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DESIGN OF AN AUTOMATIC REPOSITIONING
MORTAR SYSTEM

G. W. Woods, et al

Watervliet Arsenal
Watervliet, New York

February 1973

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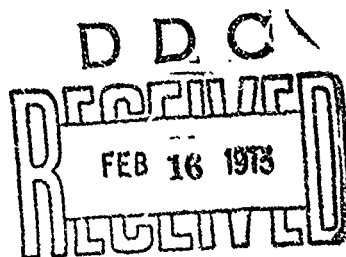
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TECHNICAL REPORT

WVT-7235

DESIGN OF AN AUTOMATIC REPOSITIONING MORTAR SYSTEM

FEB 1973



BENÉT WEAPONS LABORATORY

WATERVLIET ARSENAL

Watervliet, New York

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BY

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DESIGN OF AN AUTOMATIC
REPOSITIONING MORTAR SYSTEM

ABSTRACT

This report describes the design, operation and test results of a fluidic system for automatic control of elevation and azimuth of a mortar. The sensing, logic and actuation are accomplished utilizing air. Interface problems are minimized by operating the entire system on a single medium.

Cross-Reference
Data

Digital Fluidics
Fluidic Amplifiers
Logic Circuits
Switching Theory

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PROBLEM

When a mortar is fired, the resulting recoil forces tend to displace the barrel and baseplate downward, backward and to either side of the initial placement. These movements change the elevation and azimuth of the mortar. Corrections in elevation and azimuth are presently made by the trained mortar crew and take from ten (10) to sixty (60) seconds.

The objective of the work described in this report is to provide a repositioning system which will automatically return the mortar to its original azimuth and elevation setting.

INTRODUCTION

Development of a mortar with an automatic elevation control was initiated in August 1969. The elevation control consisted of an analog repositioning system using a back pressure nozzle sensor and a fluidic proportional amplifier. This system was completed and test fired at Cold Regions Research and Engineering Laboratory, Hanover, N. H. on 15-16 January 1970. The test results showed that (1) the concept of automatic elevation control for a mortar is a definite possibility since repositioning is accomplished in 3-4 seconds; (2) the use of a tripod mount provides an acceptable reference for elevation sensing as indicated by the ± 5 mil error in automatic repositioning; and (3) due to the loose coupling between the barrel and sleeve, the shock and vibration loading on the tripod mount and associated control mechanism is acceptable so that the use of conventional devices in the mechanical design is practical. These test results show feasibility of the concept of automatic repositioning and that further work should be initiated to implement the azimuth and

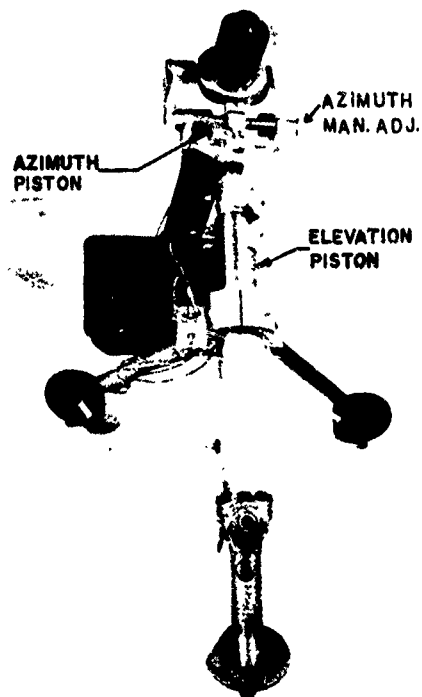


Figure 1
Mortar, Front View

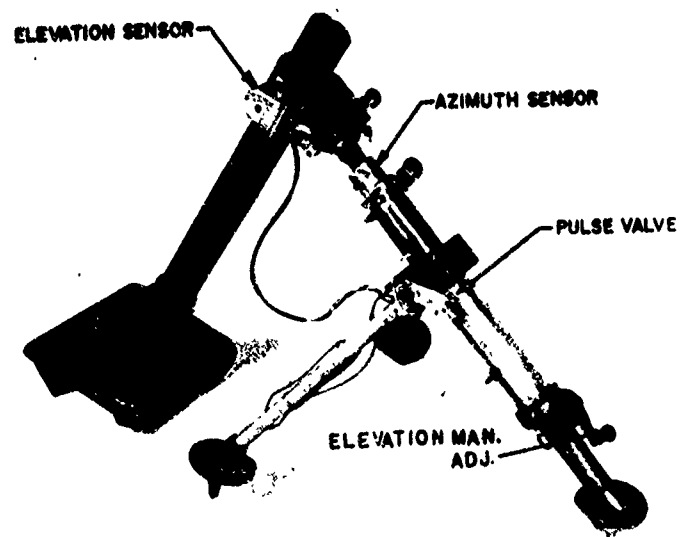


Figure 2
Mortar, Side View

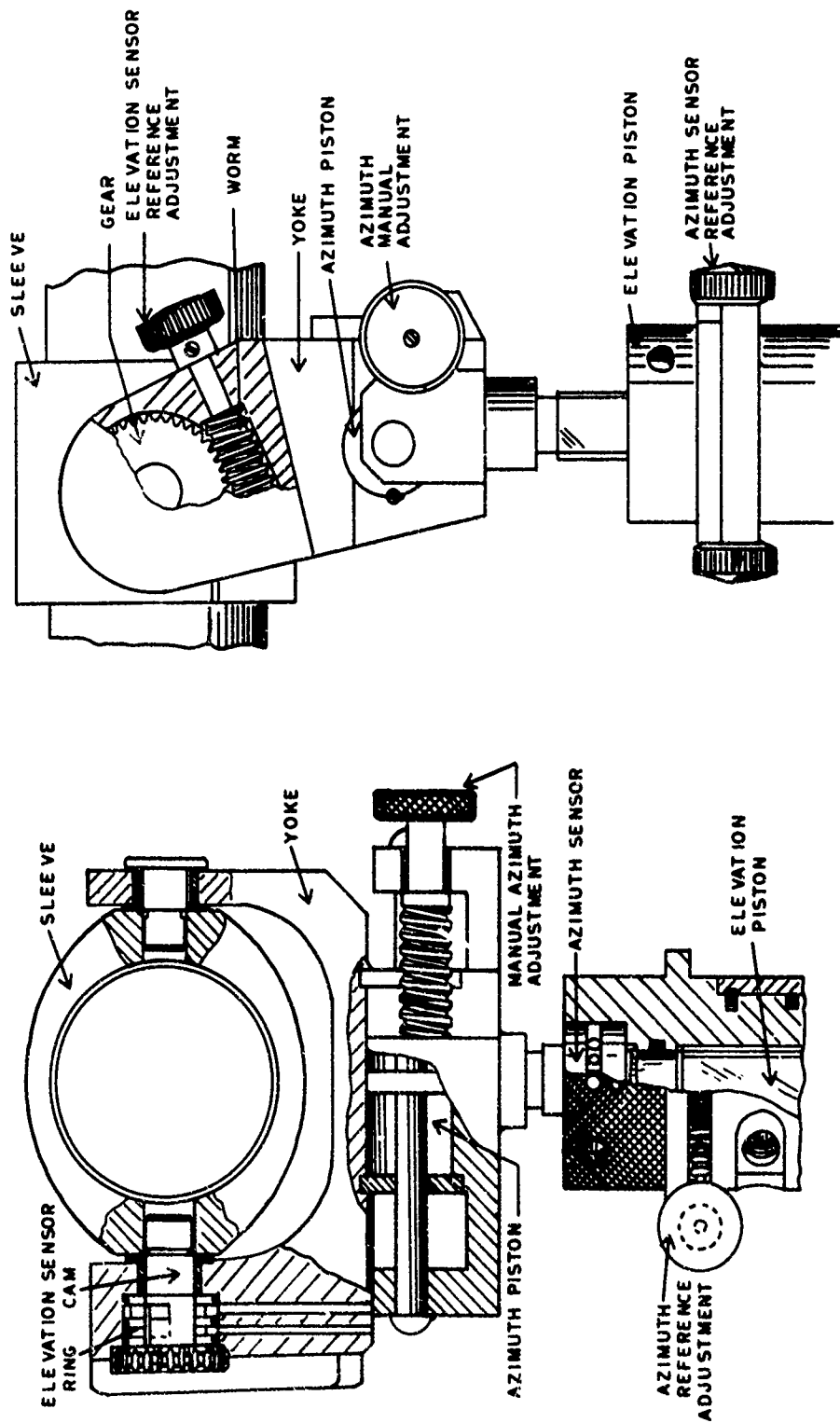


Figure 3
Control System, Front View

Figure 4
Control System, Side View

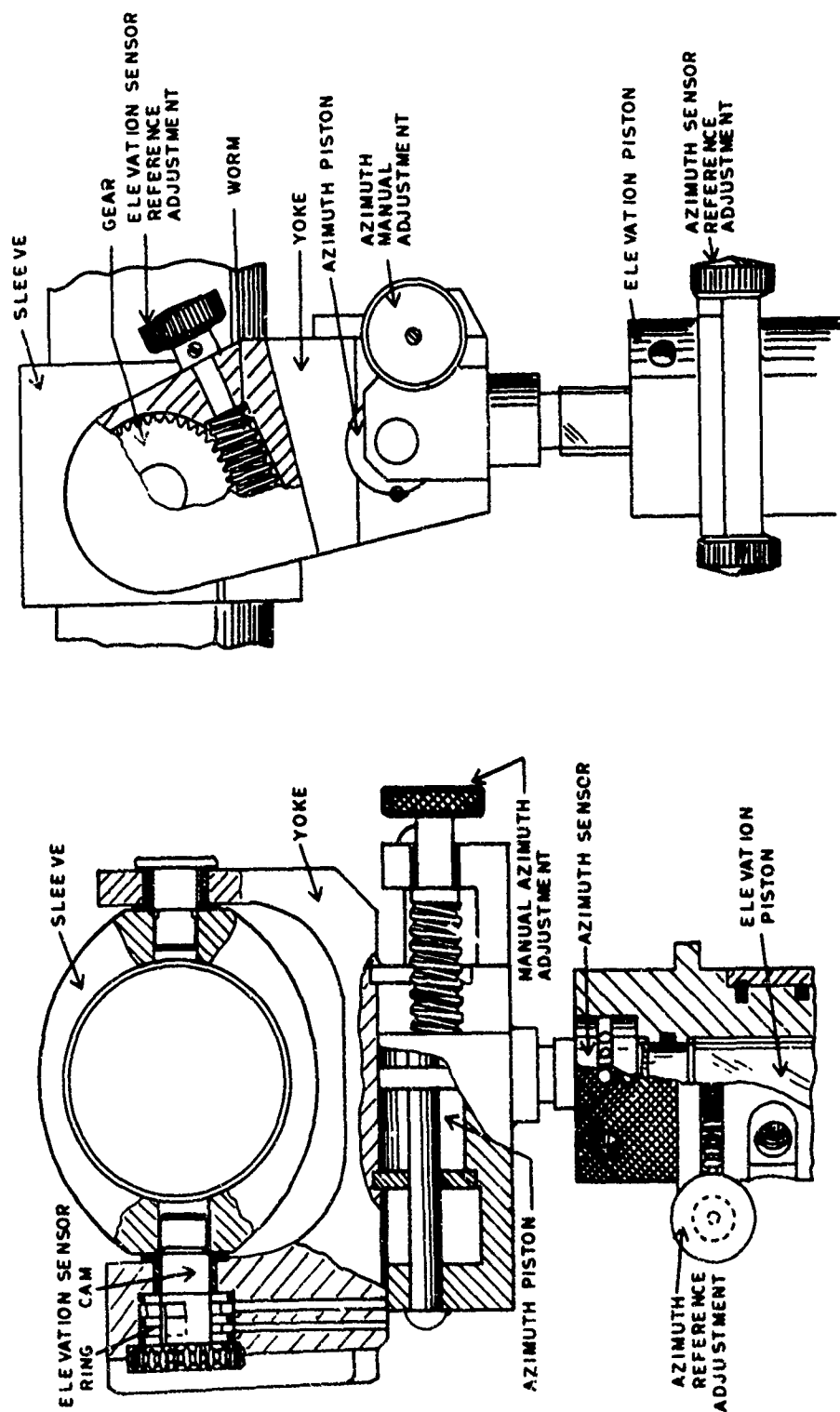


Figure 3
Control System, Front View

Figure 4
Control System, Side View

elevation control together with a self-contained power supply.

In order to minimize power requirements, air consumption must be minimized. To accomplish this a different control scheme was designed using digital sensors and circuitry instead of the proportional system described above. An on-off system to conserve air consumption between firings, and a locking mechanism to maintain actuator position while the air supply is turned off is also included.

APPROACH TO THE PROBLEM

Both the elevation and azimuth systems utilize similar components and each system is described separately in detail.

Digital Elevation System:

DESCRIPTION: The elevation control system consists of an elevation sensor, a front leg containing the elevation actuator (piston and cylinder), a control unit containing the two or-nor elements, two fluidic interface valves, a 4-way valve, and the reference setting system. Figures 1-4 include two photographs and two cut-away diagrams to aid in identifying components.

Below is a block diagram of the elevation system:

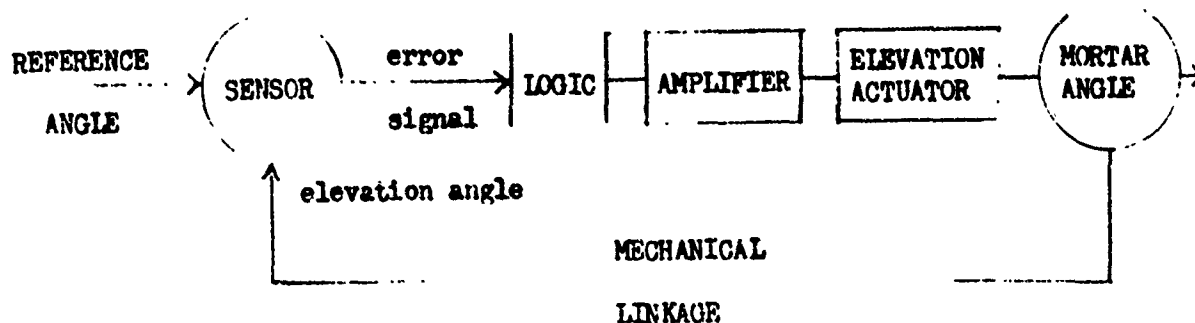


Figure 5 Elevation Block Diagram

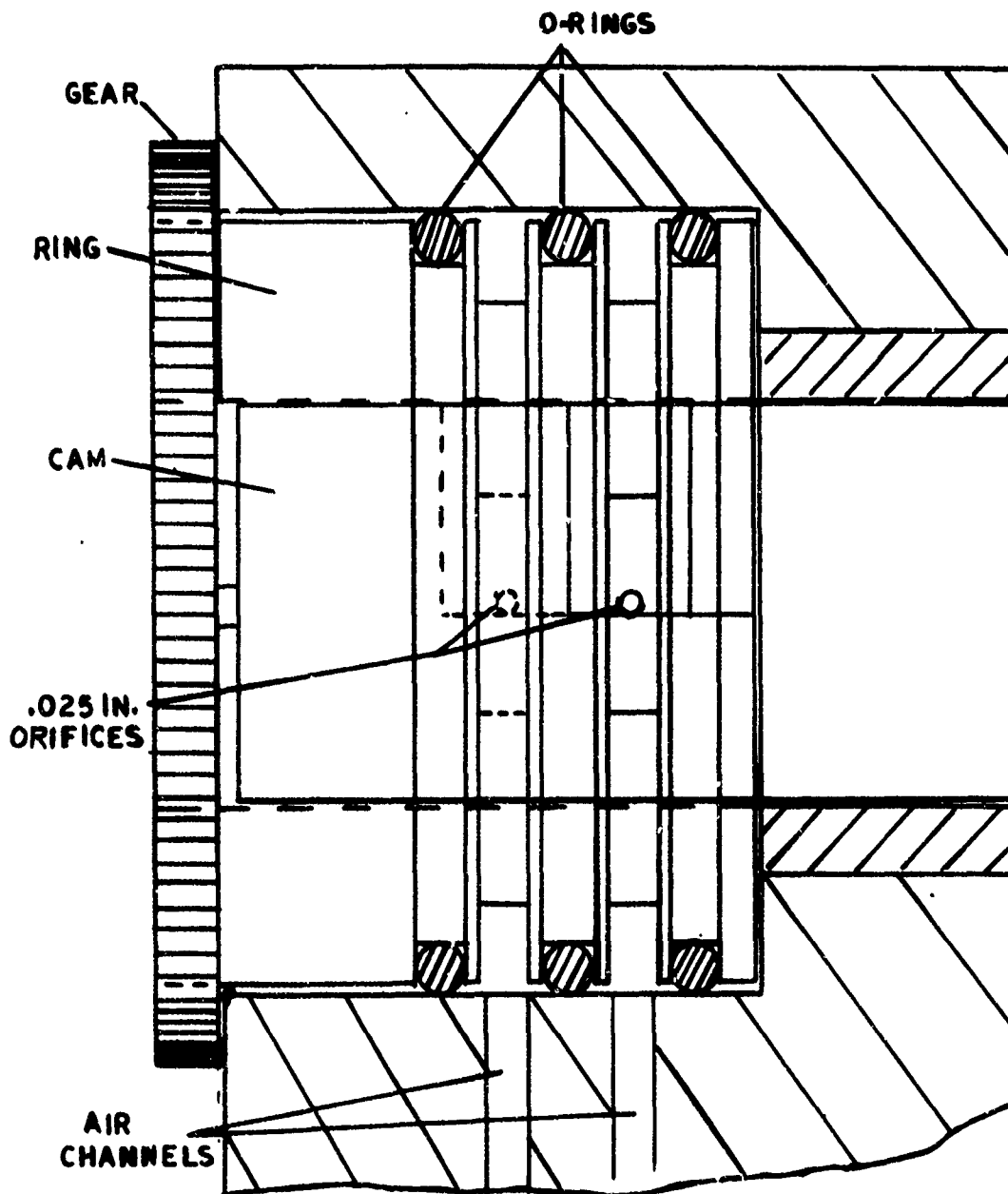


Figure 6
Elevation Block Diagram

A reference angle is determined and indexed on the sensor. The actual angle is supplied to the sensor through the gun's barrel-sleeve linkage. The sensor detects a difference between the reference and actual angle and sends this error signal to the logic. Then the signal is amplified and sent to the elevation actuator to correct the angle of the mortar barrel.

The digital elevation system is a fluidic "on-off" control system. The power comes from a regulated 30 psi supply. The pulse valve is an inertial switch with a time delay action. When the mortar is fired, the recoil energy activates the pulse valve which turns on the supply air for a specific time, about three seconds. The supply is regulated to 30 psi, passes through the pulse valve when actuated, and is divided into a 30 psi and a 2 psi supply. The 2 psi supplies the two or-nor key logic elements (2A, 2B) and the 30 psi supplies the two interface valves (3A, 3B) and the pilot actuator of the 4-way valve.

Each logic or-nor key operates from a 2 psi supply entering the element and a small flow of supply air passes through a resistor and out of the key port and to the sensor. A majority of the supply air normally flows through output port (01). If the key port is blocked, the air flow switches from (01) output to (02) output port.

The elevation sensor consists of a cam, a cylindrical ring with an attached gear, and a worm with an adjusting knob, Figures 3, 4 and 6. The mortar tube is free to slide in the sleeve, and the sleeve with the attached cam can pivot about the axis of the sensor in the yoke. The ring in the yoke may be turned by the worm and gear for setting the reference

angle of the elevation sensor. The yoke has two channels carrying air to two O-ring separated annular grooves in the sensor ring. The two annular grooves each have a .025 inch orifice which are 180 degrees apart facing the cam in the center of the sensor. The cam has two cut-away sections providing two edged surfaces approximately 180 degrees apart. Air (1 psi) is supplied by the key ports of the two logic element through the yoke channels to the elevation sensor. In a centered position, both orifices are blocked by the cam which creates a back pressure or input signal to the logic elements. This is a neutral or "no action" condition for the control system. As the cam turns, one orifice is unblocked and the other orifice remains blocked. The unblocked orifice allows the air in that channel to escape through the orifice to the atmosphere, eliminating back pressure, or input signal in that channel. This causes the logic element to switch its output from the neutral condition to the active condition in which the interface valve, the power amplifier, is turned off and air is allowed to escape from one end of the elevation actuator and the air pressure on the other side forces the piston to move.

OPERATION: The mortar is initially set at some angle θ with the horizon (Figure 7) and the elevation control system is in the state represented in Figure 8; the sensor is in a centered position, the pulse valve is off, the interface valve is off, the 4-way valve is closed, and the air is trapped in both ends of the elevation actuator.

Immediately after the mortar is fired the baseplate has moved back and the angle of the tube is now ϕ where $\theta > \phi$ (Figure 9). The elevation

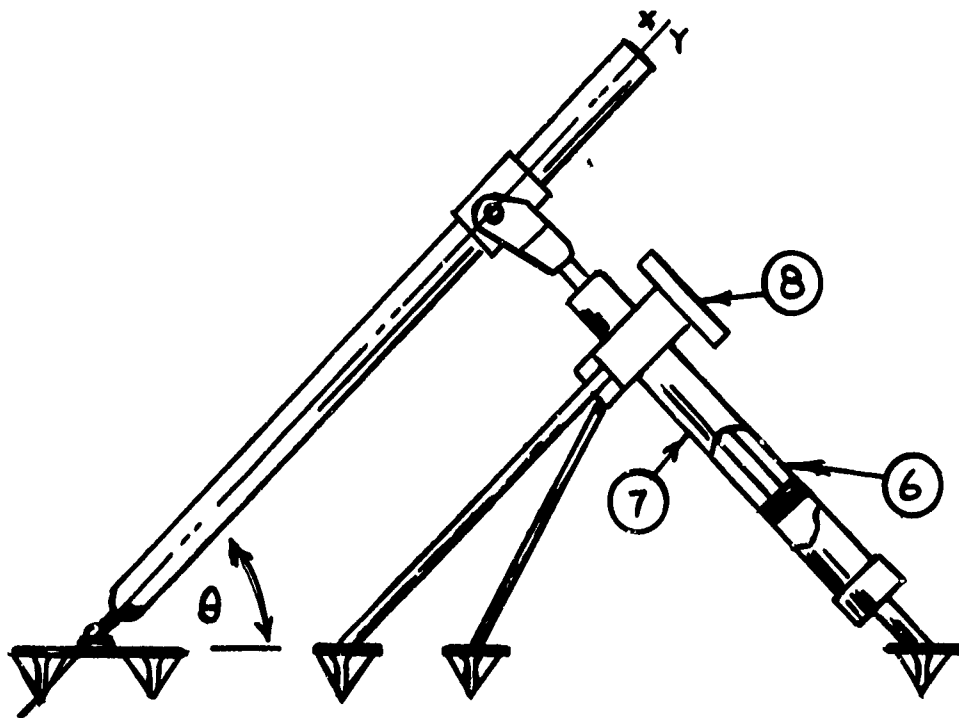


Figure 7
Mortar Before Firing (Elevation)

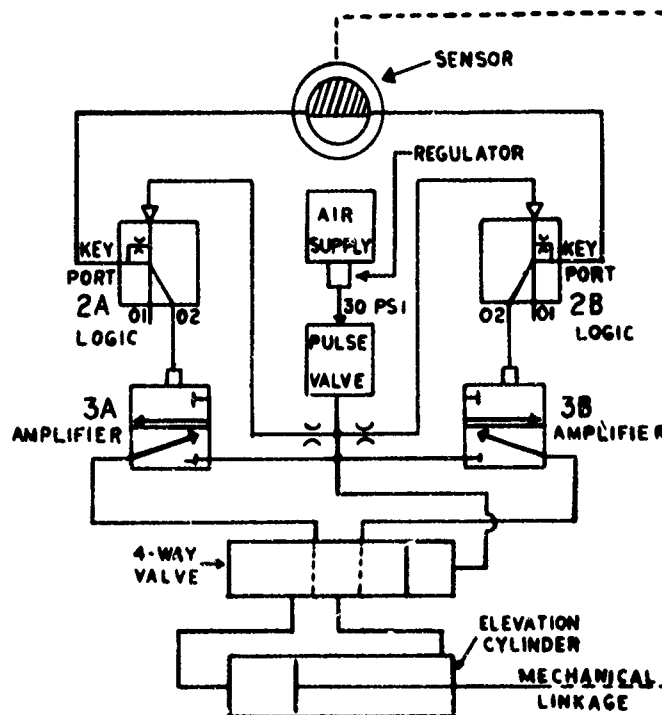


Figure 8
Elevation Control Schematic

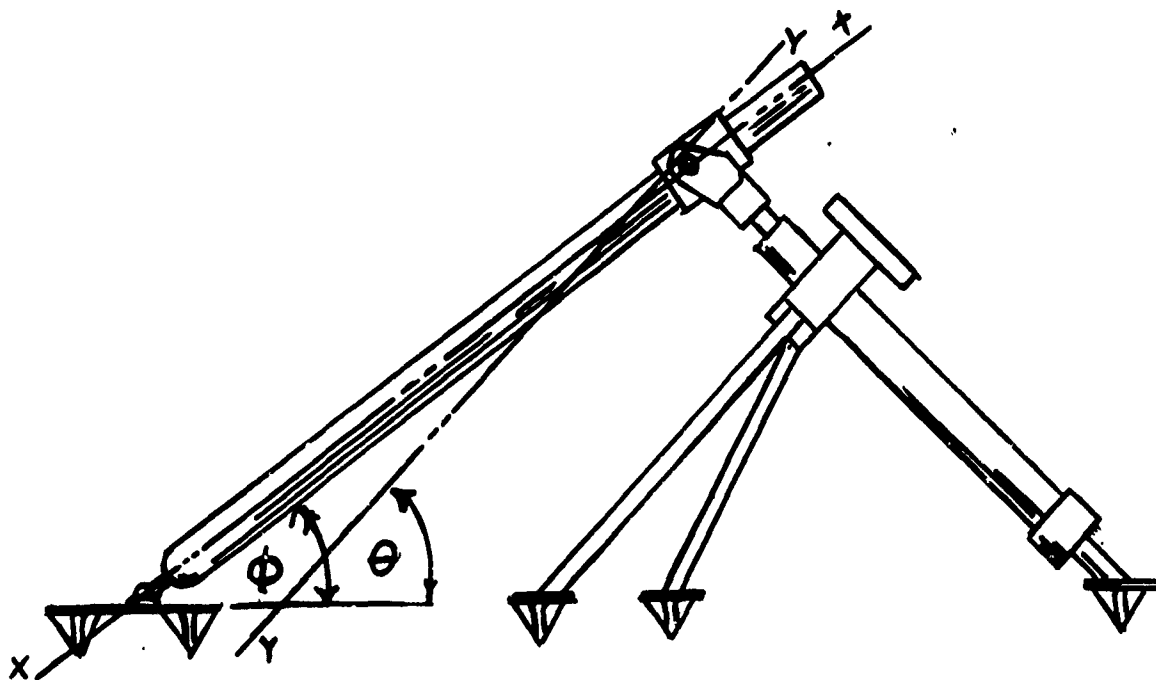


Figure 9
Mortar After Firing (Elevation)

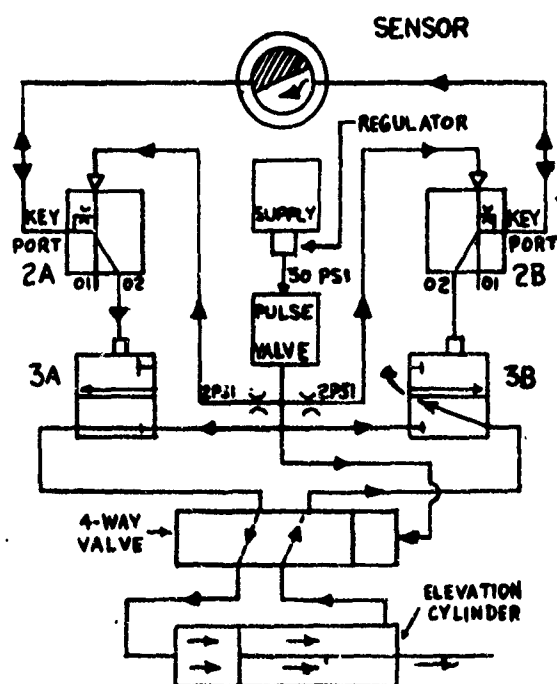


Figure 10
Elevation Control Schematic

control system is now in the state (Figure 10) where the pulse valve is on, and the cam has been rotated blocking the key port of 2A and opening the key port of 2B, resulting in turning the interface valve (3B) off and the interface valve (3A) on. When the pulse valve is "on", the pilot actuator opens the 4-way valve allowing air to flow from the interface valve 3A through the 4-way valve to the bottom of the elevation piston actuator; at the same time, air leaves the top of the elevation actuator, passes through the 4-way valve, and escapes through the interface valve (3B) to the atmosphere. This causes the elevation actuator to extend upward, raising the mortar tube until the original angle θ of elevation has been reached (Figure 11). With the tube now at the original angle, the control system is as described in Figure 12; both key ports are blocked; both interface valves (3A, 3B) are on; the 4-way valve is open; and 30 psi is maintained across the piston holding the piston stationary. The pulse valve then shuts off and the conditions as described in Figure 8 prevail.

A similar chain of events occurs if the baseplate should move forward; the sensor rotates, the appropriate or-nor logic keys and the interface valves function, causing the actuator piston to lower the tube (Figure 13) until the original angle of the tube has been reached (Figure 12) and the system shuts off (Figure 8).

The conventional manual repositioning of the mortar's elevation angle has been preserved in this device. The manual elevation adjustment is the conventional screw jack mechanism which positions the entire elevation actuator when it is hand cranked.

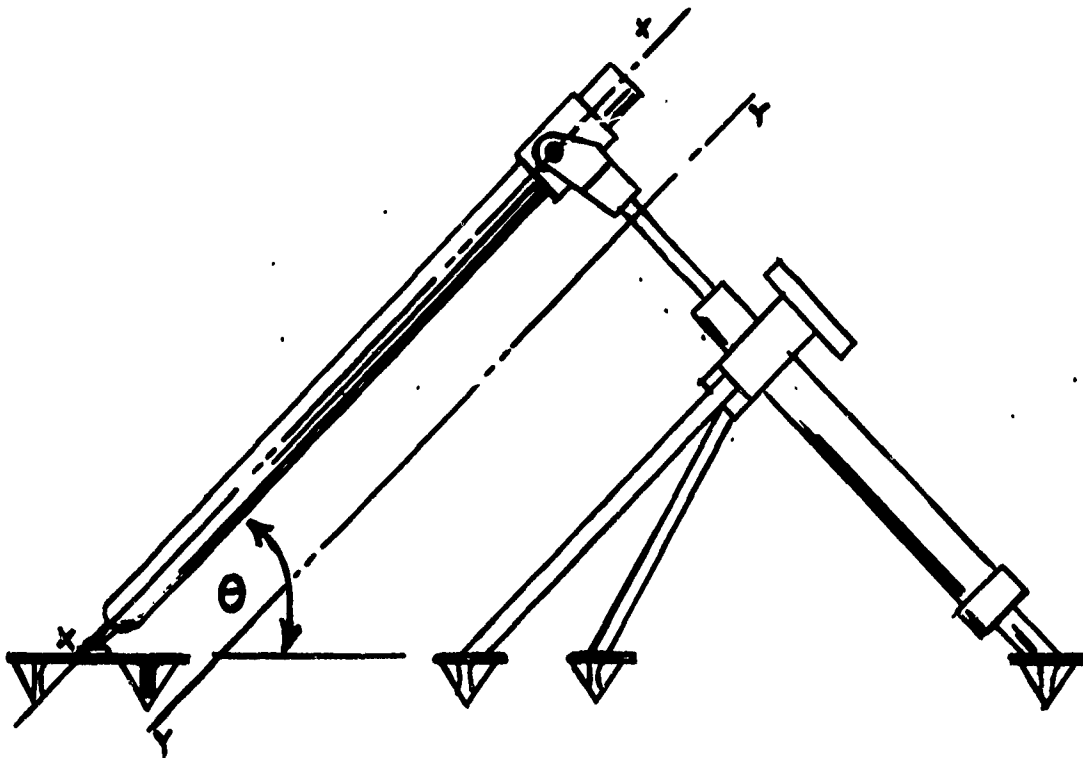


Figure 11
Mortar After Repositioning (Elevation)

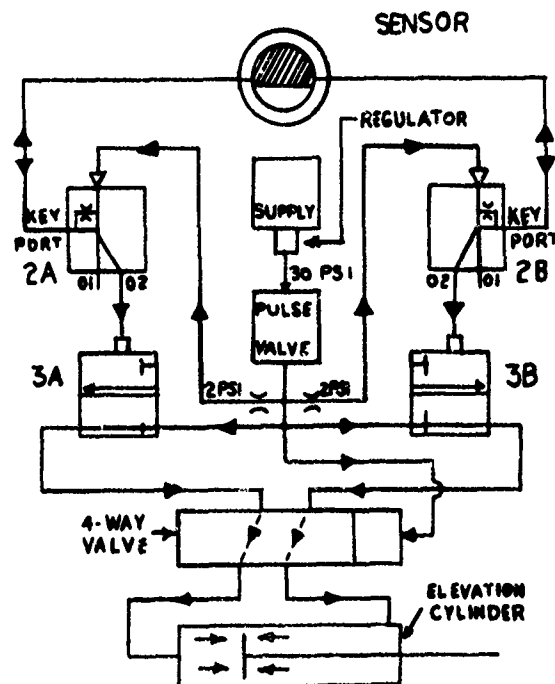


Figure 12
Elevation Control Schematic



Digital Azimuth System:

DESCRIPTION: The digital azimuth system is very similar to the digital elevation system. Both systems use the same type of logic, amplification and actuation components. The digital angle sensor for each system is similar in design and operation and differs only in its adaptation to its particular location on the mortar.

Below is a block diagram of the azimuth system:

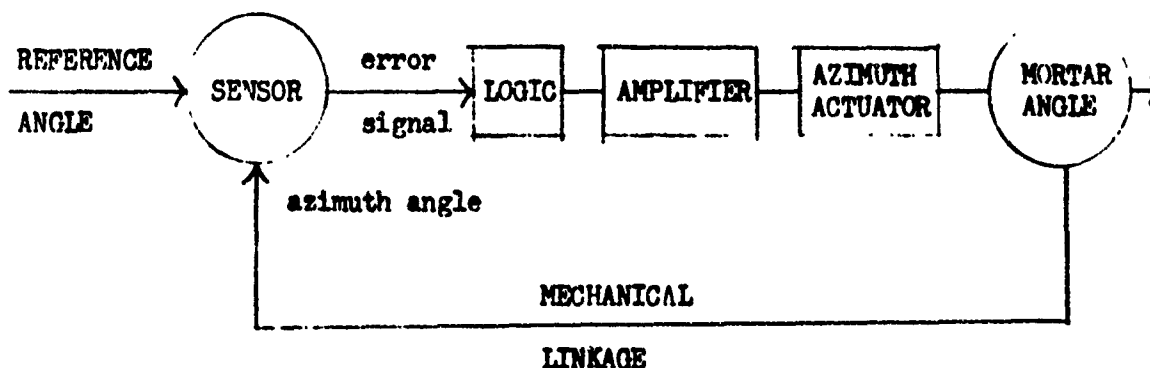


Figure 14:
Azimuth Block Diagram

The sensor consists of a flat-sided cam; it is also the piston rod for the elevation control. The top section of the elevation actuator contains the azimuth sensor and reference setting components. A unique feature of the azimuth sensor is that: it is mounted in such a way as to detect the angular position of the flat-sided elevation piston rod, which rotates when the azimuth angle changes as well as moving axially to position the barrel sleeve in elevation as part of the elevation control.

Figure 15 shows the mortar azimuth position before firing. The cam is shown in a centered position. No air is allowed to flow out of the

sensor orifices and back pressure is being generated due to blockage to the or-nor key input port.

Figure 15 a shows the mortar just after firing. The baseplate has deflected to the right (viewed from front). This has caused the cam to rotate about its axis, allowing the free flow of the air from orifice 2. The resulting loss of back pressure in orifice 2 triggers an or-nor key element, causing an output which activates one of the pneumatic amplifiers, which in turn allows high-pressure air to move the azimuth piston in the direction shown.

In Figure 15 b, as the azimuth piston moves in the desired direction, it causes the cam to rotate back to the centered position, blocking the sensor orifices and locking the azimuth position. In correcting for an azimuth error, it can be seen in Figure 15 b that no cant results.

The design of the azimuth positioner includes a manual reference setting device to position the sensor orifices, and can be used when firing the mortar for effect or laying a pattern. Also included is a worm and disengagable gear to manually position the azimuth setting, as in a conventional mortar, allowing it to be used without the automatic positioner.

Automatic Pulse Valve:

One consideration in the development of the "Automatic Positioning Mortar", is the conservation of the air from the power source which is used as the actuating medium. If the air supply is not shut off between rounds, the air is used during the non-operating interval.

To provide maximum efficiency, it is desired to:

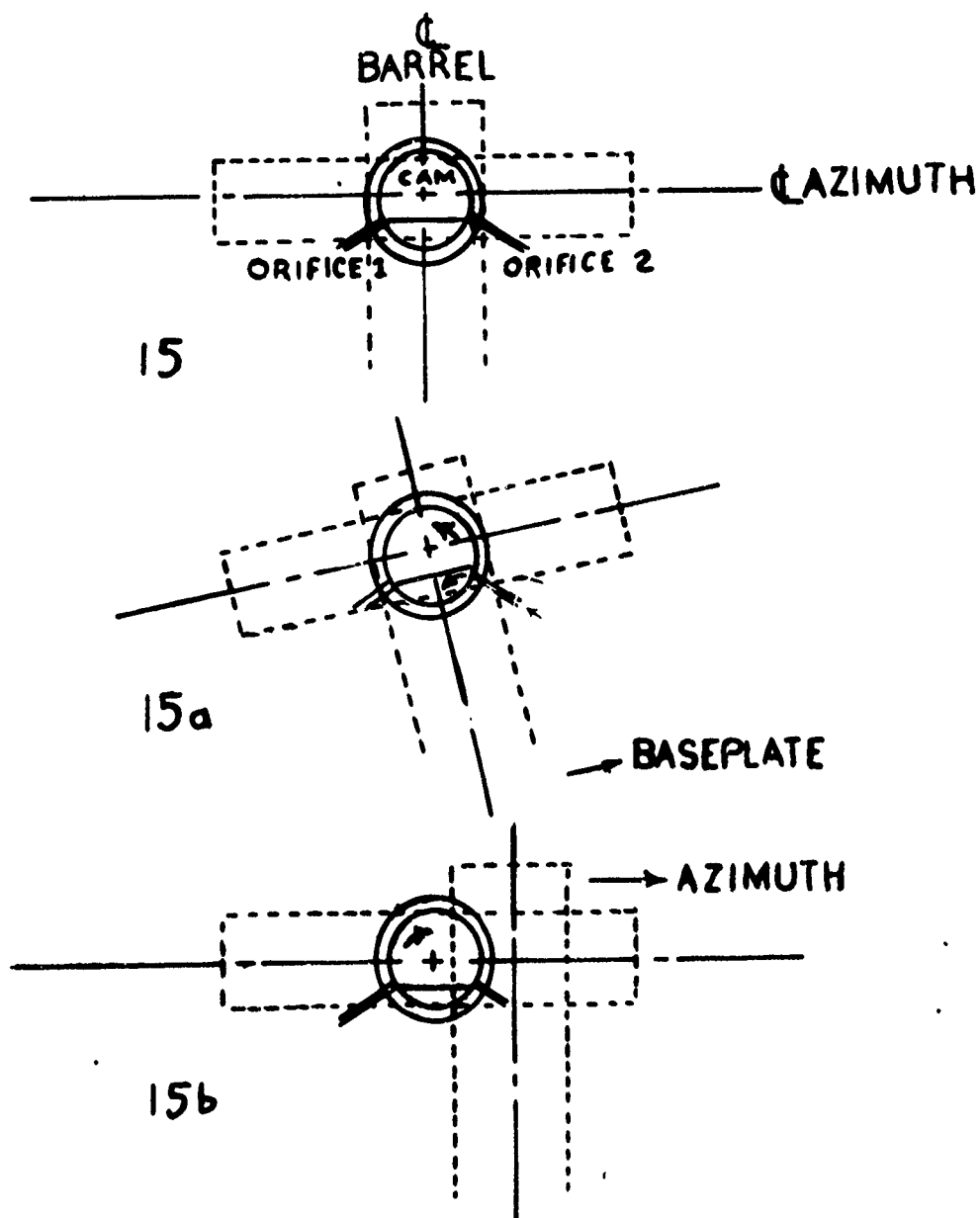


Figure 15 Mortar Before Firing (Azimuth)
 15a Mortar After Firing (Azimuth)
 15b Mortar After Correction (Azimuth)

Fire the mortar

Turn on the air supply

Allow air to stay on long enough to reposition the mortar

Shut off air to control mechanism .

This action must be accomplished automatically, reliably, and should not require bleed air for operation.

No commercial valves could be found to fill the above requirements; a special system was designed and fabricated.

Figures 17 through 19 show the general design, as well as the mechanical parts of the valve; it contains one moving part, the rubber disc. The aluminum body and cover is machined from bar stock; all of the external and internal parts are of brass or steel and plated to resist corrosion. The whisker or trigger valve is obtained commercially. Actuation of this pulse valve is accomplished by the recoil force of the mortar acting on a seismic mass connected to the trigger valve.

Figure 20 shows the condition of the valve before actuation of the trigger valve. The predetermined time of the valve action has been set by adjusting the needle valve. The main input supply pressure on the upper side of the disc holds it down against the output port. There is no output from the valve.

Figure 21 shows the valve when the trigger valve is momentarily actuated. Air escapes rapidly through the trigger valve, and as the pressure on top of the disc decreases to a low value, the higher supply pressure on the bottom of the disc moves it upward, uncovering the output port.

In Figure 22 , the trigger valve has closed. Pressure on the top side

of the disc is increasing, at a rate depending on the needle valve setting. Flow across the output valve seat causes a static pressure drop between the valve seat and disc. This decreases the pressure effect on the bottom side of the disc. When the pressure on the top side is high enough, the disc is forced down in the shut-off position of Figure 20 and the output is returned to atmosphere.

TESTS DESCRIPTION AND RESULTS

Elevation: The automatic fluidic elevation control system's accuracy was evaluated by setting the mortar at some initial angle of elevation and the baseplate was moved backward, then moved forward repeatedly. After the initial setting and each successive movement, the angle of elevation of the mortar tube was measured with a gunner's quadrant.

<u>Accuracy:</u> Initial setting	1115.1
Mean	1114.2
Mean deviation	2.3 mils
Variance	8.8 mils
Standard deviation	3.0 mils

A normal distribution curve contains 68.26% of the data points within ± 1 standard deviation and 95.44% within ± 2 standard deviations of the mean. The test results contained 73% of the data points within ± 3 mils.

Azimuth: Tests were run to investigate fully the accuracy of the azimuth control. In general, the test set up consisted of measuring the corrected off center readings of the azimuth control cam and converting this reading to mils.

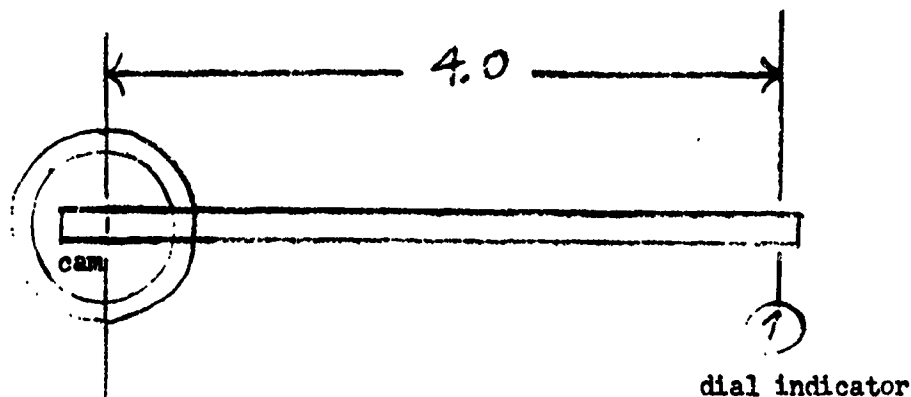


Figure 16
Azimuth Measuring Schematic

A parallel bar was affixed to the azimuth cam with a dial indicator (.001 graduations) placed four (4) inches from the center of the cam, (Figure 16). The baseplate of the mortar was manually moved sideways, to simulate firing. The azimuth system was then allowed to reposition automatically and the off center correction was read from the dial indicator and converted to mils.

The following data are a sampling of six (6) out of forty-two (42) repositionings:

	<u>Repositioned Error</u>	
	Off Center	Mils
1. Left to right movement of baseplate	-.018	3.
2. Left to right movement of baseplate	-.015	2.48
3. Left to right movement of baseplate	-.015	2.48
4. Right to left movement of baseplate	+.002	.32
5. Right to left movement of baseplate	+.007	1.16
6. Right to left movement of baseplate	+.002	.32



Figure 17 Pulse valve, Assembled

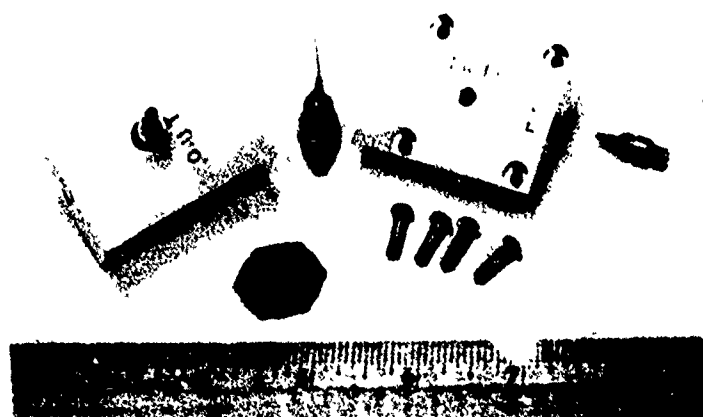


Figure 18 Pulse valve, Disassembled

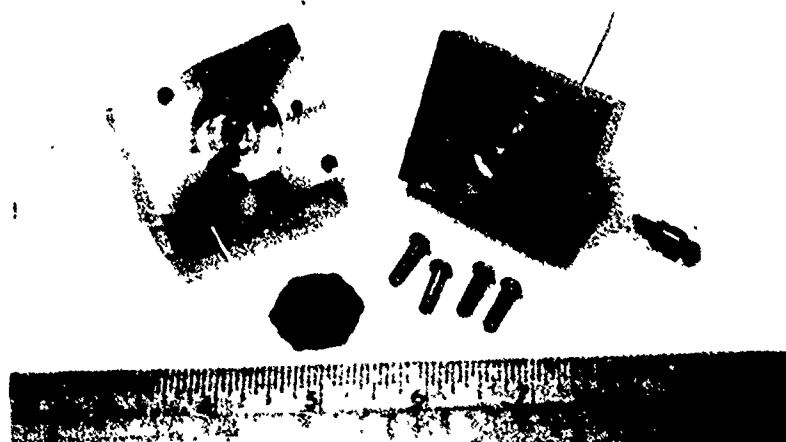


Figure 19 Pulse valve, Disassembled

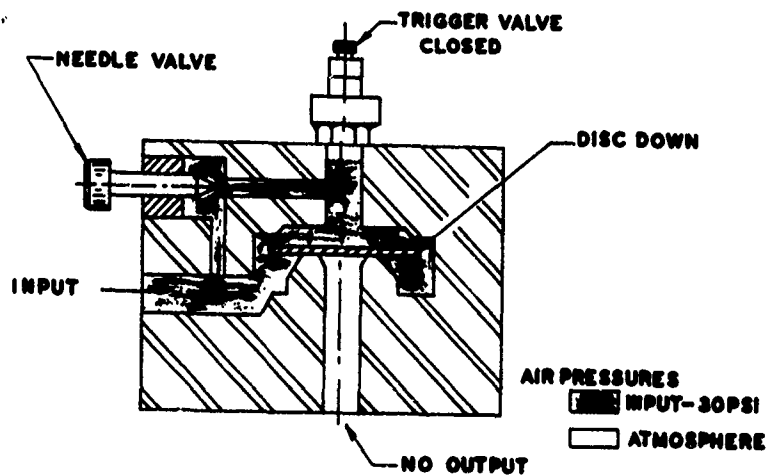


Figure 20 Pulse Valve Schematic

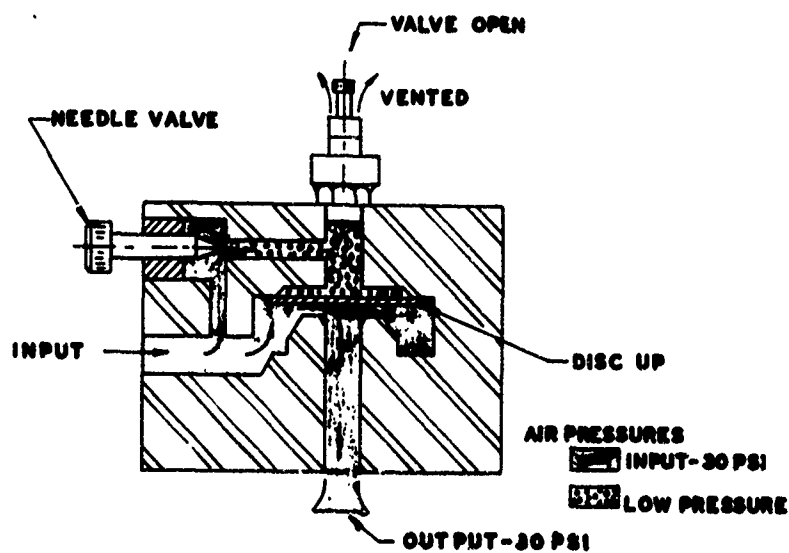


Figure 21 Pulse Valve Schematic

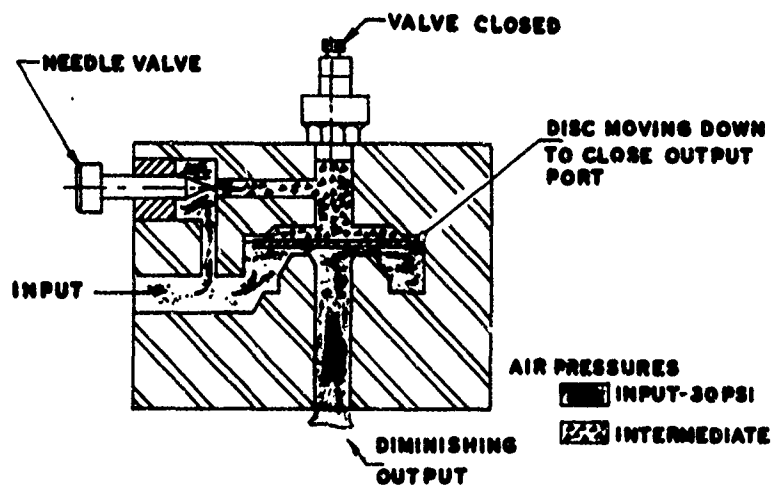


Figure 22 Pulse Valve Schematic

Accuracy: The average error from the group of 42 repositionings was 1.26 mils. The greatest error being 3. mils and the least .16 mils.

CONCLUSION:

Developments in fluidics have made available to ordnance designers controls which are reliable, simple, and quick responding. Fluidic devices are inherently reliable because they have no moving parts to bend, break, stick or wear. They are affected only slightly by temperature changes, or shock and vibrations, all of which are common when a mortar is fired.

This report has described an effective, quick-responding, repositioning system which can be provided using fluidic technology. It remains to test fire this device and evaluate its combat usefulness.