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CONCEPTUAL VALVE DESIGN FOR THE DRIVER TUBE OF THE LARGE-BLAST, THERMAL SIMULATOR

T. R. REED
EG&G IDAHO, INC. (INEL)

MAY 1989

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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The results of a conceptual design study of fast acting throat valves for metering the flow out of the driver tubes of the proposed U.S. LB/TS are reported. The short response times specified make it necessary to adopt a multi-element valve design for development of this wave shaping technique.

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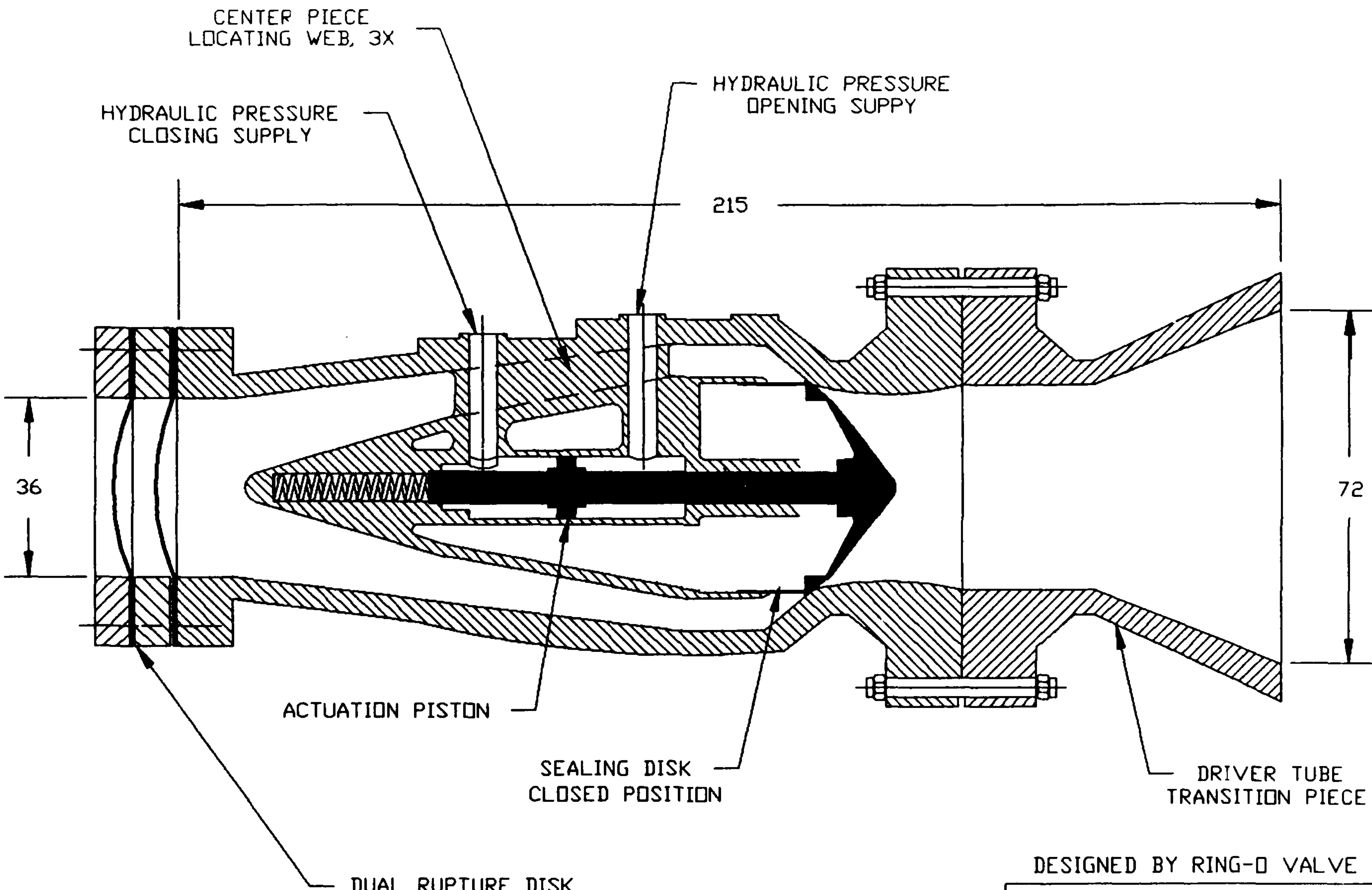
INTRODUCTION

A key component required in the development of the Large Blast Thermal Simulator is the high speed driver tube valves. Although successful blast simulation facilities have been built without using driver tube valves, the simulation envelope, simulation accuracy, test turn around, and per test costs can be considerably improved by incorporating valves in the facility design. EG&G Idaho Mechanical Engineering has completed investigation and evaluation of different valve designs which could be used in this application. It is planned to develop a half scale model based on the preferred design which will be tested and evaluated by the Ballistics Research Laboratory, Aberdeen Maryland.

Although highly desirable, no existing valves could be found which would meet the operating requirements necessary for blast simulation, thus such a valve design needs to be developed. The initial phase of this development was the procurement of four separate conceptual designs from valve specialty companies. A fifth design concept was pursued independently by EG&G Idaho to be used as a comparative design. From these efforts, three basic designs emerged, 1) single element, 2) double sliding sleeve and 3) multi-element. Two of the vendor concepts were of the multi-element type, one chose the double sliding sleeve concept, while the remaining vendor developed a single element design. EG&G's baseline design was a double sliding sleeve type. Figures 1 through 6 of this report illustrate each of these designs. In the case where there are two similar designs, only one is shown.



DESIGNED BY RING-O VALVE

LBTS VALVE
SINGLE ELEMENT DESIGN
CLOSED POSITION
FIG. 1

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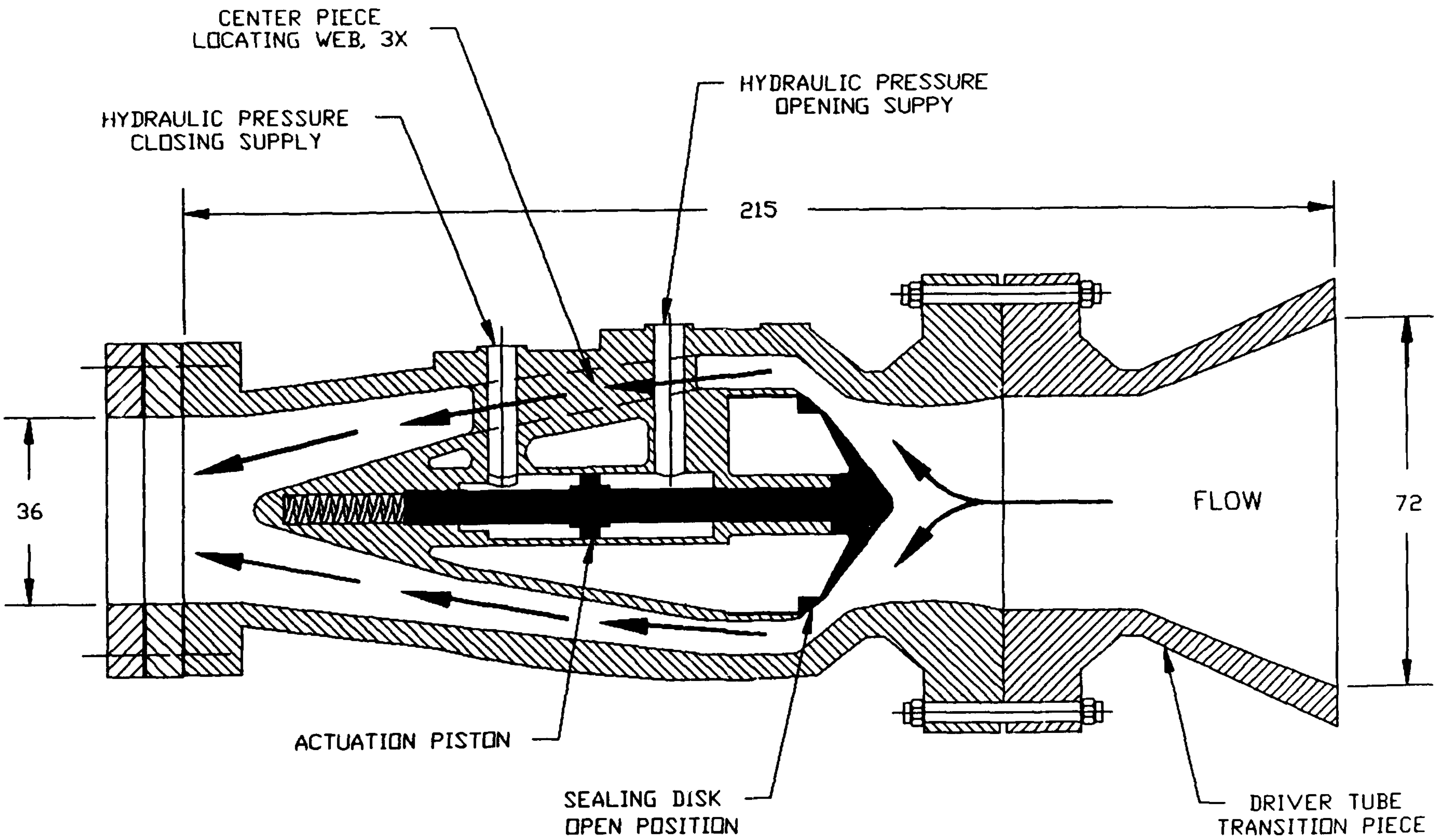

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LBTS VALVE
SINGLE ELEMENT DESIGN
OPEN POSITION
FIG. 2

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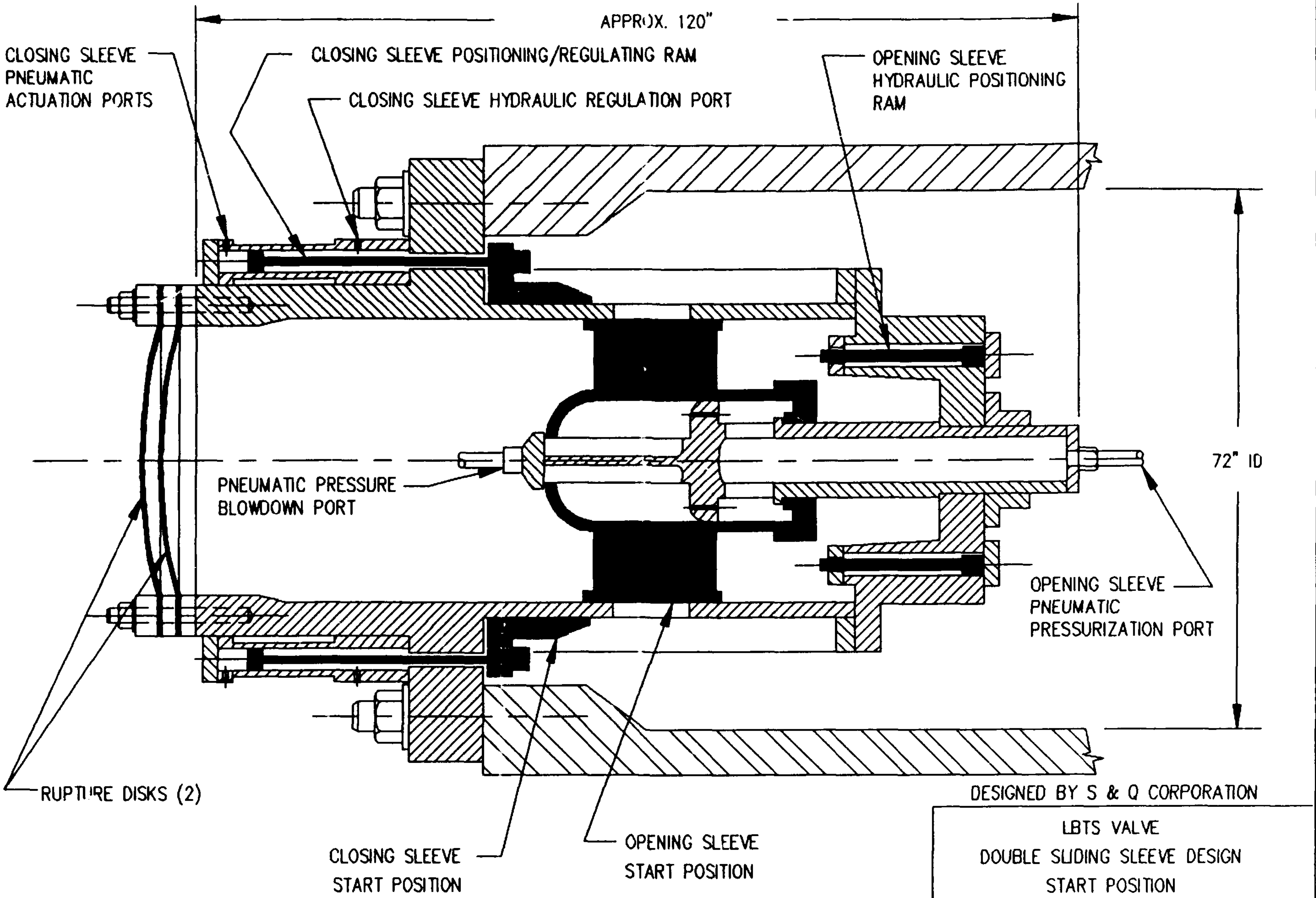
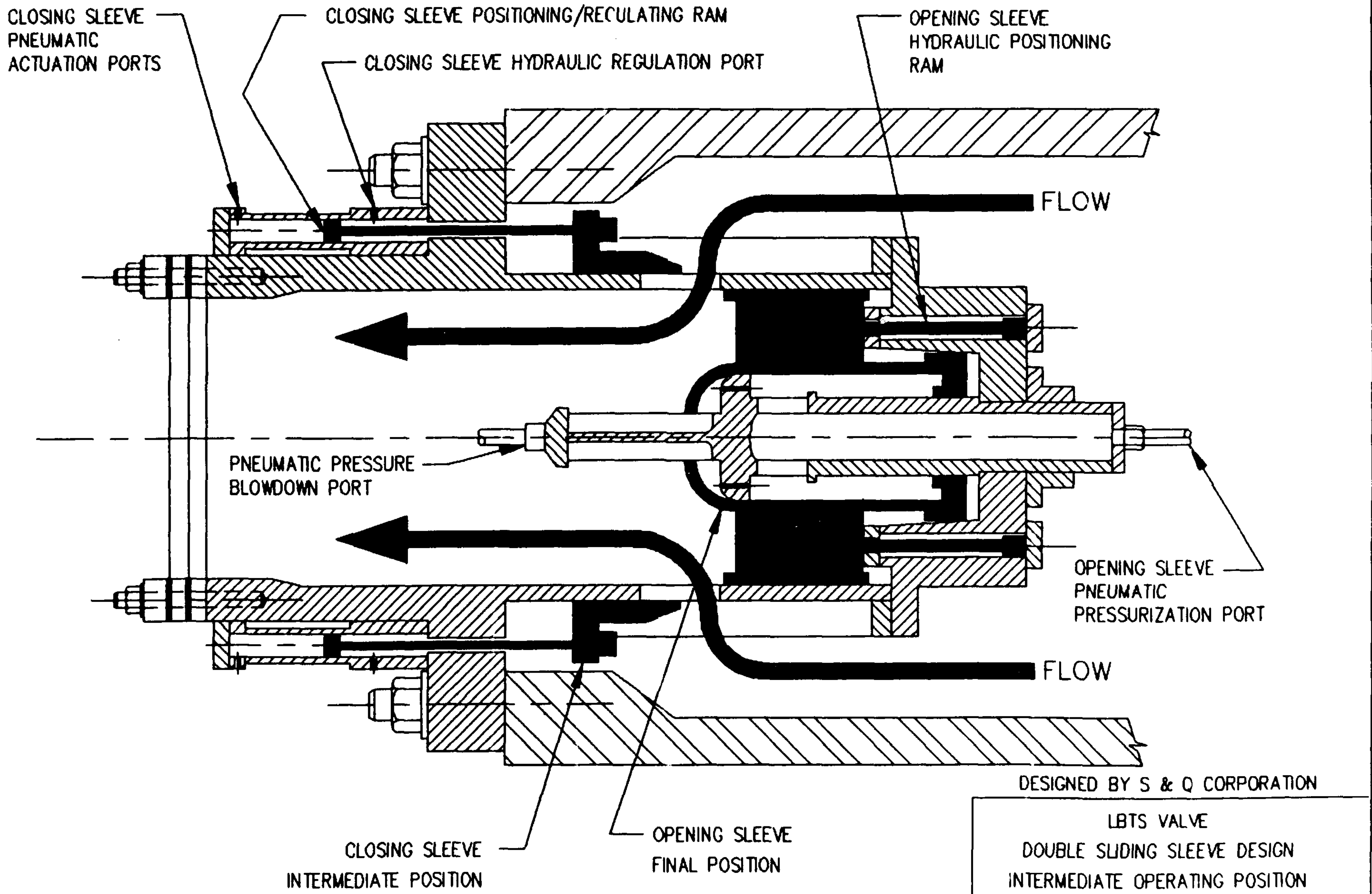


DESIGNED BY S & Q CORPORATION

LBTS VALVE
DOUBLE SLIDING SLEEVE DESIGN
START POSITION
FIG. 3

426425



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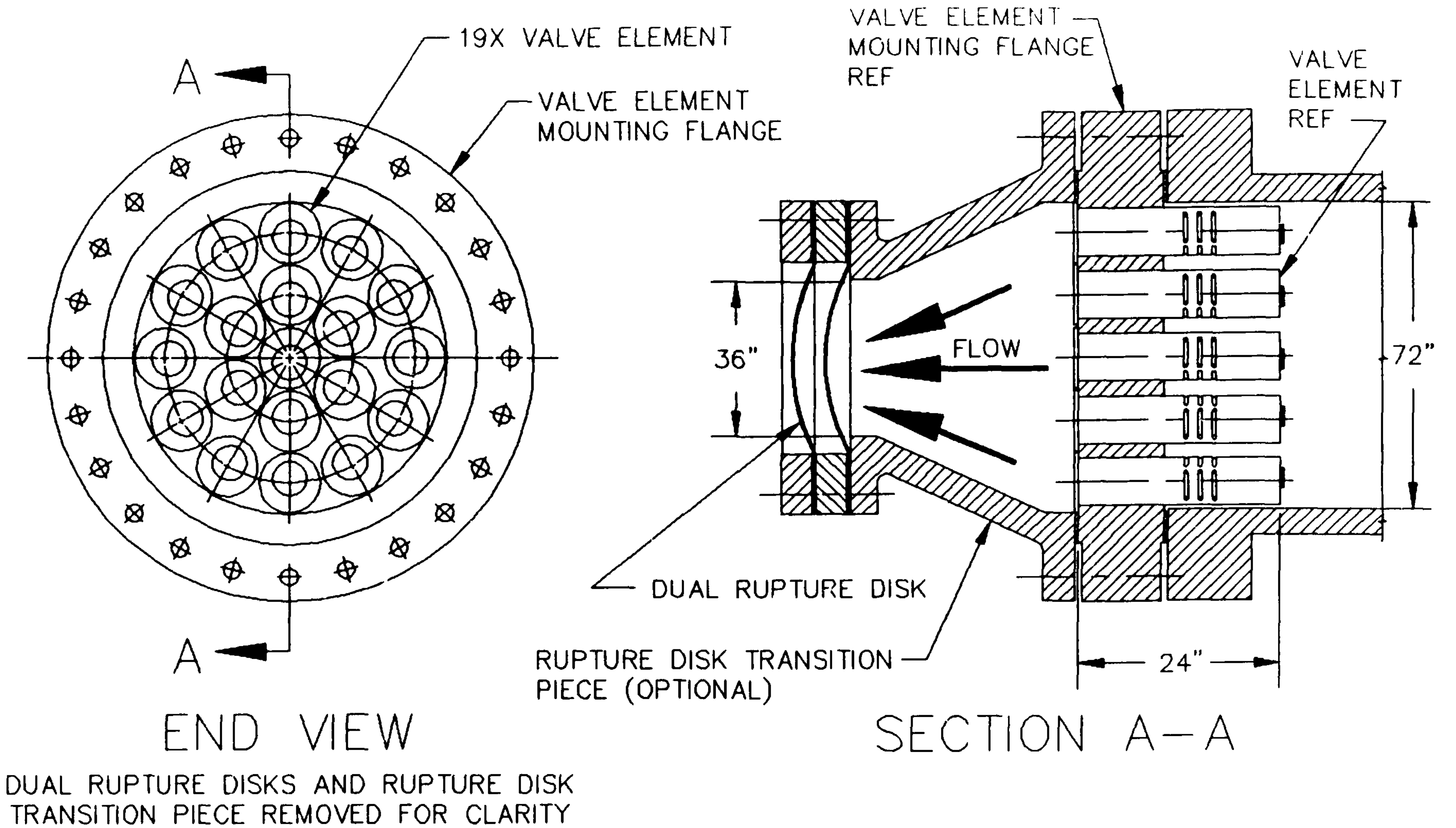
LBTS VALVE
DOUBLE SLIDING SLEEVE DESIGN
INTERMEDIATE OPERATING POSITION
FIG. 4

426426



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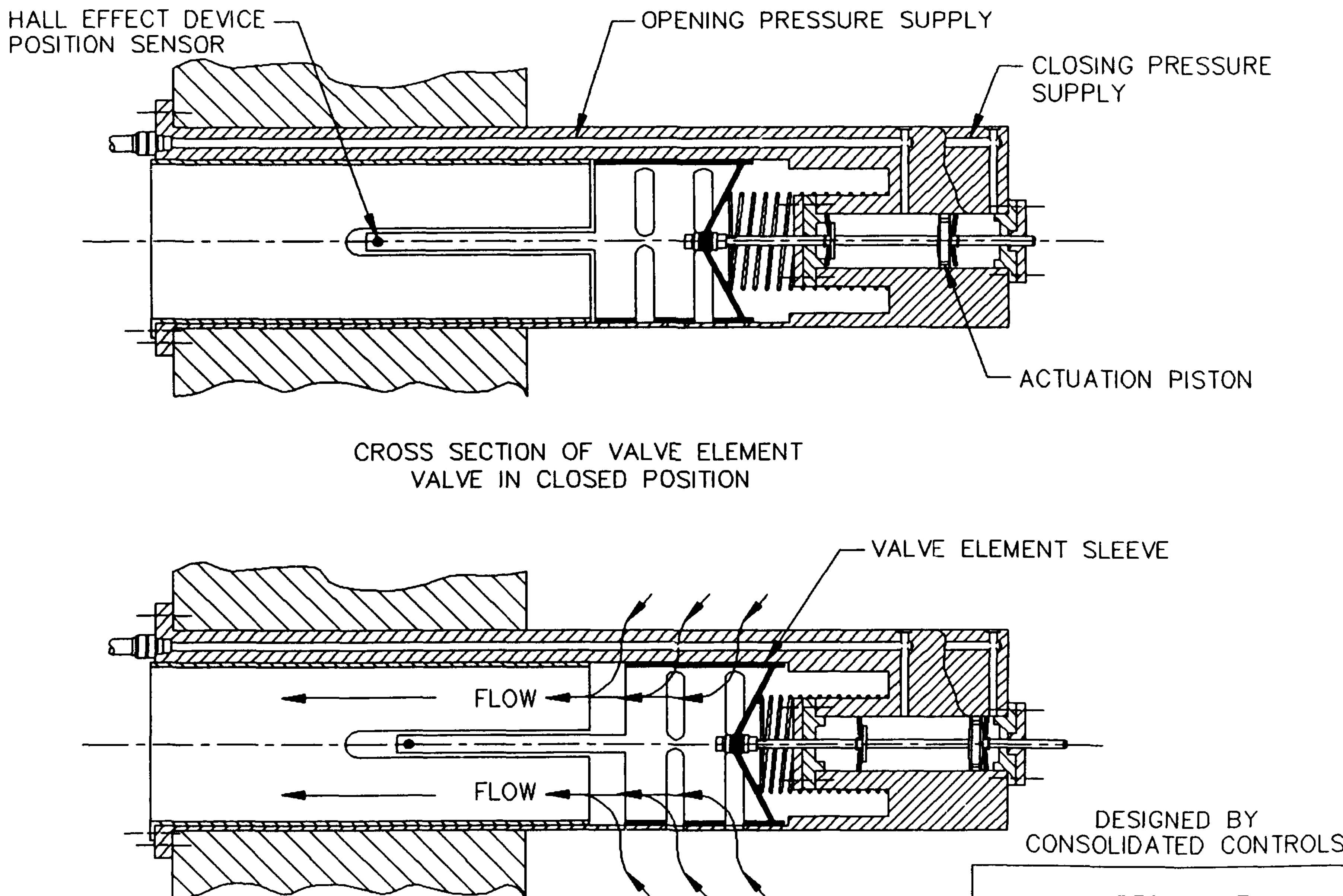
LBTS VALVE
MULTI-ELEMENT DESIGN
OVERALL ARRANGEMENT
FIG. 5

426427



CROSS SECTION OF VALVE ELEMENT
VALVE IN CLOSED POSITION

CROSS SECTION OF VALVE ELEMENT
VALVE IN OPEN POSITION

DESIGNED BY
CONSOLIDATED CONTROLS

LBTS VALVE
MULTI-ELEMENT DESIGN
ELEMENT DETAILS
FIG. 6

426428

VALVE REQUIREMENTS

In the conceptual design of these valves the following general design requirements were used:

1) Flow Media: Nitrogen

2) Inlet Pressure: 35-2250 psig

3) Outlet Pressure: 0-1000 psig

4) Media temperature: 700 F max

5) Ambient conditions: -40 to 130 F at 0 to 100% relative humidity

6) Opening time: 10 ms max

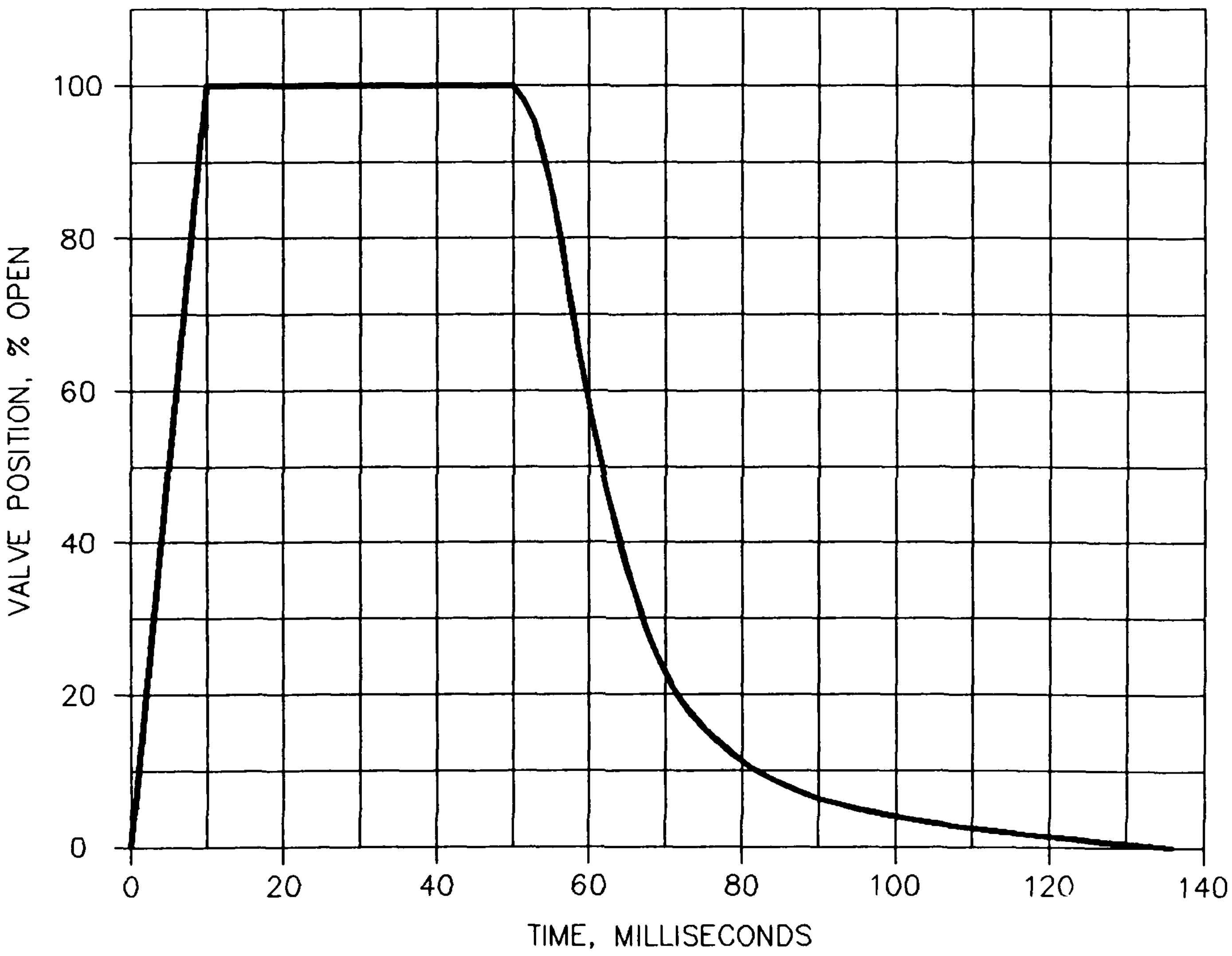
7) Dwell time (time valve is fully open): 0 to 200 ms

8) Closing time: Valve must have variable open area verses time schedules which can be modified to produce the desired blast simulation. A typical closing schedule is shown in figure 7.

9) Upstream connection: Full scale - 72 in. ID driver tube
   Half scale - 36 in. ID driver tube

10) Downstream connection: Full scale - 36 in rupture disks
    Half scale - 18 in rupture disks

11) Flow coefficient: Full scale valve must flow the equivalent of a 36 inch pipe of similar length. Half scale valve must flow the equivalent of an 18 inch pipe of similar length.



VALVE OPENING/CLOSING SCHEDULE
35 PSI–1KT BLAST WAVE
FIGURE 7

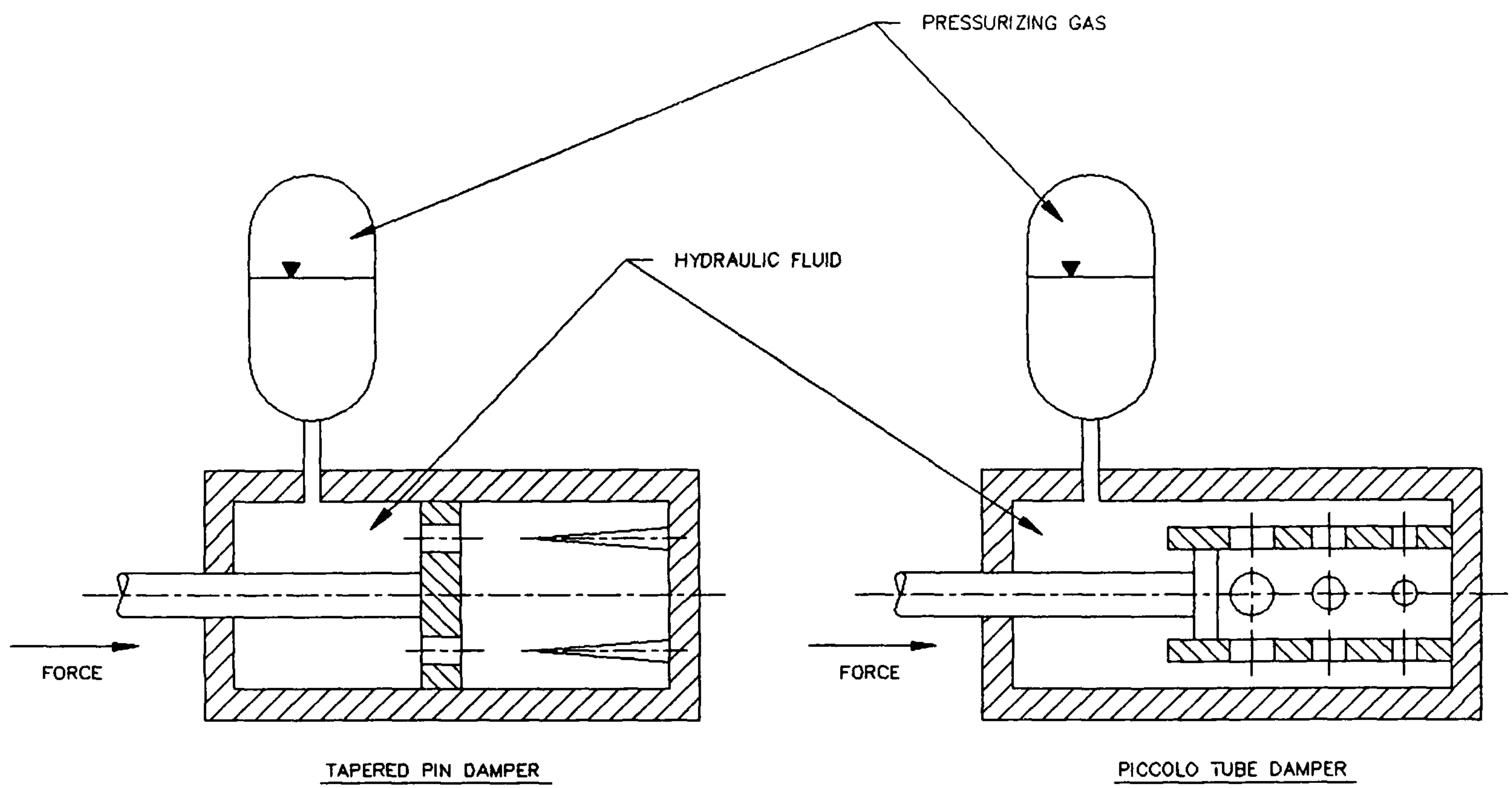
MAJOR DESIGN DIFFICULTIES

The primary difficulties in the design of a valve to meet the above requirements is 1) achieving the 10 ms opening times, 2) achieving 0 dwell time and 3) producing a closing schedule which is adjustable as well as capable of the fast cycle times. The fact the the valve is large, as well as subject to high pressure and temperature certainly complicates the design, but these items themselves are certainly within the capability of existing technology.

Achieving a 10 ms opening time in a valve of this size can be accomplished by several methods, including hydraulic actuation, gas actuation, propellant driven actuators and kinetic energy transfer devices. All of these methods require that a relatively large amount of energy be deposited in short period of time. Of these different methods, gas actuation was judged by EG&G Idaho to be the technology of choice. Dynamic simulation of a gas actuator was performed and verified that 10 ms opening times were possible in a valve of this size. However, in a single element valve design, opening times faster than 10 ms become difficult to achieve. Using helium as a driver gas, incorporating self venting actuator designs and utilizing exotic materials, opening times of 5 ms are possible. Of course if smaller valves are used, 10 ms opening times become easier to achieve. It is interesting to note that one of the major limitations of valve opening speed is the ability to transport the actuator gas into and out of the actuator volume. To attain high valve speeds the actuator control valves and supply/vent lines need to be large is comparison to the actuator size. Indeed, in most cases actuator flow restriction is the limit on valve speed rather than the mass of the moving element or the actuating pressure. However, in general, quick opening times are a balance of actuator pressure, actuator flow area, moving element mass and actuator piston area.

The requirement of a 0 dwell time is a significant complication in the design of single element large valves. This means that as the valve comes to 100% open it must immediately be driven in the opposite direction. If this were not a concern, the valve moving element could be accelerated throughout its travel so as to minimize the opening time and, after opening being completed, be snubbed to a stop. However, to achieve 0 dwell, a single element valve must be decelerated prior to reaching 100% open. In effect the valve element must be accelerated for half of its travel, and then decelerated for the remaining half. This requires higher acceleration forces than would be necessary merely to open the valve quickly.

Perhaps the most challenging requirement is the necessity of a variable closing schedule. This requires that the valve element is in a specific position with respect to time. Complicating the matter is the fact the time duration for the closing is very short. In some instances the valve is 90% closed in about 80 ms. This would require that an active control system have to have a response time of less than 10 ms to adequately control the closing schedule. A complete control loop which would operate at these speeds would require custom fabrication and development. A simpler approach to this problem is to use open loop control in which the time delay for the control equipment can be accounted for. This approach requires highly repeatable control system components. Mechanically the most simple approach to this problem is to use damping equipment which is position sensitive, such as tapered pin or piccolo tube dampers. These devices, illustrated in figure 8, allow the hydraulic resistance to be related to damper position. However, these items have reduced flexibility. To alter the damping profile in the tapered pin type would require change out of the tapered pin. To some degree the damping profile on the piccolo tube type can be altered by connecting valves to the holes on the piccolo tube and adjusting these valves for the different conditions. This eliminates the need for equipment change out but still produces damping profiles within a limited envelope. Whatever control scheme is used, recording the actual closing schedule delivered would be useful in tuning the system and troubleshooting problems.



POSITION DEPENDENT HYDRAULIC DAMPERS

FIGURE 8

VALVE DESCRIPTION

Single Element Design

This concept was developed by Ring-O Valve S.p.A. and is illustrated in figure 1 and 2. This valve is an axial flow design using a single moving assembly. The sealing disk moves to the left to expose an annular flow area. Disk actuation is provided by hydraulic fluid which is routed to the piston actuator through each of three drilled locating webs. The hydraulic fluid pressure is attained in two gas charged accumulators. Sealing disk travel is approximately 9 inches. Closing schedule control is achieved by controlling the hydraulic fluid flow rate through an array of on/off cartridge valves. Control of the cartridge valves is via a computer which receives position input from a transducer in the valve.

Double Sliding Sleeve Design

This concept was developed by S & Q Corporation, and was also investigated independently by EG&G Idaho as a baseline design. An illustration of the S & Q design is found in figure 3 and 4. This valve uses two separate sleeves, one of which operates on the outside of a ported cylinder, while the other operates on the inside. During a blast sequence, the inner closing sleeve uncovers the flow port, while the outer sleeve is used to close the port. Each of the sleeves are pneumatically actuated, the opening sleeve being also pneumatically snubbed. The controlled closing schedule is provided by limiting the flow of hydraulic fluid from the closing sleeve actuating rams. Positioning rams are used to reset the inner opening sleeve to the armed position. The outer sleeve is likewise set to the start position using the positioning/regulating rams. Two separate sleeves are used to allow each sleeve some approach distance to 'get up to speed' prior to uncovering/covering the port. This also allows the opening sleeve to be accelerated throughout the port opening, and decelerated after the port is fully open. This results in fast opening times at reduced actuating forces while maintaining the capability for 0 dwell time.

Multi-Element Designs

Eaton Consolidated Controls and The Digital Valve Company independently developed a multi-element type design. The Eaton concept is illustrated in figures 5 and 6. These concepts incorporate 19 to 36 identical valve elements which have an total equivalent flow area of the single element valve. These elements are pneumatically operated to either an open or closed position at a fixed rate. No closing schedule regulation for an individual element is provided. The capability to achieve a closing schedule is provided by sequentially closing valve pairs to produce a stepped closing curve which approximates the required closing schedule. Other than the center valve element, the valves are closed in pairs, each pair being diametrically opposite so as to produce coaxial loading on the driver tube. The one off nature of these valve elements results in a stepped closing schedule which approximates the ideal closing profile. Control for this sequential closing will be provided by a digital computer which will time the closing of each valve. Position sensors are used on each element to monitor system performance.

DESIGN EVALUATIONS

Single Element Design

This design is the most basic, and at first look appears to have promise. The primary advantages of this concept is its mechanical simplicity. However, on closer inspection several problems can be seen with this approach:

1) When using a actuator piston diameter of 12.6 inches, and a moving element weight of 1500 lbs, approximately 10,000 gpm hydraulic fluid at 5000 psig would be required to open the valve in 20 ms. To open the valve in 10 ms would require 20,000 psig pressure at 10,000 gpm. Another approach would be to double the diameter of the cylinder which would give a 10 ms opening time at a flow rate of

40,000 gpm at 5000 psig. From this it can be seen that this design requires the use of high pressure hydraulics at very high flow rates particularly when fast opening times are desired. Small hydraulic actuated valves can be made to operate very fast, however as the valve is scaled up, the actuating forces to maintain the same opening time increase with the square of the valve diameter.

2) The force required to accelerate the hydraulic fluid in the line is considerable. Assuming the 20 ms opening time stated in the base case above, and also assuming that three 25 foot lines of 10 inch ID are to be used for each valve, then an additional 1500 psi would be required to accelerate the hydraulic fluid. If smaller line sizes are chosen the required accelerating pressure rises dramatically. Conversely, larger hydraulic lines are thought to be impractical. This item then tends to further increase the necessary hydraulic pressure requirements.

3) Using hydraulic actuation will require large lines and high pressures. Leakage at these high pressures is likely, and with the large volumes of oil involved, can result in very costly and time consuming maintenance.

4) This valve design is vulnerable to control system malfunction. For example, should the hydraulic valves which slow the piston fail to open, the valve disk can slam into the seat at speeds in excess of 75 ft/s. This can result in serious valve damage, necessitating valve replacement. A passive damping unit which could adsorb the maximum kinetic energy of moving elements and hydraulic fluid could be incorporated but would complicate the design and interfere with the requirement for controlled closing.

5) As previously stated this valve will have a hydraulic flow rate of at least 10,000 gpm. Since the programmable closing schedule is provided in this design by sequentially closing pilot operated on/off hydraulic valves, a large number of specialty high pressure high flow rate valves would be required.

6) In comparison with the multi-element concept, maintenance and repair of the valve would be difficult and time consuming.

7) Due to the single element nature of this valve, scale up problems from a smaller prototype could be expected. Also, development of the hydraulic control system is viewed as a potential problem area. Therefore this concept is seen to entail considerable risk in development.

<u>Double Sliding Sleeve Valve</u> The use of two moving elements rather than one offer some distinct advantages. This allows each sleeve to utilize acceleration and deceleration approach zones which result in high sleeve velocities as they open/close the ports. Over travel distances with the use of passive snubbing allow the sleeves be brought to rest in a reliable manner. With two sleeves a 0 dwell time is easily met by the proper timing of the closing and opening sleeves. Additionally, the closing sleeve can be at some velocity before opening the port which allows for greater flexibility in the possible closing schedules.

The major difficulty seen with this design is the hydraulic regulation of the closing sleeve. In order to meet a variety of closing schedules the hydraulic resistance in the regulating system needs to be sleeve position dependent. A single hydraulic resistance will not produce the variety of closing schedules required. Several passive snubbing systems are available that are position sensitive, such as the tapered pin and piccolo tube dampers previously discussed, but their lack of flexibility is judged to be a serious handicap. A closed loop control system would be very flexible, but difficult to engineer due to the response times required. In addition, similar to the single element design, significant risk is seen in the scale up development of this valve.

<u>Multi-Element Design</u>

By using a multitude of smaller elements many of the problems with the single element and double sliding sleeve valves can be minimized. Due to their smaller size the individual elements can be made operate acceptably fast while keeping the kinetic energy of the elements low. Likewise, attaining a 0 dwell time is easier with a smaller element. The multi-element concept has other advantages which include:

1) Because the valve elements are small a single valve element can be fabricated and tested at a relatively modest cost. This would assure that the the desired valve speed and leakage could be attained, and would greatly reduce scale up problems.

2) Timing of the opening and closing schedule is easily changed and very flexible.

3) Failure of a single element would not seriously compromise test results.

4) Maintenance or replacement of a valve element is relatively easy since each element could be handled by hand or small handling equipment.

The major criticism of this proposal is that a stepped closing schedule is produced rather than a smooth transition. Although this appears to be a problem, computational models of the LBTS indicate that this stepped curve will not significantly compromise the blast simulation. Although not a serious limitation, this valve design requires a larger physical envelope to accommodate the reduced flow efficiency of the smaller elements.

CONCLUSION

The development of a LBTS valve which meets the design requirements is within the capability of existing technology. Although several viable approaches are available, the concept that appears to have the most promise is the multi-element design. This design will allow for early prototype testing which will highlight possible design problems. Thus the risk to the overall program is considerably reduced with this concept. Also, the multi-element concept is thought to have the most technical merit. It is therefore recommended that the multi-element design be pursued for further development.

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