times with the FMCRD out; however, in the unlikely event it also has to be removed, a temporary blind flange is first installed on the end of the CRD housing to prevent draining of reactor water.

If the operator inadvertently removes the control rod after FMCRD is out without first installing the temporary blind flange, or conversely, inadvertently removes the FMCRD after first removing the control rod, an unisolable opening in the bottom of the reactor will be created, resulting in drainage of reactor water. The possibility of inadvertent reactor draindown by this means is considered remote for the following reasons:

(1) Procedural controls similar to those of current BWRs will provide the primary means for prevention. Current BWR operating experience demonstrates this to be an acceptable approach. There has been no instance of an inadvertent draindown of reactor water due to simultaneous CRD and control rod removal.

(2) During drive removal operations, personnel will be required to monitor under the RPV for water leakage out of the CRD housing. Abnormal or excessive leakage occurring after only a partial lowering of the FMCRD within its housing will indicate the absence of the full metal-to-metal seal between the control rod and control rod guide tube required for full drive removal. In this event, the FMCRD can then be raised back into its installed position to stop the leakage and allow corrective action.

See Subsection 4.6.6.1 for COL applicant license information.

The FMCRD design also allows for separate removal of the stepping motor, position indicator probe (PIP) and spool piece for maintenance during plant outrages without disturbing the upper assembly of the drive. While these FMCRD components are removed for servicing, the associated control rod is maintained in the fully inserted position by one of two mechanical locking devices that prevent rotation of the ball spindle and drive shaft.

The first anti-rotation device (Detail A in Figure 4.6-10) is engaged when the motor assembly consisting of the stepping motor, brake and synchro is removed. It is a horizontally acting spring-actuated sliding pin located on the bottom of the spool piece. When the motor assembly is lowered away from the spool piece, the sliding pin is released from its normally retracted position and engaged by spring force with gear teeth on the spool piece drive shaft, thereby locking the shaft in place. This design is similar to that of an anti-rotation device that has been successful for many years in the same application by a European FMCRD design.

With the motor assembly removed, the sliding pin can be visually checked from below the drive to verify that it is properly engaged. When the vessel head is removed, another means of verification of proper locking is for the operator to view the top of the control rod from over the reactor vessel. If the top of the control rod is visible at its normal full-in position, it provides both direct indication that the control rod remains fully inserted and additional assurance that the ball spindle is restrained from reverse rotation. The drive shaft remains locked in this manner until the motor assembly is reattached to the spool piece. During motor installation, a pin-and-roller device on the top of the motor engages with a lever attached to the sliding pin as the motor is raised in to contact with the spool piece. The pin-and-roller forces the lever and sliding pin away from the drive shaft and into the normally retracted, unlocked position.

The second anti-rotation device (Detail B in Figure 4.6-10) is engaged when the spool piece is removed from the FMCRD. As described in Subsection 4.6.2.3.3.1.3, this device is a spline arrangement between the ball spindle lower portion and the middle flange backseat. When removing and lowering the spool piece, the weight of the ball spindle, hollow piston and control rod provides a vertical force in the downward direction that brings the two splines together. This locks the ball spindle into the backseat and prevents reverse rotation. As with the first anti-rotation device, proper engagement of this device can be visually checked from below the drive. If the splines did not completely lock together, there will be indication of this because the ball spindle will not seat against the backseat and there will be a small gap for leakage of water. If this should occur, removal of the spool piece can be discontinued and corrective action taken. If there is no leakage, it confirms that the splines are properly locked together. Also as in the case of the first anti-rotation device, visual observation of the top of the control rod from over the reactor vessel provides another means for verifying proper locking of the ball spindle. The ball spindle remains locked in this position until the spool piece is reattached to the FMCRD. During spool piece installation, the end of the drive shaft fits into a seat on the end of the ball spindle. As the spool piece is raised off the middle flange backseat, the anti-rotation splines disengage and the weight of the ball spindle, hollow piston and control rod is transferred to the spool piece assembly.

4.6.3 Testing and Verification of the CRDs

4.6.3.1 Development Tests

The initial development of the FMCRD involved testing of a prototype based on a European drive design. Testing of this prototype included more than 600 scrams and 67,000 motor-driven cycles. A subsequent prototype was developed for installation in an operating BWR for the purpose of demonstrating FMCRD performance under actual BWR operating conditions. This in-plant FMCRD prototype was tested extensively prior to installation at the operating plant, including over 500 scrams and 63,000 step cycles. The inplant FMCRD was installed at LaSalle Unit 2, where it was tested for one complete operating cycle.

A reference FMCRD prototype design, based on refinements of initial development prototypes described above, has been developed and tested. To date, testing of this reference prototype has included over 1,000 scrams and 150,000 step cycles. These tests have demonstrated the following:

(1) The drive easily withstands the forces, pressures and temperatures imposed.

(2) No abnormal distortion or deformation was found. Wear, abrasion and corrosion were negligible.

(3) The basic scram speed of the drive has a satisfactory margin above minimum plant requirements at any reactor vessel pressure.

4.6.3.2 Factory Quality Control Tests

The quality control specifications and procedures will follow the general pattern established for such specifications and procedures in BWRs presently in operation.

Quality control of welding, heat treatment, dimensional tolerances, material verification and similar factors will be maintained throughout the manufacturing process to assure reliable performance of the mechanical reactivity control components. Some of the quality control tests performed on the CRD mechanisms and HCUs are listed below:

(1) CRD Mechanism Tests

  (a) Pressure welds on the drives are hydrostatically tested in accordance with ASME codes.
  (b) Electrical components are checked for electrical continuity and resistance to ground.
  (c) Drive parts that cannot be visually inspected for dirt are flushed with filtered water at high velocity. No significant foreign material is permitted in effluent water.
  (d) Drive shaft seals are tested for leakage to demonstrate correct seal operation.
  (e) Each drive is tested for shim (drive-in and -out) motion and control rod position indication.
  (f) Each drive is subjected to cold scram tests at various reactor pressures to verify correct scram performance.

(2) HCU Tests

  (a) Hydraulic systems are hydrostatically tested in accordance with the applicable code.
  (b) Electrical components and systems are tested for electrical continuity and resistance to ground.
  (c) Correct operation of the accumulator pressure and level switches is verified.
  (d) The HCU’s ability to perform its part of a scram is demonstrated.

4.6.3.3 Functional Tests

These tests evaluate drive performance under conditions of crud/contamination, seismic misalignment, channel bulge, failed buffer, rod drop (to test hollow piston latch functionality), and rod ejection (to test FMCRD brake functionality).

4.6.3.4 Operational Tests

After installation, all rods and drive mechanisms can be tested through their full stroke for operability.

The switches which detect separation will provide indication and automatic rod withdrawal block should a control rod separate from the drive mechanism during rod withdrawal. Additionally, the operator can observe the incore monitor indications to verify that the control rod is following the drive mechanism. All control rods that are partially withdrawn from the core can be tested for rod-following by inserting or withdrawing the rod one or two steps and returning it to its original position, while the operator observes the incore monitor indications.

To make a positive test of control rod to CRD coupling integrity, the operator can withdraw a control rod to the end of its travel and then attempt to withdraw the drive to the overtravel position. Failure of the hollow piston to overtravel-out demonstrates the integrity of the rod-to-drive coupling.

CRDHS pressures can be observed from instrumentation in the control room. Scram accumulator pressures can be observed on the nitrogen pressure gauges.

4.6.3.5 Acceptance Tests

Criteria for acceptance of the CRD system and the associated control and protection systems will be incorporated in specifications and test procedures covering the preoperational test phase and the startup test phase.

The preoperational tests (Chapter 14) include normal and scram motion and are primarily intended to verify that piping, valves, electrical components and instrumentation are properly installed. The test specifications include criteria and acceptable ranges for drive speed, scram valve response times, and control pressures. These are tests intended more to document system condition rather than tests of performance.

As fuel is placed in the reactor, the startup test procedure (Chapter 14) is followed. The tests in this procedure are intended to demonstrate that the initial operational characteristics meet the limits of the specifications over the range of primary coolant temperatures and pressures from ambient to operating. The detailed specifications and procedures are similar to those in BWRs presently in operation.

In the preoperational and startup test phases, the drive insertion times measured during scram tests are compared with scram performance criteria derived from data taken during the development testing of the reference FMCRD prototype design (see Subsection 4.6.3.1). Similar to current BWRs, the performance criteria specifies the acceptable range of drive insertion times at reactor vessel pressures extending from ambient to full operating pressure. In the preoperational test phase, the scram tests are typically performed with the reactor vessel at ambient pressure. If a drive is operating properly, it will insert within the specified time limits corresponding to this low pressure condition. Given there is no significant change to any other condition which can affect scram performance (e.g., accumulator pressure, scram lines losses, driveline friction), the drive can then be expected to also operate within the limits specified for high reactor pressure. Projection of the drive performance to the high pressure condition in this manner provides confidence for proceeding with the high pressure scram testing of the startup test phase.

4.6.3.6 Surveillance Tests

The surveillance requirements for the CRD System are described below. While these requirements have not yet been formalized, the intent is to follow the general pattern established for surveillance testing in BWRs presently in operation.

(1) Each fully withdrawn control rod is exercised at least once each week. Each partially withdrawn control rod is exercised at least once each month.

(2) The coupling integrity is verified for each withdrawn control rod when the rod is fully withdrawn the first time. The procedure, as described in Section 4.6.1.2.2.7, is to withdraw the drive into the overtravel condition and observe the operation of the overtravel reed switch. If the drive is properly coupled to the control rod the overtravel reed switch will not actuate. If the reed switch actuates, it indicates the drive is uncoupled from the control rod.

(3) During operation, accumulator pressure and level at the normal operating value are verified.

Experience with CRD systems of the same type indicates that weekly verification of accumulator pressure and level is sufficient to assure operability of the accumulator portion of the CRD System.

(4) At the time of each major refueling outage, each operable control rod is subjected to scram time tests from the fully withdrawn position.

Experience indicates that the scram times of the control rods do not significantly change over the time interval between refueling outages. A test of the scram times at each refueling outage is sufficient to identify any significant lengthening of the scram times.

4.6.4 Information for Combined Performance of Reactivity Control Systems

4.6.4.1 Vulnerability to Common Mode Failures

The Reactivity Control System is located such that it is protected from common mode failures due to missiles, failures of moderate and high energy piping, and fire. Sections 3.5, 3.6 and 3.7, and Subsection 9.5.1 discuss protection of essential systems against missiles, pipe breaks, seismic and fire, respectively.

4.6.4.2 Accidents Taking Credit for Multiple Reactivity Systems

There are no postulated accidents documented in Chapter 15 that take credit for two or more reactivity control systems preventing or mitigating each accident.

4.6.5 Evaluation of Combined Performance

As indicated in Subsection 4.6.4.2, credit is not taken for multiple reactivity control systems for any postulated accidents documented in Chapter 15. (See Subsection 4.6.2.3.4)

4.6.6 COL License Information

4.6.6.1 CRD and FMCRD Maintenance Procedures During Maintenance

The COL applicant shall develop procedures to ensure that maintenance procedures have provisions to prohibit coincident removal of the CRD blade and drive of the same assembly. In addition, the COL applicant shall develop contingency procedures to provide core and spent fuel cooling capability and mitigative actions during CRD replacement with fuel in the vessel.

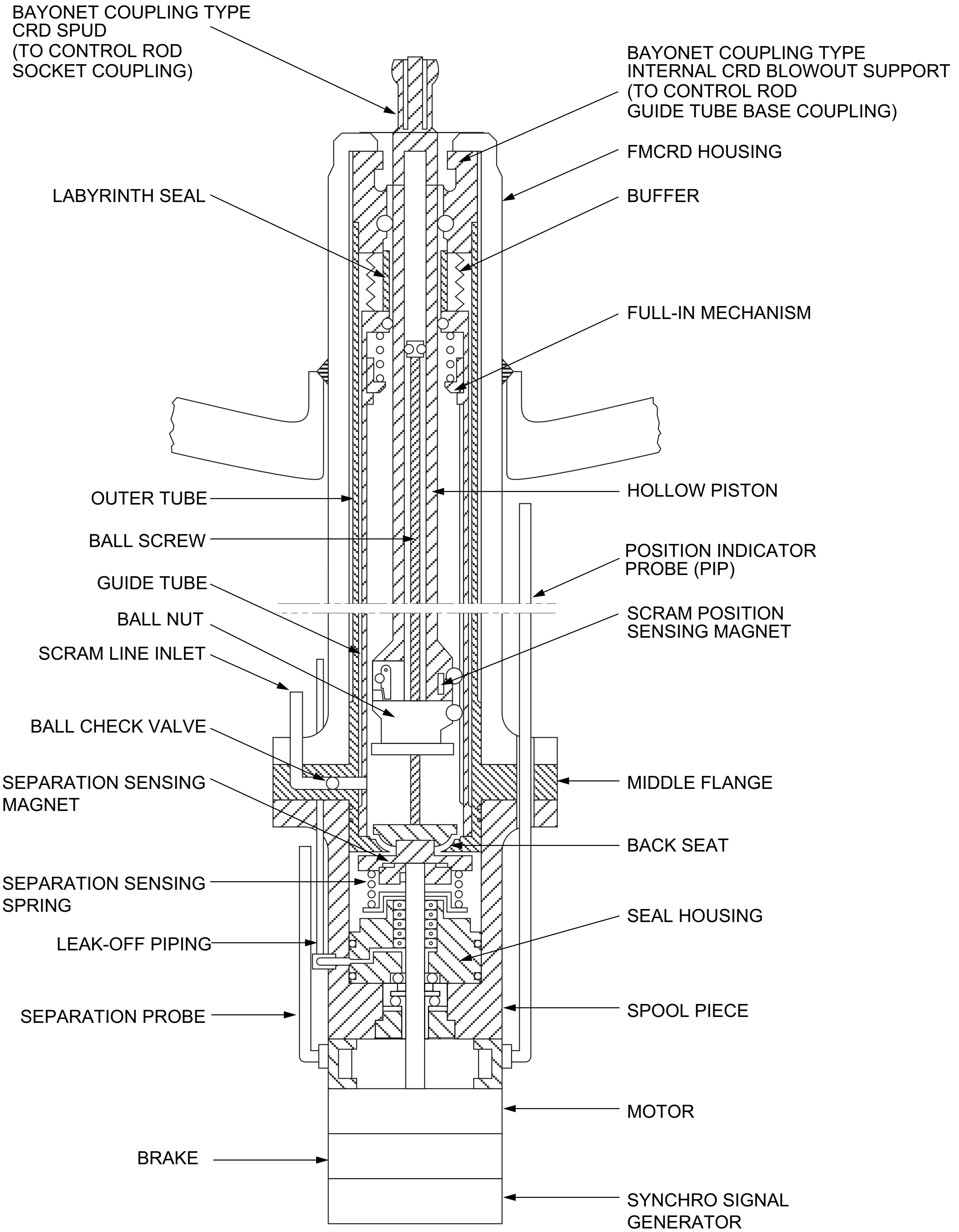


Figure 4.6-1 Fine Motion Control Rod Drive Schematic

NO.	MAIN PART NAME
1	SEAL HOUSING
2	DRIVE SHAFT
3	BEARING
4	GLAND PACKING
5	SPRING (FOR GLAND PACKING)
6	SPOOL PIECE
7	BALL SCREW SHAFT
8	BALL NUT AND BALLS
9	GUIDE ROLLER AND PIN (FOR BALL NUT)
10	SPINDLE HEAD BOLT
11	SPINDLE HEAD BUSHING
12	SEPARATION SPRING
13	MAGNET
14	BUFFER SPRING
15	BUFFER SLEEVE
16	GUIDE ROLLER, PIN
17	STOP PISTON
18	PISTON TUBE
19	PISTON HEAD
20	LATCH
21	LATCH SPRING
22	BAYONET COUPLING
23	COMPRESSION ROD
24	GUIDE TUBE
25	OUTER TUBE
26	MIDDLE FLANGE
27	CHECK VALVE BALL
28	RUBBER SEAL
29	O RING SEAL (BETWEEN CRD HOUSING AND CRD)
30	CRD INSTALLATION BOLT
31	UPPER GUIDE (CRD BLOWOUT SUPPORT
32	ANTI-ROTATION SPLINES
33	ANTI-ROTATION PIN

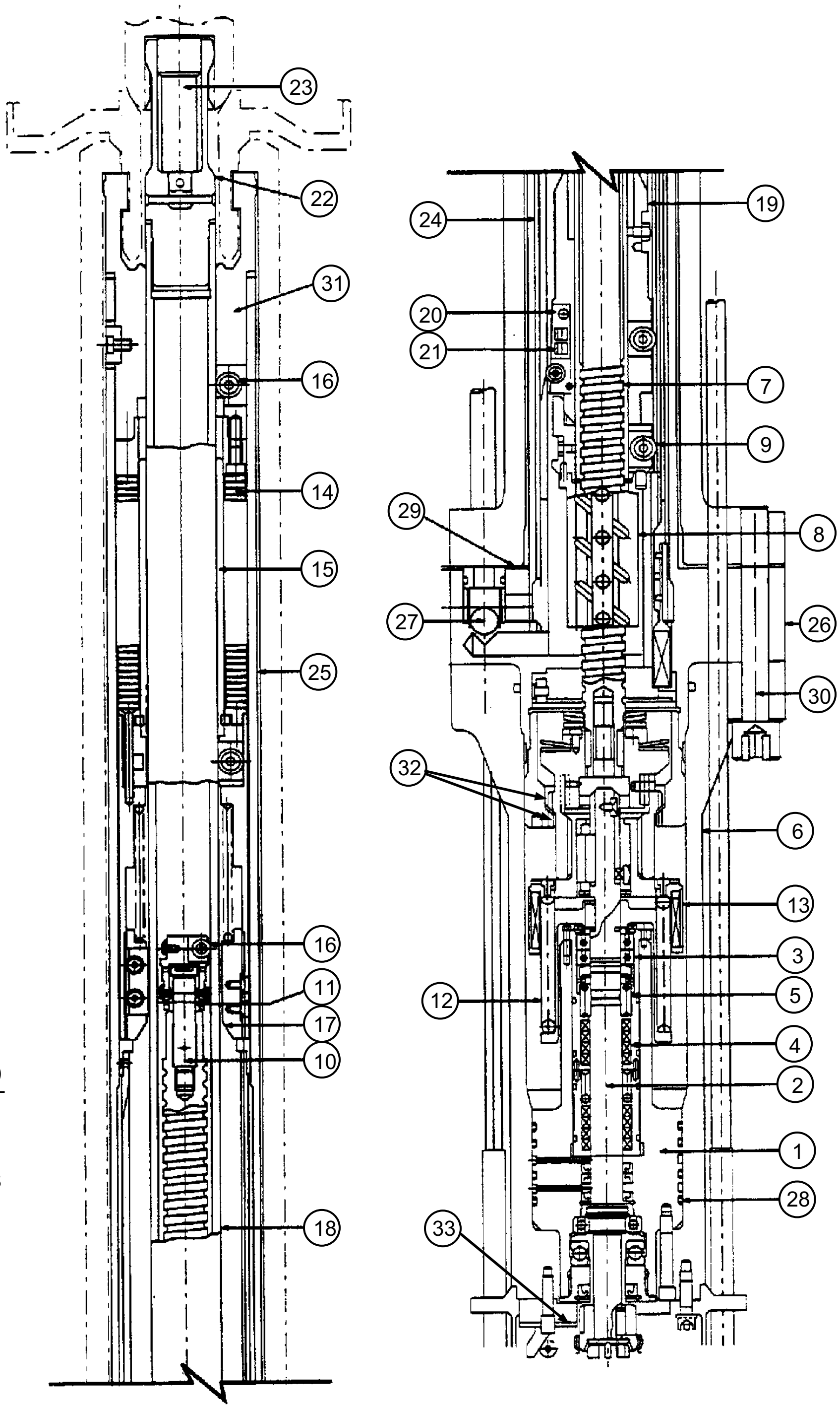
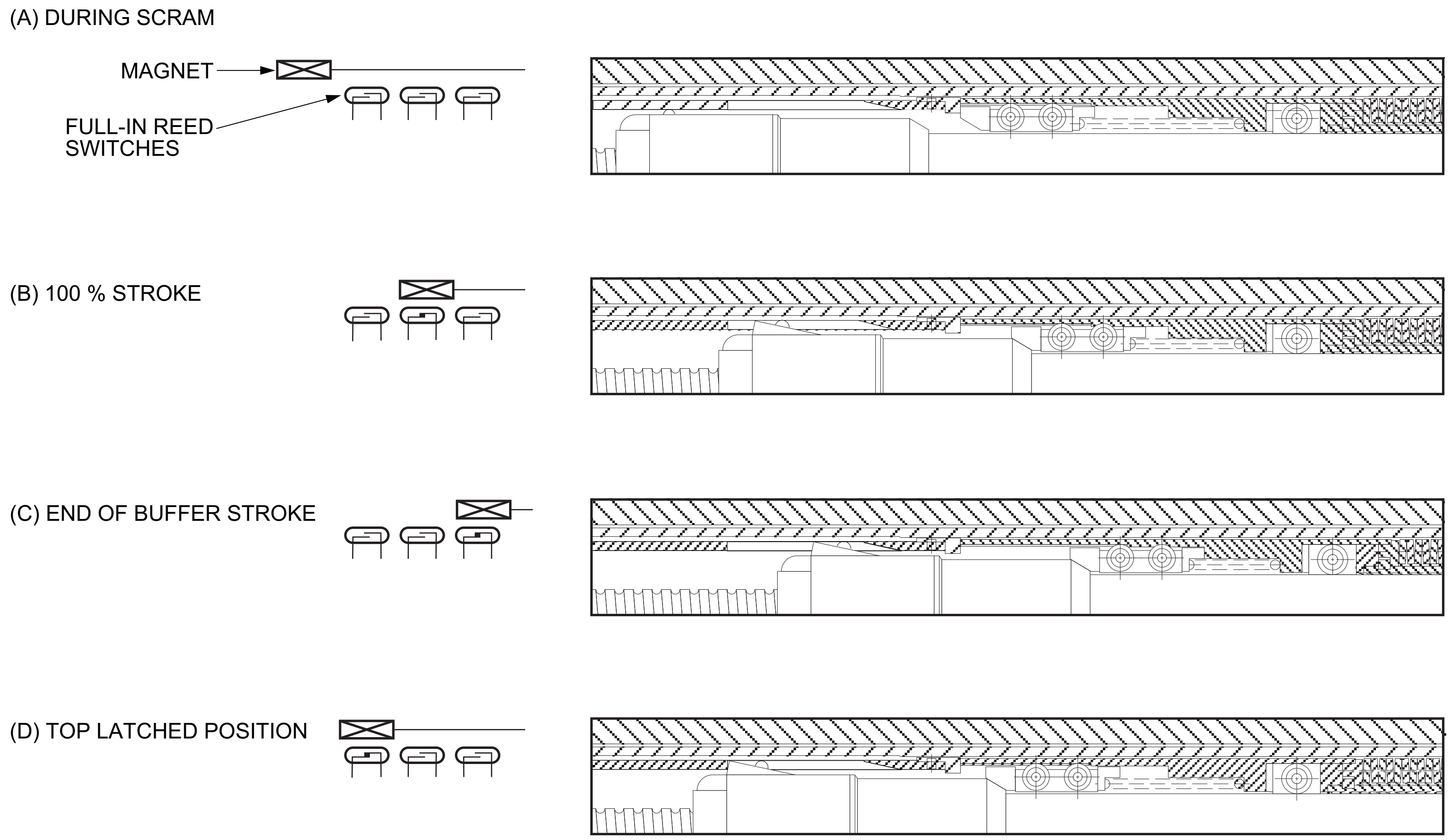


Figure 4.6-2 Fine Motion Control Rod Drive Unit (Cutaway)



(A) DURING SCRAM

(B) 100 % STROKE

(C) END OF BUFFER STROKE

(D) TOP LATCHED POSITION

Figure 4.6-3 Continuous Full-in Indicating Device

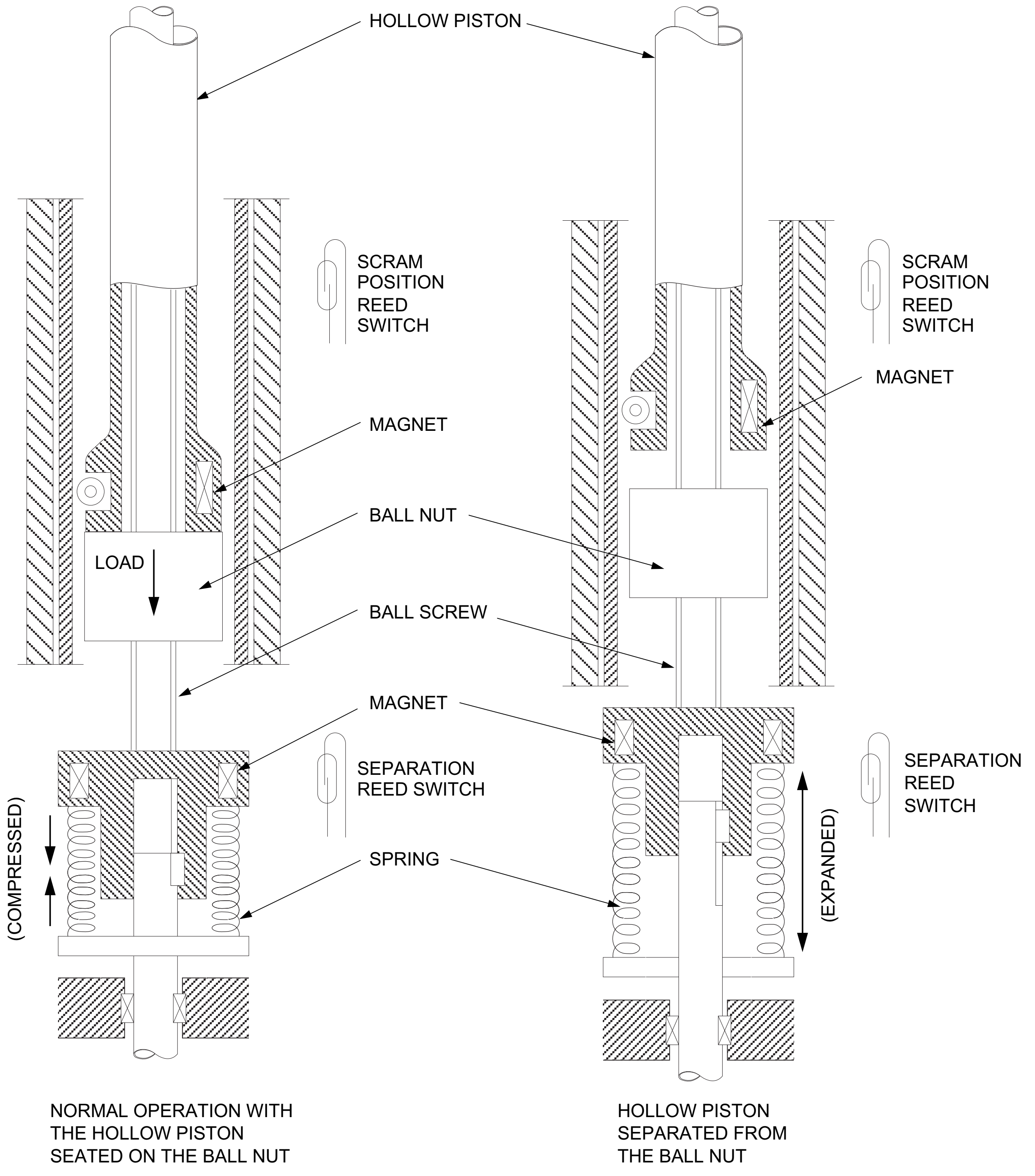


Figure 4.6-4 Control Rod Separation Detection

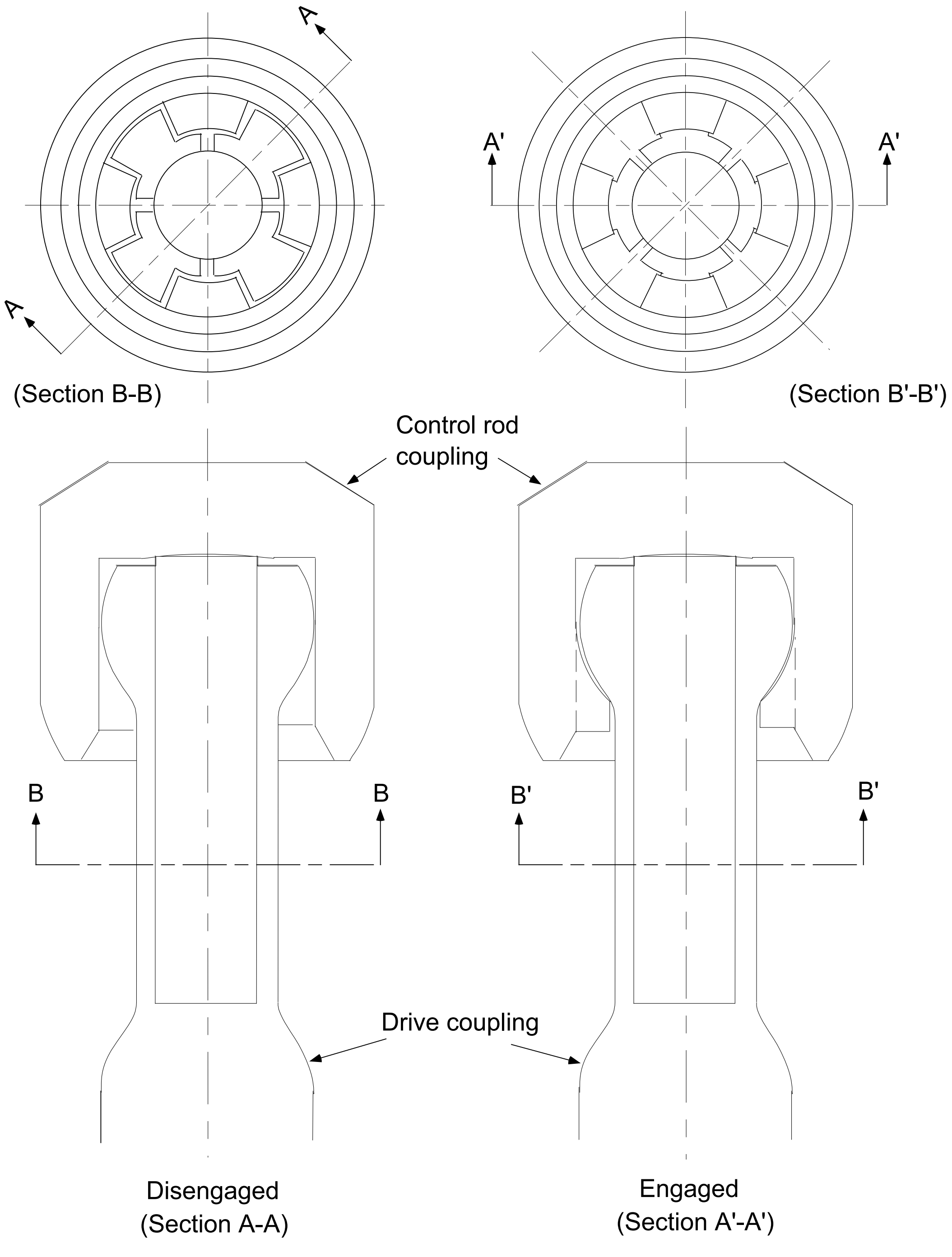


Figure 4.6-5 Control Rod to Control Rod Drive Coupling

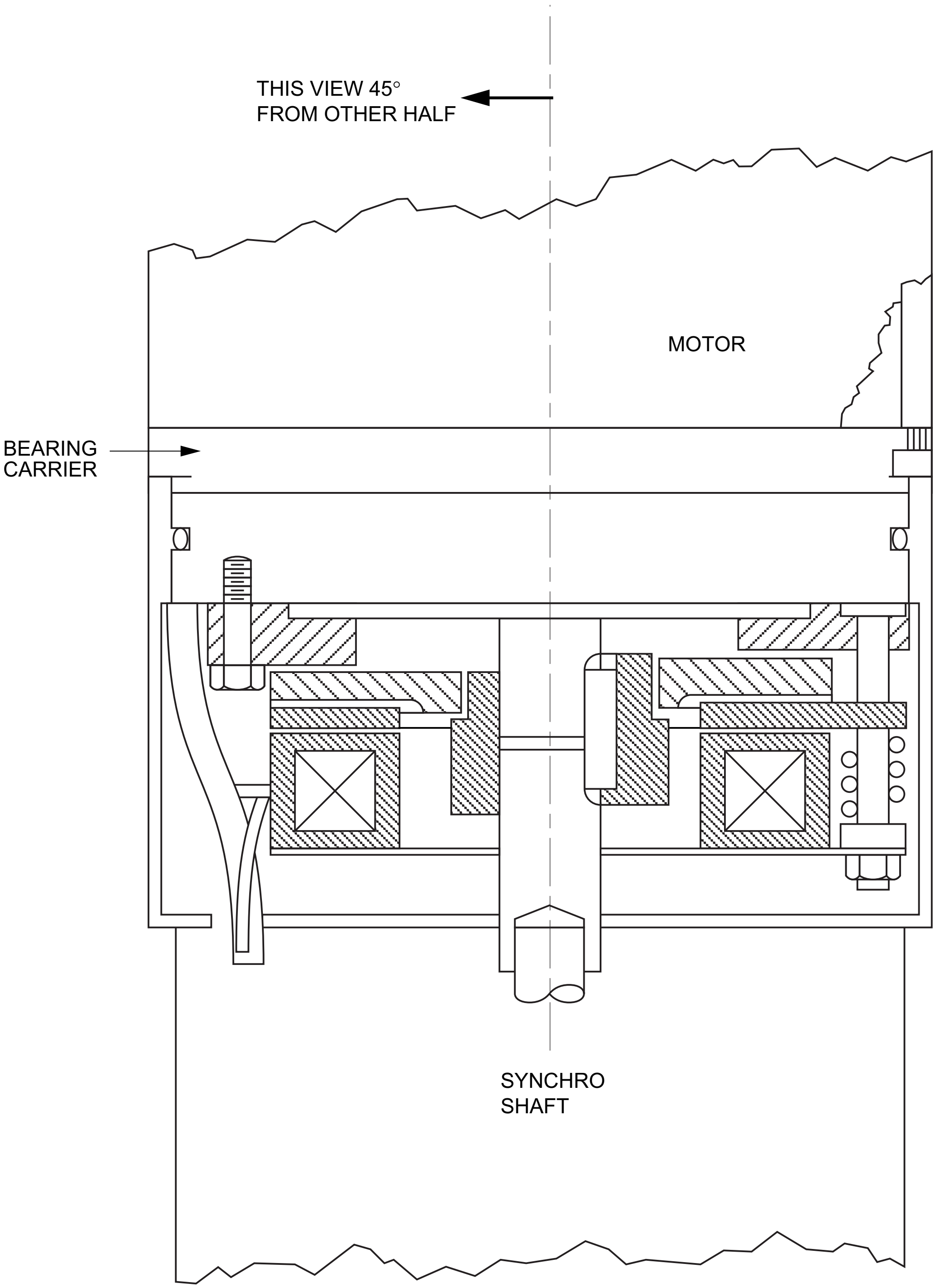


Figure 4.6-6 FMCRD Electro-mechanical Brake

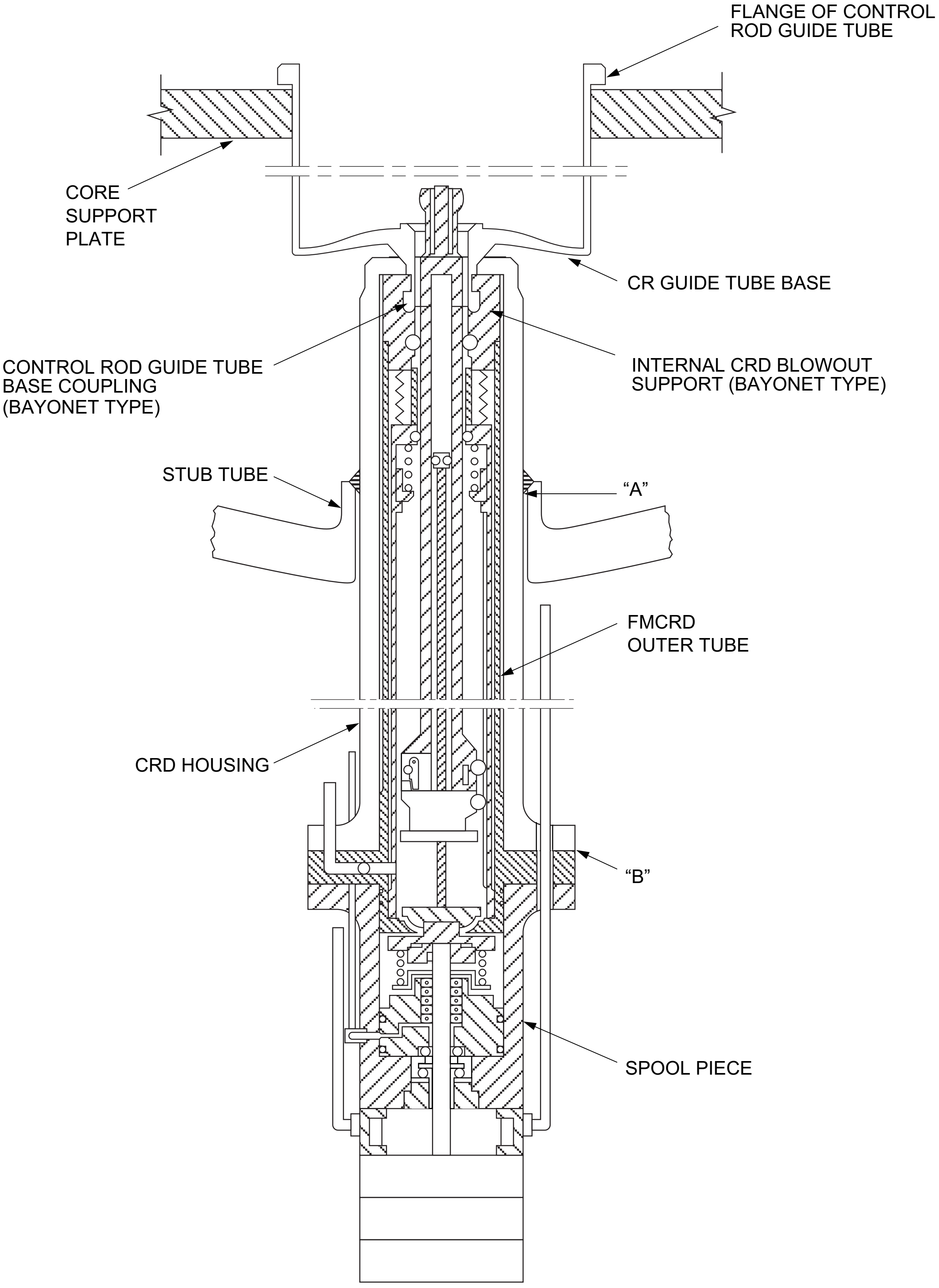


Figure 4.6-7 Internal Blowout Support Schematic

The following figures are located in Chapter 21:

Figure 4.6-8 Control Rod Drive System P&ID (Sheets 1-3)

Figure 4.6-9 Control Rod Drive System PFD

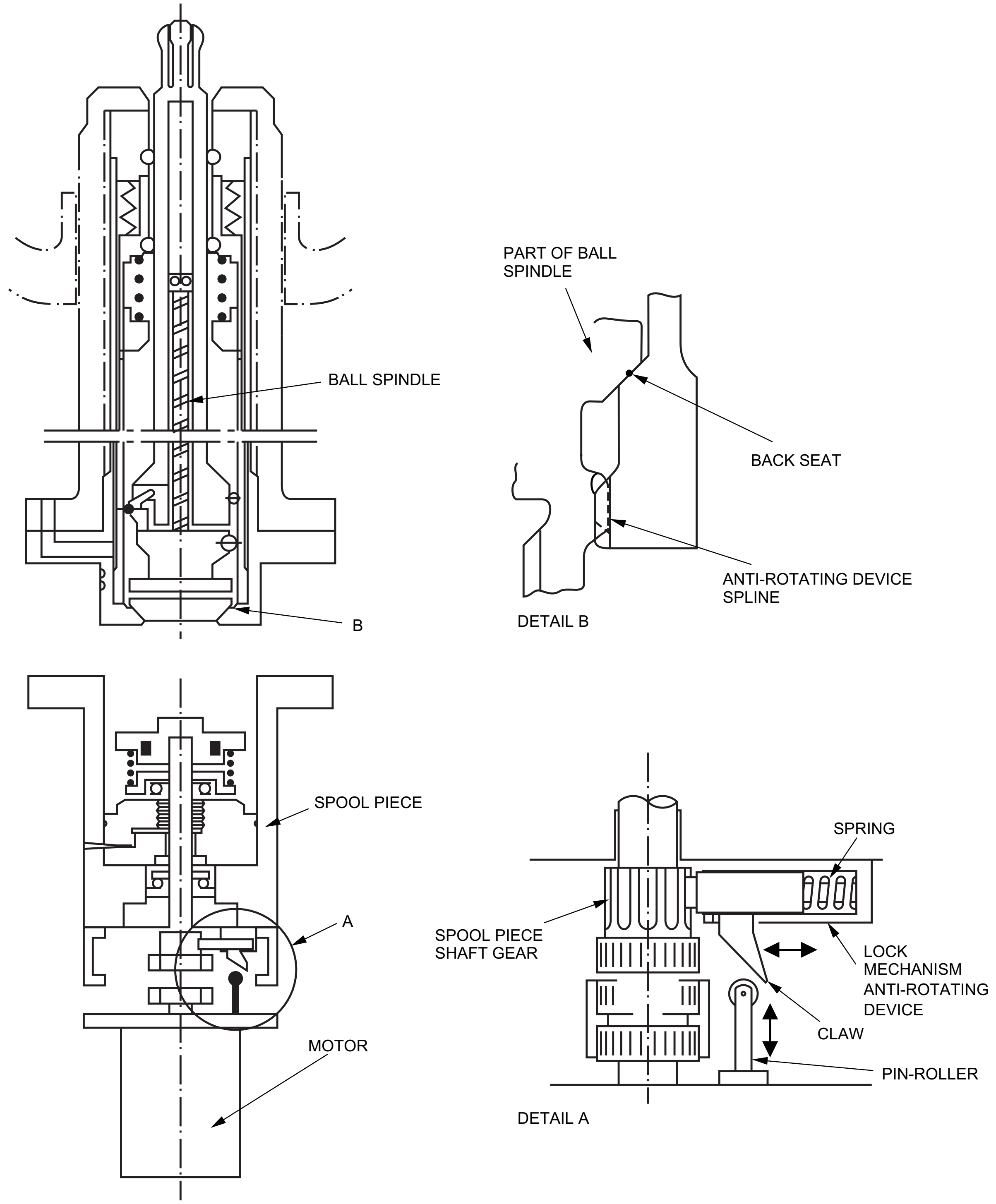


Figure 4.6-10 FMCRD Anti-Rotation Devices