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CONTROL ELEMENT DRIVE MECHANISMS FOR LAMPRE I*

by

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SUMMARY

The use of hydraulically-powered reactor control rod drive systems may, in some applications, offer certain advantages over the more conventional control element actuators. This paper deals with an instance in which such a rod drive system was successfully utilized on an experimental reactor.

INTRODUCTION

A control element actuating system based upon the use of simple hydraulic cylinders, to which the working fluid is supplied by a common gear-type pump and controlled by electrically actuated valves, possesses several desirable characteristics; some of these are listed below:

1. It is readily adaptable to cases where massive control elements (moveable reflector) are used, since the large forces required to move such elements vertically are easily obtained.
2. The basic hardware in such a system is relatively cheap, is commonly manufactured to adequate tolerances, and is available in a variety of types and sizes.
3. Speed control may be obtained without resorting to the use of variable speed motors, slip clutches, or the like. Within broad limits, the system can be made to provide any desired, preset rates of control element motion.
4. Mechanical stops may be applied easily to the system to limit control element travel during special experiments; no mechanical torque-limiting devices need be installed in the drive train to protect the unit when the end of travel has been reached.
5. When suitable cylinders, valves, etc. are selected gravity-driven scram capability may be obtained for any control element through

the action of a single valve. (Redundancy in the valve system can be incorporated if desired.) No magnetic couplings, nor mechanical latches, are required to release the control element from its drive unit in order to permit the element to scram. Snubbing of the element's motion at the end of the scram action may be had without any complication in the drive train, since deceleration forces can be obtained very simply in the hydraulic cylinder.

6. If it is desired, a source of stored energy may be incorporated into such a drive system very easily.
7. It is not difficult nor expensive to construct the system so that very large forces are available, if desired, to move a "stuck" control element. Moreover, the actual force applied may be readily measured, and can be adjusted to whatever is considered mechanically safe in the particular situation.

Features such as these led to the decision to use hydraulic cylinders as the drives for the Los Alamos Scientific Laboratory's LAMPRE I, an experimental, 1 Mw fast reactor, fueled with a molten alloy of plutonium and cooled by liquid sodium. It was possible, because of the large neutron leakage associated with the small core of the reactor, to provide reactivity control by means of massive stainless steel and nickel reflector segments exterior to the reactor vessel, which had an outside diameter of only ten inches. Because the control elements were outside the reactor vessel, it was not necessary for any of the control element drive mechanism to penetrate the vessel's wall. A substantially more sophisticated design would have been required had the control elements been inside the vessel, immersed in sodium.

DESCRIPTION OF THE CONTROL SYSTEM

A. The Control Elements

There is no need to elaborate upon the design of the LAMPRE I control elements, since this discussion is concerned primarily with the drive units for the elements. A brief description of the control elements will however serve to illustrate some of the reasons why the selection of hydraulic actuators was made.

Figure 1 is a photograph of the control assembly which surrounded the reactor vessel. The assembly consisted of five reflector segments-- an annular cylinder called the shim, and four control rods. The stainless steel shim was 16 in. long, 10-3/4 in. i.d., 4-5/8 in. thick, and weighed about 1200 lbs. A single nickel control rod, together with attached shielding, weighed approximately 350 lbs; the rods themselves were cylindrical in shape, 16 in. long, and 3-3/4 in. in diameter.

Each of the control elements could be moved vertically by the drive units through a distance of 16 in. The change in reactivity produced by this motion was $\sim \$27$ for the shim and $\approx \$2$ for each rod ($\beta \cong 0.0021$). When the shim and the rods were in their uppermost position, the horizontal midplane of the control elements was congruent with the horizontal midplane of the reactor core. This was the configuration of maximum reactivity.

The original design criteria for the control elements specified a "free fall" scram capability for the shim only. During the second year of operation, scram capability was added to the control rod system and the shim scram function was eliminated.

B. Mechanical Details of the Control System

It is difficult to discuss the mechanical and hydraulic parts of the control system independently. The control elements and their associated hydraulic cylinders, position readouts, etc., can, however, be considered

Fig. 1 The control element assembly for LAMPRE I.

as a mechanical subsystem and described without immediate reference to the fluid supply system, the control valving, the interlocks, and similar hardware. The mechanical subsystem is dealt with in this section.

The entire control element assembly was supported below the reactor by a shield plug in the floor of the reactor cell. Figure 2 is a cross sectional view through the complete control assembly. The hydraulic cylinders for moving the control elements were located in a room below the reactor cell and were attached to the bottom of the shield plug. All parts of the drive mechanisms were accessible for inspection or servicing.

Alignment of the shim with the vessel was accomplished by the shim actuating members, which passed through the bottom vessel shield and the floor shield plug and connected the shim to its actuating unit.

Vertical sections of 4-in. i.d. stainless steel tube, rigidly attached to the bottom vessel shield, passed through the four channels in the shim. The control rods moved inside these tubes and were guided by them.

All hydraulic cylinders used for moving the rods and shim were conventional units* with double ended piston rods. The cylinders were rigidly attached to the bottom end of the cell floor shield plug, which had mounting surfaces machined square with the bores of the channels through the plug. The upper end of the piston rods were attached to the rod and shim actuating members. Position readout devices were attached to the lower end of each piston rod; these consisted of a rack, a pinion, a reduction gear box, and a selsyn unit driven by the gear box.** Figure 3 shows the hydraulic

*Additional information on the cylinders is given in the Appendix.

**Shim position was indicated with an accuracy of 0.010 in. Initially, rod readout was in 0.002 in. steps, but when the scram capability was added to the rod drives, the value was changed to 0.010 in.

Fig. 2 Cross sectional view through LAMPRE I control system.

Fig. 3 LAMPRE I control rod drive unit.

cylinders installed on the floor shield plug, and indicates the relative positions of gear boxes, limit switches, etc., associated with position readout and interlocks. Figure 3 also shows the small servo motors which were attached to the shafts in the gear boxes and operated at stalled-torque in order to take up all backlash in the gear trains.

Because the shim had a large reactivity worth, it was important that its position relative to the reactor core be accurately maintained once the shim had been raised during an approach to a critical configuration. It was also desirable to be able to adjust the "full up" position of the shim in order to compensate for changes in core loading, to permit intercalibration of the rods with the shim, etc. These requirements were met by incorporating an adjustable mechanical stop into the shim drive cylinder assembly (see Fig. 2).

The shim stop was designed so that variations in the temperature of the reactor vessel would not significantly affect the position of the shim relative to the core. This was accomplished by using the bottom of the reactor vessel as an abutment for the stop. Should the reactor temperature increase, for instance, the bottom of the vessel and the core would move (downward) approximately the same amount, and the reactor vessel would exert a force on the shim stop. The shim would respond to this force by ejecting oil from its drive cylinder and moving downward by very nearly the same amount as the core of the reactor had been displaced. The degree to which this floating stop provided compensation for changes in vessel temperature was never measured, but it was estimated that residual effects would not exceed $0.1\phi/^{\circ}\text{C}$ change in average vessel temperature.

As indicated in Fig. 2, the stop was attached to the shim cylinder's piston rod by a threaded connection fitted with a detent mechanism. This permitted the position of the shim stop to be adjusted in 0.025 in. increments over an 8-in range. The design of the stop adjustment assembly was such that the "shim up" limit switch was automatically and correctly repositioned whenever the stop was adjusted.

In the design of the control elements, their guides and supports, close fits were avoided between all nonlubricated parts which were capable of motion relative to one another. The largest frictional forces which were expected to occur during control element movement were therefore those originating in the pistons and piston rod seals in the hydraulic cylinders. These forces were small compared to the weights of the control elements.

When the reactor was shut down for checkout and maintenance, a split collar was placed around the exposed bottom end of the shim cylinder piston rod and secured by a lock. This action provided assurance that unauthorized reactor startups could not be executed while personnel carried out routine test procedures in which it was necessary to unlock and energize the control console. An inadvertent attempt to operate the control system with the collar in place on the shim drive would not damage the drive.

C. The Hydraulic Circuits of the Control System

The hydraulic portion of the LAMPRE I control system was required to perform only a few basic functions. These were:

1. To supply oil, on demand, and at a preselected and preset rate and at a preset pressure, to the appropriate input port of the hydraulic cylinder associated with a particular control element.
2. To provide reliable capability for dumping the pressure in the driving cylinders upon receipt of a scram signal.
3. Insofar as possible, to fail safe so that loss of electrical power, system pressure, etc. should not produce a control element motion which would increase reactivity in the reactor.
4. To provide a capability for holding a control element in a selected position to a precision of ± 0.005 in.

The hydraulic systems constructed to perform these functions are described in this section.

Two separate, low pressure hydraulic systems were used; each had its own pump and supply reservoir.* One system served the shim drive cylinder and the other supplied oil to all four of the rod drive cylinders. It was determined by experiments that the shim circuit should be operated at a pressure of about 175 psig; the corresponding value for the control rod circuit pressure was 160 psig.

The pump output in each circuit was equipped with a pressure regulator set at the appropriate figure as indicated above. To protect the control element assembly against damage in the event of pressure regulator failure, each regulator was backed by a rupture disc rated at 280 psig bursting pressure. These discs actually failed at a lower pressure (247 psig) because the equilibrium temperature of the oil and piping was nearly 50°C. This burst point was high enough that there were no ruptures as a result of the pulsating pump delivery pressure, which reached peaks some what above the average value.**

The shim and control rod circuits were very nearly identical; they are shown schematically in Figs. 4 and 5. The pumps in each circuit operated continuously. Flow paths associated with up or down motion of the control elements were selected by means of cross-over valves operated from the reactor console. Two flow rates were available to produce either up or down motion at two different control element speeds; these speeds were different by about a factor of 10. The change in flow rate was effected by throttling

*Pump specifications are given in the Appendix.

**Rupture discs rated at 500 psig were available to operations personnel. They were only to be used in the event that the largest control element were to stick. Under these emergency conditions, the 500 psig rated discs would be substituted for the standard ones. A shim withdrawal force of about 8000 lbs could then be applied. There was never any occasion to execute this procedure.

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NOTE
THE 4 WAY VALVE MUST BE
ENERGIZED TO ALLOW UPWARD
MOTION OF THE CONTROL ROD

CONTROL ROD OPERATION	POSITION OF VALVE					
	#1	#7	#3	#4	#5	#14
SLOW UP	CLOSED	CLOSED	CLOSED	OPEN	ENERGIZED	CLOSED
FAST UP	CLOSED	CLOSED	OPEN	OPEN	ENERGIZED	CLOSED
OFF	CLOSED	CLOSED	CLOSED	OPEN	DE-ENERGIZED	CLOSED
SLOW DOWN	CLOSED	OPEN	CLOSED	OPEN	DE-ENERGIZED	CLOSED
FAST DOWN	OPEN	OPEN	OPEN	CLOSED	DE-ENERGIZED	CLOSED
SCRAM	OPEN	OPEN	OPEN	CLOSED	DE-ENERGIZED	OPEN

TELEPHONE - RADIO - COMMUNICATIONS SECTION					TITLE	
FUNCTIONALITY	TYPE	DATE	GROUP NO.	NAME		
COMMUNITY	ILL				HYDRAULIC SCHEMATIC	
COMM	PLM	12/85			LAMPRE I	
COMM	ILL				CONTROL ROD	
TELEPHONE						
RADIO						
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the oil return line from the hydraulic cylinder through either of two different impedances (see Figs. 4 and 5). Rates of shim insertion were 2 in./min and 0.2 in./min, which corresponded to 10¢/sec and 1¢/sec reactivity addition rates. The maximum rate of rod insertion was about 5 in./min.

All control valves operable from the reactor console were of the solenoid controlled, pilot actuated type. Cross-over valves were actuated by solenoids only, with spring return. Both normally open and normally closed valves were utilized in order to achieve the fail safe characteristic of the circuit. Valve leakage could not result in a reactivity addition.

It was found by experience that performance of the hydraulic system was improved by the installation of certain bypass valves. These are indicated in Figs. 3 and 4; i.e., valve No. 16 in Fig. 4 and valve No. 4 in Fig. 5. When these valves were connected to function as indicated in Figs. 4 and 5, they compensated for the fact that the pump operated at a different point on its characteristic curve depending upon whether it was supplying oil for an up element motion or for a down element motion.

A control element drop, or reactor scram, was produced by interrupting electrical power to the normally open scram valves indicated in Figs. 4 and 5. When the valves were opened, the differential pressure across the piston in the drive cylinder was reduced to approximately zero. The weight of the control element and its associated parts (350 - 1200 lbs) forced the piston down. Oil flowed from the bottom to the top of the cylinder through the scram valve and the associated large diameter piping. Deceleration of the massive moving parts was accomplished in the last one or two inches of downward travel by forces generated in the cylinder's "hydraulic cushion."

An electrical power failure (or a scram signal) not only opened the scram valve but also resulted in an overall valve configuration which allowed oil to escape from the bottom of the cylinders and return to the oil storage reservoir. This provision contributed slightly to the rate of rod drop, but oil flow through

the scram valves was by far the more important factor in determining rod drop time, which was typically 0.95 ± 0.05 sec for 10 in. of rod travel.

While most details of the operation of the hydraulic circuits can be determined by analysis of data in Figs. 4 and 5, the means by which a control element was held in the up position, or in some position intermediate between up and down, during reactor operation is not completely apparent from information given there. The manner in which this was accomplished is therefore described below. It will be necessary to note the existence of certain electrical interlocks in this discussion.

During reactor operation, the shim was always in the up position, so the problem of holding it at a position intermediate between up and down was unimportant. In order to hold it up, it was of course possible to close the valves in the oil return lines from the bottom of the drive cylinder, by turning the shim control switch on the console to the "off" position (see Fig. 4). Static pressure in the cylinder would then hold the shim in position. But, if there were valve leakage, or leakage across the piston, the shim would gradually drift downward. To eliminate this possibility, the shim circuit was arranged as follows:

When the shim was raised to within 0.020 in. of the point where the shim stop would contact the reactor vessel, an "up limit" switch in the assembly was automatically activated (see Fig. 2). Appropriate electrical circuits then energized the proper valves in the hydraulic system so that pressure from the continuously operating pump held the shim up against its stop.

A similar arrangement was used in the case of the control rods. In order to do so, it was necessary to interlock the rod control circuits so that the first rod was fully raised before the second could be actuated, etc. Each fully raised rod was then held in its up position in exactly the same manner as the shim was held up. The last rod in the sequence, if only partially raised,

could be held by static pressure in its drive cylinder, since in practice both leakage across the piston and leakage through valves was very nearly zero. It should be noted that when the rod was stopped at a partially raised position by turning the console control switch for that rod to the off position, the cross-over valve for that rod circuit would be de-energized and therefore assume the configuration associated with a demand for "rod down" motion. Any leakage across the seats of the valves which blocked the supply lines to that rod's hydraulic cylinder could therefore produce only downward rod motion, or a reduction in reactivity.

Gas-ballasted accumulators were fitted to the shim and control rod drive hydraulic systems. As long as control power was available, manipulation of control elements could therefore be effected even though a pump failure had occurred. The accumulator also provided some backup capability to cope with a stuck rod during a scram produced by an electrical power failure. If, for instance, a rod failed to drop, or if a scram valve failed to open, the pressure in the accumulator would be applied to the top of the rod drive piston in the malfunctioning unit. The resulting force tending to lower a rod would then be about twice that due to the weight of rod assembly. This extra force on the top of the piston would be sufficient to lower the rod at a rate about equal to that normally obtainable by turning a console rod control switch to the fast down position even though the scram valve had failed to open.

The hydraulic system was constructed mainly from one half inch diameter stainless steel tubing. Connections were made with ferrule type fittings except to those components which were available only with NPT fittings. All tubing was degreased, washed, dried, and inspected for presence of particulate, foreign material before use. Valves were disassembled, inspected, reassembled, and checked for seat leakage before installation. The hydraulic cylinders were also disassembled and inspected before use.

Figures 6 and 7 indicates the layout of the hydraulic system, its control valves, and some of the control relays.

Fig. 6 Piping layout LAMPRE I control element drive system.

Fig. 7 Piping and relay layout, LAMPRE I control element drive system.

D. Miscellaneous

Electrical equipment associated with the control system was conventional in all respects. Power for valve solenoids, control relays, etc., was 110 volts a.c., throughout. Position readout was, as previously indicated, accomplished by means of gear trains, selsyn transmitters and receivers, and mechanical digital display devices; gear ratios were selected so that position readout was obtained directly as inches of control element travel, to an accuracy of 0.010 in. All interlocking and sequencing of control elements was done via contacts on control relays; i.e., no attempt was made to utilize pressures in the hydraulic circuits, positions of valve spools, etc., as a means for providing interlock signals.

Each control element was operated by its own five position switch at the control console; overall response of the switchgear, valve solenoids, etc., was such that the experienced operators could easily adjust indicated control element positions to within 0.010 in. of any preselected value.

Rod drop time was automatically measured during every scram. This was accomplished by an electronic interval timer which was gated "on" when any of the "up limit" switches on the four rods was opened; the timer then operated until gated "off" by the completion of a circuit through all four "down limit" switches on the rod. This method did not indicate the drop time of any particular rod, but measured the time required for all the rods to complete their scrams. As long as this time interval remained constant,* it was assumed that all rods were functioning properly.

*Values (in seconds) observed during a nine month period were:

0.92	0.99	1.01
1.00	0.97	0.97
0.96	0.91	0.97
1.00	0.91	1.01
		1.01

OPERATING EXPERIENCE

No significant troubles or malfunctions occurred in the control element drive system during the 2-1/2-year period in which it was in operation. Neither piston, nor piston rod, seals were replaced in the cylinders, and no leakage occurred. One or two valve solenoids were replaced. It was found that after a few hundred hours of operation, control rod valves which had been used mainly in the closed position (to hold a rod at a location intermediate between up and down) developed slight leaks across their seats; this problem was apparently solved by replacing the original Teflon valve seats by ones made of "Buna N" rubber.

On occasion, such as while a core change was made in the reactor, the shim was held in the down position for a month or two; the shim pump was kept in continuous operation throughout the period, however. Under these conditions it appeared that some air, or other gas, was introduced into the bottom end of the shim drive cylinder. Its origin is not known, though perhaps it was the result of air entrainment in the oil reservoir. At any rate, it was observed that when "shim up" motion was subsequently demanded of the system, delays of up to 30 sec occurred before shim motion began. When the shim did move, its rate of motion was greater than normal over the first three inches of its travel. The shim drive was easily restored to a normal condition, however, by a simple purging technique which involved pumping oil into the bottom of the cylinder while the scram valve was open.

In summary, the control element drive system performed to the complete satisfaction of the operating staff.

APPENDIX

Data on components of the hydraulic system used in the LAMPRE I control rod drive are listed in this appendix.

1. Hydraulic Pumps

Supplier or Manufacturer - Rivett Lathe & Grinder, Inc.

Model No. - 9101-B

Pump No. - Gerator, Type QDB - 1.5

Motor size - 3/4 h.p. @ 1800 rpm

Pump speed - 1800 rpm

Pump output pressure, maximum - 1000 psig

Pump delivery at maximum pressure - ~ 1.4 gpm

Pump delivery, maximum - ~ 1.7 gpm

2. Hydraulic Oil

Supplier or Manufacturer - Mobil

Type - Aero hydraulic oil (HFA) as per MIL Spec (MIL-O-5606)

3. Check Valves

Supplier or Manufacturer - Republic Manufacturing Co., Cleveland

Model - No. 483 - 1/2 SS - 2

Opening pressure - 2 ± 1 psig with oil of viscosity

76 SSu at 100°F

Size - 1/2 in.

4. Relief Valves

Supplier or Manufacturer - Republic Manufacturing Co., Cleveland

Model - No. 650 - 1 - 1/2, semi-steel

Operating pressure - 50 - 1200 psig

Size - 1/2 in.

5. Metering Valves

Supplier or Manufacturer	Hoke, Inc.
Type	Needle valve
Model	2PY - 281, 1/16 in. orifice, equipped with No. 280-25 vernier hard-wheel kit 4PY - 281, 1/8 in. orifice, equipped with No. 280-25 vernier hard-wheel kit
Size	1/4 in.

6. Hydraulic Cylinders

	<u>Control Rods</u>	<u>Shim</u>
Supplier or Manufacturer	Hannifin	Hannifin
Model	Series H, square flange mounting	Series H, square flange mounting
Stroke	17 in.	17 in.
Bore	3-1/4 in.	5 in.
Piston rod size	1-3/8 in	2 in. o.d. x 1 in. i.d.
Effective piston area	6.81 in. ²	16.49 in. ²
Piston seal	"Lip Seal," synthetic rubber	"Lip Seal," synthetic rubber
Piston rod seal	"Lip Seal," synthetic rubber	"Lip Seal," synthetic rubber
Pressure rating	2000 psig	2000 psig
Hydraulic cushion	yes, 1 in. length	yes, 2 in. length

7. Control Valves

Supplier or Manufacturer	Atkomatic
Type	Piston-pilot operated
Model and size	No. 4100, type BG, 3/8 in. - N.C. (2-way shutoff) bronze No. 4101, type BNG, 3/8 in. - N.O. (2-way shutoff) bronze
Pressure rating	300 psig
Valve disc material	Teflon or Buna N rubber
Coil	No. 13110, 115 volt, a.c., 60 cycle, high pull, single wound, class H insulation, holding current $\cong$ 0.7 amp

8. Cross-Over Valve

Supplier or Manufacturer	Racine Hydraulics
Type	Solenoid operated, spring return, solenoid coil rated for continuous duty
Model	No. ODY - DTET - 103S01