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SUBSIDIARY, CURTISS WRIGHT CORPORATION

December 13, 1990

SUBJECT: TRC Service Bulletin Number SB9006.

Gentlemen:

Accompanying herewithin is a copy of Target Rock Corporation service bulletin number 9006. This bulletin informs the recipient of the characteristic of solenoid valves to open "spuriously" when subjected to high pressure surge in line pressure.

Questions regarding the subject characteristic may be directed to Mr. Steve Karidas, engineering Manager, 5166-293-3800; ext. 526.

Very truly yours,

Vito Liantonio
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Product Support Manager

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SERVICE BULLETIN

S.B. 9006

Date: 7-2-90

SPURIOUS OPENING CHARACTERISTIC
OF
PILOT OPERATED SOLENOID ACTUATED VALVES

Scope: This bulletin is intended to inform the recipient of the tendency of pilot operated solenoid valves to open spuriously in response to a sudden increase in supply pressure at the valve inlet. The bulletin will also describe results of tests conducted to evaluate the problem and steps that can be taken to avoid or minimize the effect.

Written By: ______________________ Date: 7/10/90
R.A. Wells, Mgr. Engineering Services

Approved By: ______________________ Date: 7/10/90
V. Liantonio, Mgr. Applications Engineering Group

TRPUB-0038(3/83)

Target Rock

Target Rock Corporation, 1966E Broadhollow Road, East Farmingdale, New York 11735

1. DESCRIPTION OF PROBLEM

Figure 1 depicts the general arrangement of a piloted solenoid valve, subject to spurious opening. In a closed, de-energized valve, inlet pressure (Ps), entering radially, provides an upward force on the piston portion of the main disc. Control Pressure (Pc) acting in oposition, negates this lifting force and additionally provides valve a closure force by its effect on the disc port area (A_d). With the pilot valve closed, Pc equals Ps. At the introduction of an inlet pressure surge, supply pressure is momentarily higher than control pressure, until control pressure re-establishes equality with supply pressure by the flow of fluid through the inlet orifice (a_1). Consequently there is a time delay in equalization of these pressures. Should the lifting force exceed the closure forces, the valve will lift. the valve will remain open until the downward force overcomes the lifting force, where upon the valve again closes, and the closure force builds up to full value again.

The problem is most severe when the first of two valves mounted in series opens rapidly, permitting full supply pressure to be sharply introduced to the second valve. In the reactor head vent application, full 2500 psi fluid pressure may suddenly be applied to the second valve causing it to open suddenly and reclose after a few seconds.

2. PROBLEM CHARACTERISTICS

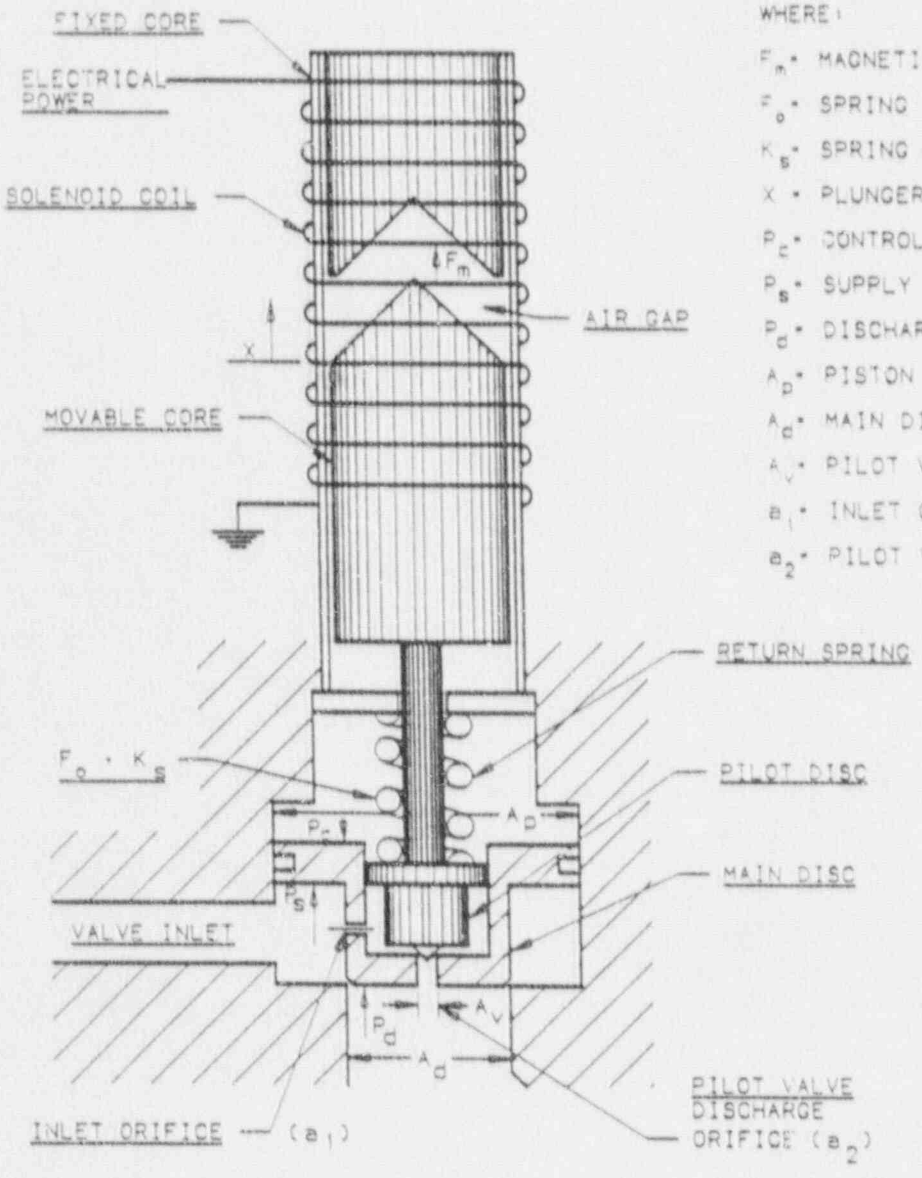
By analysis and test, a number of significant characteristics are noteworthy.

a. Speed of Transient - Since the increased inlet pressure is being neutralized by flow through the disc inlet orifice, a slow supply pressure increase will not cause spurious opening. By test, it was determined that a supply pressure transient in excess of 250 psi per second is required to cause opening in a standard Target Rock 1" valve. Other size valves would respond somewhat differently, depending on orifice size, control chamber volume, fluid, etc.

b. Fluid - The combination of fluids that may cause the longest opening time occurs when the second valve contains ambient pressure air, and the upstream valve is charged with high pressure water. As the first valve opens, the second valve experiences the high lifting force which will be nulled out when the high pressure water, flowing into the control chamber through the inlet orifice (al) in the disc, compresses the air in the control chamber thus raising its pressure.

c. Static Pressure - Most piloted solenoid valves employ a piston whose area is larger than the disc seating area, generally by a factor of 2. The lifting pressure therefore must be higher than twice the static pressure in the affected (downstream) valve. If the expected surging pressure is 100 psi, then a static pressure in the downstream valve of 50 psi could prevent spurious opening.

TYPICAL PILOTED SOLENOID VALVE CONFIGURATION



WHERE:

F_m = MAGNETIC ATTRACTIVE FORCE
F_o = SPRING LOAD FORCE
K_s = SPRING RATE
X = PLUNGER DISPLACEMENT
P_c = CONTROL PRESSURE
P_s = SUPPLY PRESSURE
P_d = DISCHARGE PRESSURE
A_p = PISTON AREA
A_d = MAIN DISC SEAT AREA
A_v = PILOT VALVE SEAT AREA
a_1 = INLET ORIFICE AREA
a_2 = PILOT VALVE EFFECTIVE AREA

PILOT VALVE

(MAGNETIC) FORCE UP = F_m

FORCE DOWN = $F_o + K_s \cdot X + (P_c - P_d) \cdot A_v$

MAIN DISC

FORCE UP = $P_s (A_p - A_d) + P_d \cdot A_d$

FORCE DOWN = $P_c \cdot A_p$

FIGURE 1

d. Inverted Valve - With the downstream valve inverted, steam flowing through the valve condenses on the cooler surface and quickly fills the bonnet tube and control chamber with water. As a pressure surge contacts the main disc piston area generating a lifting force, fluid flowing through the inlet orifice (al) raises the pressure in the control chamber rapidly due to the high bulk modulus (incompressability) of the water filling the control chamber. Thus the lifting force is quickly nulled and the valve is kept from opening.

3. SUGGESTED FIXES

a. Inverted Valve - The most effective method of preventing valve openings is to keep the control chamber filled with water.

b. Static Pressure - Maintaining a pressure between the upstream and downstream valve of over 50% of system pressure can prevent spurious opening.

c. Revised Operating Procedures - A number of utilities have chosen to sequence operations to prevent suprise opening of affected valves.

4. ACCOMPANYING DOCUMENTS

- ASME Publication 81-PVP-39, April 1981, "Spurious Opening of Hydraulic-Assisted, Pilot Operated Valves - An Investigation of the Phenomenons".
- Target Rock Report No. 2866, Dec. 17, 1980, "Solenoid Valve Response to Inlet Pressure Transient".

MEMO

October 2, 1984

TO: D.K. Vater

FROM: V. Liantonio

SUBJECT: Spurious Opening of Pilot Operated Solenoid Valves

REFERENCES:
1) Target Rock Report #2866; Solenoid Valve Response to Inlet Pressure Transient, 12/17/80
2) ASME Publication 81-PVP-39, April 1981, Spurious Opening of Hydraulic-Assisted, Pilot Operated Valves - An Investigation of the Phenomenon.

The two referenced documents provide an adequate understanding of the subject phenomenon. The design of most pilot assisted valves will develop a transiently applied force tending to open the valve when a rapidly applied pressure increase is sensed at the valve inlet. The most effective deterrent to this action is to maintain the valve filled with liquid. The pressure build up in a liquid filled control chamber is fast enough to prevent valve opening for all practical pressure transient rates applied to the valve inlet. Also, one of the easiest methods to achieve this is to mount the valve with the bonnet tube directed downward, or as a minimum, below the horizontal.

The worse case scenario is one where the bonnet tube is filled with a gas (usually air at atmospheric pressure) and a pressure build up occurs at the valve inlet. The pressure build up, however, was required (per Reference 1) to occur at a rate of 250 psi/sec or higher. This build up must also exceed two times the pressure existing in the control chamber, immediately prior to the application of the pressure increase. Should transient pressure buildup be predictably slow, therefore, no special consideration is required.

Recommendations:

1 - For valves discharging liquid to ambient (as is the case of the last valve in the chain of reactor head vent valves), mount the valve with the bonnet tube below the horizontal.

2 - Where possible, maintain positive pressure at the valve discharge port (See Reference 1).

3 - Locate valves discharging to ambient where spurious opening will not compromise personnel or plant safety.

Vito Liantonio
Manager, Engineering

VL/cj

cc: Messrs: D.M. Pattarini
Code Engineers

Attachments - References 1 and 2.

COPY NO.

REPORT NO. 2156
PROJECT NO. 702-39
DATE 12/17/80
TOTAL PAGES 8

SOLENOID VALVE RESPONSE

TO

INLET PRESSURE TRANSIENT

TESTS CONDUCTED AT

TARGET ROCK CORP.

11/13/80 thru 11/15/80

TARGET ROCK CORPORATION

EAST FARMINGDALE, LONG ISLAND, N. Y.

REVISIONS

LETTER	DESCRIPTION	DATE	BY	APR	LIST OF EFFECTIVE REVISIONS OF PAGES									
					NO.	-	A	B	C	D	E	F	G	
-----	First Issue	12/17/80	RAW	12/24/80	TITLE	x								
					i	x								
					1	x								
					2	x								
					3	x								
					4	x								
					5	x								
					6	x								
					7	x								
					8	x								

Static Condition A) The test valve and piping system was flushed with water to remove most of the trapped air. Some quantity of air probably was retained in the upper region of the valve bonnet tube since this area is out of the normal flow stream. (see Table I for test data).

Static Condition B) The test valve and piping system was drained, purged with air, then pressurized at 500 psig with Argon gas. Some small quantity of water probably was retained in the area of the valve disc due to the bonnet tube position of approximately 40° from vertical. (see Table II for test data)

Static Condition C) The test valve and piping system was drained, purged with air, and vented to establish atmospheric conditions within the system. (see Table III for test data)

RESULTS:

STARTING AT STATIC CONDITION (A): (Ref. Table I)

A series of pressure transients were initiated after establishing a water filled system at 0 psig. or slightly higher to prevent the entrance of air. The piping system was reduced to this pressure level before each transient test.

The transients were conducted by increasing the pressure within the piping from 0 psig to: 100, 200, 300, 400, 500, 750, 1000, 1500, 2000, and 2500 psig. At each pressure level, at least one test was conducted at a transient rate of 2500 psi per second.

STARTING AT STATIC CONDITION (C):(Ref. Table III)

These tests were conducted with the valve and piping drained and purged with air prior to each transient as in (B) above, except the system was at atmospheric pressure prior to introducing water at pressures of 100, 150, 200, 300, 450, 500, 700, 800, and 900 psig.

The transient rates varied from 250 to 2750 psig per second.

At a number of these test points, the main disc lifted momentarily, allowing various amounts of water to flow before re-seating against upstream pressure. Because of the limited flow capability of the test facility, when the disc opened, the pressure transient rate could not be maintained. Because of this, the accuracy of the rate of pressure change measured from the actual recording of the test may be in error.

In some cases, an increase in the transient rate did not result in increased water flow through the valve.

A review of the data indicates that the Condition at which a pressure transient is most likely to cause the valve disc to momentarily open, is one where the valve and piping is charged with air at atmospheric pressure prior to a pressure transient that introduces water into the system at a rate in excess of 250 psi per second.

Water filled systems and air filled systems pressurized to 500 psig, appear to be able to withstand far greater pressure transient rates than air filled systems at atmospheric pressure without causing the valve disc to momentarily open.

One transient test was conducted starting at 500 psig static pressure within the system. The pressure was then increased to 1500 psig. At a rate of 7750 psi per second, there was no evidence of water flow through the valve during this test, indicating that the valve disc remained seated.

Of the 18 pressure transient tests conducted, only one resulted in water flow from the valve outlet. This test was conducted in the range of 0 to 100 psig at a rate of 1700 psi per second. This test was initiated immediately after bleeding the accumulator to atmospheric pressure and recharging to 100 psig. Apparently air entered the piping system during this operation causing the valve disc to memoentarily lift during the following test. Three additional tests were conducted at this pressure level at rates of 2000, 2250, and 2750 psi per second with no evidence of water flow from the valve outlet.

<u>STARTING AT STATIC CONDITION (B)</u>: (Ref. Table II)

After purging, the valve and piping system was charged with gas (Argon) at 500 psig. These conditions were established prior to each pressure transient.

The transients were conducted by introducing water into the piping system at pressures of 1500, 1600 and 1900 psig at rates of 2000, 2500, 3000, 3750, 4000 and 5500 psi per second.

There was no evidence of water flow from the valve outlet during these tests.

TABLE I

WATER FILLED SYSTEM PRIOR TO TRANSIENT TESTS

TRANSIENT NO.	STATIC PRESSURE PRIOR TO TRANSIENT PSIG (H_2O)	SYSTEM PRESSURE @ COMPLETION OF TRANSIENT PSIG	TRANSIENT PRESSURE RATE PSI/SEC.	WATER ACCUMULATION TOTAL C.C.
1	Atmospheric	1000	750	None
2	Atmospheric	1000	5350	None
3	Atmospheric	1500	3500	None
4	Atmospheric	1500	11,000	None
5	500	1500	7750	None
6	Atmospheric	2000	4750	None
7	Atmospheric	2500	7000	None
8	Atmospheric	750	5500	None
9	Atmospheric	500	4250	None
10	Atmospheric	400	3750	None
11	Atmospheric	300	2500	None
12	Atmospheric	200	1000	None
13	Atmospheric	200	1000	None
14	Atmospheric	200	3750	None
15	Atmospheric	100	1700	215
16	Atmoshperic	100	2000	None
17	Atmoshperic	100	2750	None
18	Atmoshperic	100	2250	None

TABLE II

GAS CHARGED SYSTEM PRIOR TO TRANSIENT TESTS

TRANSIENT NO.	STATIC PRESSURE PRIOR TO TRANSIENT PSIG	SYSTEM PRESSURE @ COMPLETION OF TRANSIENT PSIG	TRANSIENT PRESSURE-RATE	WATER ACCUMULATION TOTAL C.C.
1	500	1500	2000	None
2	500	1500	2500	None
3	500	1500	3000	None
4	500	1500	3000	None
5	500	1500	3000	None
6	500	1600	3750	None
7	500	1900	4000	None
8	500	1900	5500	None

TABLE III

AIR FILLED SYSTEM PRIOR TO TRANSIENT TESTS

TRANSIENT NO.	STATIC PRESSURE PRIOR TO TRANSIENT PSIG (AIR)	SYSTEM PRESSURE @ COMPLETION OF TRANSIENT PSIG	TRANSIENT PRESSURE RATE PSI/SECOND	WATER ACCUMULATION TOTAL C.C.
1	Atmospheric	700	1750	1750
2	Atmospheric	700	1900	380
3	Atmospheric	800	2500	300
4	Atmospheric	900	2000	85
5	Atmospheric	900	1250	20
6	Atmospheric	900	1200	None
7	Atmospheric	300	1000	505
8	Atmospheric	450	1000	385
9	Atmospheric	500	1500	95
10	Atmospheric	500	750	None
11	Atmospheric	300	1900	110
12	Atmospheric	300	2750	25
13	Atmospheric	300	250	None
14	Atmospheric	300	1100	35
15	Atmospheric	300	1750	25
16	Atmospheric	300	1500	85
17	Atmospheric	300	500	None
18	Atmospheric	300	600	20
19	Atmospheric	200	2100	None
20	Atmospheric	200	1750	50
21	Atmospheric	200	2000	70
22	Atmospheric	200	500	None
23	Atmospheric	200	900	12
24	Atmospheric	200	750	None
25	Atmospheric	150	1250	None
26	Atmospheric	100	1000	None
27	Atmospheric	100	1200	None
28	Atmospheric	100	1200	None

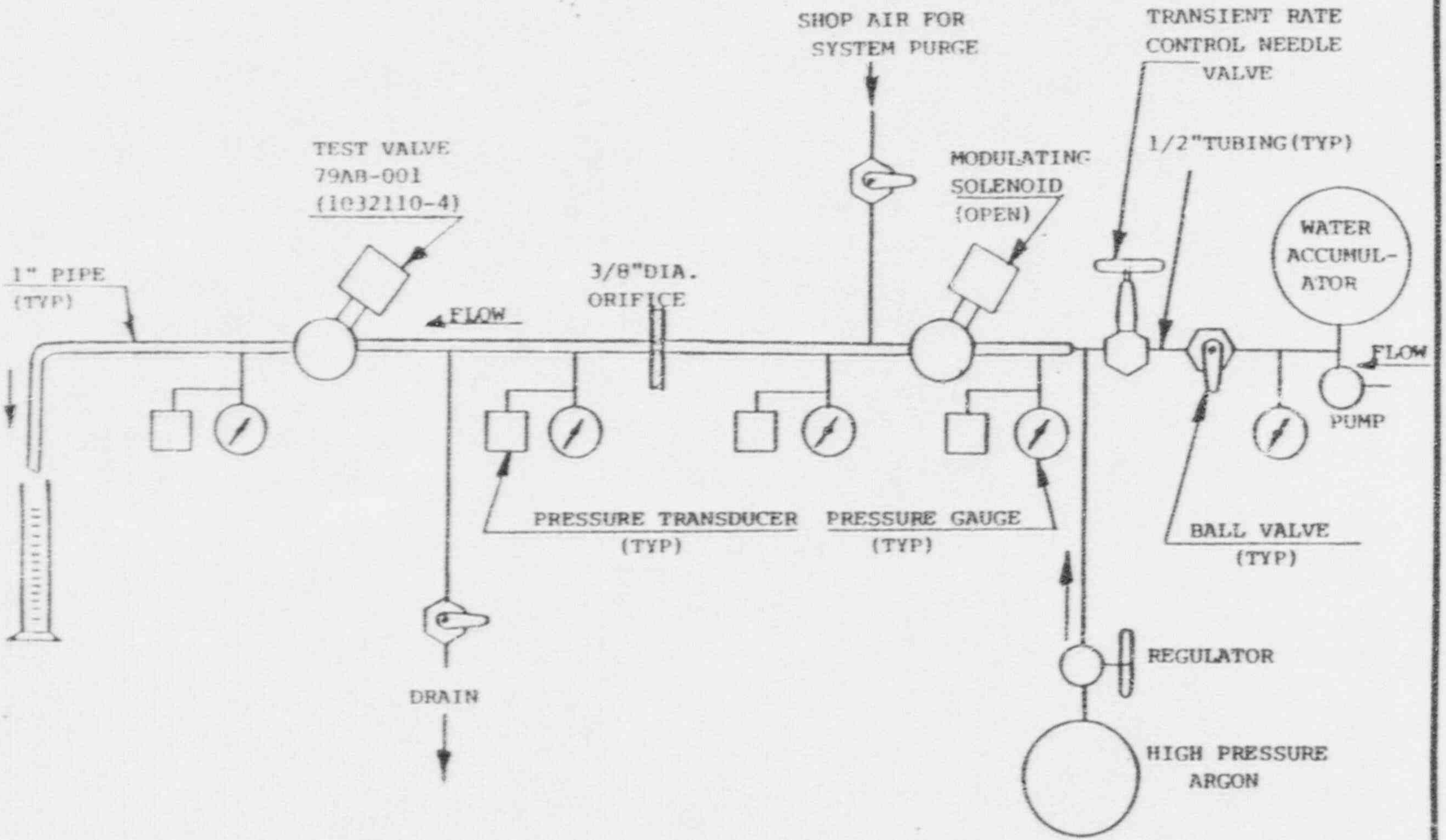

SHOP AIR FOR SYSTEM PURGE
TRANSIENT RATE CONTROL NEEDLE VALVE
TEST VALVE 79AB-001 (1032110-4)
MODULATING SOLENOID (OPEN)
1/2"TUBING(TYP)
WATER ACCUMUL-ATOR
1" PIPE (TYP)
3/8"DIA. ORIFICE
FLOW
FLOW
PUMP
PRESSURE TRANSDUCER (TYP)
PRESSURE GAUGE (TYP)
BALL VALVE (TYP)
DRAIN
REGULATOR
HIGH PRESSURE ARGON

FIGURE I

AN ASME PUBLICATION
$4.00 per copy $2.00 to ASME Members

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
345 E 47 St., New York, N.Y. 10017

Spurious Opening of Hydraulic-Assisted, Pilot-Operated Valves—An Investigation of the Phenomenon

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This paper investigates the spurious opening phenomenon of hydraulic-assisted, pilot-operated valves. The equations governing the valve response were developed to provide an insight into the phenomenon. Sensitivity studies were then performed to demonstrate the possibility of this type of valve spuriously opening under certain pressure transient events. The deductions were later confirmed by tests to show how a typical pilot-operated valve might respond to pressure transients in water solid and compressible fluid media. The significance of this phenomenon is discussed in terms of its effect on valve usage.

NOMENCLATURE

A_o = orifice area
A_p = piston area
A_s = plug seat area
C = discharge coefficient
F_o = spring preload
g = acceleration due to gravity
K_a = pneumatic spring constant
K_s = mechanical spring constant
n = polytropic exponent
P_c = steady-state chamber pressure
P_i = steady-state inlet pressure
P_{it} = inlet transient pressure
P_f = chamber pressure at force reveral point (p_{it}/α)
P_o = valve outlet pressure
V_a = air volume
V_{ai} = initial air compressed volume
V_{at} = air flow volume
V_c = control chamber volume
V_p = piston displacement volume
V_w = water flow volume
Y = compressible flow expansion factor
ΔP_{cr} = critical pressure drop
ρ = density
τ = time (sec)
δ = displacement
α = ratio of pressure surge to steady-state pressure
ΣF = sum of forces

INTRODUCTION

The demands for nuclear valves to withstand adverse environment of radiation and temperature and at the same time be able to sustain high seismic loads have spurred innovative use of fluid media to assist conventional electric operators in valve actuation. This class of valves is generally referred to as hydraulic-assisted, pilot-operated valves. Figures 1a and 1b and 2a and 2b show two versions of the valve design. Basically, the valve incorporates a pilot valve in conjunction with system differential pressure across the valve to open or close the valve port. The pilot valve can be external, as in Figure 1a, or internal as in Figure 2a. Although these valves are usually electric solenoid-operated, they could be pneumatic, or even manual.

Referring to Figure 1a, with the pilot valve closed, the control chamber pressure builds up to inlet pressure value. The resulting force differential on the main valve plug plus the force on the compression spring closes the valve. With the pilot valve open, as in Figure 1b, there is a direct flow path between the control chamber to the valve outlet port. The chamber pressure subsequently drops to the level of downstream pressure. A pressure differential builds up across the main valve plug, thus opening the valve. In the second version of hydraulic-assisted, pilot-operated valve, the pilot valve is internal. Referring to Figure 2a, with the pilot valve closed, the pressure in the control chamber increases to the level of the inlet pressure. When the control chamber pressure force exceeds the inlet pressure force, the force differential closes the valve, shutting off flow. However, when the pilot valve is open, as shown in Figure 2b, the control chamber is vented. The venting creates an opening pressure differential across the main valve plug, opening the valve.

Contributed by the Pressure Vessels & Piping Division of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS for presentation at the Joint Conference of the Pressure Vessels and Piping, Materials, Nuclear Engineering and Solar Divisions, June 21-25, 1981, Denver, Colorado. Manuscript received at ASME Headquarters April 6, 1981.

Copies will be available until March 1, 1982.

Use of this type of valve offers significant advantages over conventional motor-or air-operated globe valves in certain applications. Chief among them are weight reduction and overall valve compactness with a low center of gravity. Valve weight and center of gravity contribute significantly to piping stresses and to the attendant corrective piping support cost. Therefore, lightening the valve weight and reducing the center of gravity are very desirable features in valve design. Another significant advantage is the fact that the valve can be totally electric-operated thus permitting IEEE qualification and still provide fast fail-safe closure capability These, and other advantages, have contributed to the increasing usage of these valves in nuclear power plants.

However, there are inherent and latent limitations with this valve as with any other valve. This paper investigates one of these limitations which is the potential for the valve to spuriously open under severe step-up pressure transients. Spurious opening phenomenon is defined as a closed valve suddenly opening and reclosing without a signal or electric power input. This phenomenon has been called "hicupping" and "burping". It was first noted by the authors to occur when valves of this type were subjected to severe step-up pressure transients. In this paper, we shall develop valve response equations in various fluid media to show when the valve would open.

RESPONSE EQUATIONS

Response times will be calculated for three systems. The first case is an air-to-air system when the valve is air-filled and suddenly exposed to higher pressure air. The second case is a water-to-air system when the valve is initially air-filled and suddenly exposed to higher pressure water. The last case is the water-to-water system when the valve is water-filled and suddenly exposed to higher pressure water.

Before the analysis can proceed, it is necessary to define what constitutes a severe pressure transient that would be of concern. To do this, we refer to Figure 3, which shows schematically a fully seated hydraulic-assisted, pilot-operated globe valve.

In this seated position, the following relations exist:

$$P_c A_p + F_o > P_i (A_p - A_s) + P_o A_s \tag{1}$$

and

$$P_c = P_i \tag{2}$$

If we neglect P_o and F_o, Equation (1) reduces to:

$$A_p > (A_p - A_s) \tag{3}$$

Equation (3) confirms what we know already, which is that the piston area has to be greater than the difference of the piston and the seat areas to provide hydraulic assistance.

Let us now examine what happens when the valve is suddenly exposed to a pressure rise. Because the refill orifice is generally too small to quickly balance pressures between the inlet and the control chamber, the valve begins to lift. When the valve plug is on the verge of opening, the following conditions exist:

$$P_c A_p + F_o = P_{it} (A_p - A_s) + P_o A_s \tag{4}$$

and

$$P_c < P_{it} \tag{5}$$

Neglecting F_o and P_o, Equation (4) reduces to:

$$P_c A_p = P_{it} (A_p - A_s) \tag{6}$$

or

$$\frac{A_p}{A_p - A_s} = \frac{P_{it}}{P_c} = \frac{P_{it}}{P_i} = \alpha \tag{7}$$

Equation (7) provides the ratio of pressure transient to steady-state inlet pressure that must be evaluated for valve stability. What this means is that step-up pressure transients, which are less than α times the normal steady state pressure need not be considered as posing any concern. If, however, the step-up pressure is equal to, or greater than, α times the steady-state pressure, the valve can open, depending on the fluid medium. The opening process continues until the control chamber pressure reaches P_{it}/α, at which point the valve begins to reclose. The position where the valve plug momentarily stops and begins to reclose is referred to in this paper as the force reversal point.

ANALYSIS

To evaluate the valve stability, the analysis proceeds to calculate the response time required for the valve to reach the force reversal point. If the time is very insignificant or a very small fraction of the normal opening time, the valve will remain closed. If, however, the response time is a significant fraction of, or is even equal to or greater than the normal valve opening time, the valve will be open.

Case 1: Air-to-Air Transient

The valve is air-filled and is suddenly exposed to higher pressure air. Figures 4a, 4b and 4c illustrate what would happen if the valve spuriously opens.

Let V_c be the volume of the control chamber. Therefore, at the force reversal point as shown in Figure 4b,

$$V_c = V_a + V_p \tag{8}$$

where

$$V_a = V_{ai} + V_{at} \tag{9}$$

Assuming isentropic compression of original air in the chamber,

$$V_{ai} = V_c \left(\frac{P_c}{P_f}\right)^{1/n} \tag{10}$$

The flow through the refill orifice is

$$V_{at} = YCA_o \left(\sqrt{\frac{2g\ \Delta P_{cr}}{\rho}}\right) \tau \tag{11}$$

The piston volume displacement is

$$V_p = A_p \delta \tag{12}$$

To determine the piston volume displacement we have to perform a force balance at the force reversal point by setting $\Sigma F = 0$

Therefore,

$$F_o + K_a\delta + K_s\delta = P_{it} (A_p - A_s) \tag{13}$$

Neglecting F_o and K_s, Equation (13) reduces to

$$K_a \delta = P_{it} (A_p - A_s) \tag{14}$$

or

$$\delta = \frac{P_{it} (A_p - A_s)}{K_a} \tag{15}$$

where K_a is the pneumatic spring constant defined by

$$K_a = \frac{n P_f A_p^2}{V_a} \tag{16}$$

Substituting Equation (16) into Equation (15), we have

$$\delta = \frac{1}{n} \left(\frac{P_{it}}{P_f}\right) \left(\frac{A_p - A_s}{A_p}\right) \frac{V_a}{A_p}$$

Since $\frac{P_{it}}{P_f} = \frac{A_p}{A_p - A_s} = \alpha$, then $\delta = \frac{1}{n} \frac{V_a}{A_p}$ (17)

The piston volume displacement becomes

$$V_p = V_a/n \tag{18}$$

Substituting Equations (9), (10), (11), and (18) into Equation (8), we have:

$$V_c = \left(\frac{n+1}{n}\right) \left[V_c \left(\frac{P_c}{P_f}\right)^{1/n} + \left(YCA_o \sqrt{\frac{2g\Delta P_{cr}}{\rho}}\right) \tau \right] \tag{19}$$

Solving for time, τ, we have

$$\tau = \frac{\left[\left(\frac{n}{n+1}\right) - \left(\frac{P_c}{P_f}\right)^{\frac{1}{n}}\right] V_c}{YCA_o \sqrt{\frac{2g\Delta P_{cr}}{\rho}}} \tag{20}$$

Case II: Water-to-Air Transient

In the water-to-air transient, the valve is air-filled and is suddenly exposed to a step-up higher pressure water. Figures 5a, 5b, and 5c illustrate the valve dynamics. As in the air-to-air case, Figure 5b corresponds to the force reversal point. At this point, the following relationships exist:

$$V_c = V_{ai} + V_w + V_p \tag{21}$$

where

$$V_{ai} = V_c \left(\frac{P_c}{P_f}\right)^{\frac{1}{n}} \tag{22}$$

$$V_w = \left(C\ A_o \sqrt{\frac{2g\Delta P_{cr}}{\rho}}\right) \tau \tag{23}$$

and

$$V_p = A_p \delta \tag{24}$$

The displacement δ is given for this case as:

$$\delta = \frac{V_{ai}}{n A_p} \tag{25}$$

Therefore, the piston volume displacement becomes

$$V_p = \frac{V_c}{n} \left(\frac{P_c}{P_f}\right)^{\frac{1}{n}} \tag{26}$$

Combining Equations (22), (23), and (26)

$$V_c = V_c \left(\frac{P_c}{P_f}\right)^{\frac{1}{n}} \left(\frac{n+1}{n}\right) + \left(C\ A_o \sqrt{\frac{2g\Delta P_{cr}}{\rho}}\right) \tau \tag{27}$$

Solving for time,

$$\tau = \frac{V_c \left[1 - \left(\frac{P_c}{P_f}\right)^{\frac{1}{n}} \left(\frac{n+1}{n}\right)\right]}{C\ A_o \sqrt{\frac{2g\Delta P_{cr}}{\rho}}} \tag{28}$$

Case III: Water-to-Water Transient

In the water-to-water transient case, the valve is initially filled with water and suddenly subjected to higher step-up pressure. This case is considered to be of no concern for the simple fact that water is virtually incompressible with a bulk modulus of 300,000 psi, hence there is no piston displacement. In this case, therefore, the valve remains closed in spite of the pressure changes.

Discussion

In the foregoing analyses, we have developed the equations describing the response times for air-to-air system and water-to-air system. At this time, therefore, it is important to restate the criteria for opening. To do this, we would like to point out that most of these valves normally open fully between 0.1 and 0.5 seconds. Therefore, any valve which responds to a pressure surge in less than 10% of its normal opening time will not open. Using this criterion, we evaluated the response times for an air-to-air case and a water-to-air case for a hypothetical valve using the parameters tabulated in Table 1. The results of the analysis are plotted in Figure 6. As can be seen, the air-to-air system is rather insensitive to pressure surges while in the water-to-air system the valve opens.

TABLE 1
Valve Parameters

Valve Size = 1 inch
$V_c = 4.2\ in^3$
$A_o = 0.002\ in^2$
$u = 2$
$C = 0.65$
Normal Opening time 0.5 sec.
$P_c = 15$ psia

Test

To verify the validity of the analysis, a limited test was conducted to demonstrate the phenomenon. Figure 7 illustrates the test setup. Three tests were conducted to simulate each of the three cases. The results of the tests are summarized in Table 2.

TABLE 2
Test Results

System	P_c (psia)	P_{ic} (psia)	Burping
Air-to-air	500	1500	None
	500	1900	None
Water-to-air	15	200	Yes
	15	500	Yes
	15	900	Yes
Water-to-water	15	100	None
	15	500	None
	15	1000	None
	15	2000	None

REMARKS

Based on the results of the analysis and the tests, it appears that this phenomenon is most likely to occur when this type of valve, in a gas or steam application, is suddenly exposed to high-pressure water. There is very little likelihood that this will occur in air-to-air or water-to-water systems.

Although the foregoing analysis is based on step change, fast pressure transients, there are actually very few occasions where such events occur. These types of transients can, however, be produced by water hammer. Also, they can be generated by opening any fast-acting upstream valve in a series double isolation application.

On the basis of the above observations, valve usage should be judiciously made to prevent the valve being exposed to fast transients, thus minimizing the likelihood of a spurious opening. Additionally, valve location should be such that, if the valve happens to open spuriously, the resultant leakage through the main seat would not compromise personnel and plant safety.

ACKNOWLEDGEMENT

The authors wish to thank Mr. A. Jen of Westinghouse Valve Engineering for his assistance in collecting the test data.

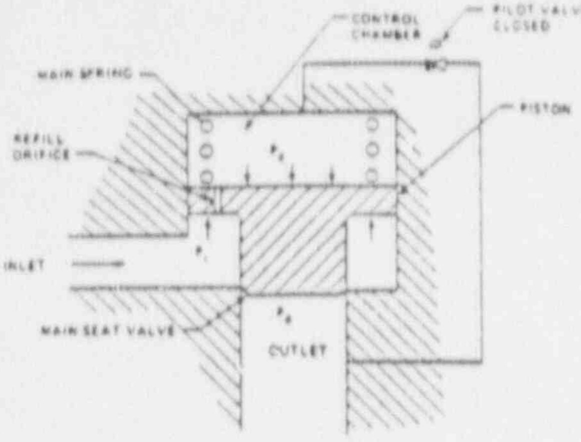

Figure 1a. External Piloted Valve (Closed Position)

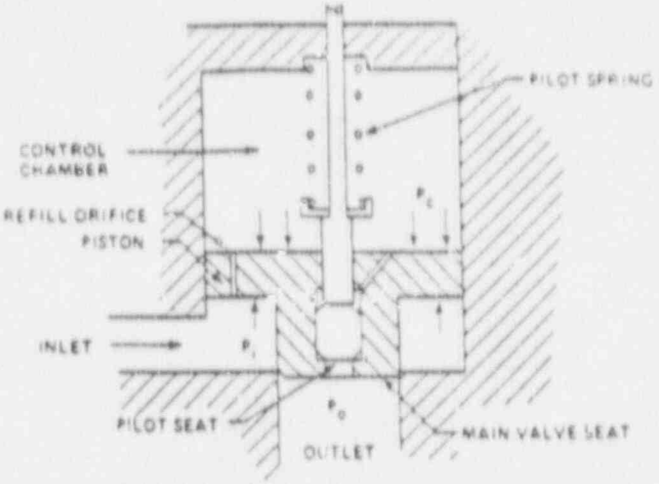

Figure 2a. Internal Piloted Valve (Closed Position)

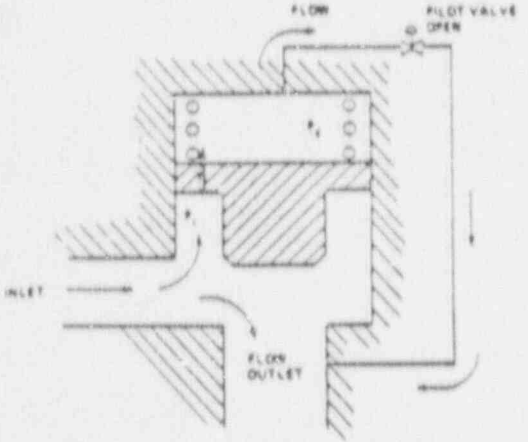

Figure 1b. External Piloted Valve (Open Position)

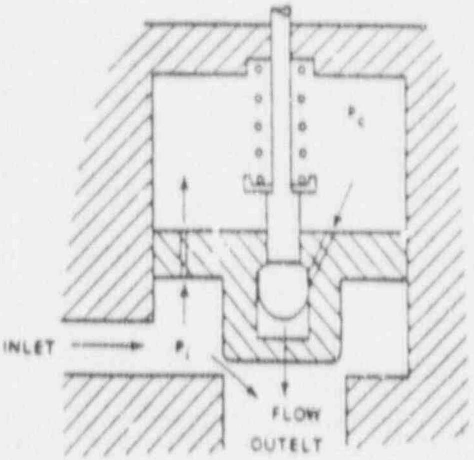

Figure 2b. Internal Piloted Valve (Open Position)

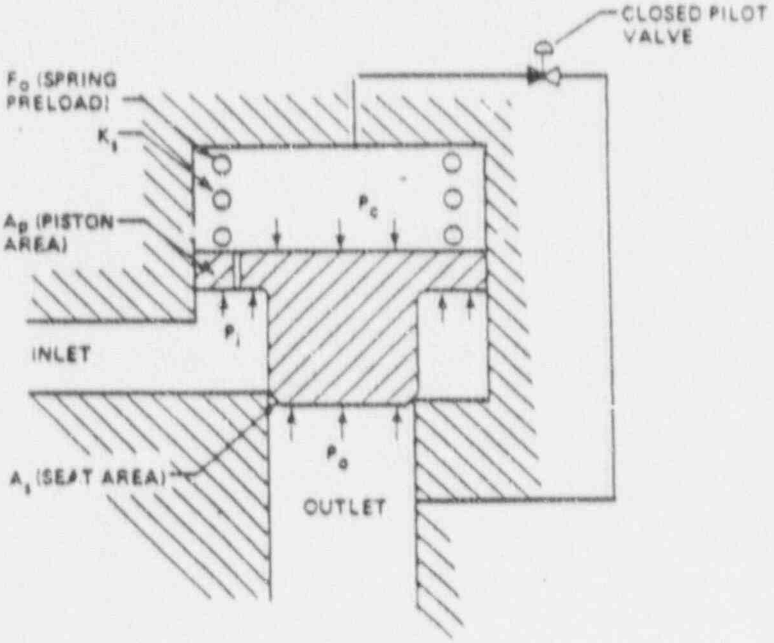

Figure 3. Closed Valve Loadings

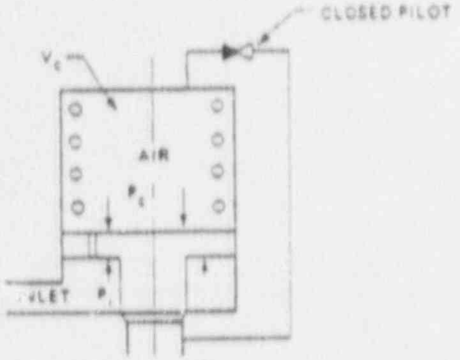

Figure 4a. Valve Closed (Air to Air)

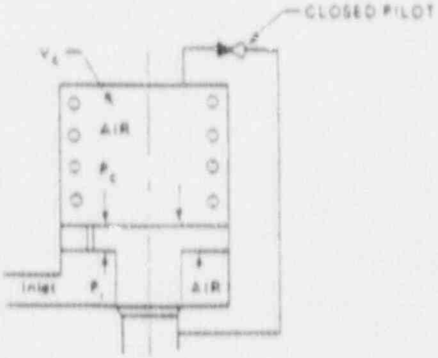

Figure 5a. Valve Closed (Water to Air)

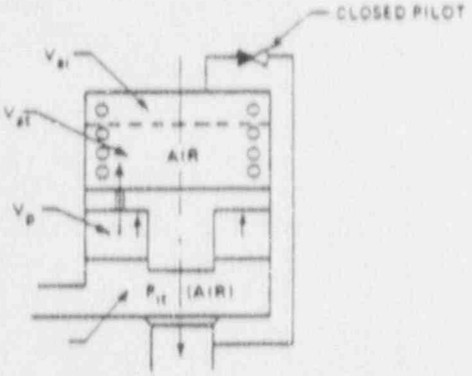

Figure 4b. Valve Opens (Air to Air)

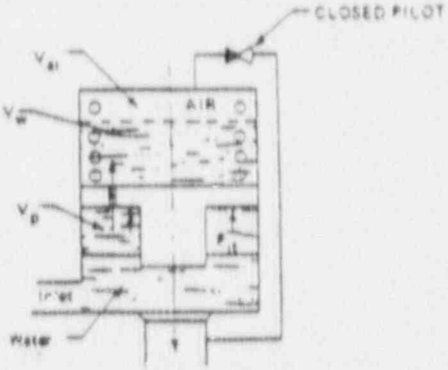

Figure 5b. Valve Open (Water to Air)

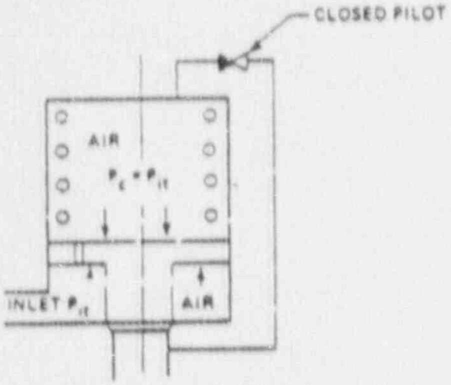

Figure 4c. Valve Recloses (Air to Air)

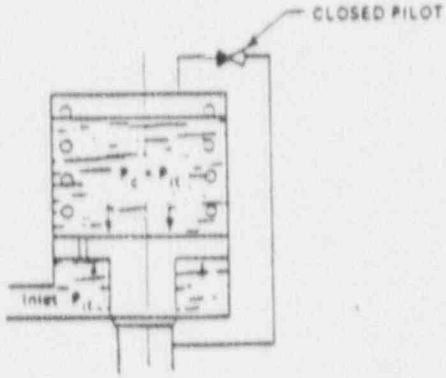

Figure 5c. Valve Reclosed (Water to Air)

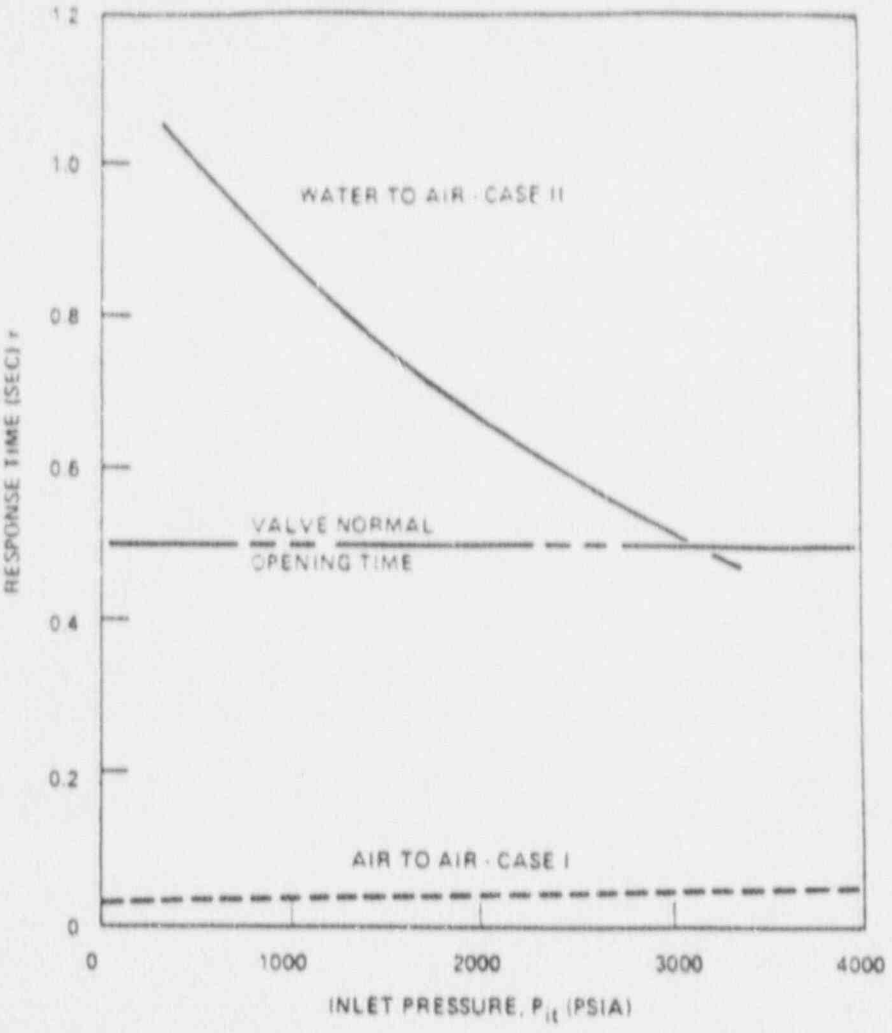

Figure 6. Response Time versus Inlet Pressure (P_c = 15 psia)

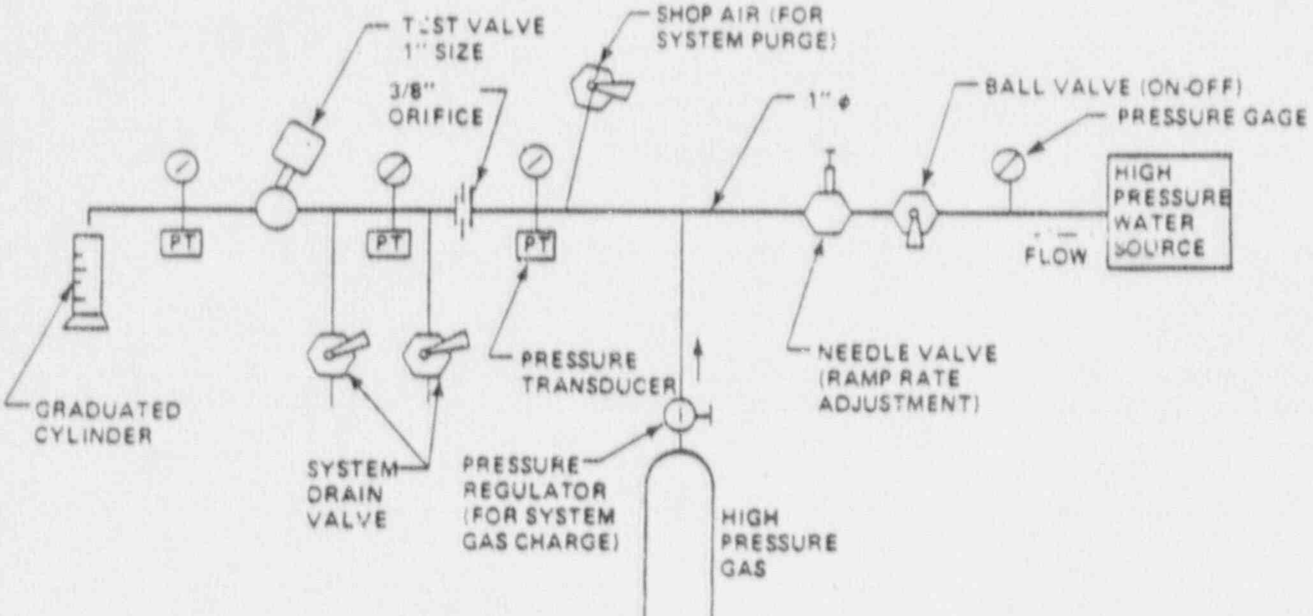

Figure 7. Valve Test Set-Up