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DEVELOPMENT OF THE OMRE CONTROL-SAFETY ROD

ATOMICS INTERNATIONAL

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34 PAGES

DEVELOPMENT OF THE OMRE CONTROL-SAFETY ROD

BY:

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ABSTRACT

A description of the control-safety rods for the OMRE (Organic Moderated Reactor Experiment) and the developmental testing of these rods are presented. The OMRE control-safety mechanism utilizes an electro-mechanical drive in conjunction with a rack and pinion for insertion or withdrawal of rods. The nuclear poison material consists of boron carbide powder compacted and sealed in AISI 4130 tubing. The twelve rods required are paired into six groups to reduce the number of drive units. Four groups are used for shimming action and have only a slow-speed drive. The other two groups can be used for either shimming or regulating action and have both slow-and fast-speed drives. The rods also function as safety rods by utilizing a quick-release mechanism.

A prototype rod was tested under reactor operating conditions. Descriptions of the drive motor and gear assemblies, rack and pinion, scram release mechanism, snubbing action, rod guidance, and a discussion of materials compatibility are presented.

I. INTRODUCTION

The purpose of the Organic Moderated Reactor Experiment (OMRE) is to investigate the feasibility of using an organic material as moderator, reflector, and coolant in a nuclear reactor. Although the design was predicated on the investigation of the behavior of diphenyl, sufficient flexibility was built into the system to permit testing of other polyphenyls or mixtures of polyphenyls. The final selection of Santowax OM (a commercial mixture of ortho and meta terphenyls, approximately 2:1) for use in the OMRE was based on the best information available shortly before completion of the construction of the facility. The OMRE is a minimum cost experimental facility designed with sufficient flexibility to permit operation under a wide range of conditions in order to establish the most favorable operating parameters for organic moderated and cooled reactors.

The OMRE control system utilizes 12 rods which are combination control and safety rods. Since it was desirable to reduce the number of rod drive mechanisms, the rods are actuated in pairs. The rod pairs are placed in two concentric rings in the core. The inner ring contains two rod pairs and the outer ring, four rod pairs.

Early development and testing on the OMRE control and safety rod was conducted using a hydraulically-driven and magnetically-coupled system. This system was selected because it was extremely simple, possessed a relatively small number of parts, and consequently appeared to promise trouble-free operation. While the test of the hydraulic-magnetic system was in progress, further system analysis revealed that the operation of the OMRE presented too many unknowns to permit satisfactory control with only the single regulating and shimming action originally contemplated. The design of the hydraulic-magnetic system was not suited for the required more elaborate type of control without major modification.

It was, therefore, decided to abandon the hydraulic-magnetic system and concentrate all effort on an alternate electrically-driven and mechanically-coupled system, which was ultimately installed in the OMRE. As a result of the change, it became necessary to accelerate all effort towards an early completion of the test if the system were to be ready for installation in the reactor on schedule. This change also meant that the reactor parts would have to be manufactured at the same time as the test parts. Therefore, there was no opportunity to change components other than those which failed to operate properly, without causing long delays before reactor operation could be started. No significant design changes could be made after the alternate rod fabrication began.

Each of the six rod pairs is provided with a slow shim motor and gear drive. Two of these pairs, one in the inner and one in the outer ring, have in addition a regulating motor producing a faster driving speed through differential gearing.

Only one of the regulating rods may be actuated at any time. The outer ring of shim rods is withdrawn first to place some of the rods in a position of maximum differential worth without seriously distorting the neutron flux. At this time, only the outer ring of shim rods is in a position which is of sufficient differential worth to control the neutron flux. For this reason, the regulating rod located on the outer ring is used during initial phases of operation. After appreciable amounts of excess reactivity have been lost, the inner ring of rods will be withdrawn to a position of large differential worth and the inner regulating rod will be used for reactor control. In this manner a rod of large differential worth is actuated, which provides less rod motion and less flux distortion in diphenyl at reactor temperatures. The drive unit was a compound unit: that is, one equipped with both a slow shim motor and a fast regulating motor.

II. DESCRIPTION OF TEST FACILITY

The test vessel consisted of three sections of 12-inch and five sections of 6-inch flanged Schedule 40 mild-steel pipe mounted one above the other (Fig. 1). The vessel was fabricated in sections to facilitate assembly, disassembly, and inspection of the control rod components. Numerous openings through the vessel walls, which could be covered with blind flanges, were incorporated to allow insertion of instrumentation to measure acceleration and deceleration of the control rod during a scram. Two sight gages were mounted on the vessel, one to indicate the reactor low diphenyl liquid level and one to indicate high diphenyl level. The drive mount plate and top thimble were nearly identical to those

Fig. 1. Test Vessel

used on the reactor grid plate and were welded inside the vessel at an elevation comparable to the reactor grid plate. The snubber cylinder was also mounted inside the vessel at the correct elevation.

A dump tank was connected to the lower vessel section for diphenyl storage. In case serious leakage occurred at any of the flanged joints, the fluid also could be drained out of the test vessel into the dump tank. An overflow tank was connected into the main vessel at the high diphenyl level so that the fluid could not rise above this point while testing at the high temperature.

In order to gain experience for possible reactor application, induction heating was utilized on the pipe sections which contained the diphenyl. Resistance heaters were used on the dump tank, overflow tank, and associated piping. Resistance heaters were also used on the vessel sections above the liquid level; these were controlled with a variable transformer because the temperature in this region had to be maintained under 300° F to protect the components of the control rod.

Since the assembly was to run at 300 psi with the main vessel heated to 700° F, automatic safety valves were utilized on the test vessel, dump tank, and overflow tank as a safety precaution.

III. DESCRIPTION OF CONTROL-SAFETY ROD DRIVE SYSTEM

A. CONTROL RODS

Early preliminary studies of various materials, types, and geometries indicated powdered boron carbide, sheathed in a 1 1/4-inch-diameter steel cylinder and located in two concentric rings in the reactor, to be the most desirable control rod for the OMRE.

The control-element nuclear poison is boron carbide, B_4C, of crystalline structure and mixed grain size. The boron carbide is vibration packed in a heavy-walled AISI 4130 tube, dry, to an approximate density of 1.90 gm/cm^3. This is 80 per cent of the crystalline specific gravity. The active length of B_4C is 38-1/4 inches, instead of the 36 inches needed for normal rod travel, to allow for misalignments, thermal expansion differentials, and over-travel due to snubber action. The packed B_4C is held in place and separated from a gas expansion chamber by a stainless-steel filter plug with a five-micron pore size.

The B_4C molecule will be damaged by thermal neutron irradiation, forming lithium and helium from the boron atom. This will cause an increasing helium pressure in proportion to the B^{10} burn-up. Since it is desirable to contain this gas, the AISI 4130 container is constructed of a 1-1/4-inch-diameter tube with a wall thickness of 0.120 inches, sealed on both ends with welded plugs.

Two of these control rods are attached to a common yoke and hanger-rod adapter at their top ends (See Fig. 2a). The yoke and control-rod ends are streamlined to reduce the hydrodynamic resistance during a scram fall. When fully inserted, the connection yoke is twelve inches above the top of the reactor grid guide bushing to reduce the alignment problem of fixed parallel rods running in fixed parallel bushings. Flexibility of the rods and the presence of a 0.032-inch annular clearance in the grid guide bushings further reduce the possibility of misalignment (with its consequent binding or galling of the rods).

These grid guide bushings are 14 inches long and are machined from cast ductile iron. The bushings extend above the fuel heads and provide support for collars on the control rods when they are disconnected from the hanger rods.

B. SNUBBER

When the control rods are dropped into the core, they have considerable kinetic energy when they reach the bottom. To avoid possible damage to the control rods or reactor structure, a hydraulic snubber (Fig. 3) is utilized to decelerate the rods during the last six inches of travel. The snubber uses the reactor coolant as the dampening fluid and is located inside the reactor tank, five inches below the low level of the coolant. A tapered piston mounted on the hanger rod enters the snubber cylinder six inches from the bottom of rod travel. The falling energy of a scram is absorbed by displacing the reactor coolant between the piston and cylinder annulus. The snubber does not prevent the rods from dropping to the bottom of their travel even when they are released in the snubber. The snubber piston has little effect on the rod motion until the piston enters the snubber cylinder six inches from the bottom. A modified Belleville spring is mounted in the lower portion of the snubber cylinder to absorb any

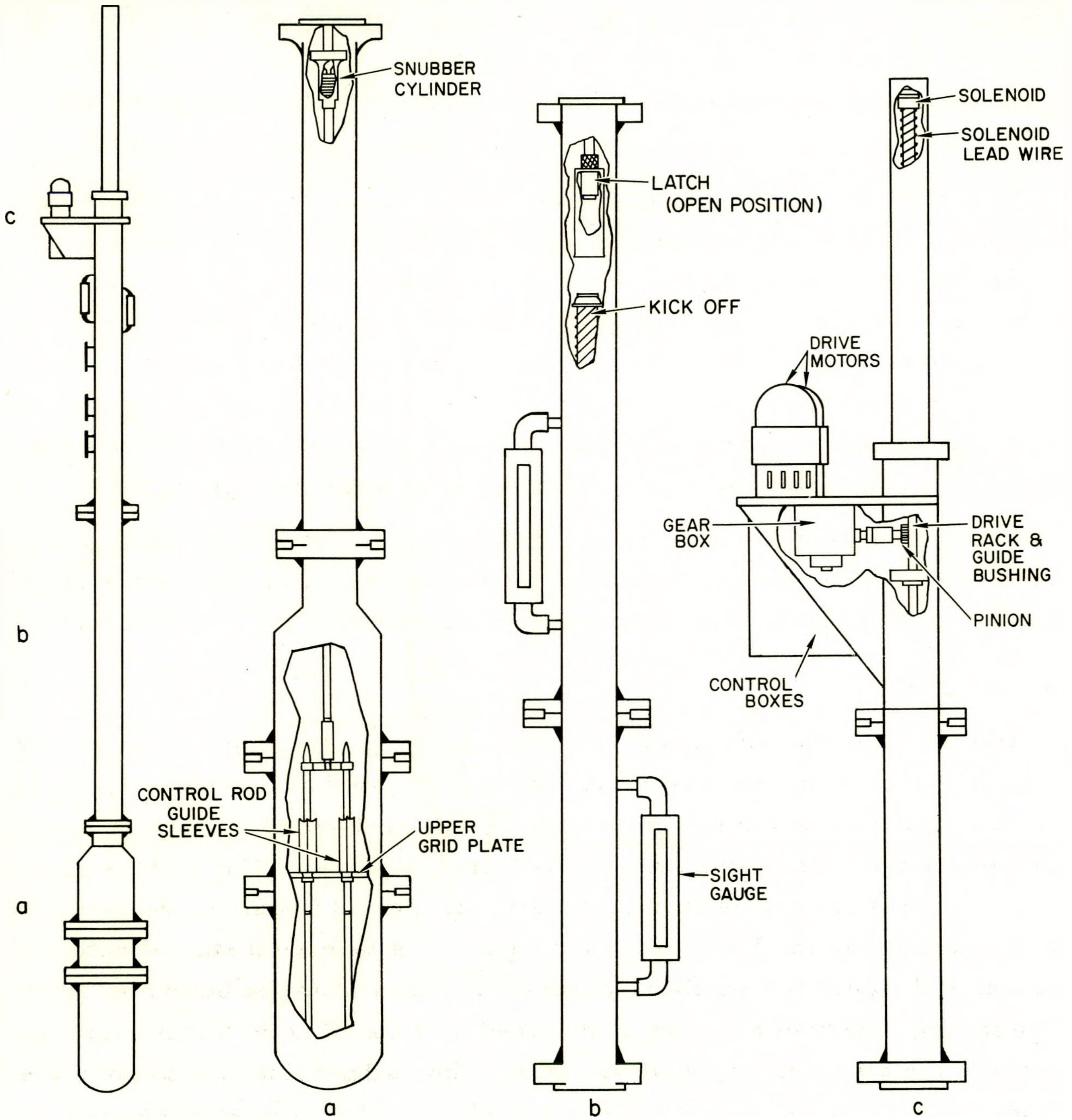

Fig. 2. Electromechanical Control Rod

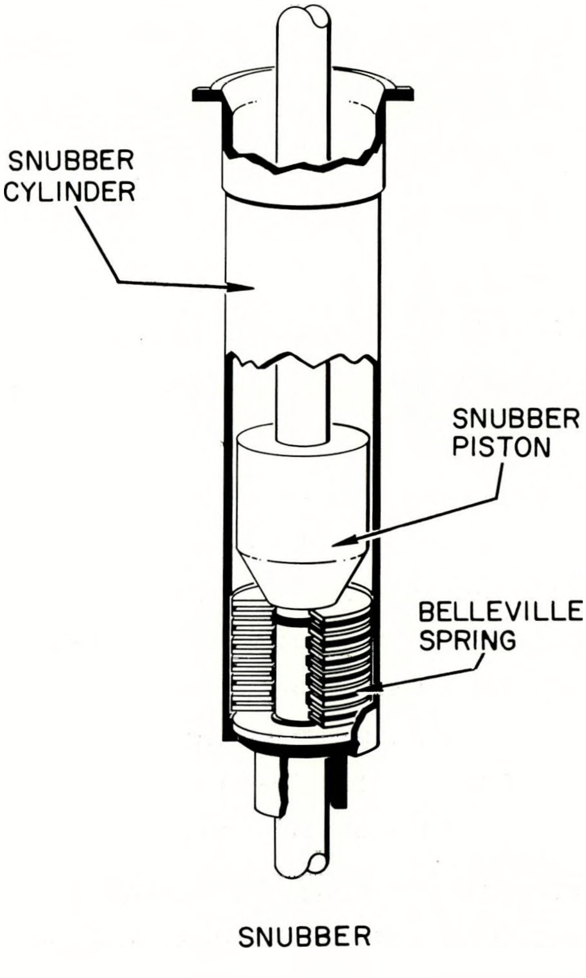

Fig. 3. Snubber

remaining energy by cup deformation. At the bottom of rod travel, the snubber piston supports the rods on the modified Belleville spring.

C. "KICK-OFF" MECHANISM

The "kick-off" mechanism (Fig. 4) is incorporated to increase the net acceleration of the control rods to approximately 1 g during a scram. This is necessary to compensate for a 15 per cent loss in free fall due to fluid and mechanical resistance and to buoyancy. A three-inch-diameter spring is utilized to provide this initial acceleration. The spring applies an average of 20 pounds downward force for its 12-inch travel. The spring is always in the cocked position when the rods are engaged with the drive rack.

D. DRIVE RACK

Rotational motion of the drive unit is converted to linear motion by use of a circular gear rack. The rack is guided in a 17-inch-long ductile cast-iron bushing. An alloy-steel pinion gear engages the rack teeth through a slot in the iron bushing.

The rack is a hollow bar which allows co-axial actuation of the disconnect cam. A release spring housing (Fig. 2c) is mounted on the upper end of the rack with the release solenoid mounted on the release spring housing. The lower end of the rack houses four tungsten carbide release balls. When the solenoid is de-energized, the release spring, compressed to 70 pounds, drives the disconnect cam down and releases the tungsten carbide balls, thus scramming the control rods. Figure 4 shows the closed position of the latch assembly. The rack and pinion do not fall with the control rods during a "scram."

The pinion drive shaft enters the reactor through a pinion housing which contains two pinion shaft bearings. These bearings are graphite bronze which are line-bored to ensure good alignment. Two opposed sets of Teflon chevron shaft seals are utilized between the pinion shaft bearing to prevent loss of the polyphenyl vapor. Provisions are made to pressurize between the Teflon seals to ensure a positive rubbing pressure with the shaft.

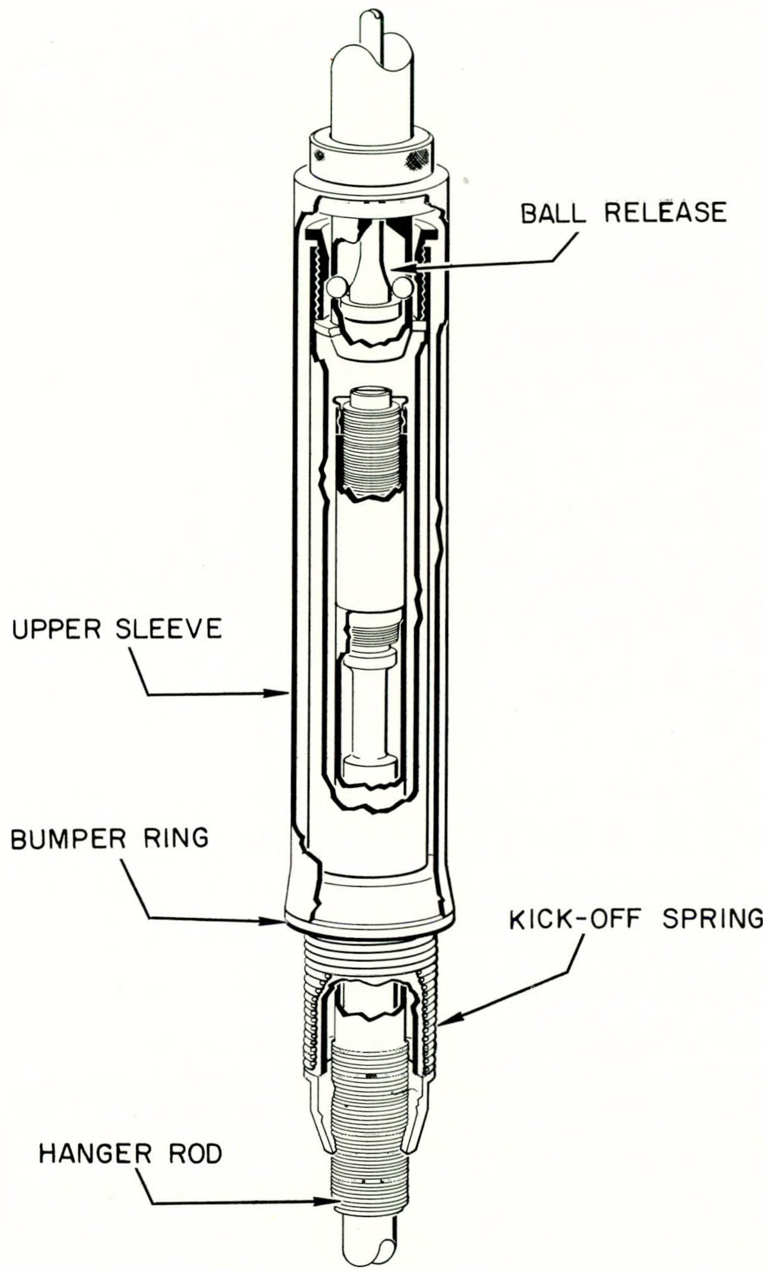

Fig. 4. "Kick-off" Mechanism

E. RELEASE SOLENOID

The release mechanism utilizes an electro-magnetic solenoid (See Fig. 2c). The solenoid, which operates on direct current, contains two windings, a high current pull-in coil and a low current holding coil.

These solenoids were designed to operate in an environment with an external pressure of 300 psi and a maximum temperature of 300° F. None of the solenoids received to date have been leak tight at 300 psi. However, tests show that the insulation is not affected by diphenyl vapor.

F. GEAR BOX

The gear box (Fig. 5), which utilizes a planetary gear system, serves to decrease the drive speed and increase the torque. Two input shafts are provided with a common output shaft. One input shaft is driven by the 1/8-horsepower shim motor while the other is driven by the 200-watt regulating motor. The output shaft is coupled to the pinion shaft. A double worm reduction was utilized to obtain a 12,000-to-1 gear ratio on the shim-rod-drive side of the gear box. This large reduction allowed the shim motor to operate at its rated speed of 3450 rpm and still drive the shim rod at a constant velocity of 0.86 inch per minute. Originally, a single worm reduction of 120 to 1 was utilized on the regulating-drive side of the gear box, since the speed was to be variable and faster speeds were needed on the regulating rod. To increase the torque, this 120-to-1 ratio was later changed to 360 to 1 by the addition of a 3-to-1 reducer between the regulating motor and the input shaft. This brought the speed of the regulating rod into the range desired.

Individual operation of either the shim- or regulating-rod motor does not produce rotation in the motor which is not being driven. When both motors are operated simultaneously, the fast regulating motor takes preference and will drive in either direction, regardless of the direction of rotation of the shim motor.

G. SHIM ROD DRIVE SYSTEM

The shim rods are driven by the shim-rod motor through the gear box where the motor speed is reduced 12,000 to 1. This reduction enables the rods to be inserted or withdrawn at a velocity of 0.86 inch per minute. This velocity is

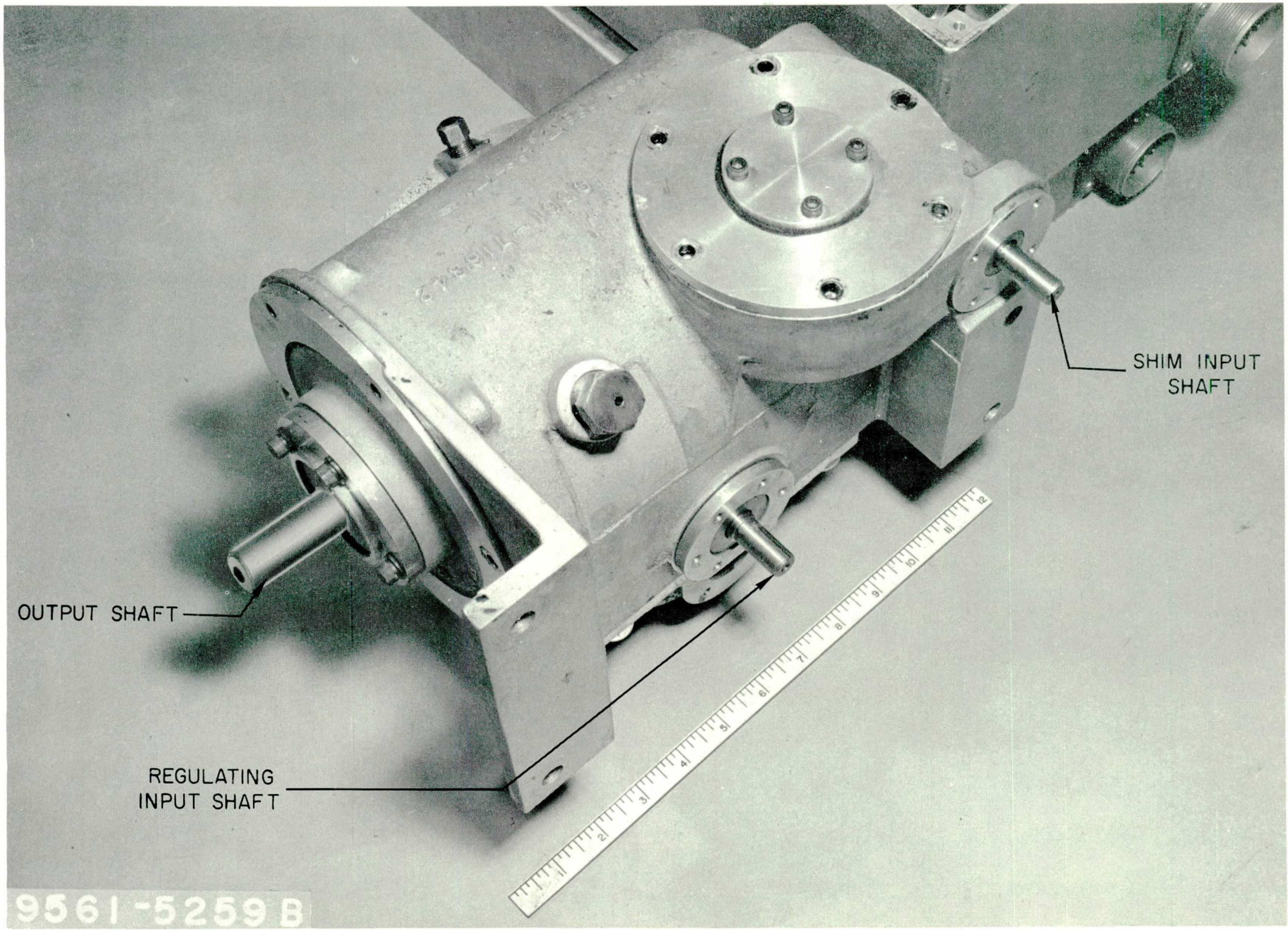

Fig. 5. Gear Box

attained within 0.3 seconds of the "rods in" or "rods out" signal and the rods come to a stop from their maximum velocity in less than 0.12 seconds. It is possible to move the rods only 0.005 to 0.010 inches by quick actuation of the "rods in" or "rods out" switch. When the "rods in" or "rods out" switch is actuated for 5 seconds, the rods travel 0.07 inches.

When no rod motion is called for, the shim-rod drift for a 36-hour period is 0.004 inches under maximum load condition. This drift is attributed to expansion and contraction caused by variations in temperature.

The shim motors are 220-volt, high-torque, intermittent-duty, hoist type, rated at 1/8 horsepower. These motors have built-in brakes which actuate automatically when the motor power is interrupted.

H. SHIM ROD CONTROL BOX AND POSITION INDICATOR

The shim-rod control is driven directly from the gear-box output shaft. In this manner the total motion of the rods, due to the sum of the motion from regulating and shim motors, is indicated on the shim position indicator, thereby ensuring that neither motor will drive the rod further than the desired travel.

A selsyn transmitter is utilized in conjunction with a selsyn receiver to drive a Roots-type counter to indicate shim rod position. The shim-rod position indicator follows actual rod travel within ±0.1 inch.

Four cam-operated Microswitches are utilized for control and operation of the shim-rod drive. Two of these switches act as upper and lower limits. Another switch actuates an alarm when the control rod is 5 per cent from the outermost position, and the fourth switch indicates to the automatic programmer that the rods are 50 per cent withdrawn from the core.

A 7-to-1 speed reducer is utilized between the gear-box output shaft and the four Microswitch cams so that the cams travel slightly less than one revolution for the full 36-inch rod travel.

A 6.3-to-1 speed increaser is utilized between the gear-box output shaft and the selsyn transmitter so the rod indicator may be read directly to tenths of an inch. The original installation utilized a 63-to-1 speed increaser to read down to a hundredth of an inch. This required a large amount of torque and was erratic in operation. It was also found unnecessary to have an indication of such extreme accuracy.

I. REGULATING ROD DRIVE SYSTEM

The fast-regulating rods are driven through a differential gear so that the position indication of the rod pairs is due to the sum of motion of the shim-rod motor and the fast-regulating-rod motor. The regulating drive motor is reduced 120-to-1 in the gear box. Due to the uncertainties involved in the parameters of the OMRE system, the regulating rod speeds are designed to be variable from a small value up to their maximum velocity of 0.94 inch per second. During early tests, the regulating-rod motor would not drive the rod up except at the maximum setting of the Variac controller. At this maximum setting, the withdrawal speed was 2 inches per second. At low input voltages, the motor did not have enough torque to drive the gear box alone (disconnected from the pinion) at the desired speeds. For this reason, a 3-to-1 external reduction (Fig. 6) was installed between the gear box and motor. During operation, it was noted the insertion speed is faster (maximum of 2 inches per second) than the withdrawal speed. This is attributed to the fact that the weight of the control rod is acting downward. The faster insertion speed is not considered detrimental to reactor operation. This rod speed should be fast enough to compensate for reactivity changes which may be encountered during reactor operation.

The regulating-rod motion is restricted to a value which limits reactivity to less than the amount which would produce dangerously short periods. It would have been possible, in case of failure of the control circuit, to drive the rod out at its maximum speed and put the reactor onto an extremely fast period before the period or level trips have time to scram the reactor. To prevent such an occurrence, the regulating rod is limited to a total travel of 5.1 inches on the outer rod pair and 3.6 inches on the inner rod pair, at which time the shim rods must be actuated to return the regulating rod to a position near the middle of its span of travel. The limitation of travel is obtained by means of switches on the regulating-rod motor circuits. A physical stop is incorporated in case the electrical switches fail to stop the motor at the end of the rod travel.

A 2-phase electric motor is used to drive the regulating rods since it has a high torque-to-inertia ratio and responds rapidly to any control action. One phase of the motor is driven by the automatic control circuits while the second

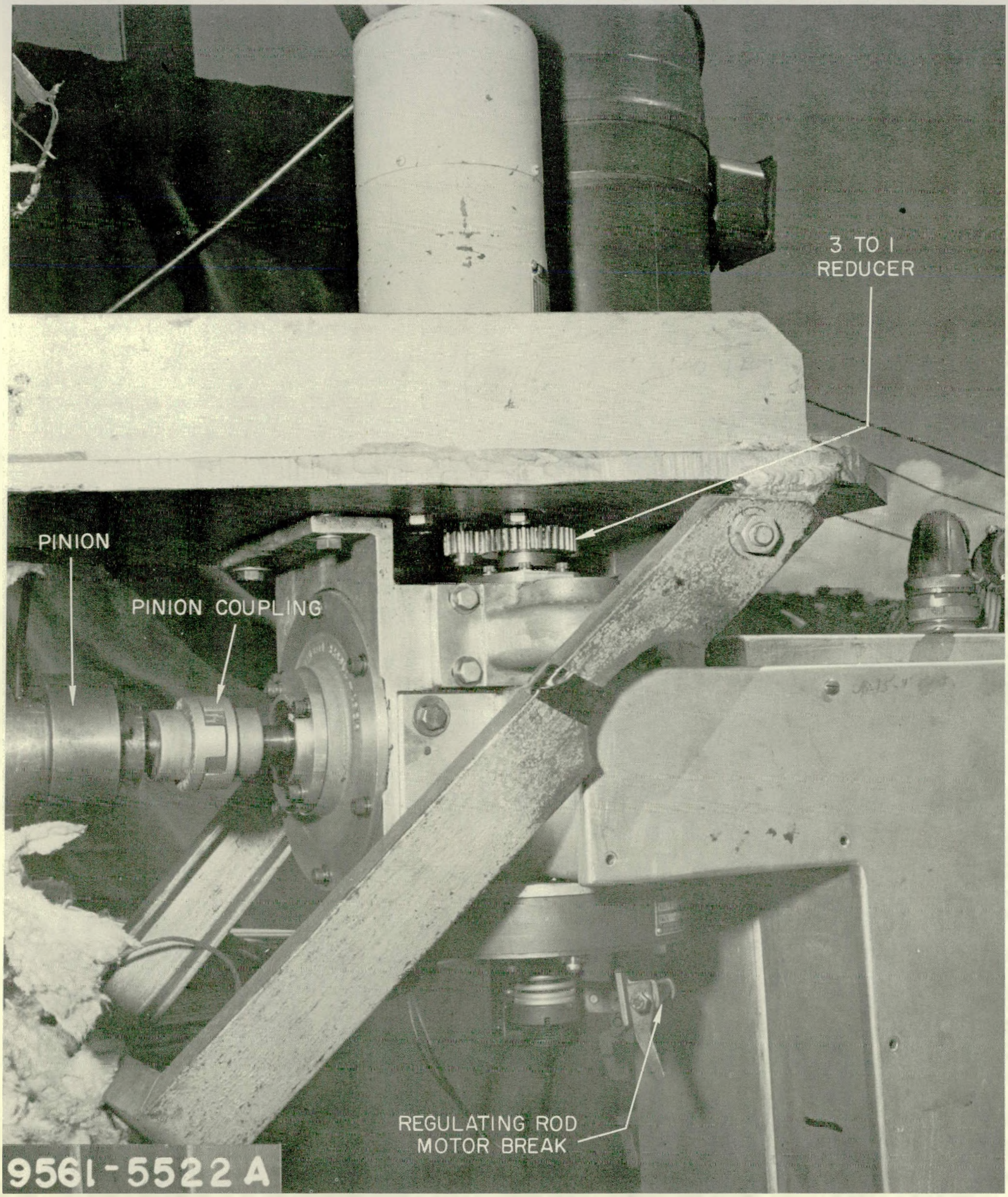

Fig. 6. External Reduction Gear Box

phase is supplied from a variable voltage source. The second phase is used to control the maximum velocity of the motor. A disk-type, spring-set, solenoid-released brake (Fig. 6) is utilized to stop the regulating motor. Running the shim motor simultaneously with the regulating motor does not affect the performance of the regulating drive system.

The regulating-rod motor was tested for acceleration and deceleration under full load. With the maximum voltage applied, 0.230 second was required for the motor to reach its maximum speed. After de-energizing the circuit, 0.140 second was required for the motor to slow to a stop from its maximum speed.

J. REGULATING ROD CONTROL BOX AND POSITION INDICATOR

The regulating-rod control box (Fig. 7) is mounted on the gear box and is geared directly to the drive motor. Included in the control box are:

1) A series of five cam-operated Microswitches. Two of these switches prevent the motor from driving the rods beyond the normal limits of travel and the other three actuate the automatic programming circuits. One of the latter three is actuated at the center of the regulating rod motor travel and de-energizes the automatic programmer. The other two are actuated one inch on either side of the center position. These two switches actuate the automatic programmer to return the regulating rod to its center position by driving the shim rods either in or out. This will ensure that the regulating rod position does not deviate more than a small amount from the position of the other shim rods in its group when the rods are being automatically programmed.

2) A ten-turn potentiometer to supply position indication and feedback to the automatic control circuits.

3) A selsyn transmitter to provide the rod position to the operator. This selsyn transmitter drives a selsyn receiver which in turn drives the position indicator. The position indicator follows actual rod position within ±0.05 inch.

A physical stop is also provided to stall the drive motor and limit the motion of the rod in either direction in case of a failure of the Microswitches. These stops are adjustable and are set 1/2 inch beyond the limiting Microswitches.

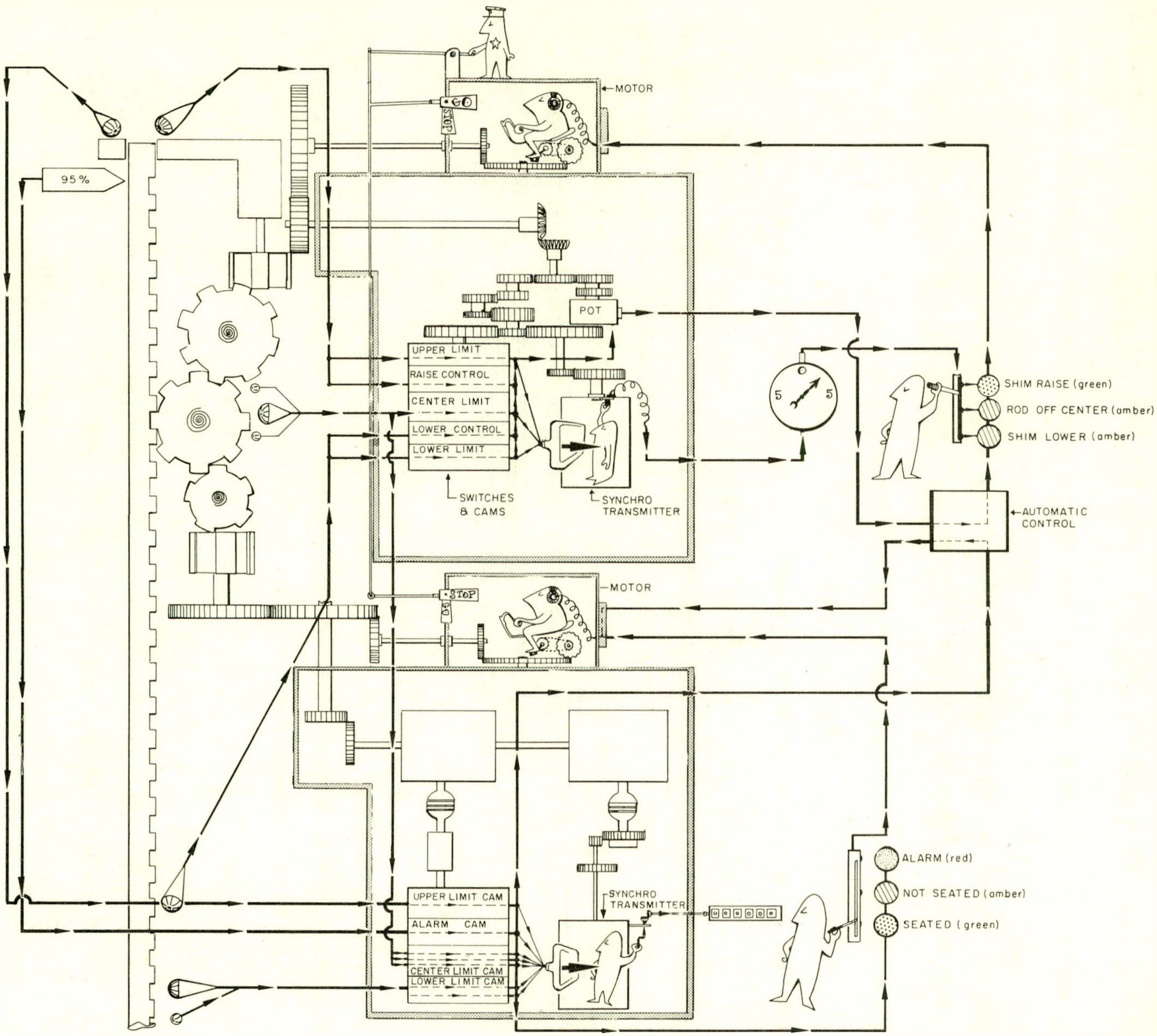

Fig. 7. Simplified Diagram of Control Box Function

IV. TESTS

A total of six series of tests was completed on the control-safety mechanism. This program was initiated to test the operation, reliability, and characteristics under reactor operating conditions of temperature and atmosphere. Diphenyl was used as the organic fluid. The rods were withdrawn to the full 36-inch stroke, scrammed, and retrieved continuously during the tests. Time response measurements were made intermittently during the scrams to determine the release times (time elapse from the moment power is removed from the solenoid until the rods begin to fall) as well as rod acceleration and deceleration.

Test number 1 was terminated after 435 cycles when the solenoid lead wire insulation deteriorated because of excessive temperature.

Test number 2 was terminated after 37 cycles due to excessive time delays recorded during a scram.

Test number 3 was terminated after 53 cycles when the aluminum coupling between the pinion assembly and gear box failed due to a seizure between the pinion shaft and the pinion bearing.

Test number 4 was terminated after eight intentional scrams due to excessive time delays measured in the ball release mechanism.

Test number 5 was terminated after 1090 cycles when excessive time delays were again measured in the ball release mechanism.

Test number 6 was terminated after 435 scram cycles. This test could have continued but it was felt that sufficient information had been obtained to permit successful reactor operation of the control rods. Time response measurements during this test were consistent on both the overall time and the release times. The rod was cycled 1000 times with the regulating drive through the 5.1-inch regulating stroke.

Following Test number 6, rods modified to conform to the prototype were installed in the OMRE and operated successfully. Details of all the test runs are contained in the Appendix.

Acceleration and deceleration data were obtained by utilizing a magnetic pickup. A small "canned" coil was mounted in the test vessel and a number of small permanent magnets were attached to the moving hanger rod. As these magnets passed the coil, a voltage was generated in the coil. This voltage, which was recorded on a Consolidated Electrodynamics Corporation Type 5-116 oscillograph, gave the rod position versus time.

The start and stop times of both the regulating and shim motor were recorded by utilizing an Electro Products Model "30-30 Htan" magnetic pickup. This pickup creates an external magnetic field, which, when interrupted or distorted by the movement of an external ferrous metal object, generates voltage which is proportional to the rate of movement of the object. A number of 1/16 inch metal strips were attached to the motor shafts to interrupt the magnetic field. These interruptions were recorded on the Consolidated oscillograph.

Shim-rod drift and actual rod position versus indicated position measurements were made by extending a rod, which was attached to the top of the release solenoid, through the top of the vessel and making physical measurements with a vernier caliper.

V. DISCUSSION AND SUMMARY

Time response measurements of intentional "scrams" were made intermittently during all six tests. The net acceleration from the instant the balls were released until the snubber piston entered the snubber cylinder (30 inches travel) was essentially 1 g during all tests. Because the control rod drops through the diphenyl, the additional resistance offered by the fluid would cause the acceleration to be less than 1 g. The kickoff spring applies an initial acceleration, resulting in a net acceleration of 1 g. A plot of control rod position, after release, as a function of time is given in Fig. 8 for two different diphenyl temperatures.

The curves are essentially similar. The control rod reached the snubber in a somewhat shorter time at 360° F than at 730° F. This is because the diphenyl level was 3 feet higher at the higher temperature. The effect of decreased viscosity on the velocity could not compensate for the effect of the added resistance of the deeper diphenyl pool. This data was obtained from the Consolidated oscillograph traces (Fig. 9). Four traces were recorded simultaneously as a

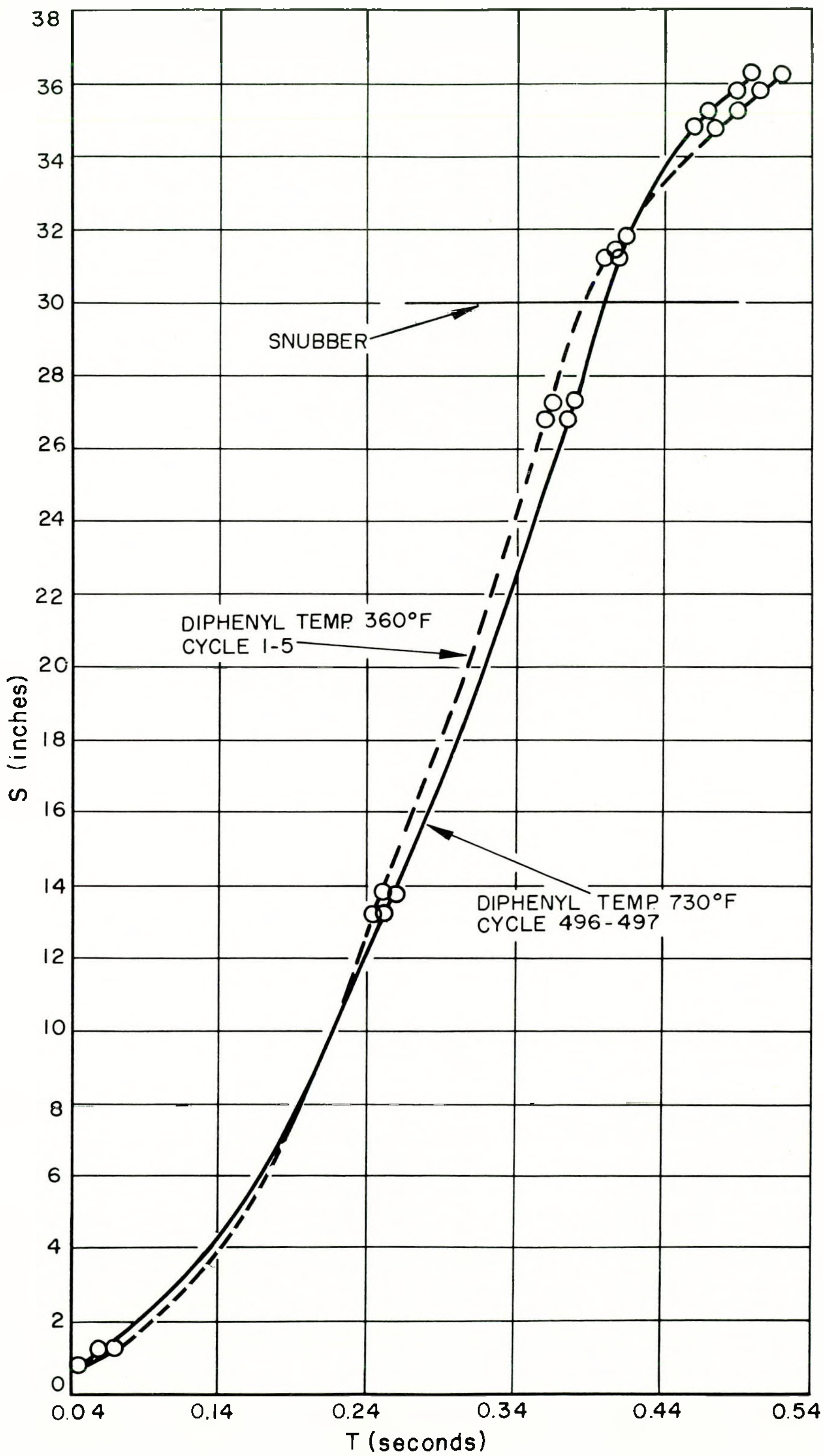

Fig. 8. Control Rod Position as a Function of Time After Release

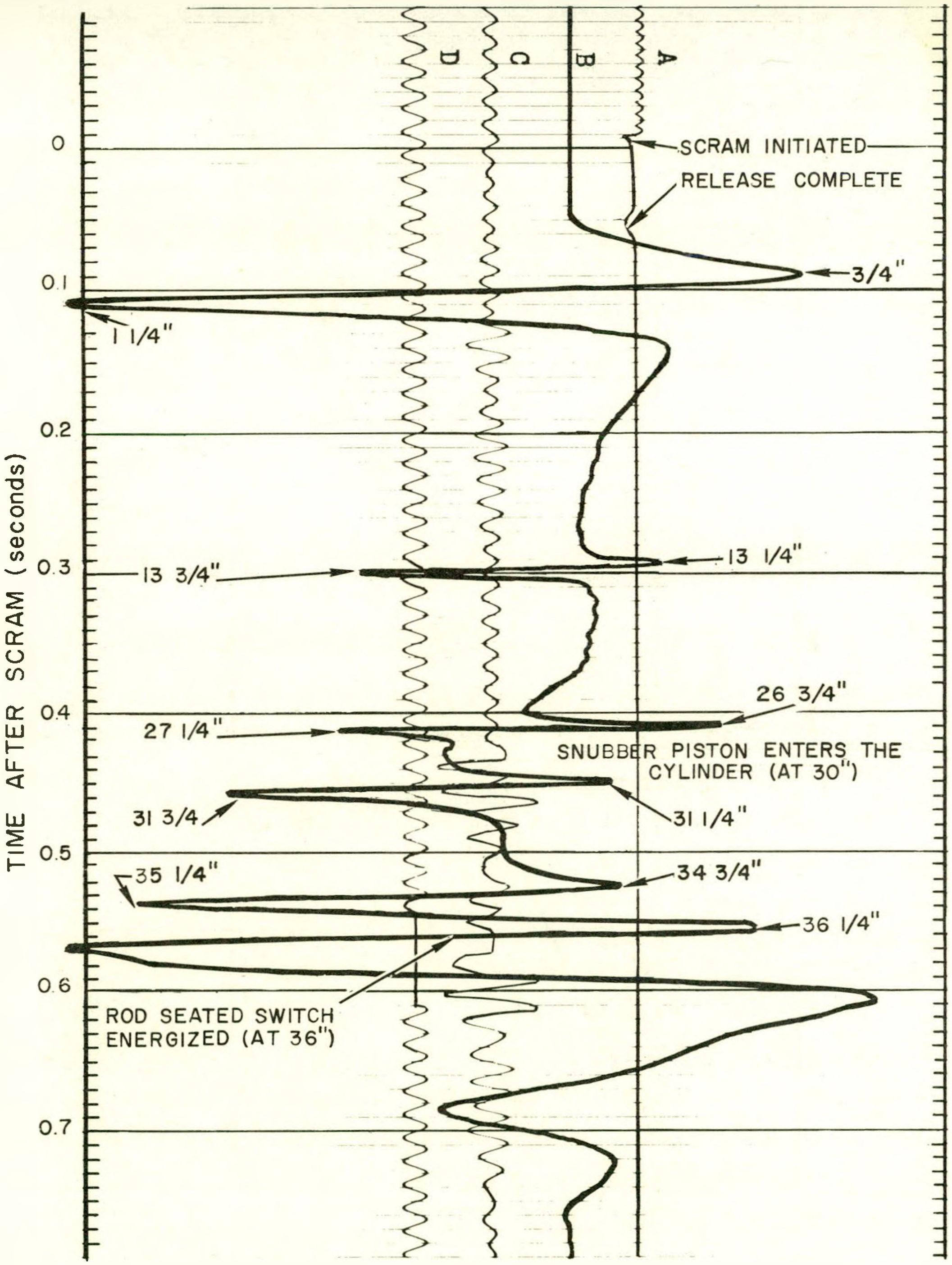

Fig. 9. Oscillograph Traces of Control Rod Time Response Tests

function of time. Trace A indicates when the scram was initiated and when the release mechanism had reached its maximum travel. Trace B indicates the rod location, from the fully withdrawn position, as a function of time. Trace C indicates when the snubber piston entered the snubber cylinder at a distance of 30 inches from the fully withdrawn position. Trace D indicates when the "rod seated" Microswitch was energized, at a distance of 36 inches. The peak at 36 1/4 inches was a result of deformation of the Belleville spring in the snubber. This deformation permits the rod to travel past the normal 36-inch stroke during a "scram."

A maximum variation of 0.020 seconds was measured from the instant the balls were released until the snubber entered the snubber cylinder. These variations may have been partially due to changes in diphenyl viscosity and liquid level caused by increasing or decreasing the diphenyl temperature between 200° and 725° F. The diphenyl temperature was held constant at 725° F during Test number 5 and the rod was withdrawn and "scrammed" 90 times. Time response measurements were made intermittently 20 times during the 90 cycles and a maximum variation of only 0.009 second was recorded.

The amount of time required for the rod to travel the last six inches through the snubber varied as much as 0.050 second. This wide variation is due partially to the snubber piston hitting the bevelled edge at the top of the snubber cylinder. This can occur because of the large clearances (0.032 inch annular) between the snubber bushing and the hanger rod. Some of the variation could also be caused by a change in the fluid viscosity.

The high-temperature, roller-plunger-type Microswitch which indicates the rod is in the fully inserted position failed during all tests, but lasted longer than any of the other switch types tested. Before installation in the test assembly, a life test was conducted to ensure that the switch would function while submerged in hot diphenyl. A switch was cycled 11,480 times while submerged in diphenyl at 305° F and 6,720 times in diphenyl at 250° to 350° F. The switch was disassembled and all parts were found to be in excellent condition.

Even though diphenyl liquid or vapor did not adversely affect the operation of the Microswitch, failures did occur while actuating the switch with the control rod. The failures were due to impact damage to the switch roller arm when it was struck by the actuator on the falling hanger rod. These "rod seated" switches are operated directly by the control rods and not by the rod drive mechanism. A high-temperature, pin-plunger-type Microswitch with an Inconel X actuator was tested as an alternate for the roller-plunger switch. A number of actuator variations were also tested in conjunction with the pin-plunger-type switch. These tests indicated that the original roller-plunger-type switch was more dependable than the others tested. For this reason, the roller-plunger type was installed in the reactor.

This switch could not be positioned on the test assembly snubber, in contrast to the case in the reactor, because of the smaller tank size at the snubber in the test assembly. Therefore, the switch was mounted 20 inches above the snubber where the magnitude of the rod whip is greater than it would be if the switch was mounted on the snubber. This switch has operated when positioned on the snubber in the reactor.

Material changes were made in the rack-and-ball release mechanism as a result of the tests. The rack was Azorized (a type of hard chrome plating) and no further wear was apparent at the conclusion of the tests. The ball-nut and cam-rod actuator material was changed from heat-treated AISI 4130 to heat-treated Airdi 150. The balls in the release mechanism were also changed from Type 440 C to tungsten carbide. The material changes in the ball release mechanism were necessary to prevent extremely deep brinneling of the associated parts, which had actually been the cause of excessive time delays in this component.

The reactor units were installed and have operated satisfactorily during pre-operational tests. The final test will be their operation at maximum temperature and pressure in the reactor.

APPENDIX

A. TEST NO. 1

When the first test was initiated, the motorized drive unit was not available. For this reason, the test was conducted by using a hand crank to drive the rods. Although the control-rod grid guides had already been installed in the reactor grid plate, it was essential that these parts be tested for galling, since earlier tests on the hydraulic-magnetic control rod had revealed extremely deep grooves which had actually jammed the rods in the grid bushing.

The rods were cycled 435 times through their 36-inch stroke during this test. It was found that the galling problem encountered in the hydraulic-magnetic system was alleviated in this design by changing the rod material from stainless steel to hardened AISI 4130 tubing and by using ductile cast-iron bushings.

The length of the guide bushings was also increased from 2 inches to 17 inches to prevent cocking. The annular clearance between rods and bushings was increased from 0.010 to 0.032 inch to prevent binding. Failure of these bushings would have necessitated the removal of the reactor grid plate.

Testing was discontinued after two failures of the solenoid lead-wire insulation. The silicone insulation deteriorated because of excessive temperature and the wire was replaced with a high-temperature insulation (Teflon).

The test unit was disassembled subsequent to the second failure of the solenoid lead wire. Examination of the grid guides and control rods revealed no detectable galling on any of these parts. However, galling was detected on the back side of the rack and on the mating surface of the rack guide bushing. Subsequently, the portion of the rack which rides the inside of the rack bushing was Azorized and a new bushing was installed prior to Test No. 2. The new bushing had an RMS finish of 125 as compared to 250 on the bushing which galled. On the tests which followed, no further difficulties were encountered on either the solenoid lead wire or the Azorized rack and grid bushing.

Throughout this test, time delays up to 15 seconds were observed during a scram before the rod started to move. Examination of the release mechanism revealed that the two 1/2-inch-diameter steel balls which were utilized to release the rods showed numerous indentations. The disconnect cam and ball nut were case-hardened and the balls were soft steel. Deformation of the balls caused them to stick, resulting in the delay in rod motion.

After a scram, it is necessary to retrieve the poison elements and their associated mechanism. To accomplish this, an upper sleeve is driven down by the rack until it passes over a retaining nut, where it engages a bumper ring and compresses a "kick-off" spring over the top end of the hanger rod. Close axial alignment of this upper sleeve, which resembles a flared cylinder, and the top end of the hanger rod is necessary to allow smooth entry. On several occasions, it was noted that misalignment occurred, causing the bumper ring to cock and jam and preventing further downward travel of the upper sleeve. In cases of extreme misalignment, the upper sleeve engaged the retaining nut (which holds the spring after release) and further downward travel of the sleeve was stopped. The misalignment was partly due to the large clearances (0.032 inch radial) in the snubber bushing. The bumper ring was modified by machining a radius on all exposed edges to prevent the possibility of hanging up or jamming. This modification allowed the upper sleeve and the bumper ring to be misaligned 3/8 inch without interfering with rod retrieval.

B. TEST NO. 2

Prior to this test, the soft balls were changed to a harder type (AISI 440C). The motorized drive and instrument boxes were received and installed on the test assembly.

The shim-rod-motor drive system performed as required, but the regulating motor would not drive the rod up except at the maximum setting of the Variac controller. At this maximum setting, the upward speed was 2 inches per second. The maximum speed required was 1.02 inches per second. The rod either did not move or else ran too fast.

The gears in two Metron speed changers used in the shim-rod instrument box deformed under load. Since the delivery time on replacement units was three months, a direct coupling was used during most of the tests. Ultimately, heavier-duty Boston gears were installed as replacements in both shim and regulating instrument boxes.

Test No. 2 was terminated after 37 cycles because of excessive time delays recorded during a scram. Examination after disassembly revealed that a hard coating had formed on the balls and cam-rod disconnect, causing the balls to stick and resulting in the excessive delays. This hard coating resulted from a preservative which was applied to the cam rod disconnect on the inside of the rack prior to shipment to the test site.

The ball nut and disconnect cam showed numerous indentations caused by the action of the balls. Subsequently a ball nut and disconnect cam was fabricated of tool steel (Airdi 150) and tungsten carbide balls were installed. The stroke of the cam rod disconnect was shortened 1/8 inch to permit faster actuation of the balls during a scram.

C. TEST NO. 3

During Test No. 3, an aluminum coupling (Fig. 6) between the pinion assembly and the gear box failed while the diphenyl temperature was at 690° F. The failure occurred as the rack was being driven down to retrieve the lower portion of the rod after a simulated scram. Subsequent examination revealed that a seizure had occurred between the pinion shaft and the outer graphite bronze bearing (just adjacent to the aluminum coupling). This seizure was caused by misalignment between the pinion shaft and the gear box output shaft. The shafts were aligned with a dial indicator with the lower portion of the rod disconnected. During subsequent tests, the shafts were aligned with the lower portion of the rod connected. A hole was drilled through the pinion housing and the bronze graphite bearing and the bearing was lubricated with a high-temperature oil. No further galling was encountered during the remaining tests.

The regulating-rod drive still would not drive the control-safety rod up, except at the maximum setting of the controlling Variac. Subsequently, a spare reactor gear box was installed in place of the test gear box for comparison since it appeared that the test gear box was causing an excessive drag on the drive motor. It was found that the operating characteristics of the two gear boxes were nearly identical. Following this comparison, torque measurements made on both gear boxes indicated power transmission efficiencies of 25 per cent. The efficiencies of the gear box assemblies were expected to be between 35 and 40 per cent.

After the torque measurements had been completed, both gear boxes were disassembled in order to determine the cause of the excessive friction. The test assembly showed excessive wear on both sides of the teeth of the regulating-side drive worm and worm gear. This test assembly was in operation during Test No. 3 when the pinion seizure occurred. The wear on both sides of the gear teeth was attributed to the excessive load transmitted to the gear teeth when the pinion seized.

A spare reactor gear box was run in by operating it in both directions without a load for four hours. The unit was then connected to the rack and pinion and the rack cycled up and down 100 times. Disassembly revealed that excessive wear existed on only one side of the worm and worm gear teeth of the regulating drive; that is, the side of the teeth used in raising the rack. Number 20 turbine oil which contained molybdenum disulfide was used as a lubricant during this run-in.

Rough edges on the gear teeth were removed and the gear teeth were polished with jewelers rouge. The gear box was reassembled and SAE 90 transmission oil was added for lubrication. The rack and a 100-lb weight (simulated lower section of the rod) was cycled up and down 150 times. The gear box was again disassembled and no further wear was apparent during subsequent tests.

D. TEST NO. 4

During Test No. 4, excessive time delays were measured in the ball release mechanism. The "start-up accident" study which was employed in establishing the parameters of the safety system required that the amount of elapsed time from the instant a scram signal is given until the safety rods begin motion should be 0.050 seconds or less. Following Test No. 4, a stress analysis was performed on the ball release mechanism and the results indicated the balls were excessively loaded. Prior to Test No. 5, the rack was remachined and four balls were installed in place of the original two. This addition decreased the load on the ball release mechanism and improved the release time.

E. TEST NO. 5

Test No. 5 was terminated after 1090 cycles when excessive time delays were measured in the ball release mechanism. During the test, the diphenyl temperature was increased to 730° F and cooled to 300° F. The control- and safety-rod was cycled 275 times while the temperature was being increased to 700° F.

The rod was then cycled 525 times while the diphenyl temperature was between 700° F and 730° F. The remaining 290 cycles were completed while the diphenyl was cooling to 300° F.

The diphenyl temperatures were being decreased when excessive time delays were measured. Disassembly revealed that the solenoid spring housing had unscrewed 1/8 inch. This increased the ball release stroke from 3/8 inch to 1/2 inch and also decreased the compression on the release spring.

The "seated-not-seated" Microswitch failed to function after Cycle No. 40. Disassembly revealed that the roller was jammed in the seated position. The aluminum coupling between the pinion assembly and the gear box failed while the rack was being driven down to retrieve the lower portion of the rod on Cycle No. 765. It was possible to raise the rod by hand after the coupling failed, indicating that seizure had not occurred and that excessive friction did not exist. A new coupling was installed and the test was continued with no further trouble with this coupling.

Prior to Test No. 6, all of the screw joints were pinned in place. The 3-to-1 external gear reduction was installed between the regulating drive motor and the gear box. The ball-release spring tension was increased from 57 to 70 pounds. This change in spring tension decreased the release delay time from 0.040 to 0.010 seconds with the unit at room temperature.

F. TEST NO. 6

No further difficulties were encountered with the release mechanism during Test No. 6. The elapse time from the moment a scram was initiated until the rods started to move was consistent between 0.025 and 0.030 seconds on all runs during this test.

The 3-to-1 external gear reducer allowed the regulating drive motor to operate at higher speeds where sufficient torque was available to drive the rods at the proper speeds. The regulating drive was cycled 1000 times through its 5.1-inch stroke to functionally check the controlling components and the 3-to-1 speed reducer.

Subsequent to Test No. 6, the complete test assembly was dismantled and all of the rod components were examined. All the components appeared acceptable for reactor installation except the "rod seated" Microswitch, which was in questionable condition.

G. TEST AT REACTOR SITE

The reactor control-safety rods were installed and cycled during pre-operational testing. Time response measurements recorded during a series of scrams were within the requirements and were nearly identical to those measured during the tests. The "rod seated" Microswitches, which failed during the tests because their exact locations in the reactor could not be duplicated in the test apparatus, have operated satisfactory with no indication of failure.