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3 CONTROL ELEMENT DRIVE MECHANISMS

Learning Objectives:

1. Describe the components in the Control Element Drive Mechanism (CEDM) that are a part of the reactor coolant system (RCS) pressure boundary.
2. Describe the power supply to the CEDMs.
3. Explain the purposes of the Control Element Assembly Control and Indication system (CEAC&IS).
4. List and state the purposes of the CEAC&IS interlocks.
5. Explain the various modes of operation of the CEAC&IS.

3.1 Introduction

The purposes of the control element assemblies are:

1. Provide sufficient negative reactivity to shutdown the reactor,
2. Provide reactivity additions to allow reactor start-ups and limited power escalations, and
3. Allow control of the reactor's axial flux distribution.

Table 3-1 CEA Assignments

Group	Function	# of CEAs
A	Shutdown	16
B	Shutdown	8
C	Shutdown	16
1	Regulating	8
2	Regulating	4
3	Regulating	4
4	Regulating	8
5	Regulating	4
6	Regulating	9

There are two different types of CEAs installed in the core, shutdown and regulating. The forty shutdown CEAs are divided into three groups (A, B, and C) and are fully withdrawn during power operations. The shutdown CEAs are driven by a dual CEA drive mechanism (one mechanism controls the position of two CEAs). The thirty-seven regulating CEAs are divided into six control groups that are withdrawn to at least the Power Dependent Insertion Limit (PDIL) during power operation. Each of the regulating CEAs has an individual drive mechanism.

The functions and numbers of CEAs assigned to each group is shown in table 3-1.

3.2 CEA Mechanism Mechanical Construction

The CEA mechanism may be divided into three sections. The first section is the drive shaft assembly. The second section is the CEDM pressure housing and drive unit. The final section is the coil assembly.

3.2.1 CEA Drive Shaft

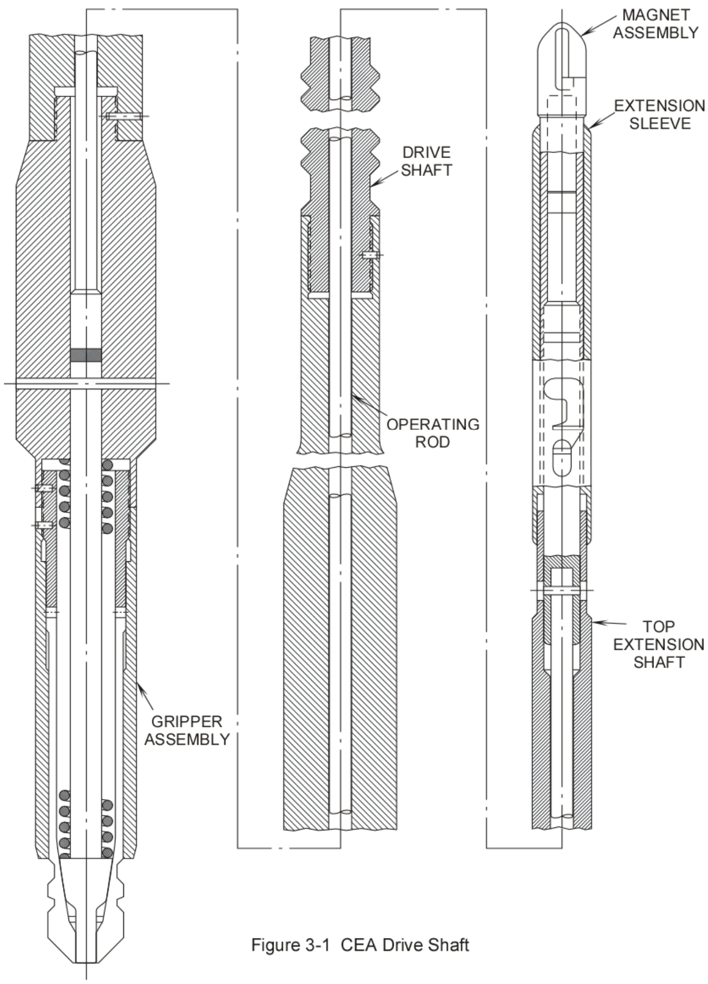


Figure 3-1 CEA Drive Shaft

The regulating CEA drive shaft (Figure 3-1) extends from the top of the CEA spider up through the CEA pressure housing and into the upper pressure housing. The drive shaft is coupled with the CEA spider by an expandable collet located at the bottom of the shaft assembly. An operating rod (located on the inside of the shaft) expands the fingers of the collet. The fingers of the collet contain lands that mate with grooves on the inside of the CEA spider hub. From the top of the CEA, the drive section continues upward to the pressure boundary housing. The portion of the drive shaft that is located on the inside of the pressure housing is grooved to allow the driving latches to position the CEA. The top extension of the drive shaft contains the necessary apparatus for the coupling and uncoupling of the CEA during refueling activities.

A magnet is also located on this section of the drive shaft. The magnet opens and closes reed switches that are used in the position indication system.

The dual CEA coupling (Figure 3-2) consists of a yoke and two collets. Each of the collets, located on either end of the yoke, is coupled to a shutdown CEA. The drive shaft connects to the center of the yoke. A magnet is also located at the top of the drive shaft and operates reed switches that are used to indicate the position of both of the CEAs that are attached to the drive shaft.

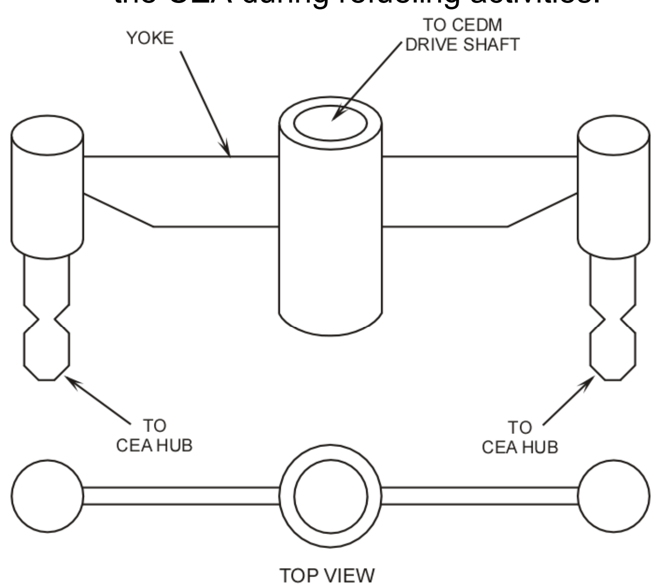


Figure 3-2 Dual CEA Coupling

3.2.2 Pressure Housing and Drive Unit

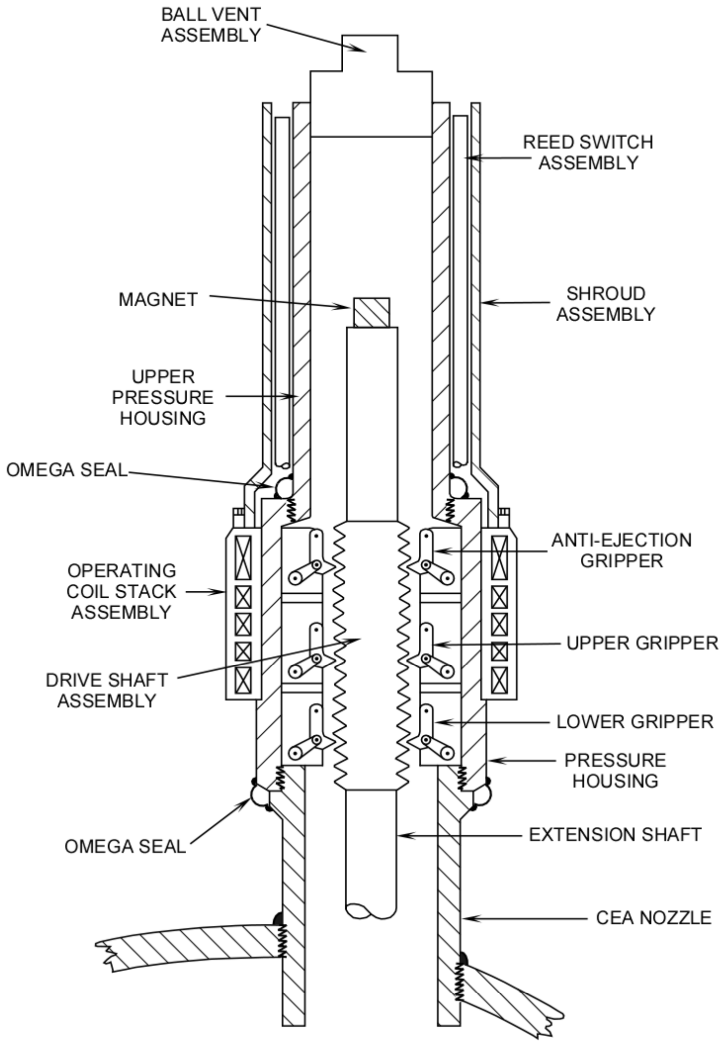


Figure 3-3 Pressure Housing and Drive Unit

The bottom of the pressure housing is threaded onto the vessel head CEA nozzles. This vessel penetration is sealed by an omega seal and is also seal welded to insure vessel integrity. The upper pressure housing completes the pressure housing assembly.

The upper pressure housing is threaded into the pressure housing and also contains an omega seal. A ball vent assembly, used to remove air from the system, completes the pressure housing. Reactor coolant pressure extends from the CEA nozzle up to the ball vent assembly.

The motor assembly portion of the drive unit is shown in Figure 3-4. As shown in this figure, the motor housing contains necked down areas that concentrate magnetic lines of flux from the CEDM coils to the gripper latches. Two drive latches or grippers are located inside of the motor assembly. The upper gripper and the lower gripper are magnetically operated and position the CEA during withdrawal and insertion. A spring loaded anti-ejection gripper is included in the CEA design to minimize the possibility of a CEA ejection accident. All of the gripper fingers fit into the grooves of the CEA drive shaft.

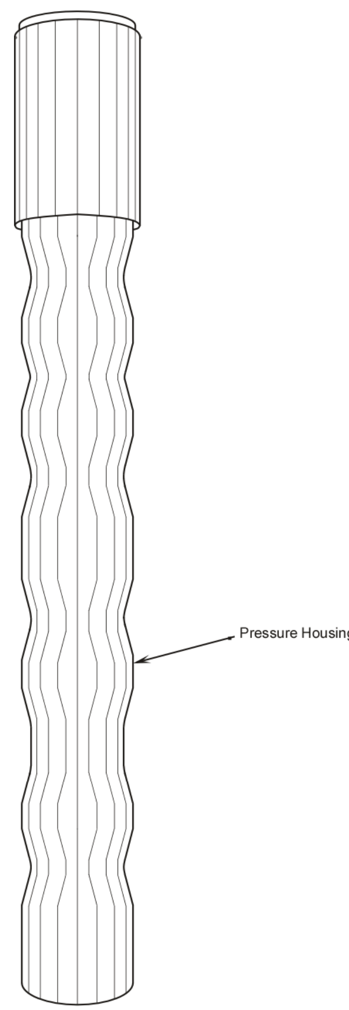


Figure 3-4 CEA Motor Assembly

3.2.3 Coil Assembly

Five electromagnetic coils, located on the outside of the pressure housing, are used to hold and move the CEA. The following list provides the function and names of each of the coils.

1. The lift coil is used to move the CEA drive shaft and to disengage the anti-ejection gripper.
2. The upper gripper coil is used to hold the CEA.
3. The pull down coil is used to reposition the upper gripper for the next CEA step.
4. The load transfer coil transfers the load between the upper and lower grippers during CEA movement.
5. The lower gripper holds the CEA during the intermediate steps of a movement sequence.

The action of these coils is best illustrated by describing CEA withdrawal and insertion sequences.

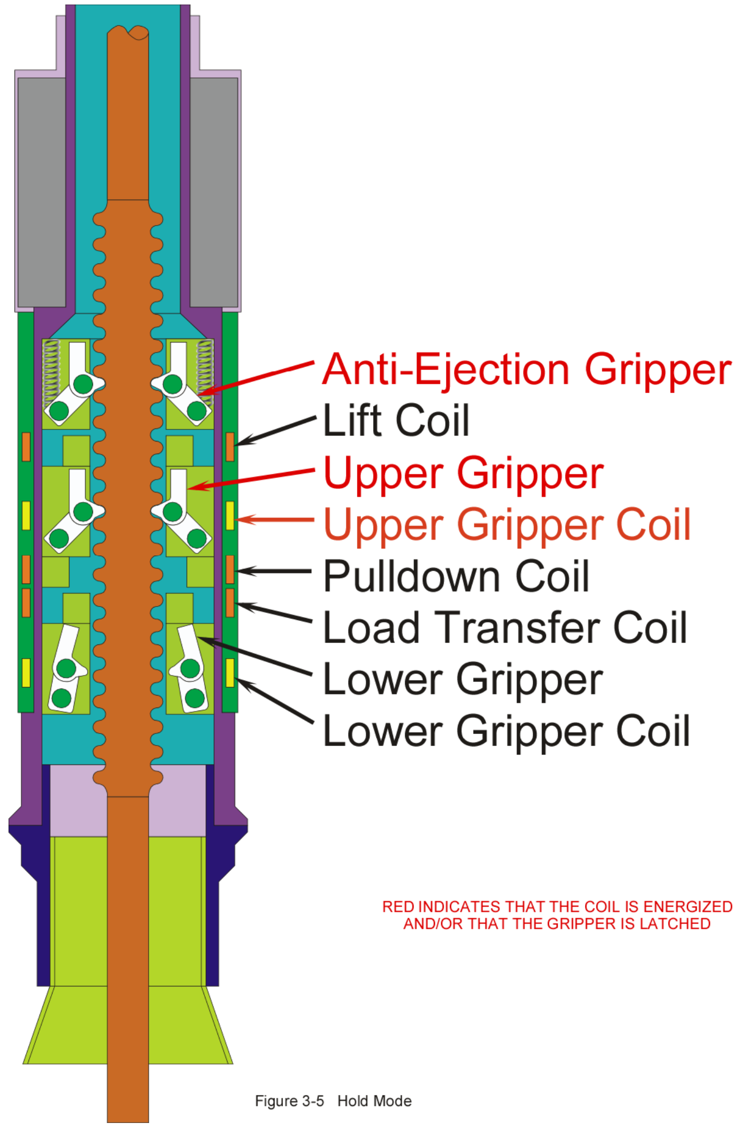


Figure 3-5 Hold Mode

3.2.3.1 Withdrawal Sequence

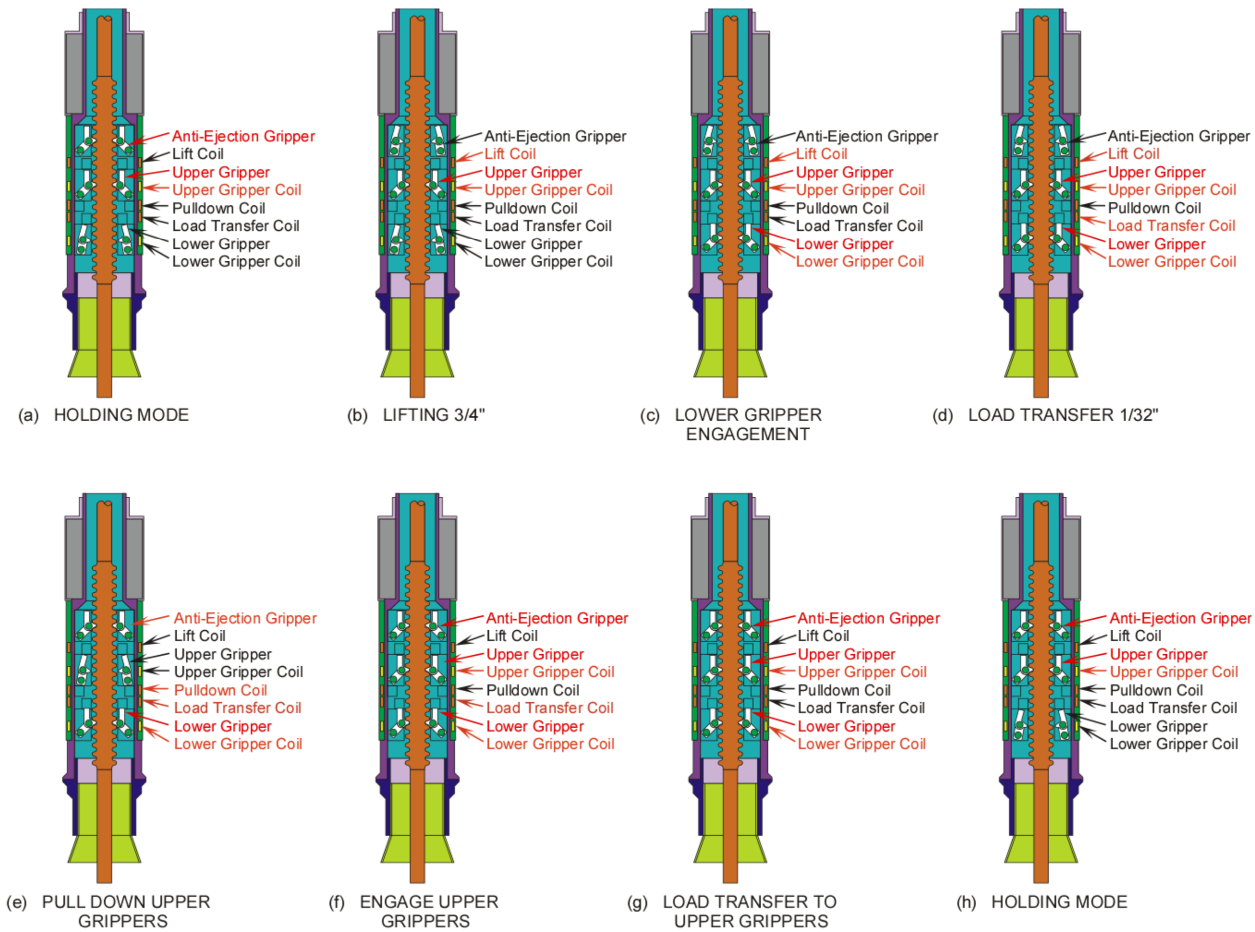


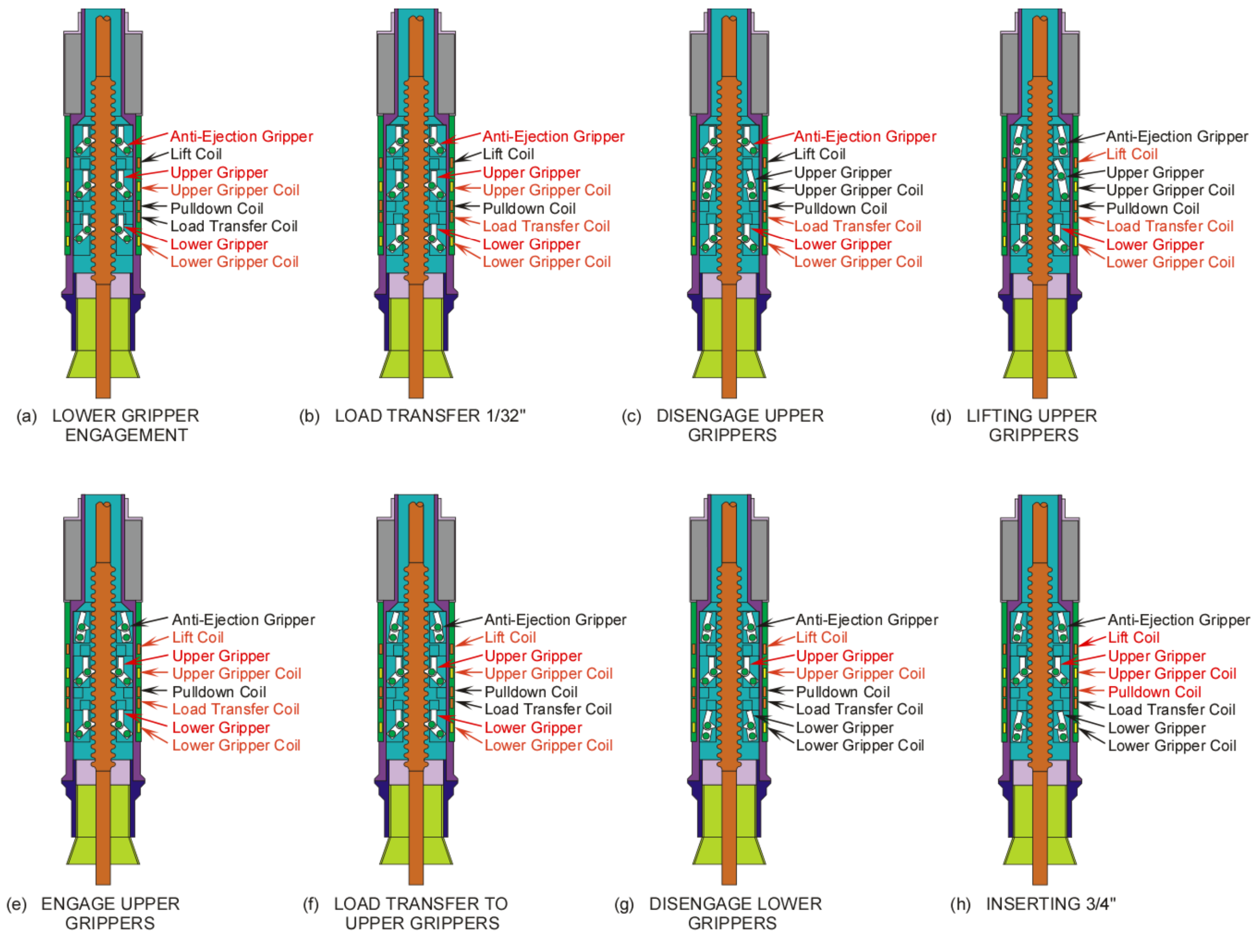
Figure 3-6 CEA Withdrawal Sequence

The CEA is moved in discrete ¾-inch steps as follows:

1. Initial conditions, the upper gripper is energized and holding the CEA. The anti-ejection gripper in also engaged. (Figures 3-5, 3-6(a))
2. The lift coil is energized releasing the anti-ejection grippers and pulling the CEA up 3/4 inch. (Figure 3-6b).
3. The lower gripper is energized to hold the CEA in the new position. (Figure 3-6c)
4. The load transfer coil is energized pulling the lower gripper up 1/32 inch. This transfers the CEA load to the lower gripper. (Figure 3-6d)
5. The lift coil and upper gripper coil deenergize and the pull down coil is energized. This action pulls the upper gripper back to its original position and allows the anti-ejection gripper fingers to engage the drive shaft. (Figure 3-6e)
6. The upper gripper coil is energized and the latches engage the drive shaft. (Figure 3-6f)
7. The load transfer coil is deenergized transferring the load to the upper gripper. (Figure 3-6g)
8. The lower gripper is deenergized, returning the mechanism to the hold mode. (Figure 3-6h)

One withdrawal sequence has been completed.

3.2.3.2 Insertion Sequence



RED INDICATES THAT THE COIL IS ENERGIZED AND/OR THAT THE GRIPPER IS LATCHED

Figure 3-7 CEA Insertion Sequence

Again, the CEA is inserted in ¾-inch steps. The insertion sequence follows:

1. The lower gripper coil is energized. The lower gripper latches contact the drive shaft. (Figure 3-7a)
2. The load transfer coil is energized and the lower gripper is pulled up 1/32 inch. This places the CEA load onto the lower grippers. (Figure 3-7b)
3. The upper grippers are de-energized. (Fig 3-7c)
4. The lift coil is energized, the anti-ejection latch is disengaged, and the upper gripper is pulled up ¾ inch. (Figure 3-7d)
5. The upper gripper coil is energized and the upper gripper latches engage the drive shaft. (Figure 3-7e)
6. The load transfer coil is deenergized transferring the CEA load to the upper grippers. (Figure 3-7f)
7. The lower gripper coil is deenergized causing the lower gripper latches to disengage. (Figure 3-7g)
8. The CEA is lowered ¾ inch by momentarily energizing the pull down coil. The pulldown coil overcomes the lift coil allowing the CEA to insert. (Figure 3-7h)
9. The lift coil is then deenergized and the anti-ejection grippers engage the drive shaft.

The mechanism is now in the hold mode and one insertion sequence has been completed.

3.3 Control Element Assembly Control and Indication System (CEAC&IS)

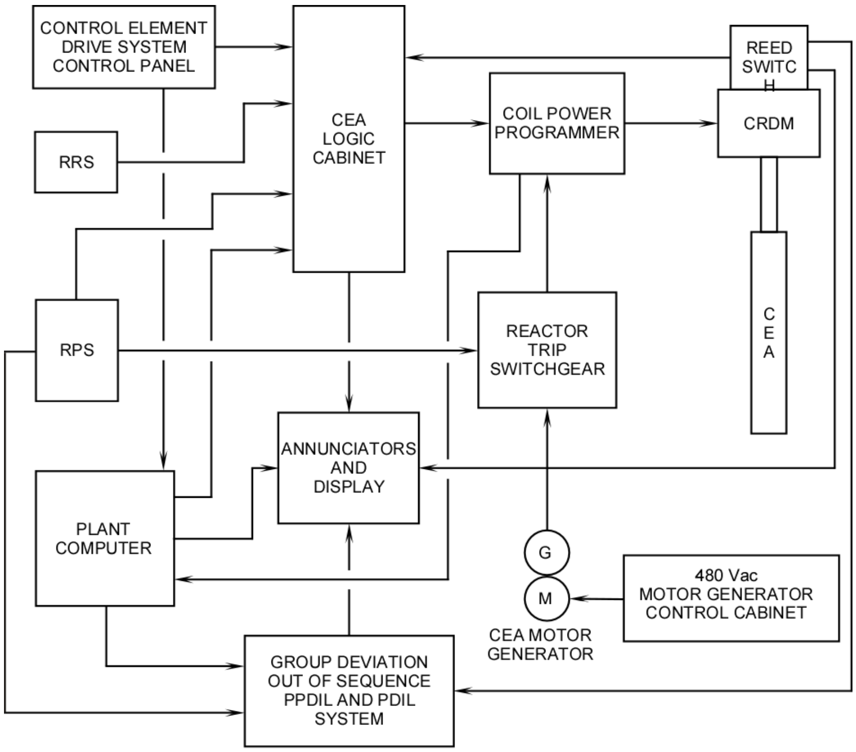


Figure 3-8 CEDS Block Diagram

The control element assembly control and indication system (CEAC&IS) generates the electrical signals that cause the CEDMs to raise, lower, or hold the CEAs. It includes the controls, logic, interlocks, indications, and alarms that ensure proper operation of the CEAs. The positions of the CEAs are controlled remotely from signals originating in the main control room and can be controlled individually or as a group. The CEAC&IS includes the CEDS control panel, CEA logic cabinet, CEA motor generator sets and associated motor generator control cabinets. Figure 3-8 illustrates the interrelationship of the CEAC&IS components and other plant instrumentation and control systems.

3.3.1 CEDS Logic

All withdrawal or insertion signals generated for the CEDMs at the CEDS control panel pass through the CEA logic cabinet. In this cabinet, CEA control signals are directed to the correct group and/or individual CEAs and then modified by protective interlocks and controls.

The CEA logic cabinet includes four logic panels which further contain logic modules. Logic modules are provided for group and individual CEA logic, group and mode selection logic, and several logic control modules for interlock and control functions. The interlock functions include CEA Motion Inhibit (CMI), CEA Withdrawal Prohibit (CWP), automatic withdrawal prohibit (AWP), CEA limit switch relay and permissives, and regulating bank sequencing system interlocks. The control functions include circuitry for the Reactor Regulating System (RRS) and the plant computer interfaces.

The CEA coil power programmers deliver control power to the coils of the CEDM. There is one coil power programmer for each CEDM which controls the time, pulse duration, and level of electrical current supplied to the coils of the CEDM. The coil power programmers receive power from the CEA motor generator sets.

The coil power programmer is comprised of the timing logic, the power switch, and the up-down counter sections. The timing logic section generates the precise timing signals for CEA motion while the power switch effectively amplifies these timing signals by switching the current from one coil to another coil. The lift and pull-down coils have two separate timing controls, one for the withdrawal cycle and one for the insertion cycle. Also each CEDM coil uses two different current levels, except the pull-down coil which uses only one current level. A typical timing control circuit for each CEDM consists of three timers. One timer is used to set the time from the beginning of the cycle until current flow is initiated into the coil, one timer is used to set the time duration for high current flow into the coil, and one timer is used to set the time duration for low current flow into the coil.

3.3.2 CEA Power Supply

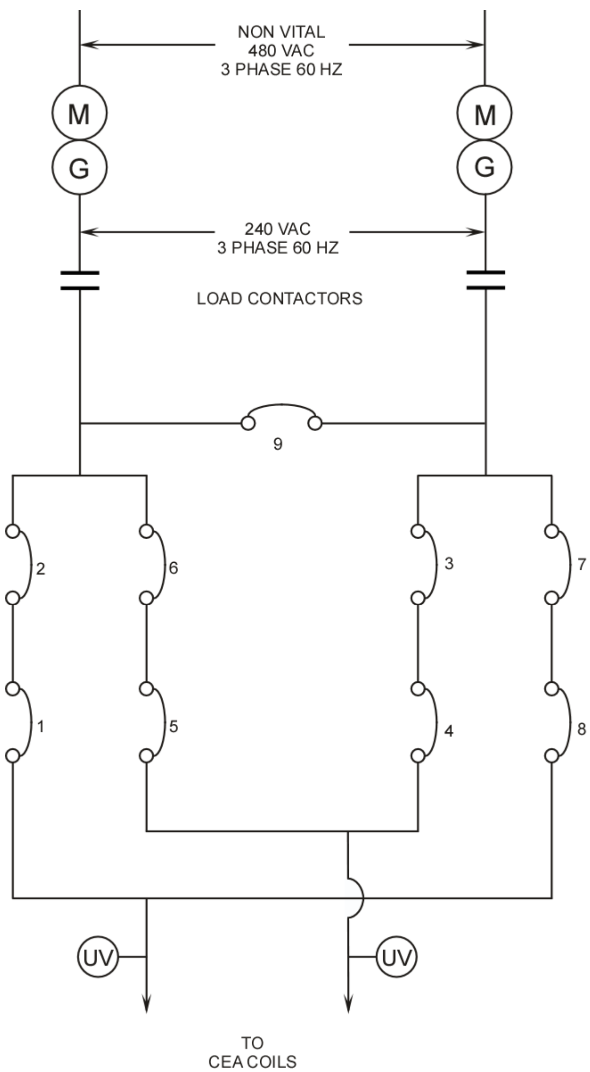


Figure 3-9 CEA Power Supply

The power for the CEA coils comes from redundant motor-generator (MG) sets. The MG set motor is a 480 Vac, 3 phase, 220 hp induction motor that receives its power from a non-class 1E bus. The motor drives a 240 Vac, 3 phase, 60 Hz, generator. A flywheel is installed on the MG set to provide for a constant power output during momentary power upsets. The flywheel provides sufficient rotating inertia to maintain generator output frequency above 59 Hz. for three-tenths (3/10) seconds and above 58 Hz. for one second after power interruption. The output of the generator is routed to the reactor trip circuit breakers via an output breaker. Control cabinets are installed to allow MG set start-up, shutdown and generator synchronization.

The Diverse Scram System (DSS) interfaces with the MG sets through the load contactors. The DSS receives inputs from the four pressurizer pressure safety channels and will actuate when two out of the four pressurizer pressure channels sense a pressurizer pressure of 2450 psia. When the DSS actuates, it opens the load contactors. The loss of power to the CEAs allows the CEAs to fall into the core. The DSS was a design backfit and is required to mitigate the consequences of an Anticipated Transient Without Scram (ATWS).

3.3.3 Reactor Trip Circuit Breakers

As shown on Figure 3-9, there are nine circuit breakers installed between the MG set output breakers and the coils of the CEAs. The 9 circuit breaker is used to ensure MG

set synchronization is maintained regardless of the order of the closure of the remaining eight breakers. To illustrate the importance of the 9 breaker, assume that all circuit breakers are open with the exception of the MG output breakers. Note that breakers 1, 2, 4, 5, 6, and 8 can be shut in any order; however, when either breaker 3 or 7 is closed, the MG sets are paralleled. There is an extremely large probability that the MG sets will not be synchronized when either of these breakers are closed. If the 9 breaker is closed, the MG sets cannot be paralleled out of phase by closing breakers 1 through 8 in any order.

Circuit breakers 1-8 are the Reactor Trip Circuit Breakers (RTBs). These breakers are controlled by the reactor protection system (RPS). When a reactor trip signal is generated by the RPS, the RTBs will open.

These breakers can be opened by two methods. First, an under voltage coil is deenergized causing the breaker to open. Second, the breaker shunt trip coil is energized, and the breaker will open. Regardless of how the circuit breakers are opened, deenergizing power to the CEA coils allows the CEAs to drop into the core.

Power from the reactor trip circuit breakers is routed to the CEAs via two distribution buses. About one half of the CEAs are powered from each bus.

3.3.4 CEA Distribution Buses

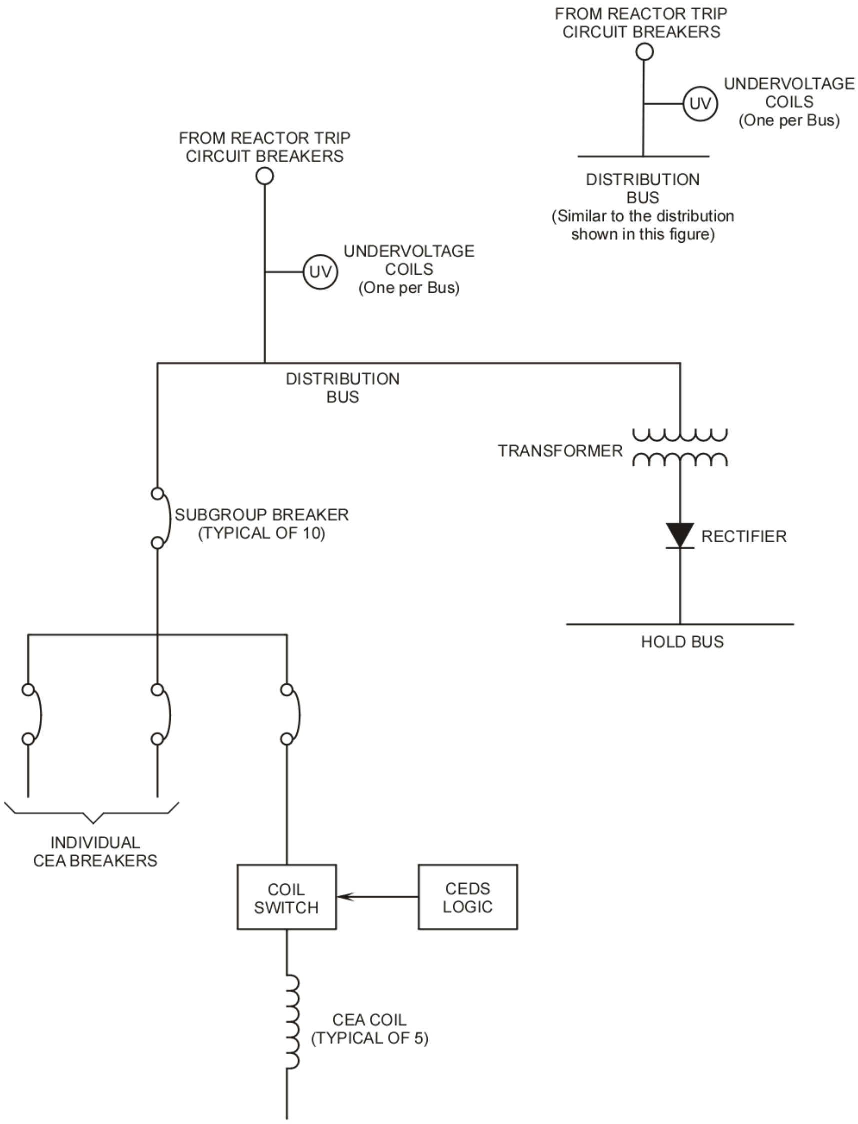


Figure 3-10 CEA Distribution Bus

The power distribution from one of the two CEA buses to the CEAs is shown. Two under voltage coils monitor the power supplied to each CEA bus (4 UV coils total). When a reactor trip occurs, the under voltage coils sense the loss of power to the CEAs. The coils provide reactor trip information to the turbine trip system (turbine trip on reactor trip) and the feedwater control system (turbine trip or reactor trip over ride).

The CEAs are divided into subgroups of four or five CEAs. Power to each subgroup is routed through a subgroup breaker. There are ten subgroups supplied by each distribution bus. Each subgroup breaker supplies up to five CEAs via individual CEA breakers.

Power from an individual CEA breaker travels through a coil switch to the CEA coil. The coil switch is a set of three Silicone Controlled Rectifiers (SCRs) that are controlled by the Control Element Assembly Control and Indication System (CEAC&IS).

In addition to the coil switch power supply, the CEAs may be powered from the hold bus. The hold bus is a maintenance device. A subgroup of CEAs may be transferred to the hold bus in order to perform maintenance on the CEA coil switches or CEAC&IC logic.

The hold bus supplies power to the upper gripper coil. If the RTBs open, power will be lost to the hold bus. Any CEAs that are receiving power from the hold bus will be deenergized.

3.4 CEA Position Indication Systems

Three independent CEA position indication systems are installed to provide CEA position information and interlocks for the CEAC&IS. The first position indication system is called the primary CEA position indication system. This system utilizes the plant computer to count the up and down pulses that are supplied to the CEA coils. The second position indication system determines CEA position by magnetic switches that are opened and closed by the magnetic section of the CEA drive shaft. This is the secondary CEA position indication system. The final position indication system also uses magnetic switches that are opened and closed by the magnetic section of the CEA drive shaft. These switches supply position information to the CEA mimic display, and are independent from the secondary CEA position indication system.

3.4.1 Primary CEA Position Indication System

The primary CEA position indication system monitors the up and down pulses sent to the CEA coils. These pulses are counted by an up-down counter in the plant computer. Each up or down pulse represents a three-quarter (3/4) inch change in CEA position. The plant computer supplies position information to nine digital meters, one for each CEA group, located in the control room adjacent to the CEA control station. Each of the nine digital meters displays position information for a selected CEA in its associated group. The selected CEA is determined by switches on the CEAC&IS panel. The plant computer can also provide a printout of all group and individual CEA positions.

In addition to position information, the primary CEA position indication system provides signals that are used to control the CEAs. An Upper CEA group Stop (UCS) is supplied to each of the nine CEA groups to stop outward group motion when the lowest CEA in the group reaches 133.5 inches. Further CEA withdrawal is allowed in the manual individual mode of control. A Lower CEA group Stop (LCS) is also provided to each of the nine CEA groups to stop inward group motion when the highest CEA in the group reaches 4.5 inches. Again, further CEA insertion is allowed in the manual individual mode.

The upper and lower sequential permissives are also provided by the primary position indication system. These permissives provide the proper sequencing of the regulating groups as they are moved in either manual sequential or automatic sequential control. When group 1 reaches 93 inches withdrawn, the upper sequential permissive (USP) will allow group 2 to start outward rod motion. Both groups will move together until group 1 hits the upper group stop. Group 2 will continue to withdraw until it reaches 93 inches, at which time group 3 will start to withdraw. This pattern will take place for all regulating groups.

When the regulating groups are inserted in either manual sequential or automatic sequential, there is a lower sequential permissive that allows rod motion inward. Assuming all groups withdrawn, when group 6 reaches 54 inches withdrawn, the lower sequential permissive will start group 5 insertion. When group 6 reaches the lower group stop, group 5 will continue to insert until it reaches 54 inches at which time group 4 will start to insert. Again, this pattern will continue for all regulating groups.

The primary CEA position indication system also provides alarms to warn the operator of CEA misalignments. If the difference between the highest and lowest CEA in a group exceeds 3¾ inches, the CEA position four inch deviation alarm is annunciated. If the difference between the highest and lowest CEA in a group exceeds 7½ inches, the CEA position eight inch deviation alarm is annunciated. The first of these alarms gives the operating staff time to correct CEA misalignment before the technical specification limit of 7½ inches is reached. The second alarm informs the operator that the technical specification limit has been reached or exceeded.

A third set of alarms provided by the primary CEA position indication system associated with power distribution is the power dependent insertion limit (PDIL) alarms. The PDIL alarms compare the CEA position of each regulating group with reactor power. The power signal used in the alarm algorithm is supplied from the computer calculation of thermal power. If the CEA position approaches the pre-programmed position for the existing reactor power, a pre-PDIL (PPDIL) alarm is generated. This alarm alerts the operator to the potential of exceeding the technical specification CEA insertion limit. If CEA position equals or exceeds the pre-programmed position for the existing reactor power, the PDIL alarm is annunciated. When this alarm is annunciated, technical specification limits may have been exceeded. Both the PPDIL and the PDIL alarms are bypassed if power, as sensed by wide range logarithmic channels, is $<10^{-4}$%.

The final limit provided by the primary CEA position indication system is the exercise limit. The ability to move the CEAs is a technical specification surveillance requirement. Insertion of the CEAs from a fully withdrawn position to the exercise position of 129 inches complies with the technical specification requirement.

3.4.2 Secondary CEA Position Indication System

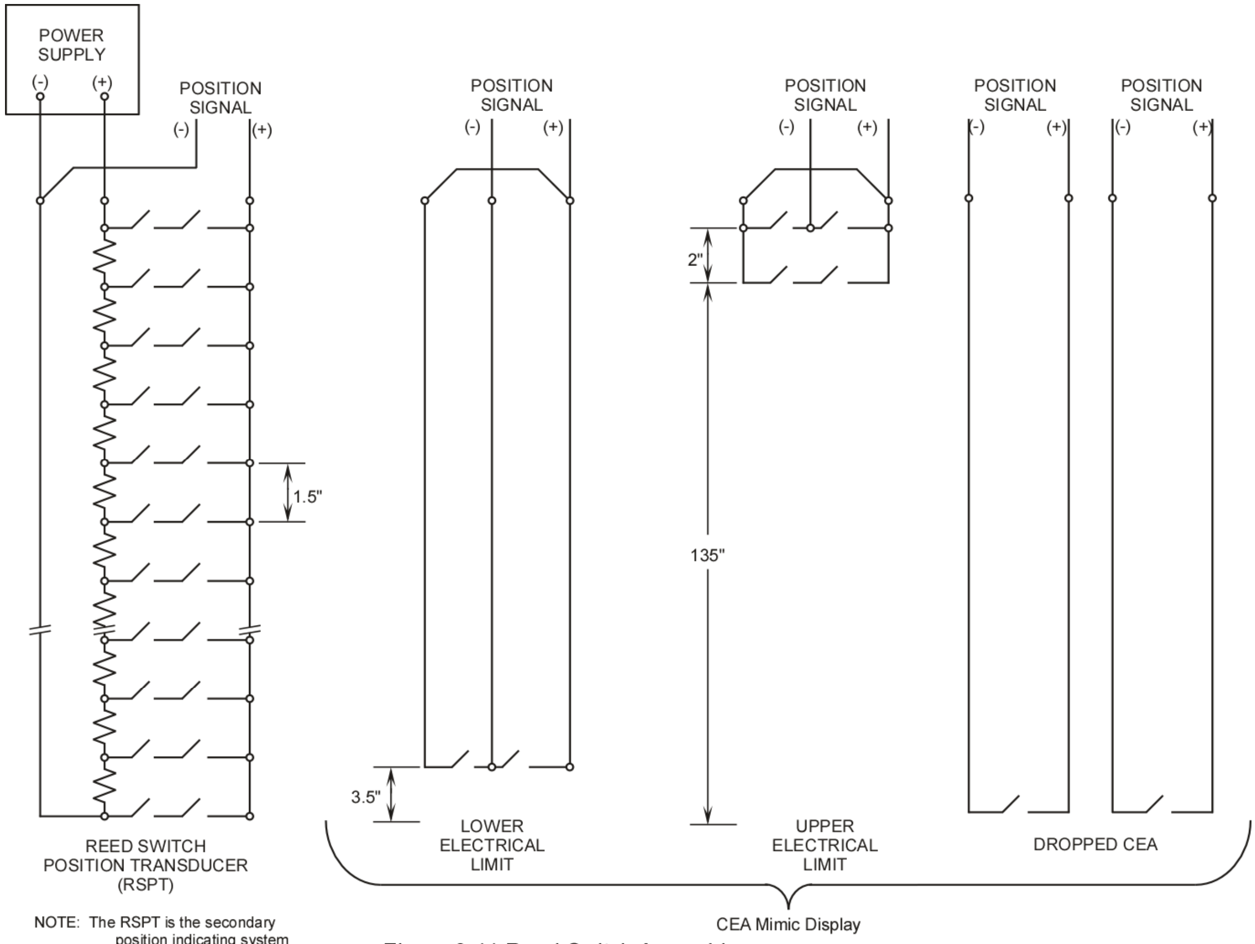


Figure 3-11 Reed Switch Assembly

The secondary CEA position indication system is redundant to, and completely independent of, the primary CEA position indication system. The position signals for the secondary CEA position indication system are initiated by Reed Switch Position Transducers (RSPTs) that are housed in the shroud assembly of the CEDMs. The switches are positioned at one and one-half (1½) inch intervals along the length of the CEDM shroud assembly and are wired into a voltage divider network. The output of the voltage divider is a stepped voltage signal proportional to CEA position that is supplied to a Cathode Ray Tube (CRT). The CRT provides two indications of CEA position. The first indication is a vertical bar graph that provides a simultaneous display of all of the CEAs in the core by group or all groups. The second indication is a digital readout of the CEA position.

In addition to position indication, the secondary CEA position indication system also provides signals that are used for alarms and interlocks. The first alarm provided by the secondary CEA position indication system deals with CEA sequencing. This alarm monitors the regulating group position to determine if too much overlap exists or if the correct CEA sequence is being maintained. If, between successive groups, the lowest CEA in the preceding group is below the Upper Sequential Permissive (USP) of 93 inches and the highest CEA in the succeeding group is above the Lower Sequential Permissive (LSP) of 54 inches then an out of sequence alarm will be generated. Additionally, if the difference between successive CEA groups is less than 79 inches, or

if the wrong CEA group is moving, then an out of sequence alarm will also be generated. The secondary CEA position indication system also provides CEA deviation alarms.

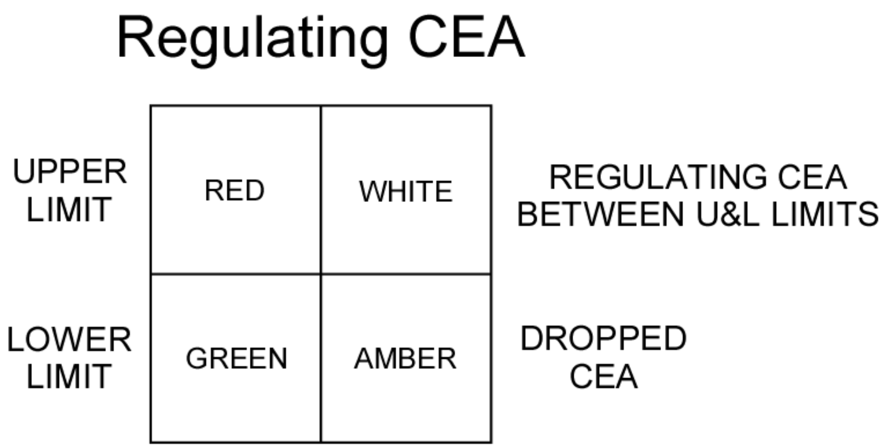
Each CEA group deviation alarm circuit consists of a high select unit, a low select unit, a summing amplifier, and two bistables. The output of the RSPTs is supplied to the high select unit and the low select unit. The high select unit passes only the signal from the highest CEA position, and the low select unit passes the signal from the lowest CEA position. The summing amplifier subtracts the lowest CEA position from the highest CEA position and sends the result to the two bistables. The first bistable determines if the difference between the highest and lowest CEA exceeds four inches. The second bistable determines if the difference between the highest and lowest CEA exceeds eight inches. The output of the bistables is routed to the secondary CEA four inch deviation and the secondary CEA eight inch deviation annunciators, respectively.

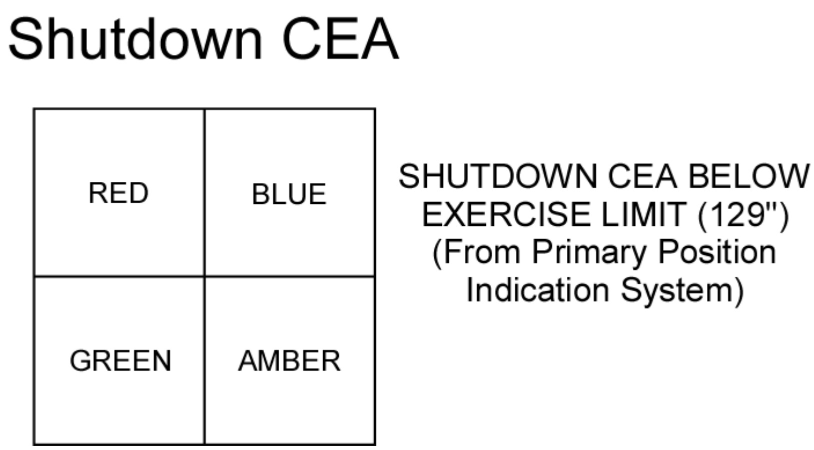
The secondary CEA position indication system also provides power dependent insertion limit alarms. The PDIL alarms also compare the CEA position of each regulating group with reactor power. Except that the power signal used in the secondary CEA position system alarm circuitry is supplied by the RPS and is the highest of ΔT power or linear power range nuclear power.

Both the PPDIL and the PDIL alarms are bypassed if power, as sensed by wide range logarithmic channels, is less than 10^{-4}%.

Two interlocks are provided by the secondary CEA position indication system to ensure that shutdown margin and power distribution assumptions are maintained. The shutdown groups cannot be inserted until all regulating CEAs are inserted to <10 inches. This interlock is called the shutdown CEA insertion permissive and is annunciated on the control board. Likewise, the regulating group CEAs cannot be withdrawn unless all shutdown CEAs are withdrawn to at least 129 inches. This interlock is called the regulating CEA withdrawal prohibit and is also annunciated on the control board.

3.4.3 CEA Mimic Indication





The CEA mimic display system consists of a core mimic panel and lights that represent CEA location and status. There are 57 light assemblies (20 dual CEA indications and 37 single CEA indications). The colored lights (except for blue) are controlled by reed switches that are independent of the secondary CEA position reed switches. The blue light is controlled by the primary position indication system.

Each light assembly has four different colored lights. The light colors are:

1. Red, indicating a fully withdrawn condition,
2. White which is the operating band for a regulating CEA,
   or
   Blue which is the exercise limit for a shutdown CEA,
3. Green, indicating a fully inserted condition, and
4. Amber, indicating a dropped CEA.

The red light is energized when the CEA is at its Upper Electrical Limit (UEL) of 135 inches. When a CEA reaches this position, logic circuits prevent further withdrawal commands.

The green light is energized when the CEA is at its Lower Electrical Limit (LEL) of 3½ inches. When a CEA reaches this position, logic circuits prevent further insertion.

The white lights are energized on the regulating CEAs when the CEAs are between the upper and lower electrical limits. For shutdown CEAs, the white light is replaced with a blue exercise lamp that is illuminated when the shutdown CEA is < 129 inches as sensed by the primary position indication system.

3.5 CEAC&IS

The CEAC&IS allows manual or automatic control of the CEAs. The shutdown groups can only be controlled in manual while the regulating groups can be controlled manually or automatically. Manual or automatic control is determined by selections made at the CEAC&IS control panel.

3.5.1 CEAC&IS Control Panel

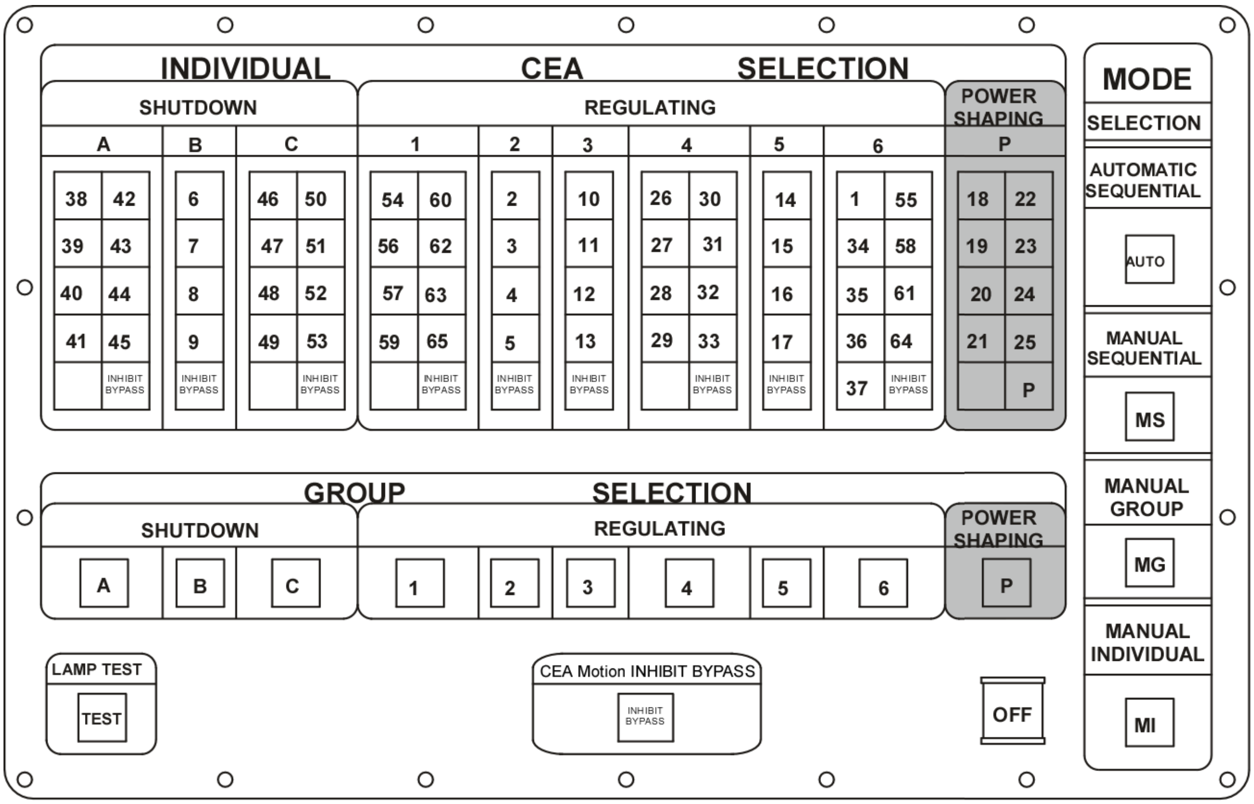


Figure 3-13 CEDS Control Panel

NOTE:
POWER SHAPING RODS
HAVE BEEN REMOVED

The CEAC&IS panel (Figure 3-13) provides selection capability for the desired mode of CEA operation and CEAC&IS indication on the core mimic panel. The use of the different CEAC&IS control modes is best illustrated by discussing the startup and power escalation of the reactor.

3.5.2 Reactor Startup

The initial conditions for the reactor startup have been established. The unit is operating in Mode 3 with an estimated critical position calculated. All other technical specifications for changing mode are satisfied.

The first step in the reactor start-up is to withdraw the shutdown groups to their fully withdrawn position. The withdrawal of the shutdown groups is accomplished in the manual group mode of control.

3.5.2.1 CEA Manual Group Control

Manual group control is accomplished by selecting the desired group of CEAs to be withdrawn by pressing the appropriate switch located in the group selection section of

the CEAC&IS panel and selecting the manual group (MG) mode push-button located in the mode selection section of the CEAC&IS. The shutdown bank withdrawal is accomplished by selecting the A position on the group select, selecting MG on the mode select, and placing the manual control switch to the withdraw position.

Outward CEA motion will be permitted provided a CEA withdrawal prohibit (CWP) is not present. A CWP signal is generated when two out of four pre-trip signals are generated by either variable over power pre-trip, high startup rate or thermal margin low pressure pre-trip bistables in the RPS. Outward CEA motion will continue until the upper CEA group stop (UCS) is reached. The upper group stop is generated by the plant computer when the selected CEA group reaches 133.5 inches withdrawn. The 133.5 inch position is almost fully withdrawn and is used as an interlock to stop rod motion. When group A reaches the upper group stop, the operator will pull each rod to the upper electrical limit (UEL) in the manual individual mode of control. Shutdown group B and Shutdown group C CEAs will be fully withdrawn in the same manner. The speed of the shutdown CEAs is 20 inches per minute in all modes of control.

The remaining interlocks in manual group control are:

1. The lower group stop (LCS) and
2. The lower electrical limit (LEL).

The lower CEA group stop stops all inward CEA motion when the plant computer calculates that the group has reached the four and one-half (4½) inch position. The lower electrical limit is a reed switch actuated interlock that stops individual CEA motion commands when the CEA is inserted to three and one-half (3½) inches from the bottom of the core.

3.5.2.2 Manual Individual Control

The manual individual control mode allows any CEA to be individually positioned. To withdraw the shutdown groups from the upper group stop to the upper electrical limit, the following steps are necessary:

1. The Manual Individual (MI) mode is selected.
2 The desired CEA is selected by depressing its selector switch located in the individual CEA selection section of the CEAC&IS panel. This switch also determines the CEA position that is displayed by the digital meter associated with the primary CEA position indication system.
3. The manual control switch is positioned to the withdraw position, and the CEA is pulled to the upper electrical limit.

The above sequence is repeated for each shutdown group CEA. In addition to withdrawing the shutdown groups to the upper electrical limit, the manual individual mode is used to recover dropped CEAs and is used during CEA testing. The lower electrical limit also applies in manual individual mode.

Now that the shutdown groups are withdrawn to the upper electrical limit, the control groups are ready to be withdrawn. This evolution is accomplished in the manual sequential mode of control.

3.5.2.3 Manual Sequential Control

The Manual Sequential (MS) mode is used only for the regulating groups. This mode of CEA control is selected after all the shutdown banks have been withdrawn to the upper electrical limit. When the operator selects MS and positions the manual control switch to the withdraw position, control group 1 begins to move outward from the core. When group 1 reaches 93 inches withdrawn, the upper sequential permissive (USP) is reached. The upper sequential permissive allows group 2 outward motion. Group 1 and group 2 move simultaneously until group 1 reaches the upper group stop (133.5"). When group 1 is at the group stop, group 2 should be at 40.5 inches. Group 2 continues to move outward until it reaches 93 inches, then groups 2 and 3 move out together.

The overlapping of motion between successive regulating groups allows for a more linear reactivity addition by the CEAs. The overlapping of the CEAs is applicable to all regulating groups. The regulating groups are withdrawn until criticality is achieved. Before continuing with the escalation of reactor power, two features of the manual sequential mode of control need to be described.

First, the overlapping of the regulating groups also occurs during CEA insertion. To illustrate the overlapping, assume that all CEAs are fully withdrawn. When the manual control switch is placed in the insert position, group 6 starts to move into the core. When group 6 reaches 54 inches, group 5 starts to drive in. Simultaneous inward motion continues until group 6 reaches the lower group stop (4½ inches). Group 5 inward motion continues until group 5 reaches the 54 inch position at which time group 4 inward motion starts. The 54 inch position (calculated by the plant computer) is called the lower sequential permissive and is applicable to all regulating groups. The withdrawal and insertion speed of the regulating group CEAs is 30 inches per minute.

The interlocks that are applicable in the manual sequential mode are:

1. Control element assembly withdrawal prohibit (CWP),
2. Upper and lower sequential permissives,
3. The upper and lower CEA group stops (UCS, LCS), and

All CEA interlocks are summarized in Table 3-2.

After criticality is achieved in the manual sequential mode, power escalation to 15% reactor power is accomplished by CEA withdrawal. At 15%, the automatic sequential mode of operation may be selected.

3.5.2.4 Automatic Sequential Control

In the automatic sequential mode of operation, the CEAs are positioned by the reactor regulating system (RRS, see Chapter 4). The RRS commands CEA motion in order to maintain T_{avg} at its desired value. Automatic outward (AR-automatic raise) and automatic insertion (AL-automatic lower) commands are generated by the RRS to cause the regulating group CEAs to move at two different rates. The low rate is three inches/minute, while the high rate is 30 inches/minute. Also, the CEAs are overlapped in the sequence described in the previous section.

In the automatic sequential mode of control, a new interlock feature is introduced. The interlock is an automatic withdrawal prohibit (AWP). AWPs are generated by (1) two conditions from Reactor Regulating System. The first condition is a high cold leg temperature (high T_c) of 548°F. The purpose of this interlock is to prevent exceeding the departure from nucleate boiling ratio (DNBR) cold leg temperature value. The second is a large difference between actual and desired T_{avg} (T_{avg}-T_{ref}). If T_{avg} is greater than T_{ref} by 6°F, an AWP signal stops automatic outward CEA motion. (2) The NI Excore Safety channel inputs to AWP if it senses a dropped rod. The AWP interlock prevents a further increase in the power mismatch between the RCS and secondary systems.

3.6 Summary

The control element assemblies provide sufficient reactivity to shutdown the reactor, provide reactivity additions to allow reactor startups and power escalations, and to allow control of the reactor's axial flux distribution.

There are two categories of CEAs installed in the core. The forty shutdown CEAs are divided into three groups and are operated by dual drive mechanisms. The thirty-seven regulating CEAs are divided into six groups and each has an individual drive mechanism. Each CEA drive mechanism forms a portion of the RCS pressure boundary and is operated from the reactivity control panel in the main control room.

The CEA control system incorporates the capability to operate the CEAs in different modes as selected by the operator at the CEAC&IS.

Table 3-2 CEA Interlocks

<u>Primary Position Indication System</u> *<u>(computer/pulse counting)</u>*	Shutdown	Regulating
Upper Sequential Permissive (USP)		93"
Lower Sequential Permissive (LSP)		54"
Upper Group Stop (UCS)	133.5"	133.5"
Lower Group Stop (LCS)	4.5"	4.5"
CEA Group Deviation 4" and 8"	4" and 8"	
CEA Out of Sequence Alarm *(difference between successive groups)*	N/A	79" or wrong group moving
Shutdown CEA Exercise Limit (on CEA Mimic)		< 129"
<u>Secondary Position Indication System</u> *<u>(RSPTs)</u>*		
CEA Group Deviation	4"	4"
CEA Out of Sequence Alarm *(difference between successive groups)*	N/A	79" or wrong group moving
Regulating CEA Withdrawal Prohibit	Any CEA < 129"	N/A
Shutdown CEA Insertion Permissive	N/A	All regulating group CEAs < 10"
CEA Motion Inhibit	4" deviation	4" deviation
<u>CEA Mimic</u> *<u>(RSPTs)</u>*		
Upper Electrical Limit (UEL)	135"	135"
Lower Electrical Limit (LEL)	3.5"	3.5"
Dropped CEA	0"	0"
Shutdown CEA Exercise Limit (from Primary Position Indication)	< 129"	

CONTROL ELEMENT DRIVE SYSTEM INTERLOCKS

CEA Withdrawal Prohibits (CWP)

Two-out-of-four coincident RPS pre-trips on any of the following:

- Thermal Margin Low Pressure (50 psia above setpoint)
- High Start-up Rate (1.5 dpm)
- High Variable Over Power Pre-Trip

CEA Motion Inhibit (CMI)

- Regulating group out of sequence
- Secondary 4 inch CEA deviation
- Regulating group motion prohibit
- Shutdown group insertion prohibit
- Secondary power dependant insertion limit

Automatic Withdrawal Prohibits (AWP)

- High T_c of 548°F as sensed by RRS RTDs (DNBR protection)
- High T_{avg} - T_{ref} of 6°F as calculated by the RRS (power mismatch)
- Dropped CEA – Excore NI Dropped Rod Bistable

Table 3.3 Important CEA Position Setpoints

135”	Upper electrical limit from RSPT, red light
133.5”	Upper group stop, from pulse counting (lowest CEA in group)
129”	Regulating CEA withdrawal permissive, from RSPT (All SD CEAs must be withdrawn this far to withdraw regulating CEAs)
129”	Shutdown group exercise limit from MPC, blue light
93”	Normal overlap begins when withdrawing rods
54”	Normal overlap begins when inserting rods
10”	Shutdown CEA insertion permissive, from RSPT (all regulating CEAs must be inserted this far to insert shutdown CEAs)
4.5”	Lower CEA group stop from pulse counting (highest CEA in group)
3.5”	Lower electrical limit, from RSPT, green light
0”	Rod bottom contact from RSPT, amber light

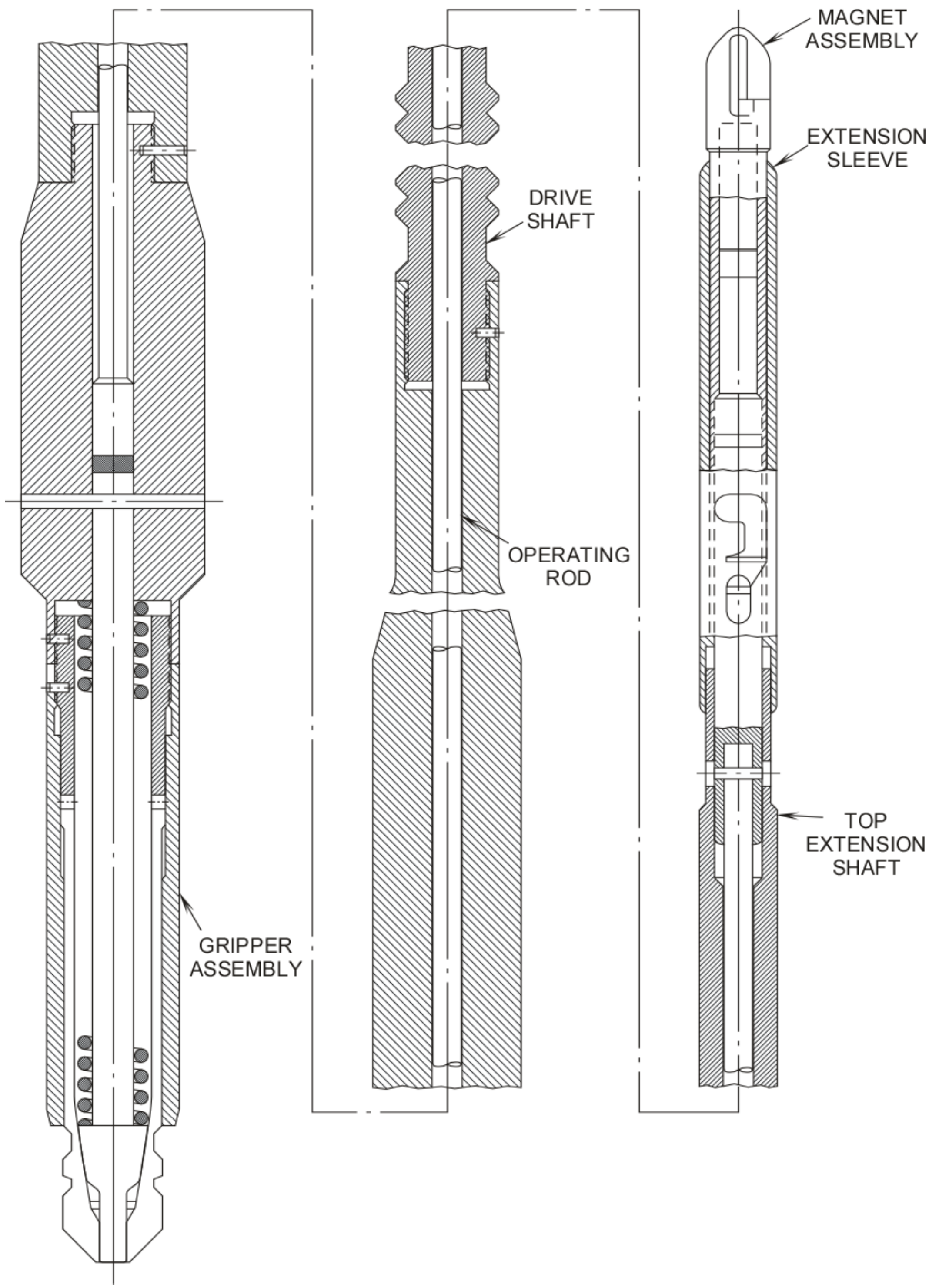


Figure 3-1 CEA Drive Shaft

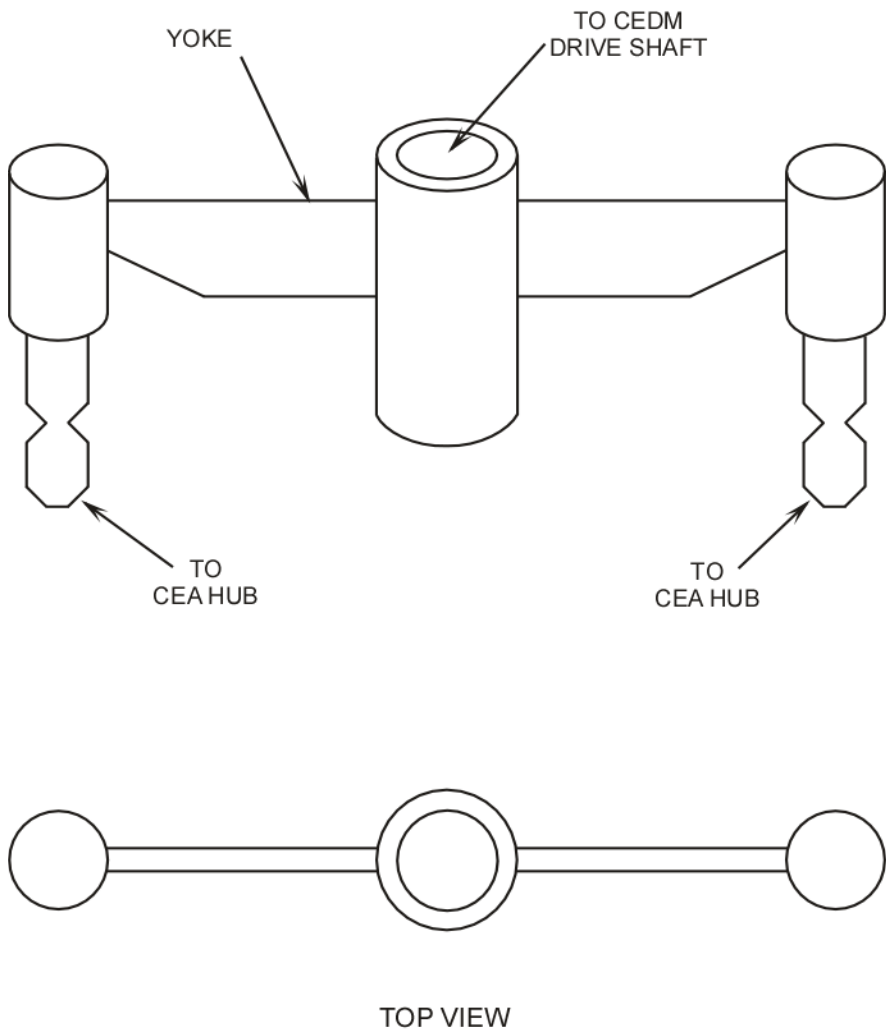


Figure 3-2 Dual CEA Coupling

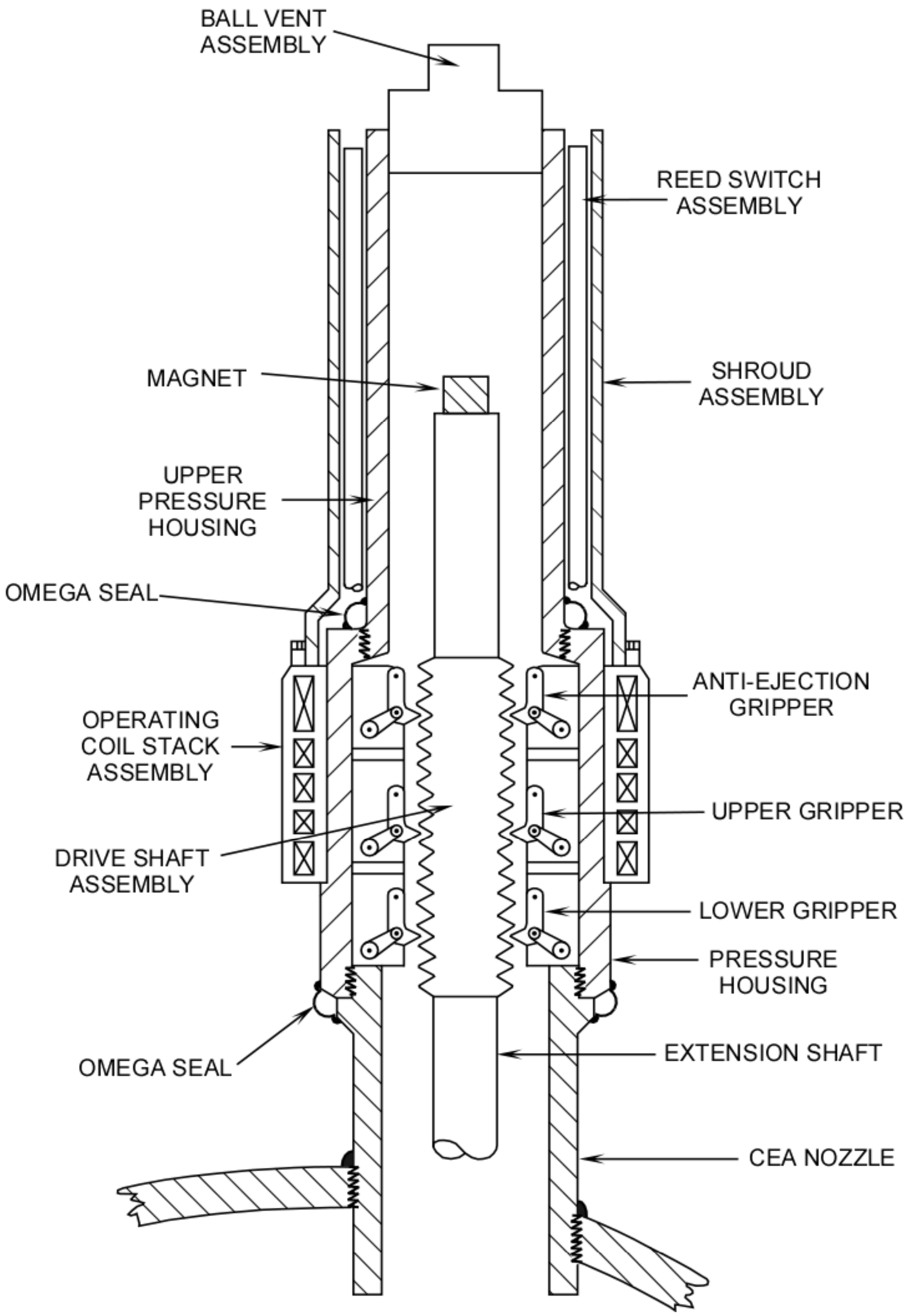


Figure 3-3 Pressure Housing and Drive Unit

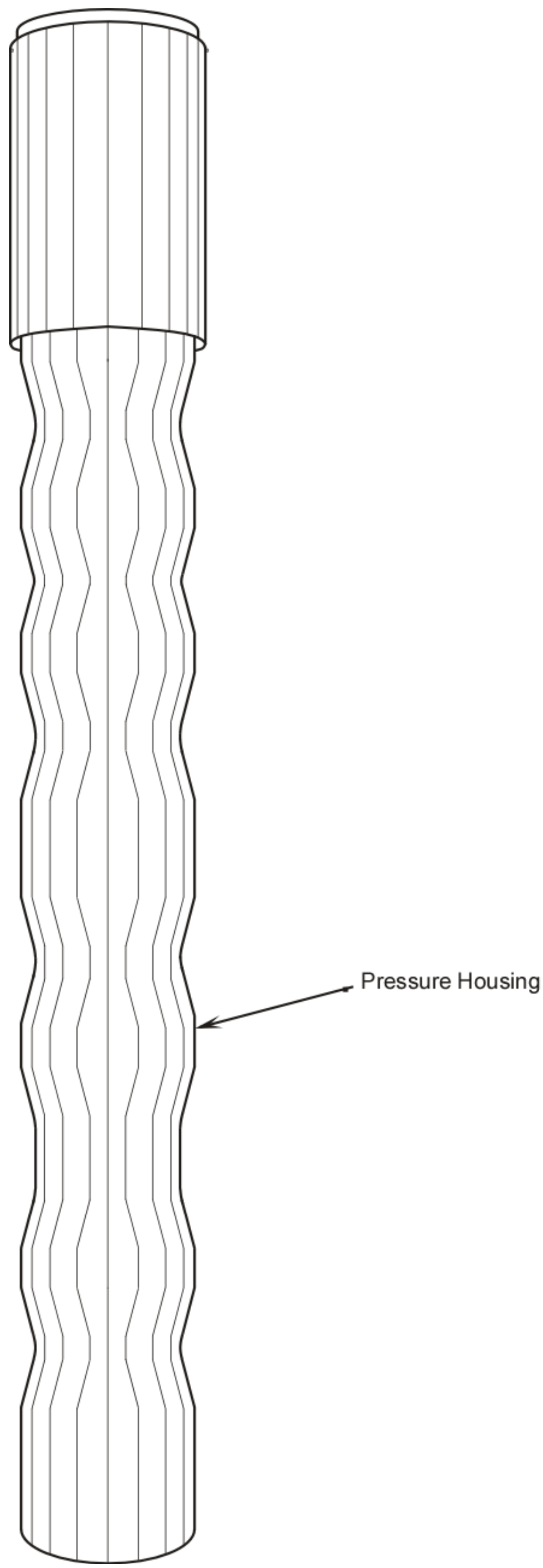


Figure 3-4 CEA Motor Assembly

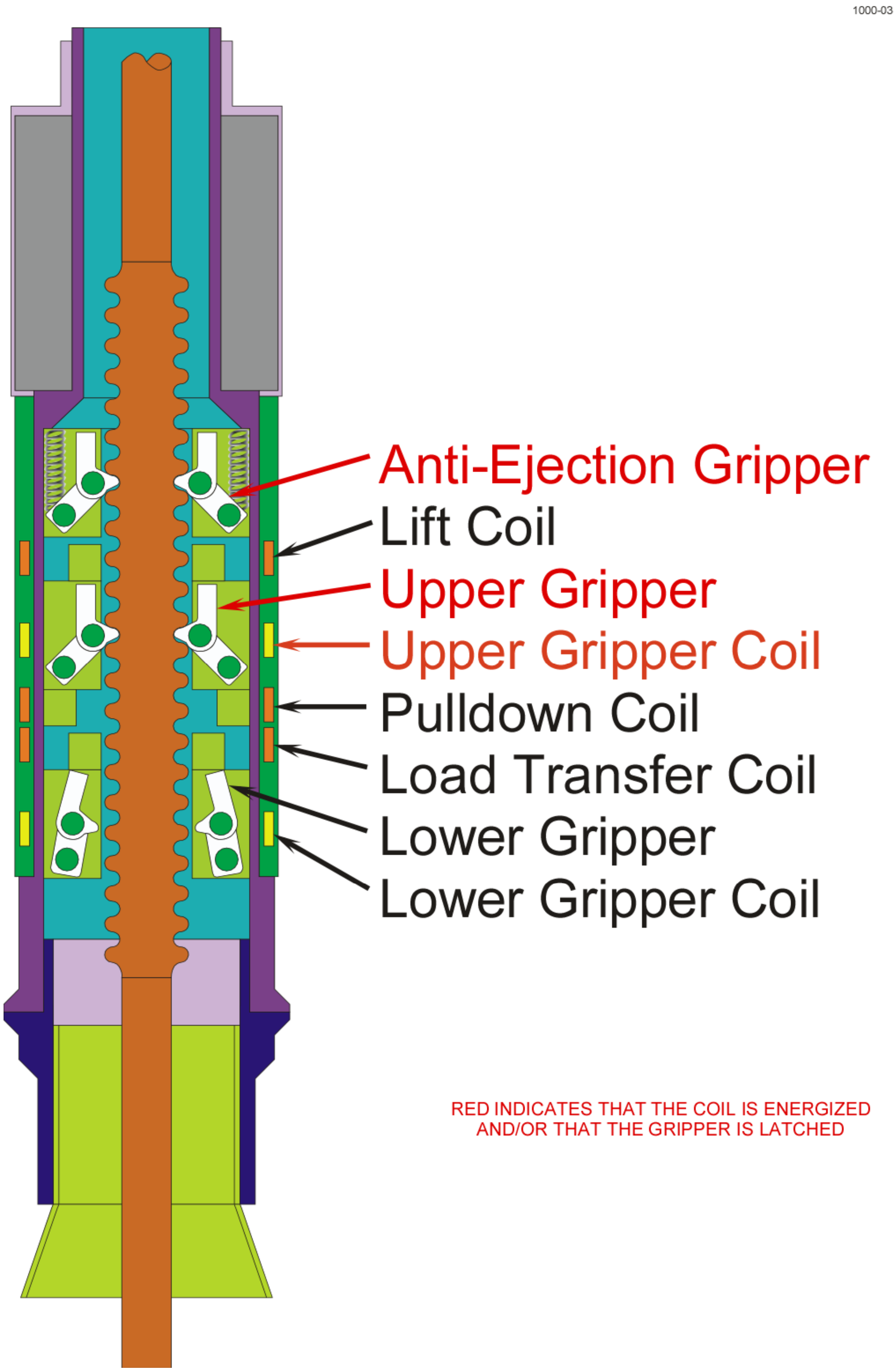


Figure 3-5 Hold Mode

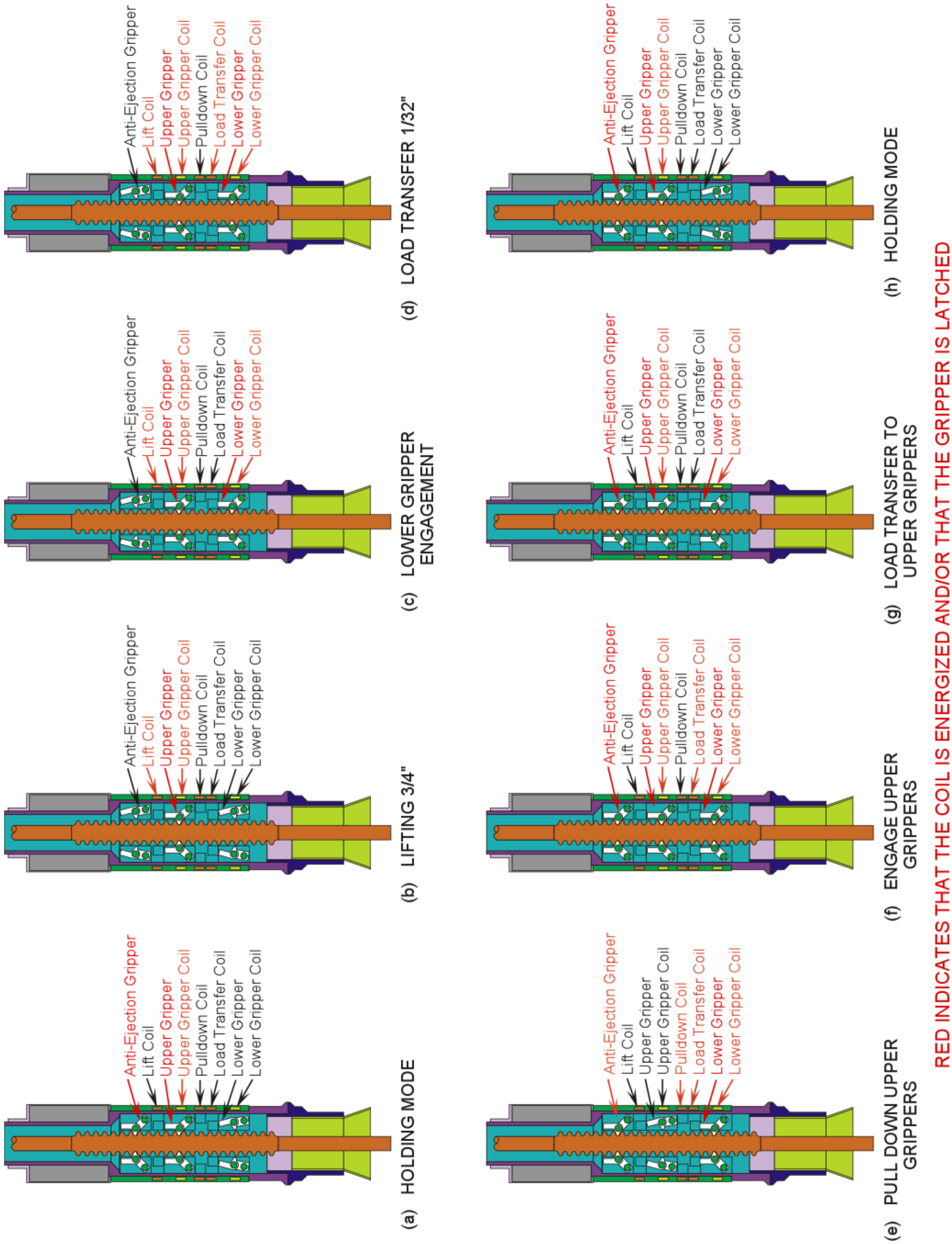


Figure 3-6 CEA Withdrawal Sequence

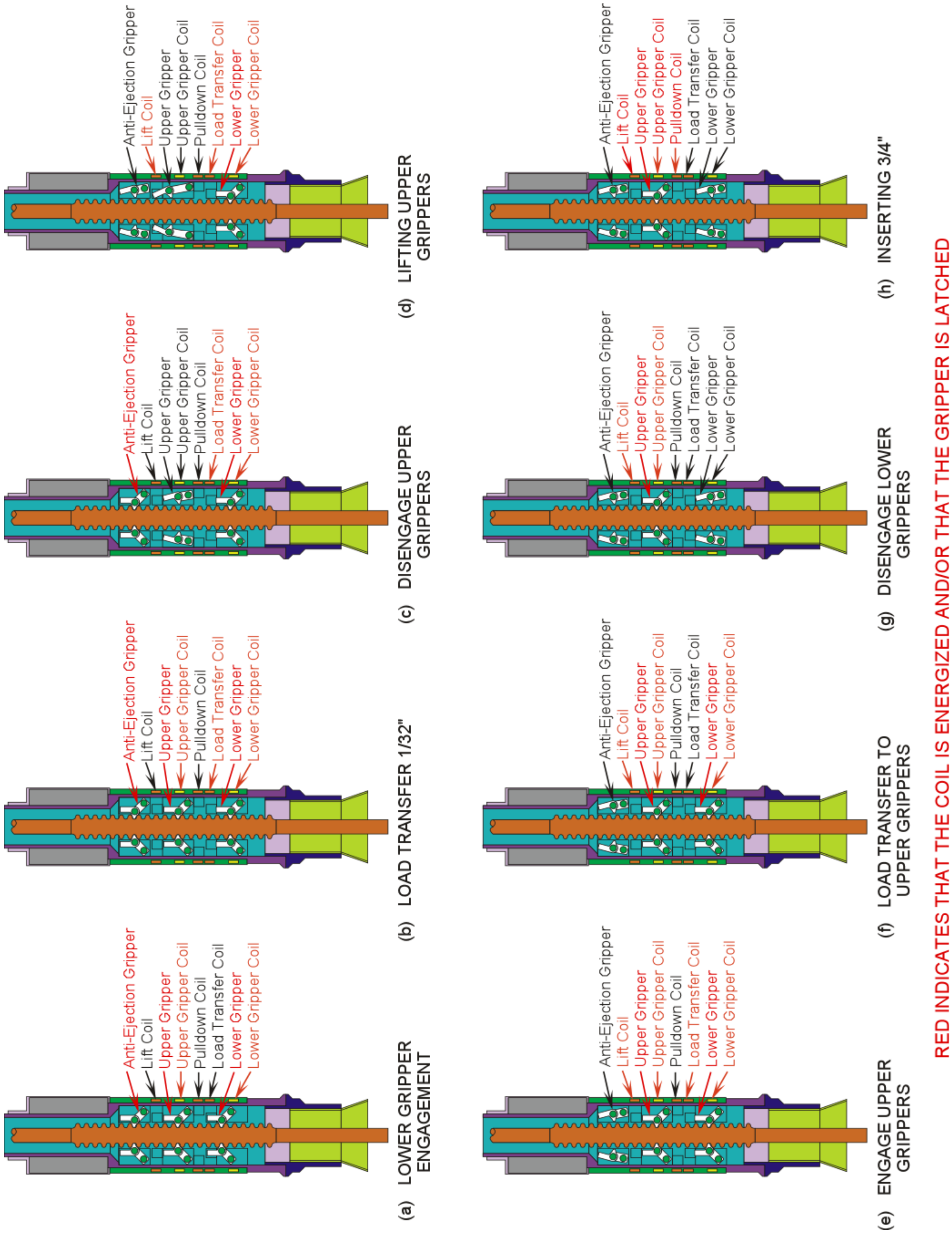


Figure 3-7 CEA Insertion Sequence

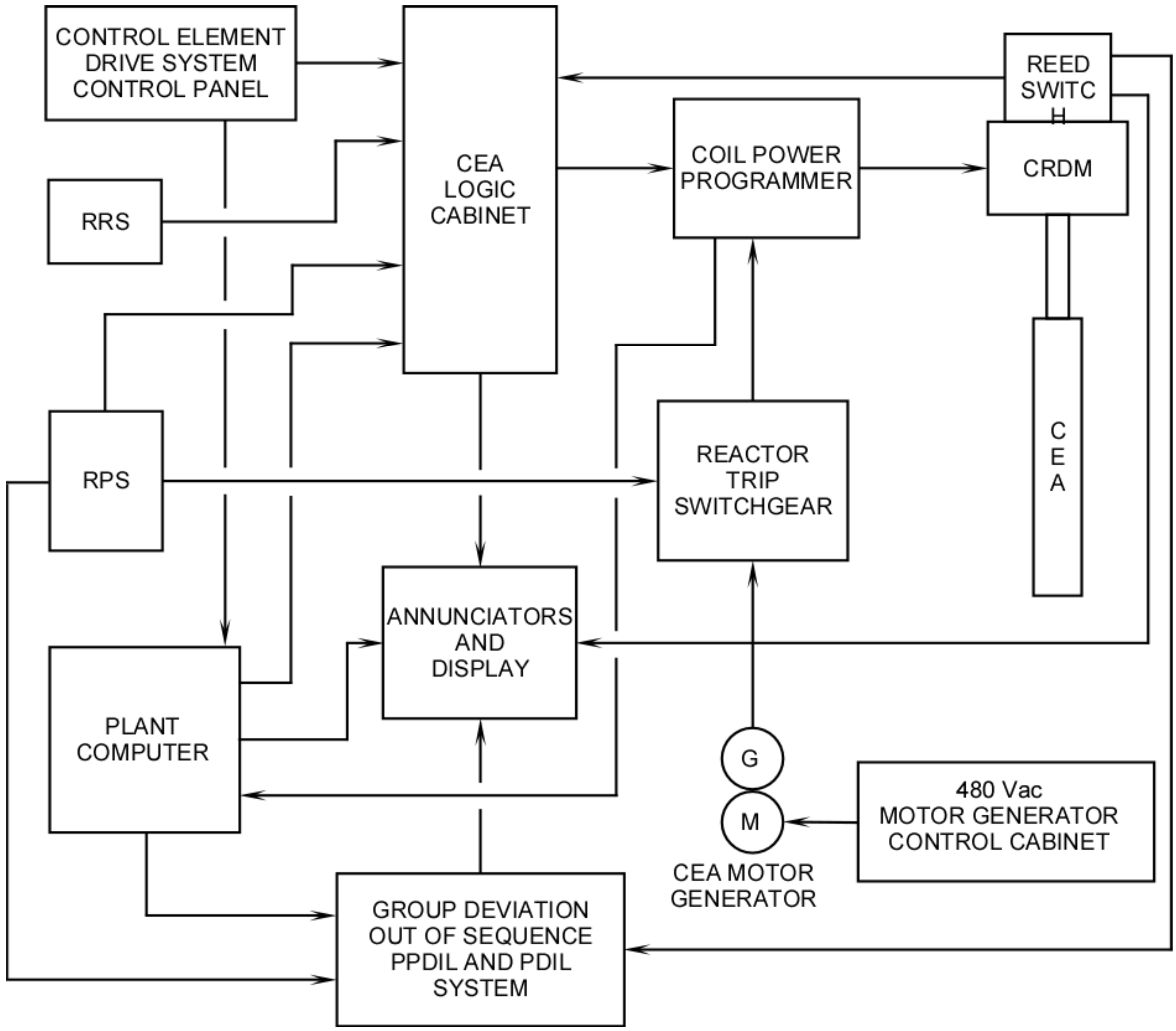


Figure 3-8 CEDS Block Diagram

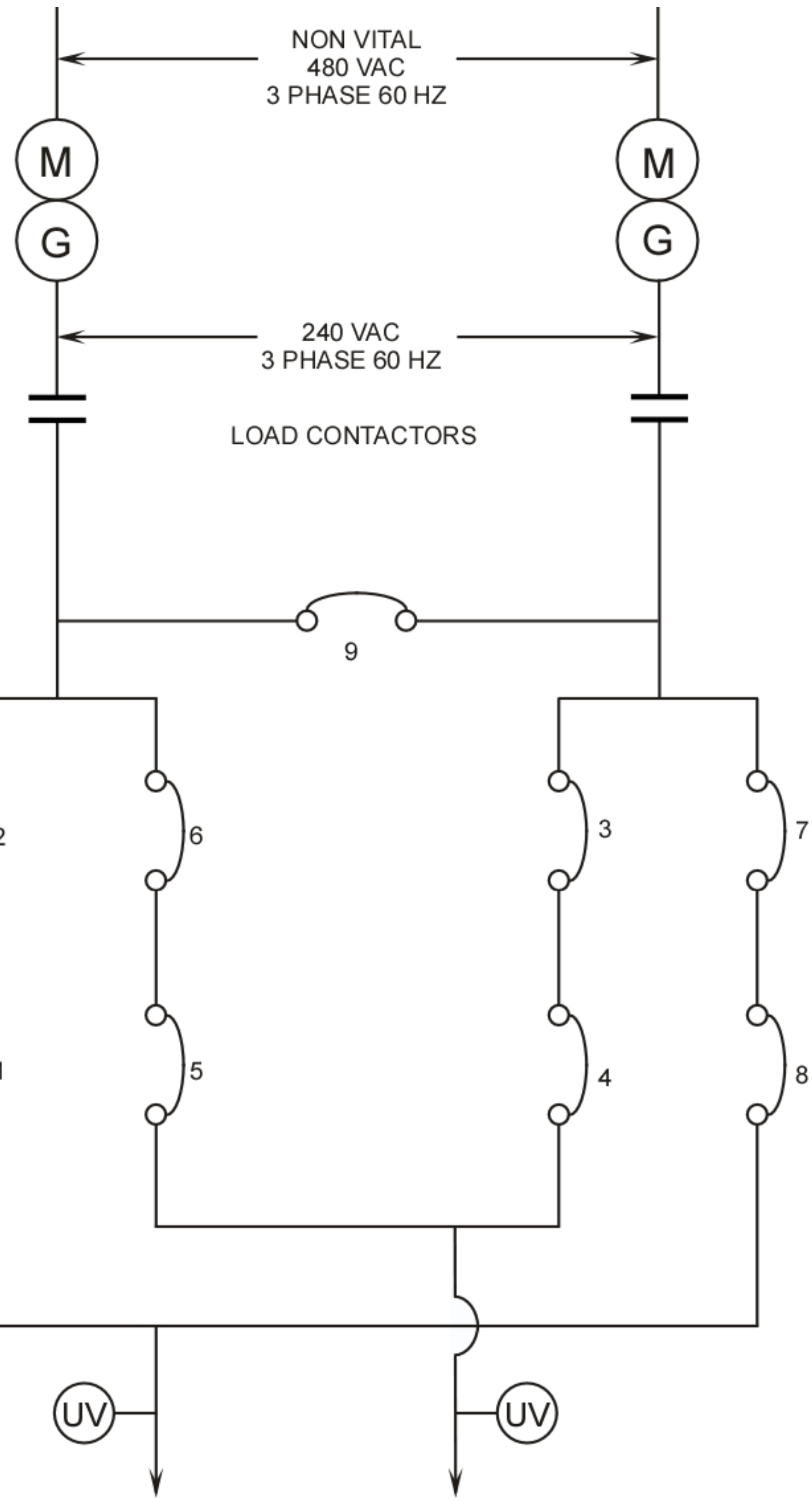


Figure 3-9 CEA Power Supply

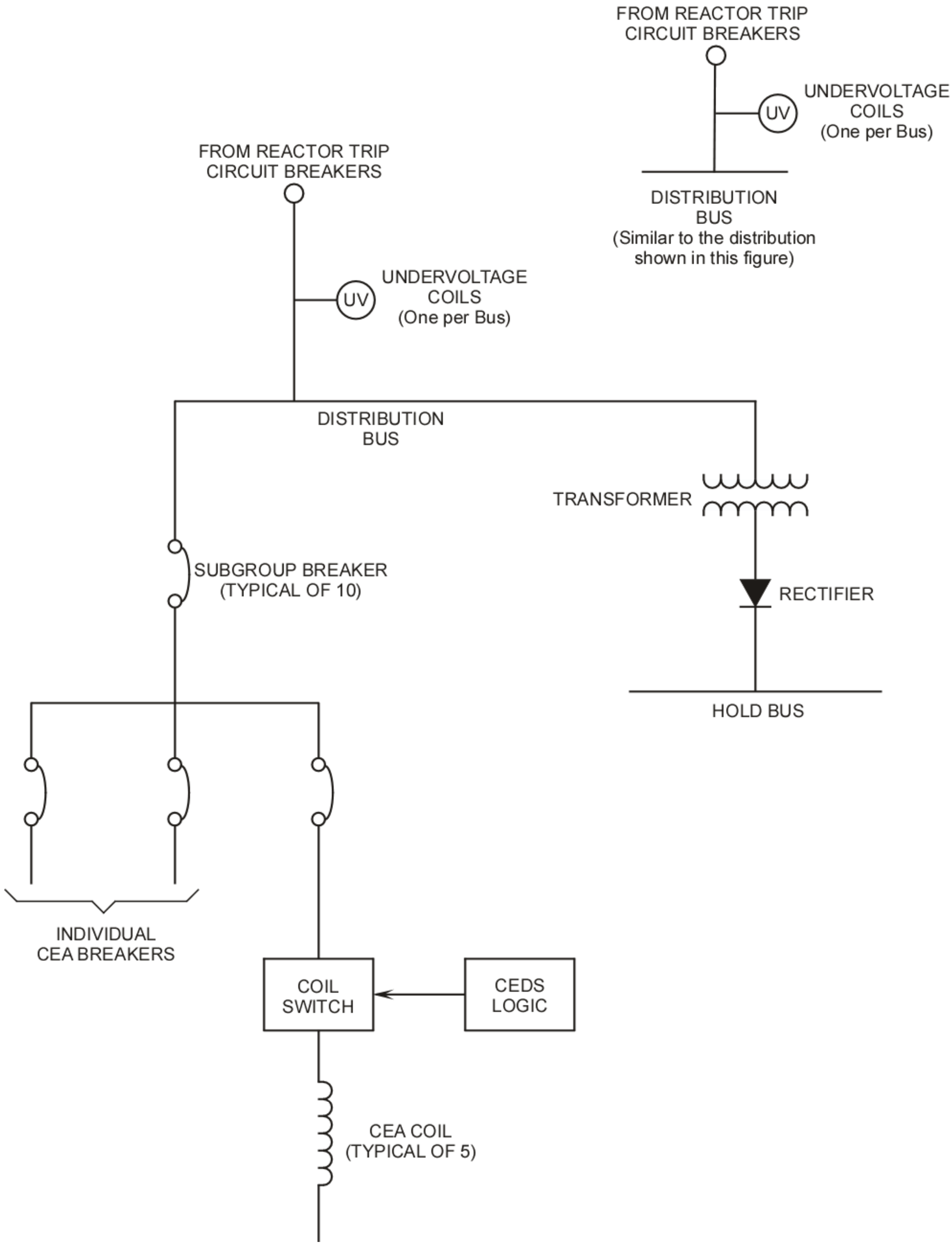


Figure 3-10 CEA Distribution Bus

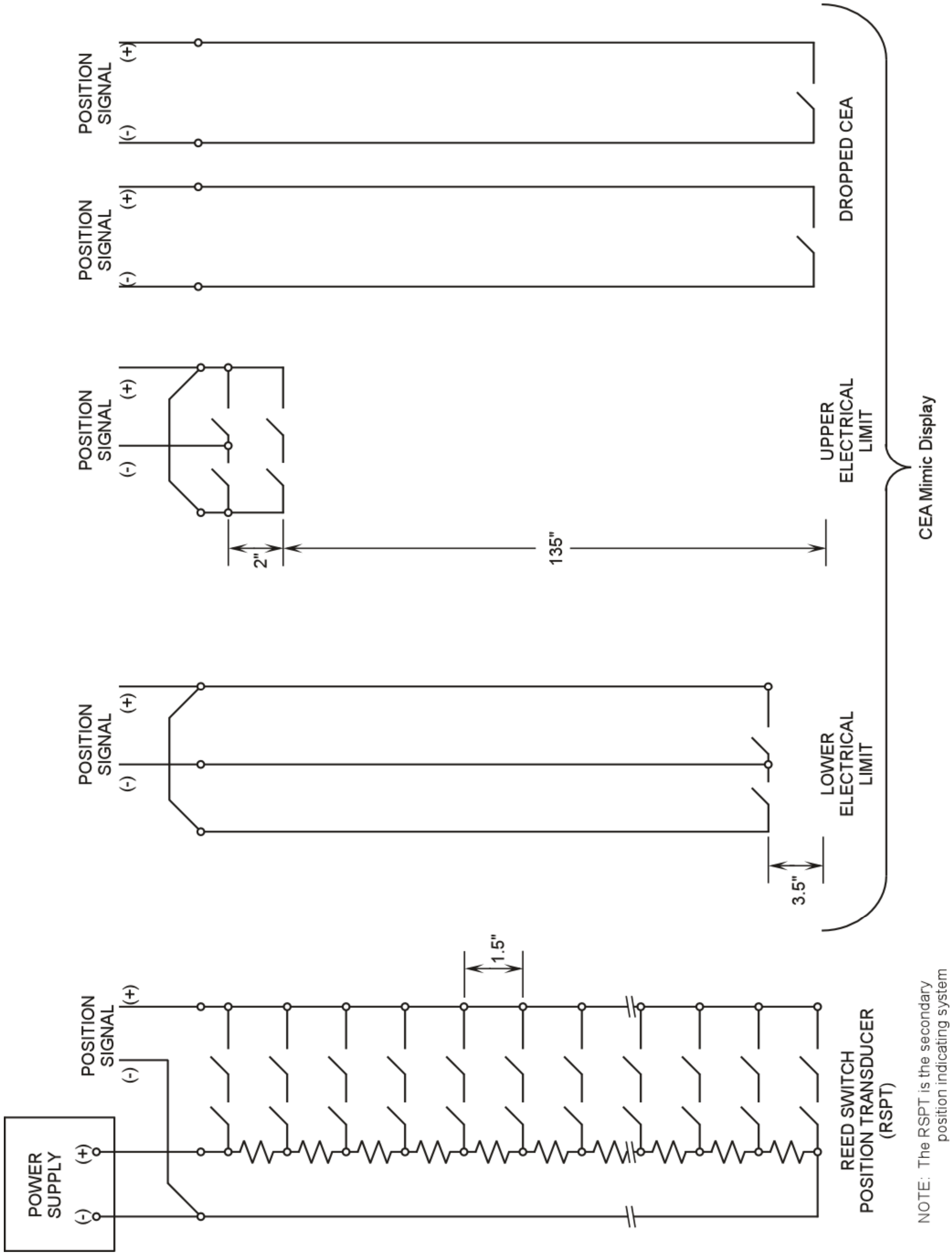


Figure 3-11 Reed Switch Assembly

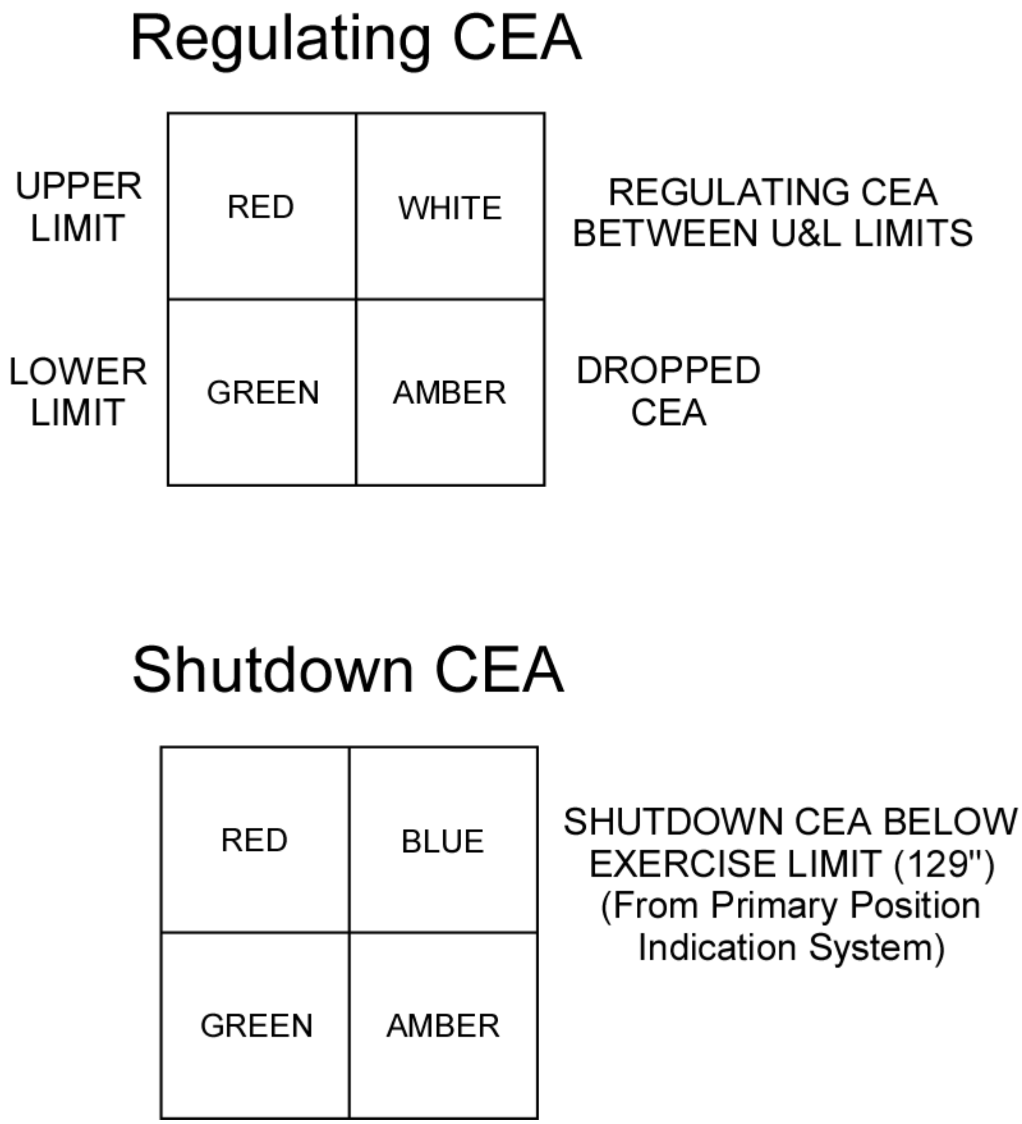


Figure 3-12 CEA Four Lamp Display

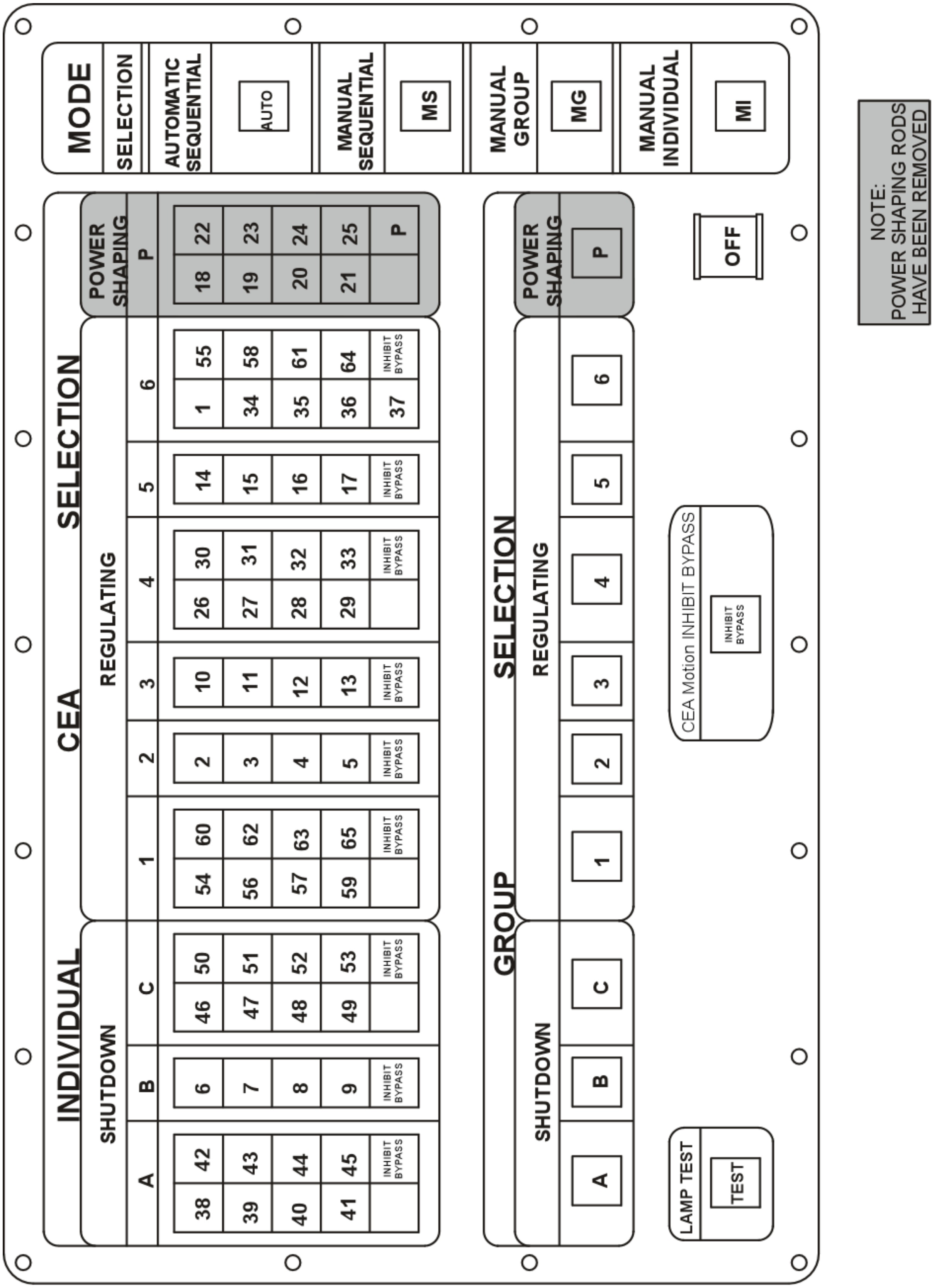


Figure 3-13 CEDS Control Panel