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DESIGN AND DEVELOPMENT† OF A LARGE DIAMETER HIGH PRESSURE FAST ACTING PROPULSION VALVE AND VALVE ACTUATOR

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This paper describes the design and development of a large diameter high pressure quick acting propulsion valve and valve actuator. The valve is the heart of a major test facility dedicated to conducting full scale performance tests of aircraft landing gear systems. The valve opens in less than 300 milliseconds releasing a 46-centimeter- (18-in.-) diameter water jet and closes in 300 milliseconds. The four main components of the valve, i.e., valve body, safety shutter, high speed shutter, and pneumatic-hydraulic actuator, are discussed. This valve is unique and may have other aerospace and industrial applications.

INTRODUCTION

The NASA Langley Research Center's (LaRC) Aircraft Landing Dynamics Facility (ALDF) in Hampton, Virginia, plays a critical role in the dynamic testing of landing gear systems for commercial aircraft, military aircraft, the space shuttle, and general aviation. Dynamic testing of these systems is performed from a 45,400-kilogram (50-ton) carriage which travels along a 1036-meter (3400-ft) track, at speeds up to 424 kmph (265 mph). The carriage is a free wheeling cart which is accelerated up to full speed in just under 122 meters (400 ft) by a propulsion system which produces over 746,000 kilowatts ($1x10^6$ hp) (theoretical). The propulsion system utilizes an innovative quick acting propulsion control valve (Figs. 1(a) and (b)) that is driven by a unique actuator mechanism, both designed by the S & Q Corporation of Morgan Hill, California. The propulsion system greatly expands the testing capability of the ALDF allowing it to remain in the forefront of dynamic testing.

SYSTEM/FACILITY DESCRIPTION

The Aircraft Landing Dynamics Facility (Fig. 2) consists of four major components: (1) An "L" vessel that is 2.44 meters (8 ft) in diameter,

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approximately 7.63 meters (25 ft) long, and 7.63 meters (25 ft) high; (2) a programmable propulsion control valve which releases a 46-centimeter- (18-in.-) diameter column of water with a thrust force of up to 374,000 kilograms (413 tons); (3) a carriage weighing 45,400 kilograms (100,000 lb) with an impulse bucket on the back end and approximately 1036 meters (3400 ft) of track; and (4) an arresting gear system that engages and stops the carriage after the test has been completed. The facility operates as follows. The "L" vessel is filled with water and pressurized with air through a 122-centimeter- (48-in.-) diameter header to a maximum pressure of 22.4 megapascals (3250 psi). The carriage, with its test payload, is placed ahead of the propulsion valve, and the valve is preprogrammed to give a desired impulse to the carriage. The system is now ready for testing. The valve opens in less than 300 milliseconds and releases a 46-centimeter- (18-in.-) diameter jet of water into the impulse bucket mounted on the rear of the carriage. The resulting impulse causes the carriage and its test payload to accelerate to 424 kmph (265 mph) within 122 meters (400 ft) of travel. The test landing gear is then lowered, impacting the runway and duplicating full-scale dynamic loading in real time. There is almost 610 meters (2000 ft) of testing runway after the carriage gets to a desired speed where landing gears can be tested for braking, skidding, hydroplaning, hitting at an angle, tire wear, etc. At the end of the test, the carriage is brought to a stop by the arresting gear. After the test is completed, water is pumped back into the "L" vessel, the carriage is pushed back to the start position, the arresting system is reset, the valve actuator is recharged, and the system is ready for the next test. This is an extremely cost effective way of accelerating such a large carriage. The energy cost per test is the electrical energy required to pump 37,900 liters (10,000 gallons) of water against a 22.4-megapascal (3250-psi) head. The energy cost is approximately $50. A very interesting comparison of the acceleration capabilities of the carriage is to compare it with the world record dragster. The present record holder is a vehicle weighing 454 kilograms (1000 lb) which accelerates to 424 kmph (265 mph) in a quarter mile, i.e., 433 meters (1420 ft). The ALDF's carriage weighs 45,400 kilograms (100,000 lb) (100 times as heavy) and is capable of reaching a speed of 424 kmph (265 mph) in less than one-third the distance.

VALVE DESCRIPTION

The propulsion valve (Fig. 3(a)) is a double shutter spherical segment valve. The inner shutter acts as a safety gate and the other performs as a high speed shutter. The inner shutter is located in the valve body and rotates to a position above the flow nozzle when opened. The outer shutter is located on the outside of the valve body and is supported by an external yoke. The safety shutter is hydraulically actuated, and the high speed shutter is hydraulically controlled and pneumatically operated by an axisymmetrical double acting high speed accumulator-piston arrangement. The actuator along with all the supporting hydraulic and pneumatic controls is packaged as a unit and is located above the valve.

DESIGN REQUIREMENTS

The major design considerations were as follows:

1. Valve to accommodate nozzles with exit diameters up to 50.8 centimeters (20 in.).

2. Open or close in 300 milliseconds and stay open from 0 to 3 seconds, maximum.

3. Control of both opening and closing time shall be repeatable to within 5%.

4. Instantaneously close if there is any fault, electrical failure or malfunction, i.e., "fail safe".

5. Recycle time of 15 minutes.

6. Designed in accordance with the nuclear section of the ASME Code for pressures up to 22.4 megapascals (3250 psi).

7. Valve to be microprocessor controlled and be programmable to tailor impulse for specific test conditions.

8. Minimum 25-year operation life.

9. Valve must produce a coherent jet of water.

10. Safety shutter to have zero leakage at 22.4 megapascals (3250 psi).

11. All wetted pressure boundary surfaces to be made corrosion proof.

VALVE DESIGN

Since no existing valve could perform or meet the specified requirements and conditions, a new valve and valve actuating system were developed by the S & Q Corporation. The assemblage (Figs. 3(a) and (b)) consists of four main components: (1) valve body, (2) safety shutter (SS), (3) high speed shutter (HSS), (4) valve actuator. The valve body is a spherical section with a 10.16-centimeter- (4-in.-) thick wall. It was designed in accordance with Sect. III, Class 1 of the ASME Code for nuclear pressure vessels, and since it is the primary pressure barrier, a thorough finite element analysis was made using a Nastran program on a Cray computer. The SS is a spherical segment which is located within the valve body and seals with the valve body on a "O' ring type seal. The SS is opened by translating it backwards, off its "O" ring seat, and rotating it into a cavity above the flow nozzle. The SS is made of stainless steel (17-4 PH) and is operated, relatively slowly, by a hydraulically powered eccentric crank mechanism which is independent of the HSS.

Sealing the SS was accomplished by using a 4.8-millimeter- (3/16-in.-) diameter "O" ring viton seal between two carefully lapped spherical surfaces. The two surfaces are preloaded through the eccentric system to assure a leak proof seal at low "L" vessel water pressure. With full "L" vessel pressure of 22.4 megapascals (3250 psi), the force at the sealing surface is over 5,500 kilonewtons (1.25×10^6 lb), and in operation, the SS has been 100% leak tight over the entire operating pressure range of the "L" vessel.

The high speed shutter is the actual control element which initiates and terminates the jet of water; therefore, it controls the impulse the carriage sees. Placing the high speed shutter outside the valve body results in a valve design which allows the shutter to be larger than the opening it covers. Therefore, the shutter can be accelerated to its maximum opening velocity prior to initiating or interrupting the jet of water. This results in a very crisp, precise jet action on the impulse bucket and makes possible the required 300-millisecond opening and closing time.

With the SS open, the force of approximately 6,200 kilonewtons (1.4×10^{-6} lb) causes the HSS support system to deflect, resulting in a 3.2-millimeter (0.25-in.) gap between the valve body and the HSS. To bridge this gap, the HSS is equipped with an outer sealing sleeve (Fig. 4) which is pneumatically forced backward against the valve body. The labyrinth type sealing surface on the HSS sleeve and its mating surface on the valve body are overlaid with Stellite, and the spherical surfaces are precisely lapped to minimize leakage. Prior to activation of the HSS, the pneumatic pressure forcing the sleeve against the valve body is released, the sleeve moves back approximately 3.2 millimeters (0.125 in.), allowing the HSS to be rotated upward opening the valve. During the closing cycle, the HSS is rotated to the closed position and then the HSS sleeve is forced against the valve body terminating flow. This closing sequence allows for a very rapid and precise termination of the jet with respect to the carriage, and, by controlling the closing rate of the HSS sleeve, "water hammer" is controlled. Water hammer, or overpressurization due to the rapid closing of the valve, was of concern during design and was extensively analyzed. The resulting spherical valve design allowed for a very short section of high velocity flow, approximately 1 meter (3 ft) of nozzle, with the bulk of the water in the "L" vessel moving at a relatively low velocity. This, plus the control of the final 100% shut off with the HSS sleeve, eliminated water hammer.

The valve can accommodate nozzles up to 510 millimeters (20 in.) in diameter. During operation, the jet does not touch any part of the valve body (coherent jet) resulting in a very efficient nozzle.

VALVE ACTUATOR

Activating a valve of this size in 300 milliseconds is no simple task. In addition, reversing the motion immediately upon opening and closing the valve again in 300 milliseconds further complicates the problem.

As mentioned earlier, the actuator (Fig. 5) consists of an inner piston that is contained within an outer piston which also acts as the cylinder for the inner piston. When the actuator is charged, it has compressed nitrogen on one side of each piston balanced by hydraulic oil on the other side. All the energy necessary to open or close the valve is contained within the inner and outer piston nitrogen chamber. To open the valve, a flow control valve on the oil discharge side of the inner piston opens, and the piston is forced backwards by the nitrogen pressure. To close the valve, oil is released from the oil discharge side of the outer piston, and the outer piston moves forward and closes the valve. Control of the opening and closing times is achieved by controlling the flow control valves on the oil side of each piston. The actuator must now be recharged prior to another operation. The actuator was designed for 34.5 megapascals (5000 psi) (60,000 lb force equivalent) system operating pressure because of uncertainties as to the force necessary to interrupt the water jet. Theoretically, and as verified with a small test model, the force should be comparatively negligible. This minimal force in actuality, however, depends on the dimensional accuracies of the valve assembly, and even small misalignments can result in large forces. Actual operational experience with the valve indicates that the force necessary to interrupt the jet is in fact minimal, and actuator pressures of 13.8 megapascals (2000 psi) (24,000 lb force equivalent) are adequate for valve repeatability regardless of "L" vessel pressure.

VALVE OPERATION

With the safety shutter closed and the HSS in the horizontal position, the safety shutter seal is translated closed. Water is then admitted from the "L" vessel to the valve cavity through a fill line. When the pressure across the SS reaches 690 kilopascals (100 psi) or less, the SS is retracted and rotated clear. The HSS seal is then translated backwards (to generate the necessary clearance between the HSS and the valve body) then the HSS is rotated open by the actuator.

The closing sequence is the reverse of the opening sequence. The actuator rotates the HSS down, and the seal is translated forward. The SS is then rotated into position and translated closed, and the HSS seal is subsequently released. As indicated, the whole procedure is microprocessor controlled and the opening and closing sequence can take as little as 250 milliseconds (1/4 sec). This short time is accomplished even though the force on the HSS is approximately 5,500 kilonewtons (1.25×10^6 lb) just prior to opening.

SUMMARY

The valve is the heart of the ALDF propulsion system which has greatly expanded the simulation capabilities of LaRC. Extensive finite element analyses were performed on various valve components, and rigorous quality control was exercised throughout the design, fabrication, assembly, and testing of the valve system. The valve has achieved or exceeded all

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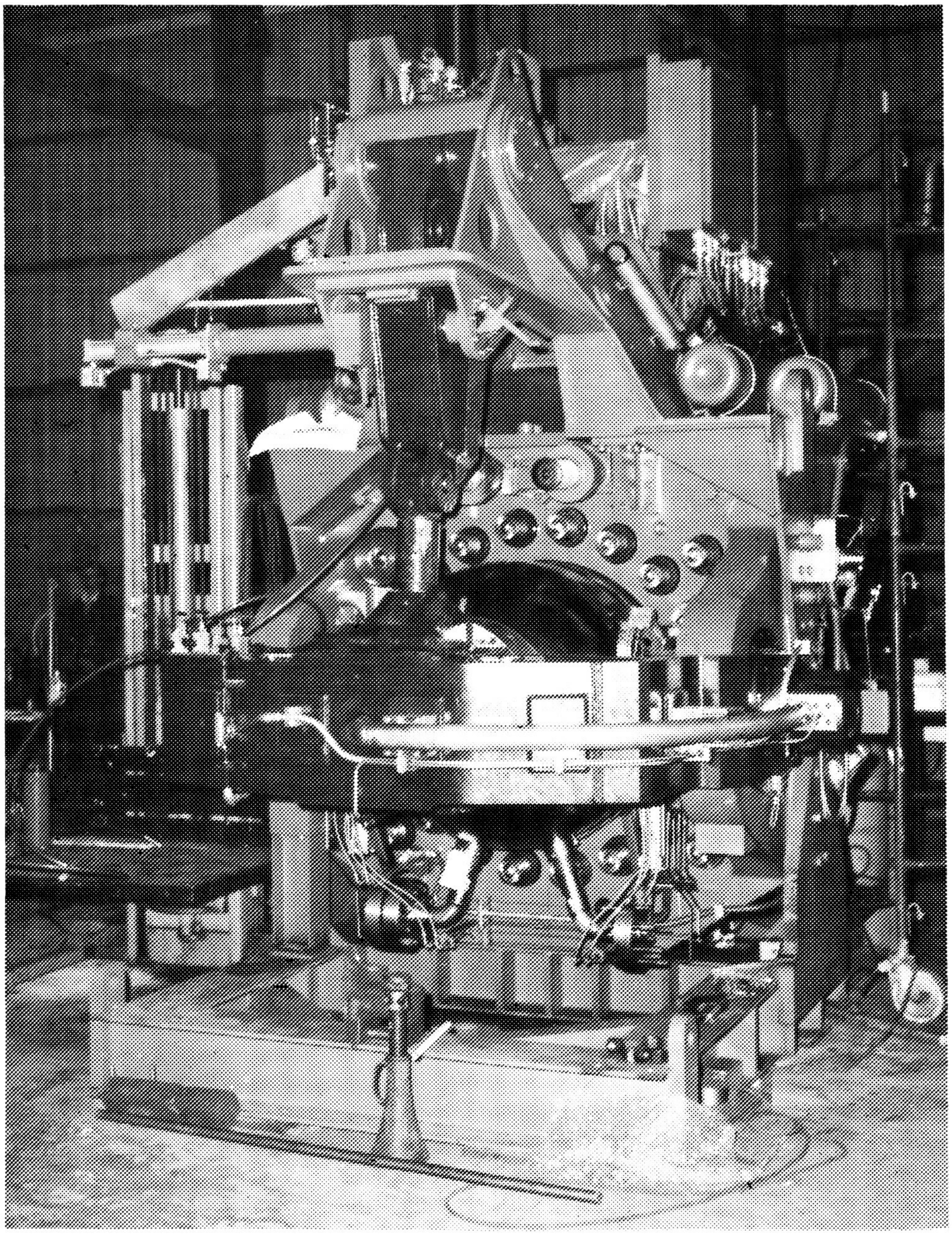
specified performance requirements. It has successfully controlled pressure surges (water hammer) and the water jet continuity is excellent. Safety shutter sealing is 100%, and the high speed shutter is drip tight exceeding the specified requirements. Repeatability of the valve opening and closing time is independent of "L" vessel pressure and is well within the 5% specified. The specified open and closing time of 300 milliseconds has been exceeded by 50 milliseconds, and the limit has not as yet been reached.



(a) Closed position.

Figure 1. - Propulsion control valve.

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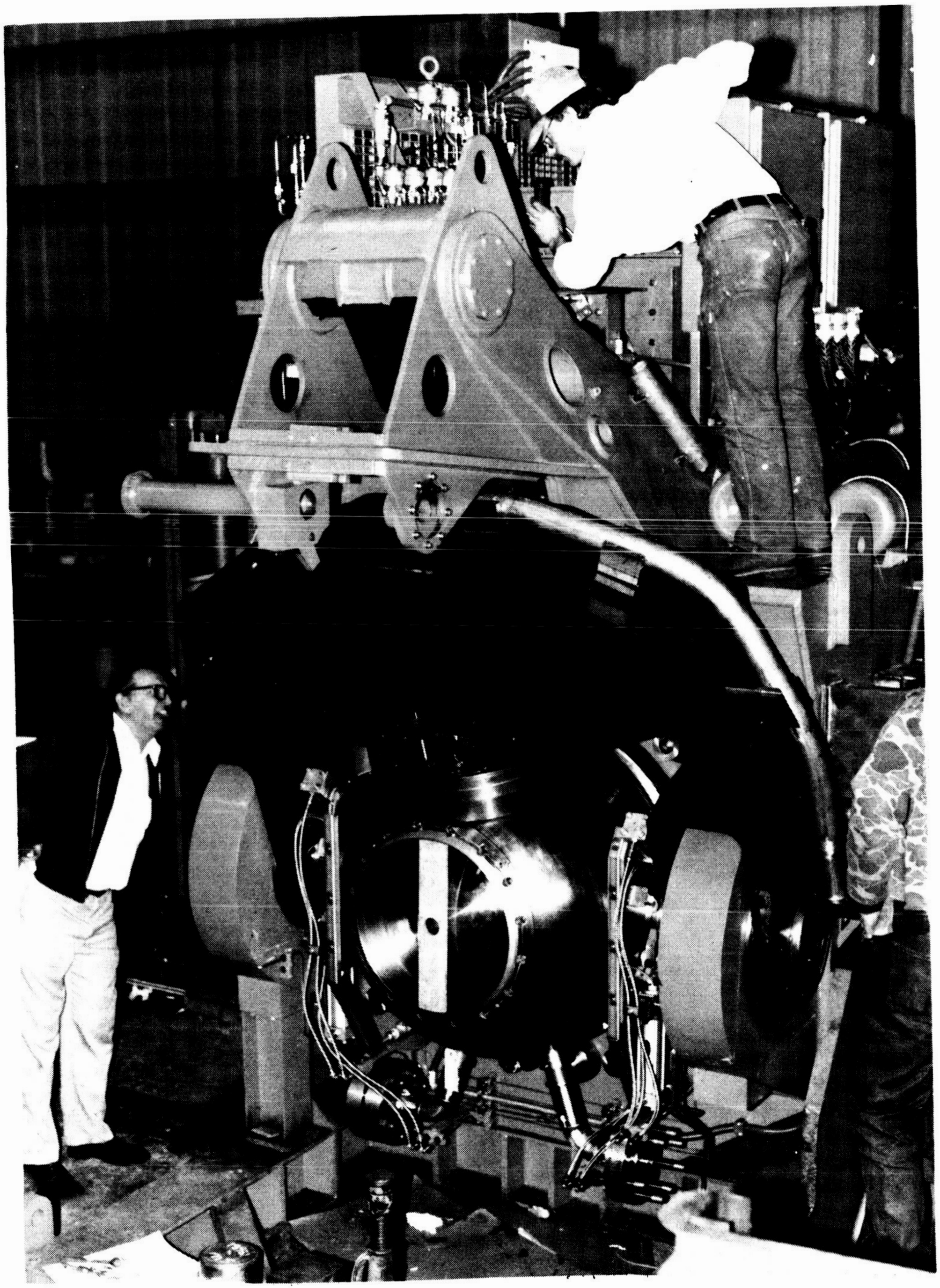


(b) Open position.

Figure 1. - Concluded.

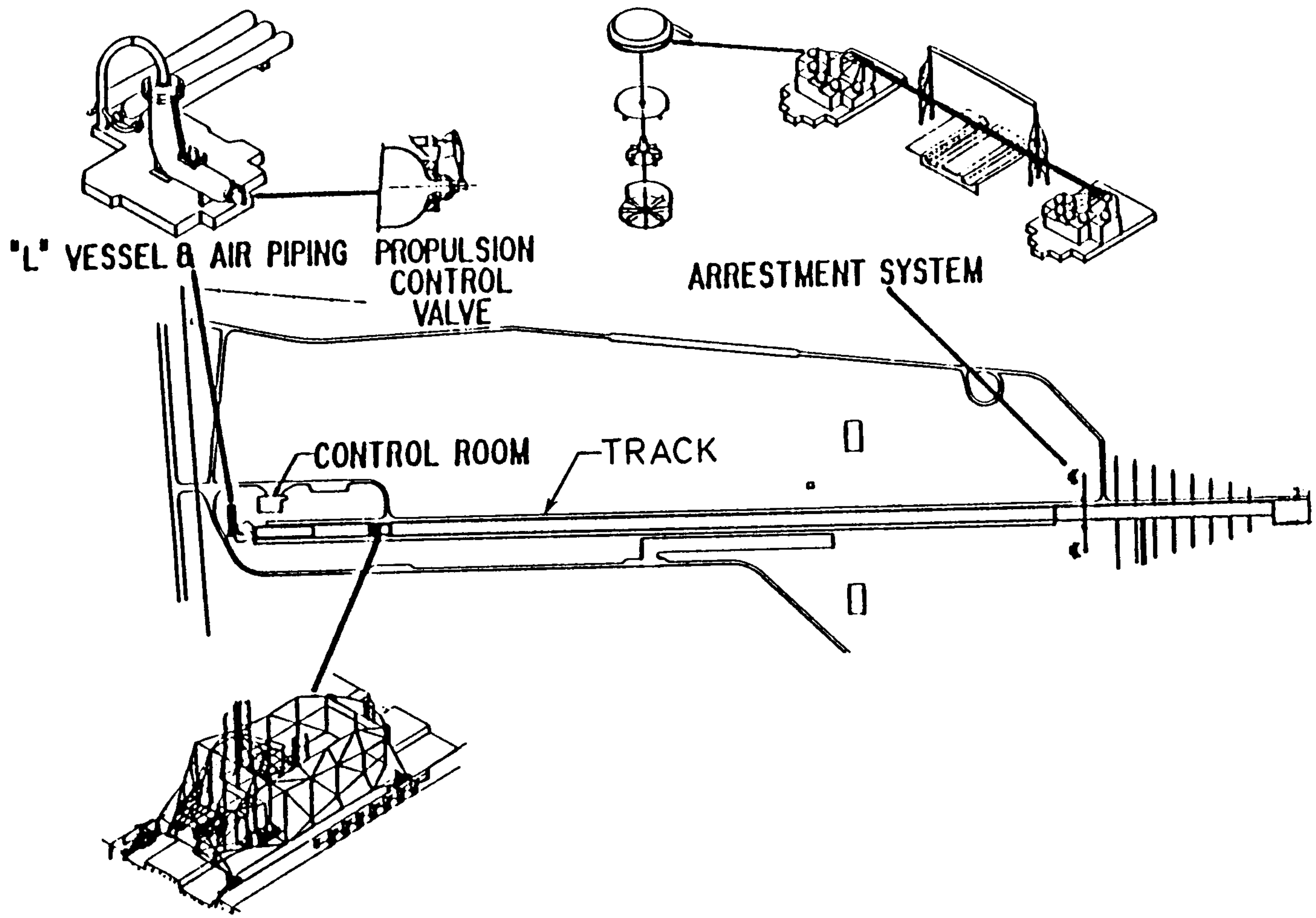
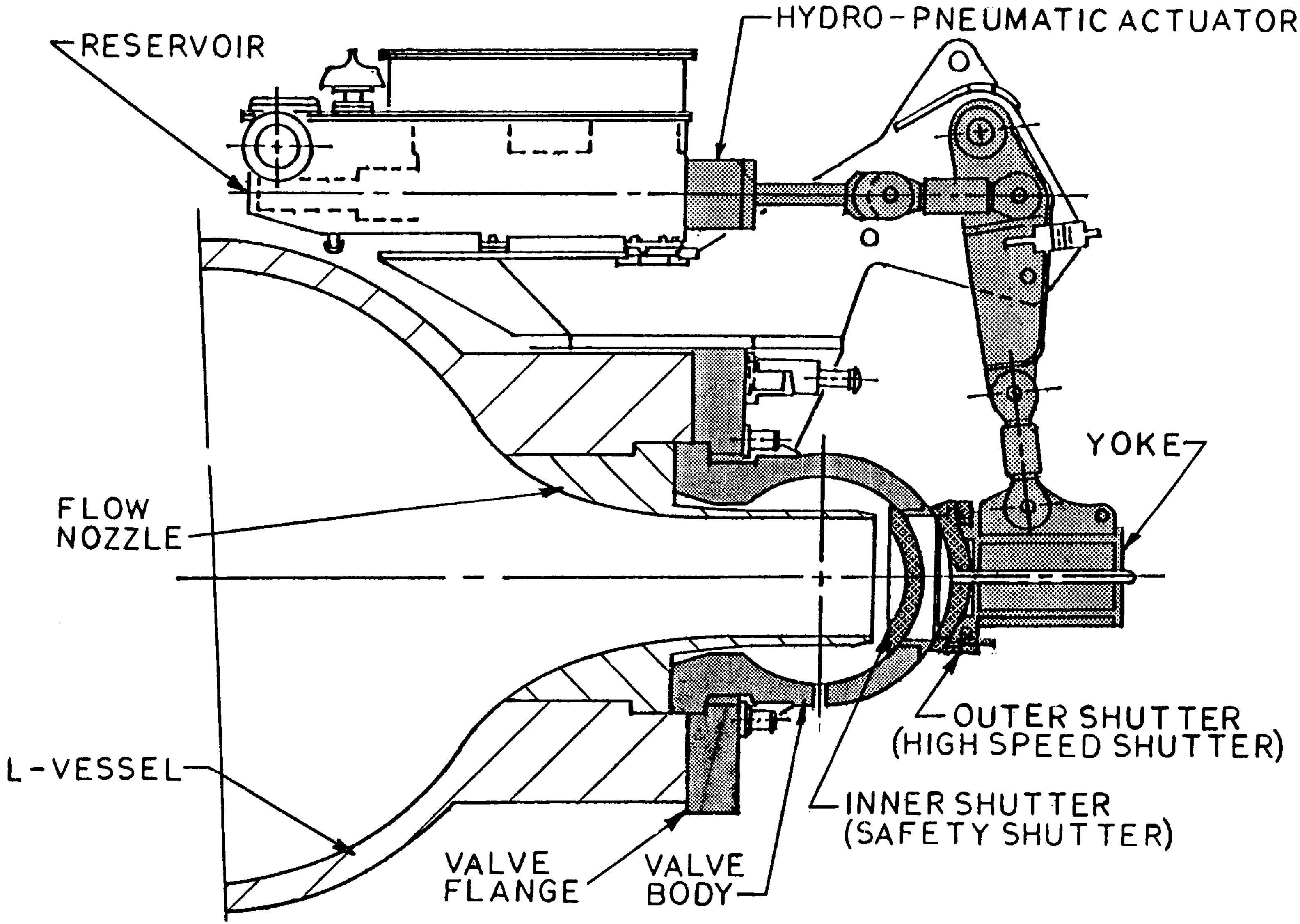
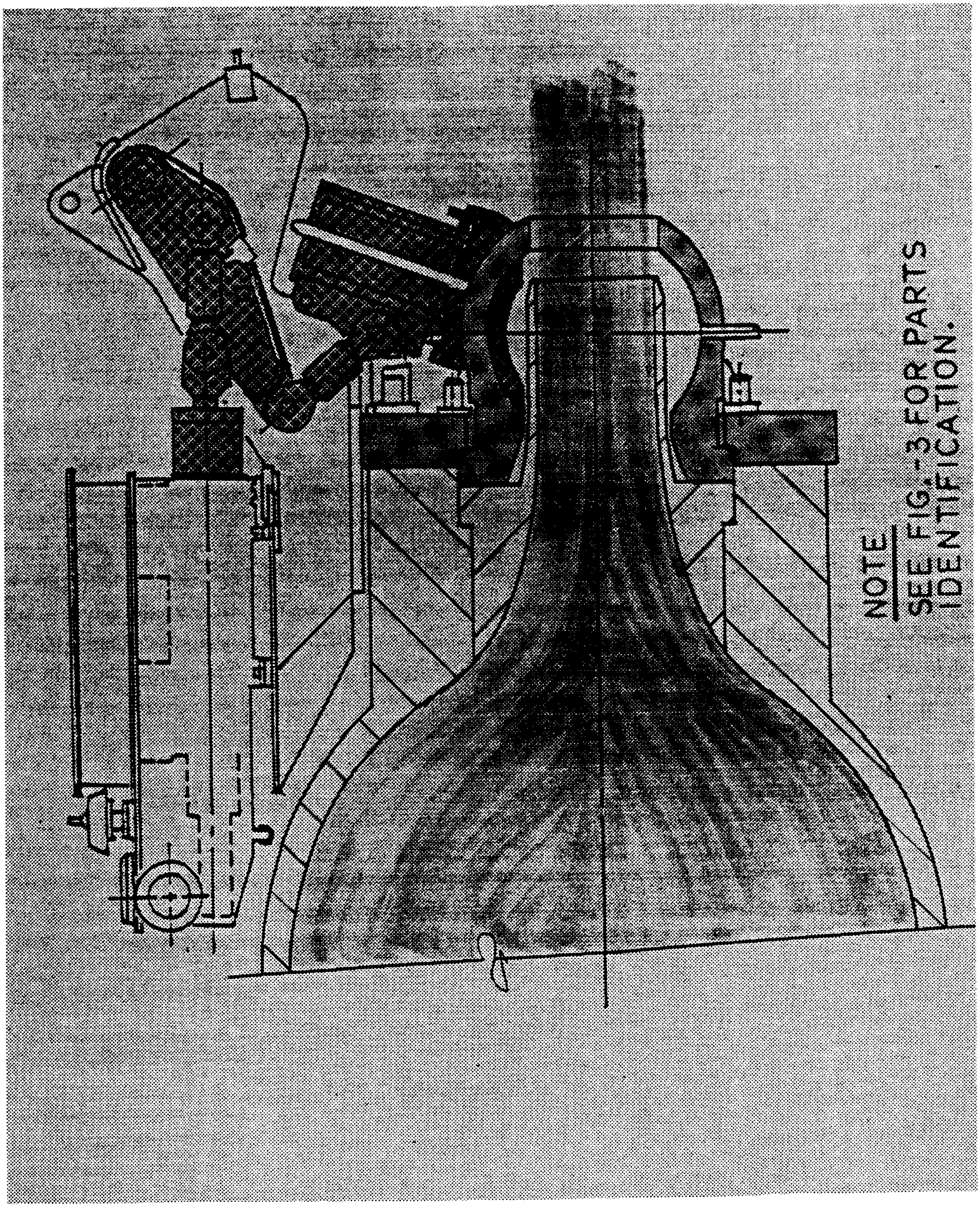


Figure 2. - Test facility general arrangement.



(a) Closed position.

Figure 3. - Valve cross section.



(b) Open position.

Figure 3. - Concluded.

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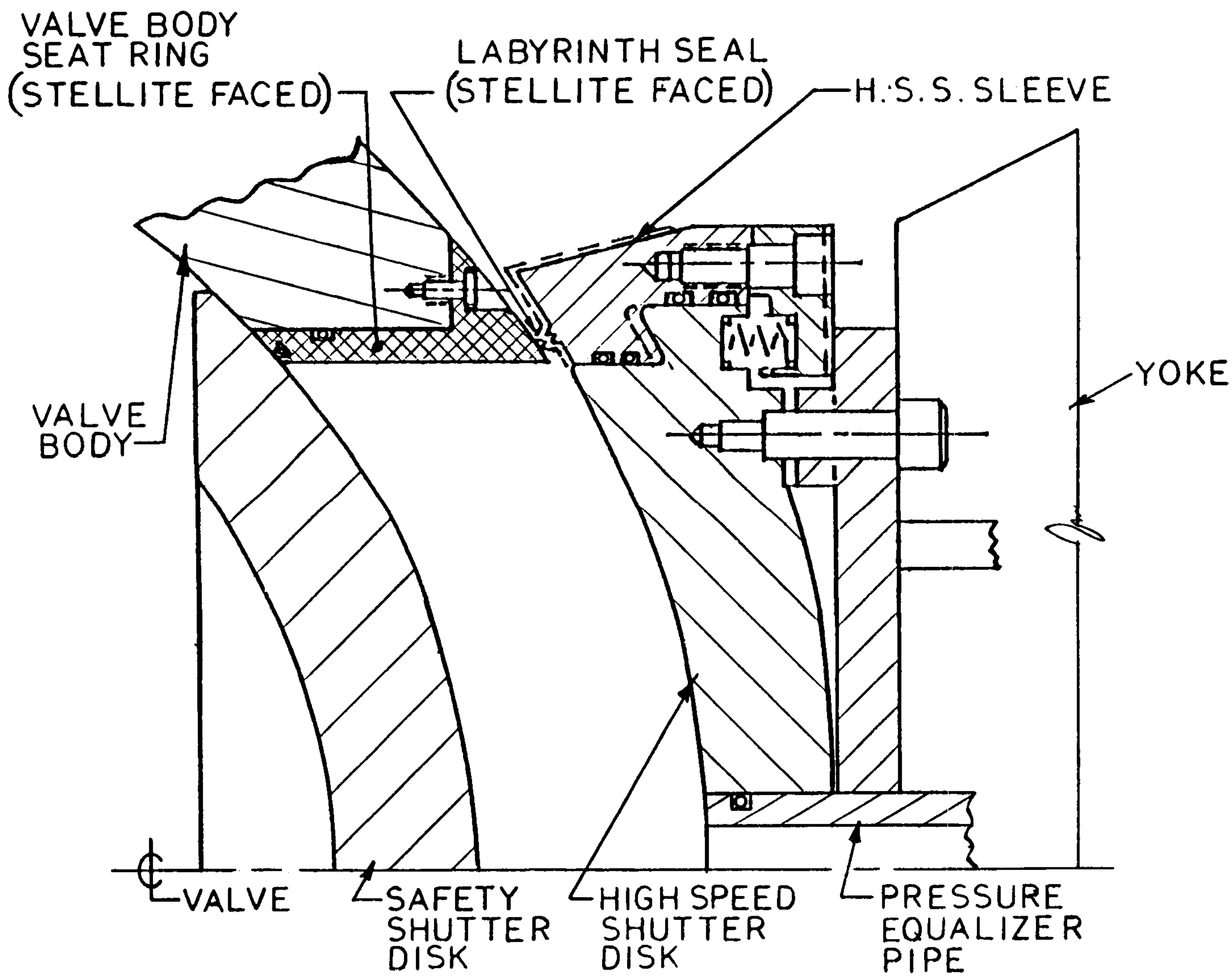

Figure 4. - High speed shutter seal cross section.

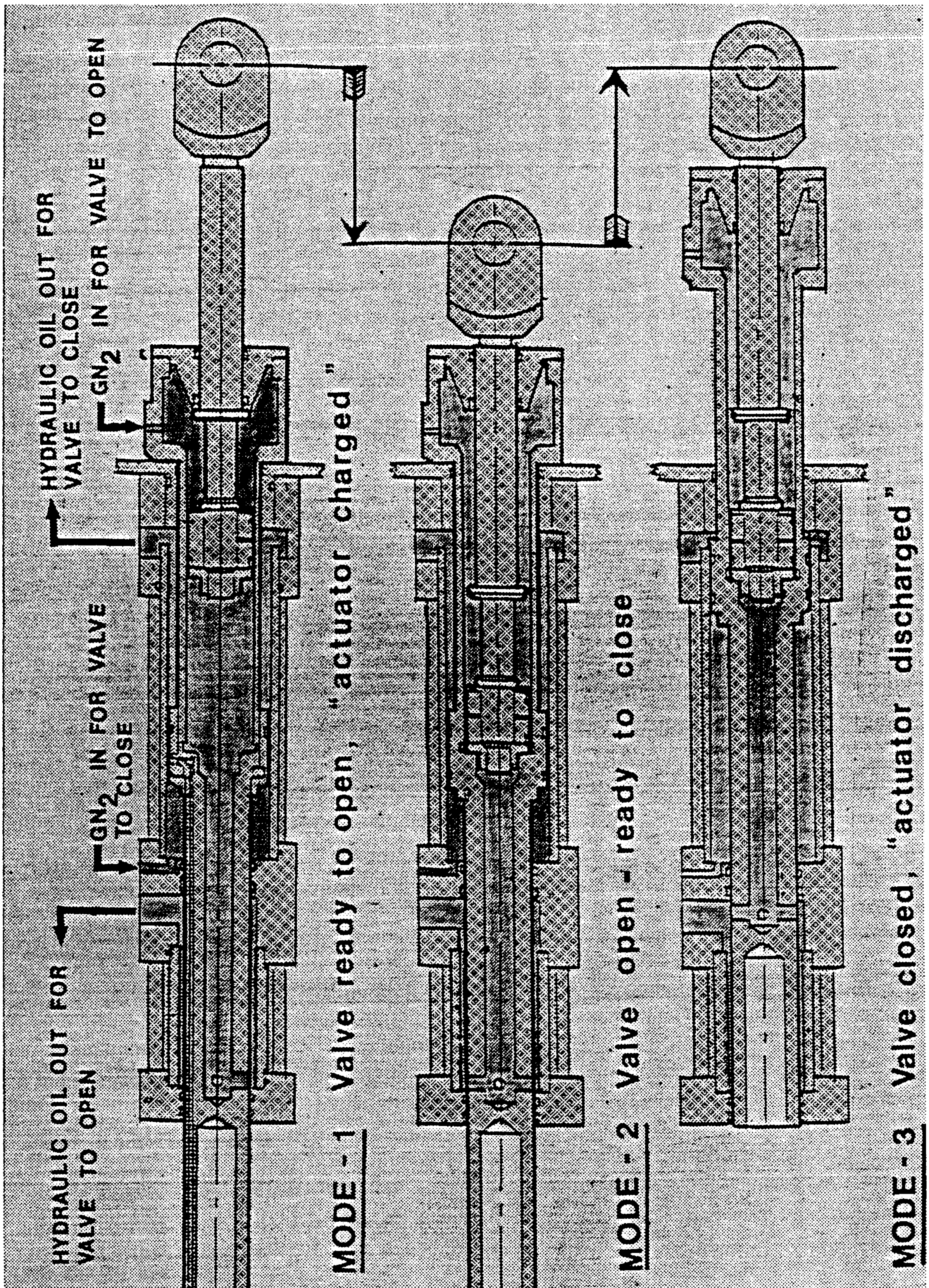

Figure 5. - Valve actuator cross section.