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GEAP-13761

AEC RESEARCH AND DEVELOPMENT REPORT

JUNE 1972

DESIGN, DEVELOPMENT AND TESTING OF THE SEFOR REACTIVITY OSCILLATOR SYSTEM

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PREPARED FOR THE
U.S. ATOMIC ENERGY COMMISSION
UNDER CONTRACT AT(04-3)-540

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OF THE SEFOR REACTIVITY OSCILLATOR SYSTEM**

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1. INTRODUCTION

1.1 GENERAL

This report describes the Oscillator Drive design and testing carried out for the Southwest Experimental Fast Oxide Reactor (SEFOR). SEFOR is a 20 MWt fast spectrum reactor which operates on $\text{PuO}_2\text{-UO}_2$ fuel and is cooled with sodium. It has characteristics similar to the large, soft spectrum fast breeder reactors which operate with mixed $\text{PuO}_2\text{-UO}_2$ fuel. Economic studies of these large power reactors have indicated a high potential for producing low-cost power. SEFOR is being used to obtain physics and engineering data at fuel compositions, temperatures, and crystalline states characteristic of power reactor operating conditions. The plant is particularly designed for the systematic collecting of Doppler coefficient data of fuel reactivity and that of temperatures near the vicinity of the fuel melting region.

There are two parts to the SEFOR project: (1) the design and construction of the reactor, and (2) a related research and development program. Funds for the design and construction of the facility were provided by the Southwest Atomic Energy Associates (a group of seventeen investor-owned utility companies located in the South and Southwest parts of the United States), together with the Karlsruhe Laboratory of the Federal Republic of Germany, Euratom, and the General Electric Company.

The United States Atomic Energy Commission is supporting the Research and Development Program which consist of two phases:

- Phase I - Preoperational Research and Development
- Phase II - The reactor test program after the start of reactor operation.

This report describes work performed during Phase I of the Research and Development Program under Task 6.2, which is entitled Oscillator Drive.

1.2 DESIGN OBJECTIVES

The following were the design objectives for the Reactivity Oscillator System:

- a. Provide reactivity oscillations of variable amplitude and variable frequency as required for the experimental program.
- b. Provide a system for varying the primary and secondary sodium flow sinusoidally with a variable phase relation from the reactivity oscillation.
- c. Provide a system to cover the following range of variables:
 Reactivity amplitude - 0ϕ to $\pm 10\phi$.
 Frequency - 0.00125 to 0.5 Hz
 Wave shape - sine wave

1.3 SUMMARY AND CONCLUSIONS

The primary objective of the Reactivity Oscillator design was to provide a controlled system for oscillating reactivity with variable frequency and amplitude. To accomplish this objective a mechanism which incorporated a d-c motor driven scotch-yoke device was designed and extensively tested. The mechanism has demonstrated reliable and reproducible performance over the complete range of frequencies and amplitudes required.

The oscillator drive uses a scotch-yoke device to provide sine wave oscillations of a poison rod about a pre-set core axial position, thus introducing oscillating increments of reactivity into the core. This mechanism was used to carry out plant dynamic response tests for determination of the full power reactivity (temperature) coefficient at SEFOR. The oscillator mechanism is supported on the reactor vessel head at the center position by the positioner and

drywell as shown in Figure 1. A d-c motor with a 30 to 1 speed range drives the scotch-yoke mechanism through a gear reducer which provides an additional 20 to 1 step speed change. The poison rod, being attached to the cam of the scotch yoke mechanism, is oscillated up and down in a sine wave motion. Amplitude is variable through adjustment of a lead screw on the rotor mechanism.

A Balanced Oscillator Control System was also developed which provides oscillating control signals to the main primary and main secondary coolant pumps as required to achieve balanced conditions with the oscillating reactivity. In this manner either the reactor coolant temperature or the reactor power can be held constant.¹

2. SYSTEM DESCRIPTION

2.1 GENERAL

The reactivity oscillator system consists of an oscillator mechanism, poison rod, positioner drive, drywell, and the associated control system for performing conventional oscillator tests and balanced oscillator tests.¹ The oscillator mechanism provides sinusoidal displacement of the poison rod by a scotch-yoke mechanism. A schematic of the scotch-yoke device is shown in Figure 2. This device is a classical mechanism for the generation of sine wave displacement from a rotating wheel. The positioner provides a method of moving the complete oscillator mechanism and poison rod up and down between the full in and full out positions. The poison rod is operated in a drywell (so that it does not operate in sodium) which extends from the reactor vessel head down through the center of the core.

The oscillator mechanism is located in the refueling cell mounted on the positioner at the center of the reactor vessel head. The control for the oscillator system is located in the control panel on the main console. The control system used for carrying out conventional oscillator tests is shown in Figure 3. The oscillator mechanism rotational motion produces the sinusoidal reactivity changes through the scotch-yoke device. The same motion also provides the input to a servo-transmitter whose output drives a servo-receiver system which in turn is used in a synchronous manner to drive a shaft encoder for the sampling interval input signal to the data acquisition system computer. For the balanced oscillator tests, the same system is used except that the servo-receiver now provides the input rotation for rotating additional devices such as the sine pots as shown on Figure 4.

2.2 MECHANISM CONTROL

Controls for operation of the oscillator mechanism during reactor tests are located on the main console as shown in Figure 5. The oscillator mechanism provides the variable speed (frequency) and amplitude control of the oscillator poison rod. Variable speed (frequency) is attained by providing variable direct current to the drive motor, which, through a gear reducer and scotch-yoke device, drives the oscillator poison rod up and down.

Motor control is accomplished by three pushbutton switches located on Panel 1 for either "fast," "slow" or "stop" modes of operation. A six-position speed-selector switch selects one of six separate precision potentiometers which are preset for a desired set of speed ranges. By manipulation of the selector switch, the preset speeds can be used and repeated if necessary for test verification.

High speed and low speed control (speed range control) is accomplished by use of gearing and clutch and brake mechanisms. The clutch and brake (see Figure 6) are controlled remotely by solenoid operation. When both solenoids are energized, the mechanism is in the "hold" position and does not rotate. The switch on the control console may be either in the low speed, hold, or high speed positions.

For low speed operation, the brake is energized and the clutch deenergized. This action makes use of a 20:1 intermediate gear reducer providing lower speeds.

For high speed operation the clutch is energized and the brake deenergized. This action removes the 20:1 intermediate gear reducer providing higher speeds.

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 REV. 8/

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 REV. 8/

Figure 1. Oscillator Mechanism

Figure 2. Scotch-Yoke Device

Figure 3. Automatic Control System for Balanced Oscillator Tests

Figure 4. Program Control System for Balanced Oscillator Tests

1 - PERIOD TIMING CONTROLS

3 - POSITIONER CONTROLS

5 - MOTOR CONTROL

7 - D. C. POWER

2 - POSITIONER DISPLACEMENT

4 - SPEED RANGE CONTROLS

6 - SPEED SETTING CONTROLS

8 - AMPLITUDE CONTROLS

Figure 5. Main Control Console

1 — UPPER GEAR REDUCER

2 — BRAKE

3 — OUTPUT GEAR

4 — INTERMEDIATE GEAR REDUCER

5 — CLUTCH

Figure 6. Oscillator Mechanism Gearing, Clutch, and Brake

Changing from high speed to low speed operation results in rotational reversal of the output drive gear. Therefore, in order to maintain the same rotational motion, the d-c drive motor must be reversed accordingly. This is accomplished by reversing contactors supplied with the d-c motor control circuit. When operating in the high speed mode, the "fast" (forward) pushbutton is used for motor start, and when in the low speed mode, the "slow" (reverse) pushbutton must be employed for motor start.

Once the oscillator controls are set, it is desirable to get a positive check on the frequency of oscillation. This is done with the timing controls on the console. These consist of an accurate timer that is turned "on" and "off" automatically by quadrant switches on the oscillator device.

The "on-off" switch for the timer also provides the "reset" action for the timer controls, which, when the "manual-auto" switch is on "auto," provides a one-shot time increment for one cycle of the oscillator. After each time run the on-off control switch must be depressed to reset the one-shot control relays.

Each quadrant switch/relay/light set is arranged so that the quadrant light (and relay) is turned on when entering the quadrant and turned off by the following quadrant switch. The operator can tell at any moment which quadrant the oscillator is positioned in, by the lights on the console.

The amplitude is varied by positioning the driving pin on the scotch-yoke mechanism by the use of a 28-volt d-c motor (see Figures 7 and 8). The rotating shaft is locked into place so that it cannot move out of position by the use of a 28-volt d-c solenoid latch which must be energized before amplitude changes can be accomplished. The controls on the console in the control room consist of an "off-on" switch for energizing the solenoid latch, a polarity selecting switch marked "increase" - "decrease" for positioning the driving pin on the scotch-yoke, and a pushbutton marked "run" for jogging the positioning mechanism into its proper position for amplitude adjustment. The d-c motor and solenoid are interlocked to prevent operating the motor unless the latch solenoid is energized.

Meters are provided that indicate the 28-volt d-c supply voltage and the solenoid and motor current. Motor and solenoid currents verify proper operation of each device and would indicate an abnormal condition by gross changes in operating current.

The oscillator position-sensing element is a linear null-type position transducer operated on high frequency (2500 Hz) alternating current and is located on the oscillator device in the refueling cell. The modulator/demodulator is located outside the refueling cell and is operated on 115V ac. The output of the modulator-demodulator is d-c volts; the full scale output is 0 to 4 volts which represents minus five inches to plus five inches displacement. An output connection on the console is provided for input to a light beam oscillograph for visual recording.

The positioner drive mechanism provides the control for positioning the slug in the proper axial position. This mechanism consists of a two-speed reversible motor with a positive brake that locks the shaft when the power is removed.

The controls for the motor and brake are conventional using a reversing motor controller for the reversing control and a two-speed controller for the two-speed control. Power for the motor is 208V ac, 3 phase, 4 wire with the ground carried through to the motor frame.

The controls for the lower and raise functions are provided with automatic interlocks so that the oscillator and Fast Reactivity Excursion Device (FRED)² functions are controlled separately and that certain restrictions provided for FRED operation do not inhibit operation of the oscillator.

On the console the speed of the positioner drive operation is selected on a two-position switch marked "slow" and "fast." Two pushbutton switches, one marked "lower" and one marked "raise" are used to control the direction of slug movement. Indicator lights show "slow," "fast," "lower" and "raise" functions.

Position of the reactivity control device, with regard to a reference point, is indicated on a four decade digital readout on the control console. The readout is in terms of inches displacement.

Figure 7. Variable Amplitude Mechanism

Figure 8. Reverse Side of Variable Amplitude Mechanism

The transmitter is a four digit decimal counter for transforming shaft rotation into digital display. The shaft of the counter is geared to the positioner drive mechanism in such a way as to read out the vertical displacement in inches. Conversion from disc/brush operation is accomplished within the encoder housing so that straight decimal output is provided and there is no intervening electronics between the encoder and the digital readout.

2.3 BALANCED OSCILLATOR EXPERIMENT

The balanced oscillator test consists of oscillating a reactivity device, and at the same time, oscillating the coolant flow so as to hold either core coolant temperature or reactor power constant. Estimates of the coolant flow oscillations necessary for the balance conditions are reported in references 3 and 4.

Automatically controlling the coolant flow in order to attain the balance conditions is very complicated. It was determined by analysis that if certain flexible parameters of flow control were made available in combination with a manual and automatic control system, a less complicated scheme could be realized for giving the necessary primary coolant temperature conditions. The flexible parameters available for obtaining the balance oscillator control conditions are as follows:

- a. Two sinusoidal signals that follow the oscillator device exactly with respect to frequency.
- b. The ability to change the phase relationship of each of the two signals, with respect to the oscillator device, independently and over nearly 360 degrees.
- c. The ability to change the wave shape of each of the two sinusoidal signals to compensate for the effects of the more influential harmonics.
- d. The ability to change the amplitude of the signals.
- e. The ability to operate each oscillatory signal about an independent and adjustable set point.

The two signals are used to control the Main Primary and Main Secondary flow rates. The Main Secondary control may not be required for some power levels and flow rates.

More specific and detailed aspects of the Balanced Oscillator Experiment are contained in reference 5.

2.4 IN-CELL HANDLING

Figure 9 shows the components of the reactivity oscillator system as they are mounted on the reactor head and their relation to the refueling cell floor wells and the grapples used in handling operations.

System installation proceeds by first installing the drywell. The drywell is approximately 14 feet long and extends approximately 12 inches above the center head and is located in the center position on the head. It bolts to the center head at joint A shown on Figure 9. Once the drywell is installed and bolted at point A, the positioner is installed. The positioner mounts to the top of the drywell and the lower part of the jack screw extends down inside the drywell for about 2 feet. Once the positioner is installed, the assembly of the drywell and positioner extends approximately 4 feet above the head, the uppermost point being the top of the guide bars which are shown with the 20 inch stroke along their length. The drive motor is shown on Figure 10 and is mounted just to the side of the positioner on a pedestal that is bolted to the head. During removal and installation of the positioner, this motor remains in place and is disconnected from the drive shaft by a coupling. Another connection made to the positioner is a cannon-type connector which also attaches to the screw jack portion for the position indication system and limit switches. The motor requires another connection of a cannon connector type for 220 volt, 3 phase power.

The next installed item of the oscillator system is the poison rod. This rod, as shown in Figure 11, is installed down through flange B of the positioner into the inside of the drywell before the oscillator mechanism is installed. The poison rod is approximately 15 feet long and 1-1/4 inches in diameter.

Figure 9. Oscillator Mechanism Removal Study

Figure 10. Positioner Drive

Figure 11. Oscillator Poison Rod

The next item to be installed in the oscillator system is the oscillator mechanism. This is designed for handling with the multi-ton grapple and is less than 24 inches across at its maximum point. It can be brought into or out of the cell through the vertical transfer port. The oscillator mechanism is installed by lowering it down onto flange joint B where it is bolted to the positioner. In order to clear the three guide bars, it requires raising and then lowering down from the top. After placement, the split ring which helps support the guide bars on the positioner are installed around the support column of the oscillator mechanism. After the mechanism is bolted in place, the poison rod is raised and inserted into a grappling device which is essentially an adapted lathe chuck (see Figure 12). This lathe chuck is a universal type which requires the rotation of a hexagonal head tool inserted at one point in order to draw the chuck jaws up tight on the poison rod and at the same time center it. This actuation of the universal chuck can be done with either a hand tool or an impact tool.

The final step in installing the oscillator mechanism is the attaching of the two cannon-type connectors which attach at the bottom of the lower base plate on which the upper case mounts.

After installation of the oscillator, if removal of the reactor vessel head is required the following steps are necessary:

- a. Grapple the oscillator mechanism with the multi-ton grapple.
- b. Remove the bolts at joint A on the center head where the drywell and center head are joined.
- c. Disconnect the shaft coupling between the positioner motor and drive screw.
- d. Disconnect three cannon-type connectors, all of which are lanyard pull-type, two on the underside of the oscillator mechanism and one on the positioner.
- e. Lift complete assembly from the reactor head with the multi-ton grapple.
- f. Transport from over vessel head to the floor well where it is lowered for storage during head handling.
- g. Shield plug open hole on the head while the drywell and drive system are out.

The connection to the positioner drive motor (220 volt 3 ϕ) is also a lanyard pull-type disconnect. This connection does not have to be broken since enough cable is provided to allow for removal of the vessel head. As shown in Figure 9, the maximum height for lifting above the head is 22 feet 6-1/2 inches and the overall length from the grapple handle to the bottom of the drywell is approximately 22 feet, allowing about 6 inches of clearance over the edge of the vessel skirt.

3. COMPONENT DESCRIPTIONS

3.1 GENERAL

The Reactivity Oscillator System consists of an oscillator mechanism, poison rod, positioner drive, drywell, and an associated control system for performing conventional oscillator tests and balanced oscillator tests.

3.2 OSCILLATOR

The oscillator mechanism provides sinusoidal displacement of the poison rod by means of a scotch-yoke mechanism. The oscillator is an assembly of the drive mechanism, rotor mechanism, support column, and poison rod.

The drive mechanism (see Figure 13) provides the input power to oscillate the poison rod and to also incorporate a variable speed system used to vary the frequency of oscillation of the poison rod. A d-c drive motor as shown in Figure 13 provides the variable frequency required. This d-c drive motor has a range of speed variation of approximately 30-to-1 and is not sufficient alone to cover the 400-to-1 range of frequencies required for experimentation. To obtain a wider range of speed variation, a step change in gear reduction is used which enables the motor to be started from its lowest speed and increased to its highest speed with an intermediate gear reducer that provides an additional 20-to-1 reduction.

- 1 — RUBBER BELLOWS
- 2 — DRIVE ROD
- 3 — POISON ROD
- 4 — ADAPTED LATHE CHUCK

Figure 12. Oscillator Poison Rod Grappling Device

Figure 13. Oscillator Drive Mechanism

To obtain the higher speeds, the intermediate gear reducer is coupled to its input shaft so that it no longer provides a gear reduction but serves only as a coupling between the upper gear reducer and the output gear. This is accomplished by energizing the clutch (see Figure 13) which functions to hold the case at the intermediate gear reducer to the input shaft. Since the intermediate gear reducer input shaft is actually the upper gear reducer output shaft, this action results in forming a shaft coupling between the upper gear reducer and the output gear.

For low speed operation the brake is energized. This action holds the case of the intermediate gear reducer stationary, thereby allowing it to function as a gear reducer with an additional 20-to-1 reduction. This method of speed control provides for a range slightly greater than that required and, in addition, allows for an overlap in the area where the change from high speed to low speed operation with the 20-to-1 intermediate gear reducer is made.

The rotor mechanism (see Figure 14) converts the rotary motion from the drive mechanism into vertical displacement of the poison rod by means of the scotch-yoke device. A schematic of this scotch-yoke device has already been shown in Figure 2. This device is a classical mechanism for the generation of sine wave displacement from a rotating wheel.

The rotor mechanism also incorporates the device for varying the amplitude of the sine wave generated by the scotch-yoke. Referring to Figure 14, the positioning screw is rotated by the gear motor. This screw causes the roller mounting piece to move either inward or outward in a radial direction from the center of the rotating wheel, thus changing the peak amplitude generated by the mechanism. The purpose of the solenoid is to provide a coupling force to lock the screw to prevent its rotating during motion of the wheel. The electrical power for operating both the solenoid and the gear motor are supplied to the rotating wheel by three slip rings.

One means of determining the speed of the rotating wheel is provided by a series of limit switches (see Figure 15) that are located on the outer edge of the stator portion and are actuated by the cam arm on the rotor. These switches actuate a timing system which is located on the main console and provide readout of the period of oscillation.

As shown in Figure 16 the oscillator support column supports the covered rotor and drive mechanisms on top of the positioner drive. It also provides the means of attaching the poison rod to the yoke of the rotor mechanism. The drive rod, which is fastened to the yoke, has a three-jaw chuck attached at the lower end, which is the coupling device for the poison rod as illustrated in Figure 12. This coupling method requires only one point of rotation to move all three chuck jaws inward or outward so that the coupling operation can be made either by hand or with a small impact-type wrench.

The oscillator poison rod (see Figure 11) is approximately 15 feet long with a poison section of approximately 26 inches in length. The poison section can extend from 3 inches below the flux center to 23 inches above and may be oscillated about a mean point which can be varied by use of the positioner mechanism. The poison rod is isolated from the sodium by a drywell, which mounts on the reactor vessel head and extends down inside the center channel to a point below the core centerline. To indicate rod position, a linear transducer is located inside the oscillator mechanism case as explained in Section 2.1, and is attached directly to the yoke which, in turn, is attached to the poison rod as shown in Figure 17.

To check the calibration on the linear transducer, a scale and pointer arm (see Figure 18) are located outside the oscillator case. The scale is attached to the support column and the pointer is attached to the coupling which couples the yoke to the poison rod. This pointer and scale will allow for calibrating and for checking the calibration of the linear transducer to within $\pm 1/32$ inch. Also, inside the oscillator case is a servo-transmitter which is used to check the rotational frequency of the wheel and to drive the balanced oscillator control system (see Figure 19).

The oscillator mechanism is protected from the cell argon gas by a sealed outer cover and a rubber bellows (see Figure 16). The mechanism is assembled and sealed outside the cell with normal air inside which provides for operation of the equipment in an atmosphere that is higher in oxygen than the normal cell. The assembled oscillator mechanism without its cover is shown on a test stand in Figure 20.

Figure 14. Rotor Mechanism

Figure 15. Rotor Mechanism Limit Switches

Figure 16. Oscillator Mechanism Assembly

1 — LINEAR TRANSDUCER FOR
INDICATING POISON ROD
POSITION

Figure 17. Top Portion of Assembled Oscillator Mechanism

- 1 - OSCILLATOR
SUPPORT COLUMN
- 2 - SCALE
- 3 - POINTER ARM

Figure 18. Scale and Pointer Arm

Figure 19. Assembled Oscillator Rotor

Figure 20. Assembled Oscillator Without Cover

3.3 BALANCED OSCILLATOR CONTROL SYSTEM

The balanced oscillator control system provides oscillating control signals to the main primary and main secondary coolant pumps, as required to achieve balanced conditions. A Balanced Oscillator Test (BOT) consists of presenting the oscillating reactivity, primary coolant flow, and secondary coolant flow data in such a manner that either the reactor coolant temperature is held constant (first BOT), or the reactor power is held constant (second BOT).

Two different control systems will be used for these tests: a manual or programmed control system, and an automatic control system.

3.3.1 Programmed Control System

The input to this control system is an oscillating signal obtained from the shaft of the rod oscillator drive motor. The output of the system consists of two control signals used to oscillate the main primary and main secondary coolant flow rates. This system can be used for either the first or the second balanced oscillator tests. A shaft encoder output (32 positions per revolution) and a pulse generator output (360 pulses per revolution) are provided for use by other systems.

Operation of the programmed control system to perform a balanced oscillator test is based on the ability to predetermine the relative phase and amplitude required for oscillation of the main primary and secondary coolant flow rates. These values will be set into the system by means of control knobs on the sine potentiometers while the reactor is operating at the initial steady-state condition. After the controls are set, the rod oscillator drive motor will be started, initiating oscillation of reactivity, primary coolant flow, and secondary coolant flow.

Simulated tests on an analog model of the plant showed⁶ that the initial amplitudes of oscillation in coolant temperature and core power are not excessive. The principal parameters are recorded on oscillographs so that reactor and plant conditions can be observed visually throughout the test.

If the initial control settings do not produce the desired balanced condition, the controls can be adjusted while the system is in operation. The effect of each adjustment can be observed directly on the oscillograph, so it should be possible to achieve the balanced condition with relatively few adjustments.

A second method of operation which may be used is to start the oscillator with the coolant flow oscillation amplitude set at zero. After the initial transients are past, the coolant flow oscillation amplitude can be increased slowly to the desired value.

3.3.2 Automatic Control System

The input to this system can be either the core coolant temperature signals (first BOT) or the core flux signal (second BOT). The output of the system is a single control signal used to oscillate the main primary coolant flow. This signal replaces the one coming from the programmed control system. However, the programmed control system must be used to control the main secondary coolant flow and to synchronize the automatic system with the rod oscillator by means of the pulse generator.

The purpose of providing an automatic control system is to reduce the time required to achieve a balanced condition, particularly in the second BOT where greater control precision is required.

A signal from the automatic control system can be used to control the main primary coolant flow during balanced oscillator tests replacing the control signal from the sine pot in the programmed control system.

Automatic control of the secondary coolant flow rate is not practical because of the large phase lag between changes in the secondary flow rate and their effect on primary coolant temperatures. Consequently, the programmed control system must be used to control the secondary coolant flow using predetermined phase and amplitude values. Studies on the analog computer demonstrated that this will be feasible.

The reactivity and secondary coolant flow oscillations will be started while the signal from the automatic control system input unit is attenuated to zero by the potentiometer as shown in Figure 3. After the initial transients are past, the potentiometer setting will be increased slowly to 1.0. The automatic control system will then cause a primary coolant flow oscillation which will result in the desired balanced oscillator test conditions.

3.3.3. Balance Oscillator Control Equipment

The elementary diagram for the Balance Oscillator Control is shown in Figure 21.

The balance oscillator control package is located on Panel 11 in the control room and consists of a balance oscillator control unit, two millivolt to current transmitters, two function generators, two proportional amplifiers, and a power supply.

The balance oscillator control unit accepts a signal from the servo torque transmitter located in the oscillator mechanism. This torque transmitter (see Figure 19) is installed to make one complete rotation for each rotation of the oscillator rotor. A servo-receiver amplifier unit on the balance oscillator control chassis in the control room provides an output shaft rotation that exactly matches that of the transmitter. This output shaft is geared to two precision dial-sine-potentiometer units such that the sine pots follow the shaft rotation, but can be offset phase-wise by changing the setting of the precision dial. A third precision potentiometer is also driven from the shaft but does not have phase-shifting capability.

Also on the same servo-output shaft is a "Gray" code (binary) shaft position transducer and an encoder that produce angular position data. The "Gray" code transducer is used to program the Data Acquisition System for the sampling interval, and the encoder is used in conjunction with the automatic balanced oscillator control system.

The sine potentiometers are provided with power from two power supplies that are connected in a special manner to yield a sinusoidal output from all three potentiometers. The non-phase variable potentiometer is used to generate an output signal for recording. The other two phase variable signals are used to eventually modulate the sodium flow in the main primary and secondary loops.

The output of the potentiometers is adjusted so that at 0, 180, and 360 degrees the output is zero, at 90 degrees the output is peak positive and at 270 degrees the output is peak negative. The peak-to-peak, sinusoidal output is adjustable from zero to ± 50 millivolts by means of an amplitude adjust potentiometer. With the amplitude adjust pot set for 10.00, the output amplitude swing is from -50 mV to $+50$ mV; with the amplitude adjust pot set for 5.00, the output amplitude swing is -25 mV to $+25$ mV, and with the pot set for 0.00, the output amplitude is reduced to zero.

The output of each sine potentiometer is connected to one of the millivolt-to-current (mV/I) converters and the mV/I's are adjusted so that -50 mV yields a 10.0 milliamp output, 0.00 mV yields a 30.0 milliamp output, and $+50$ mV yields a 50.0 milliamp output. Over the oscillatory cycle then, the output of the mV/I varies about a mean of 30 milliamps up to a maximum of ± 20 milliamps, depending upon the amplitude adjust potentiometer setting.

The output of each mV/I is connected to a function generator so that the 10 to 50 milliamp sinusoidal signal can be reshaped to reduce the effect of some of the loop interaction harmonics. Mathematically, the function generator can be thought of as a device which will accept an input signal (x) and generate an output (y) which is a function of x.

$$Y = F(x)$$

x and y are normally both 10 to 50 mV signals.

The output of each function generator is connected to the "I₁" input of one of the proportional amplifiers. The output of the flow set point station on the control console (either main primary or main secondary) is connected to the "I₂" input of the proportional amplifier (the output of the flow set point stations is 10 to 50 milliamperes for 0 to 6000 gpm set point flow). The output of the proportional amplifier is then used to control the flow in the respective loop that previously had been controlled only by the flow controller on the console.

Figure 21. Balance Oscillator Control Elementary Diagram

The proportional amplifiers output can be described by the formula:

$$I_0 = (\pm I_1 \times C_1 \pm I_2 \times C_2 - K_1)R + K_2$$

where:

- I_0 = Output
- I_1 and I_2 = 10-50 ma inputs
- C_1 and C_2 = input scaling adjustments
- K_1 = input bias adjustment
- K_2 = output bias adjustment
- R = amplifier (span or gain) adjustment

I_2 is set up on a one-for-one basis so that the oscillatory signal modulates the output around the set point flow, (that is; with an I_1 input corresponding to zero flow oscillation, there would be exactly the same output of the proportional amplifier as there was from the flow set point station). The amplitude of the I_1 signal is set up to provide a flow oscillation of ± 500 gpm for 100% amplitude adjustment at the oscillator control chassis. For example, for a plus and minus 250 gpm oscillation around 3000 gpm flow, the amplitude control pot at the oscillator control chassis is adjusted to 50% and the panel 1 set point flow to 3000 gpm.

Only the amplitude control at the oscillator control chassis is used for oscillation amplitude control for the balance oscillator test. The amplitude control is set to provide a maximum flow oscillation of ± 500 gpm.

3.4 POSITIONER DRIVE

The primary purpose of the positioner drive is to provide a means of moving the oscillator mechanism or the Fast Reactivity Excursion Device (FRED) in an axial direction, either into or out of the core region.

The positioner raises or lowers the FRED or oscillator mechanism as complete units since, in either case, the reactivity device that is being used is mounted on the mounting base of the positioning drive. The positioner drive is shown in Figure 22 with the oscillator mechanism mounted on the mounting base. The poison rod from either device extends down through a hole in the large lifting screw of the positioner. The positioner without the drive motor is shown in Figure 23. The rotation of the input shaft causes the bevel gear seat to rotate the lifting nut, since the bevel gear is keyed to the lifting nut. The rotation of the lifting nut causes the screw to move up or down. Rotation of the screw is prevented by the guide bars extending through the lifting platform guides.

The basic lifting mechanism is a 50,000 pound lifting jack. The maximum load expected on the device is 1250 pounds which is imposed by the reaction when the FRED piston is expelled from the core. The critical loading mode occurs when the FRED is fired in the raised position where the screw is loaded as a column extended the full 30-inch stroke above the positioner. This extreme condition still imposes very little load on the screw (see Figure 24) relative to its capacity since the minimum "Euler" critical column buckling load for this configuration is 500,000 pounds.

The position indication for this drive is displayed on the main control panel for reactor control. The position indication mechanism is a rotary counter attached to the input shaft of the positioner mechanism and transmitting its signal to a digital readout in the control room. This system provides readout to four digits, for example, 18.54 inches. There are upper and lower limit switches on the positioner that allow a 20-inch stroke when the oscillator is used, and a 30-inch stroke when the FRED is used. The difference in the stroke length for each device is due to handling limitations within the refueling cell, and the fact that the oscillator mechanism case extends out over the guide bars so that the guide bars can be no longer than the support column of the oscillator mechanism. The drive motor for the positioner is a two-speed reversible motor with a worm gear reducer and a disc-type brake. The disc brake will stop the motor rotor so that coasting will be essentially eliminated. The fastest speed is 10 inches per minute and the slow speed is 2-1/2 inches per minute. An additional feature of this device to aid in checking position indication is a scale and pointer that has been placed along one of the guide bars so that the position can always be verified by use of either the periscope or the in-cell TV system.

1— OSCILLATOR

2— POSITIONER DRIVE MECHANISM

3— POSITIONER DRIVE MOTOR

Figure 22. Oscillator and Positioner Assembled for Checkout Tests

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Figure 24. Positioner Screw

The positioner drive was tested with the oscillator system to determine proper operation at room temperature and at simulated reactor temperatures to establish any possible adverse effects that might come about due to mounting the device on the reactor head. These tests were performed both at room temperature and at temperatures when the drywell was heated to 500°F. Over 200 cycles were carried out under these conditions and no problems were encountered with the mechanism.

The materials from which the positioner is fabricated were chosen for the specific function for each piece. The outer case and exposed surfaces other than the screw are all type-304 stainless steel. The internal parts are made of different material as required and are listed below:

Component	Material
Listing Screw	4140 Alloy Steel (nitrided)
Lifting Nut	Aluminum Bronze (heat treated)
Bevel Gear Set	4140 Alloy Steel (heat treated)
Bearings (all)	Alloy steel (heat treated)

The screw jack mechanism is designed to operate without lubricants, but to improve operation, molybdenum disulfide was used on the lifting nut and screw, and a small amount of radiation-resistant grease will be applied to the surface of the bevel gear set.

The connection between the drive motor and the drive mechanism is made by a coupling which allows for misalignment between the shafts. If binding were to occur in the mechanism, this coupling is designed to be the weakest link in the system, so that it will fail without damaging other parts of the system.

3.5 DRYWELL

The drywell is shown in Figure 25 and a cross-sectional view is presented in Figure 26. This cross-sectional view of the drywell shows the enlarged internal diameter at the upper end where the positioner screw extends down inside. Below this point the drywell narrows to the 1.380 inch internal diameter where the poison rod extends. The actuator rod is 1.25 inch and the poison slug is 1.315 inch o.d.

This drywell is designed according to specifications in Section III (Nuclear Vessels) of the ASME Boiler and Pressure Vessel Code. The portion of the drywell above the reactor head, which transmits the oscillator and FRED reaction loads to the vessel head, has been designed for 10,000 pounds of force, which is well above the 1250 pounds maximum expected for the FRED. The bolts which attach the drywell to the head are captured fasteners and stretch bolts to absorb the energy due to the design basis accident. The heavy walls provide a greater or equivalent amount of shielding below the head to that in the fuel rods thus protecting the reactor head from activation.

4. ANALYSIS

4.1 MOTION ANALYSIS

In order to achieve balanced conditions during testing, the motion of the oscillator poison rod (and resulting reactivity) is required to be compatible with the oscillating control signal input to the main primary and secondary pumps. This is achieved by using a scotch-yoke device to drive the oscillator poison rod (and resulting reactivity) in a sine wave motion. Referring to Figure 27, the development of the equation of motion for the oscillator poison rod proceeds as follows:

Let w = the constant angular velocity of the rotor.

X = the displacement of the oscillator poison rod at any time
(t) (Displacement when motion starts at $t=0$, $X=0$)

A = distance from center of rotor to yoke-driving pin.

Figure 26. Drywell - Section View

Figure 27. Oscillator Motion Model

Then, at time t , from Figure 27, the displacement of the oscillator poison rod is:

$$X = A \sin \alpha$$

and since $\alpha = \omega t$, the equation of motion for the oscillator poison rod becomes:

$$X = A \sin \omega t.$$

4.2 STRESS AND LOADING ANALYSIS

A detailed stress analysis has been carried out on the various components of the oscillator mechanism. The loadings and pressures used in the analysis were well above those expected during operation of the oscillator mechanism.

The following is a description of the loading and maximum stress in the major components:

1. Rotor Cam Roller

The cam roller on the rotor drives the oscillator poison rod up and down through the scotch-yoke. Loading on the cam roller is due to the weight and acceleration of the oscillator poison rod. Combining maximum loadings results in a maximum stress in bending of 15,000 psi.

2. Base

The base supports the oscillator mechanism on the positioner. Slots along the cylindrical section of the base make it possible to couple and uncouple the poison rod at the three-jaw chuck. Two types of loading occur at the lower flange:

- a. Axial loads which occur due to acceleration of the poison rod or when the grapple picks up the oscillator mechanism, positioner, and drywell for removal from the reactor vessel head.
- b. Bending loads which occur due to side loads.

The maximum stress of 14,600 psi occurs in the bolts due to the bending load assuming a 1/2 g side load which is more than twice the design earthquake load. The stress in the tube wall for this condition is less than 2,000 psi. These calculated stresses are well below the allowable yield stress. The upper flange of the base has less loading than the lower flange, therefore, the stresses will be less.

3. Drywell Lower Flange

The drywell supports the oscillator mechanism on the reactor closure. Stresses in the lower flange area are due primarily to three reasons: axial loads due to acceleration of the poison rod, bending loads due to side loads, or pressure loads due to reactor cover gas pressure.

The maximum stress of 6,730 psi occurs in the bolts when the bending load (assuming a 1/2 g side load) is more than twice the design earthquake load. This stress compares favorably with the ASME (Section III) allowable stress of 8,750 psi. The maximum stress in the flange due to the above loadings is less than 2,000 psi.

4. Case

The case, along with the rubber bellows, seals the oscillator mechanism in an air environment and isolates it from the cell argon. The oscillator mechanism equipment performs better in air than in argon. The case, being made of 1/8 inch thick material, is susceptible to buckling failure due to a differential pressure being applied during cell leakage tests. Calculations have shown that a 5 psi pressure differential can be safely applied to the case. Since the pressure internal to the case is normally atmospheric, the cell pressure will be limited to 5 psig or, when cell leakage testing is carried out, the internal pressure will be equalized with the cell test pressure.

5. Oscillator Poison Rod

A detailed heat transfer analysis was carried out on the oscillator poison slug. The result of this analysis indicated that for maximum rod insertion at 20 MW, the maximum cladding temperature would be less than 1000°F. If the emissivity of the drywell were only 0.75 instead of the 0.9 assumed, then the maximum cladding temperature would be approximately 1050°F. A special surface treatment was applied to the drywell in the core area to increase the emissivity to approximately 0.9 but certainly greater than 0.75.

The above heat transfer calculations were made assuming no natural convection in the drywell, no conduction along the length of the poison rod, and a uniform drywell temperature of 800°F. All of these assumptions tend to make the calculations conservative since the drywell is between 700°F and 820°F, and some conduction and convection along the length of the rod are to be expected.

5. SAFETY EVALUATION

The oscillator tests are performed by oscillating one or more of three controlled parameters: reactivity, main primary coolant flow rate, or main secondary coolant flow rate. The oscillator mechanism and control systems for the coolant flow rates have been designed so as to avoid the onset of an unsafe operating condition in the reactor system. The principal features which provide protection for the coolant systems are listed below. These features are included in both the main primary and the main secondary coolant system.

1. Reactor scram will occur if the coolant flow rate falls below 80 percent of the setpoint value.
2. The oscillating component of the control signal is added algebraically to the setpoint signal to obtain the final coolant flow control signal (see Figure 4). This provides a constant setpoint signal for the reactor scram circuit during oscillator tests.
3. Scale factors and bias signal for the Oscillator Control System will be chosen so that the minimum control signal (10 mA) will result in a flow rate of less than 20 percent below the setpoint value, and the maximum control signal (50 mA) will result in a flow rate less than 20 percent above the setpoint value. This limits the amplitude of flow oscillation to a safe value and also provides protection against unsafe flow rates caused by a failure in the oscillator control system.
4. Trip amplifiers for the input and output signals of the automatic control system are provided to protect against failures in this system. If either the input or output signal exceeds a predetermined value, the automatic control system will be disconnected from the coolant flow control (see Figure 3). If this occurs, the primary coolant flow will return to the setpoint value while reactivity and secondary coolant flow will continue to oscillate. This will be a safe reactor condition and the action will prevent unnecessary reactor scrams.

From a mechanical point of view, the scotch-yoke mechanism of the oscillator device has several safety advantages. The amplitude is fixed and would require the failure of a component to allow the rod to drop a distance greater than the fixed amplitude. The maximum speed of this device is 0.56 Hz. For speeds greater than 0.56 Hz, the response of the reactor is such that the oscillations would not significantly perturb the reactor.

The speed control switch on the control console is a three-position one. This has the added advantage of assuring that if both solenoids are de-energized, by turning off the power or by a 90-volt d-c power failure, the oscillator mechanism releases and the poison slug will move into the lowest position in the core.

6. DEVELOPMENT TESTING

6.1 CHECKOUT TESTS

The oscillator mechanism mounts on the positioner drive (see Figure 22) in the center hole position of the reactor and is used to oscillate a poison slug about different levels of the core in a sine wave motion with variable amplitude and variable frequency.

Initial checkout testing of the oscillator mechanism identified some problems that were corrected by minor changes. After the changes were made, testing was continued in order to quantitatively evaluate the performance of the oscillator mechanism. The time to change the amplitude of the oscillations was measured and found to be about 35 seconds per inch of change. For example to change the amplitude from ± 1 inch to ± 2 inches would require 35 seconds while the oscillator is in motion. Also, the frequency range in each mode was measured as follows:

Slow mode - 0.00083 cps to 0.028 cps

Fast mode - 0.016 cps to 0.56 cps

The functional requirement for the frequency range was 0.00125 cps to 0.5 cps.

Additionally, a preliminary test program was carried out with 105 hours of running time at various speeds and amplitudes over the range of operation expected at the plant. Temperatures of various components were recorded during tests which included continuous running periods at both slow and high speeds for 5-hour periods. The maximum temperature rise was about 50°F.

An additional 25 hours of testing was completed with added loading on the actuator shaft of the oscillator mechanism. The purpose of this series was to determine what effect added loading might have on the temperature rise of the motor and other components within the oscillator mechanism. A temperature rise of 10 degrees occurred with an added 15 pounds of weight. This 15 pounds was approximately double the weight of the poison rod.

A final series of tests were run to verify whether the oscillator mechanism would operate satisfactorily under simulated reactor operating conditions. A description of these tests is presented below.

6.2 TEST PLANS

The following tests were run at room temperature to establish reference conditions for the heated tests:

- a. With the covered oscillator mechanism mounted on the positioner and the positioner screw near the upper limit of the stroke, the oscillator mechanism was operated for 1 hour at a frequency of 0.001 cps and an amplitude of 4.5 inches. All oscillator thermocouple temperatures and one ambient air temperature were monitored and recorded at start of test, at midpoint (1/2 hour), and at the end of the test (1 hour).
- b. The positioner mechanism was lowered to mid-stroke (10 inches) and the above test was repeated.
- c. After allowing the oscillator mechanism to cool down, the above sequence (a and b) was repeated with the cover off the oscillator mechanism.

Then, to simulate the reactor-cell temperature environment, a special heated test setup was employed for some additional testing. This special test setup consisted of an enclosed air space and a heated positioner mounting plate and drywell. The system was brought up to temperature by maintaining the positioner mounting plate temperature between 475°F and 525°F for at least 1/2 hour before starting the tests. The following tests were then run:

- a. The oscillator mechanism (with cover off) was operated at a frequency of 0.001 cps, and an amplitude of 4.5 inches for one hour with the positioner set near the upper limit of the stroke. Temperatures of all thermocouples were recorded at start, midpoint, and end of test.
- b. The positioner was lowered to mid-stroke (10 inches) and the above test was repeated.

- c. The system was allowed to cool down and then the cover was installed on the oscillator. The system was then brought back up to temperature and the test plan indicated in Table 1 was carried out. All temperatures were monitored and recorded at periodic intervals during the tests.

6.3 TEST RESULTS

The operability of the oscillator mechanism was demonstrated by satisfactory performance under the varied conditions of the test program.

Neither the temperature nor the positioner location had a significant effect on the operability of the oscillator mechanism. This was witnessed several times as an almost constant output to input response under the varied test program conditions. A close scrutiny of the oscillator mechanism temperatures monitored during the testing showed a maximum temperature of $\sim 170^{\circ}\text{F}$ which is well below the 250°F design temperature used.

Table 1
OSCILLATOR MECHANISM TEST PLAN

Testing Sequence No.	Energized (Clutch Or Brake)	Frequency (cps)	Amplitude (in.)	Positioner Screw Location	Running Time (h)
1	Brake	0.001	4.5	Near upper limit (20 in.)	1-1/2
2	Brake	0.001	4.5	Near mid-stroke (10 in.)	1-1/2
3	Brake	0.025	4.5	Near mid-stroke (10 in.)	1
4	Brake	0.025	4.5	Near upper limit (20 in.)	1
5	Clutch	0.020	4.5	Near upper limit	1
6	Clutch	0.020	4.5	Near mid-stroke (10 in.)	1
7	Clutch	0.500	4.5	Near mid-stroke (10 in.)	1/2
8	Clutch	0.500	4.5	Near upper limit (20 in.)	1/2

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