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DRESDEN NUCLEAR POWER STATION

Supplement A to Special Report No. 18

Dresden 2/3 Safety Valve Investigation

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DRESDEN SAFETY VALVE ANALYSIS

Preliminary Report

Causes of Premature Safety Valve Actuations, based on Investigations Performed by:

1. Commonwealth Edison Company
2. General Electric Company
3. Franklin Institute Research Laboratories
4. Mechanical Technology Incorporated
5. Wyle Laboratories Incorporated

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2001.3

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I Introduction

These investigations into the causes of premature safety valve actuations were initiated by Commonwealth Edison following several occurances where safety valves opened at a lower than setpoint pressure.

The initial conclusions presented here are based on Commonwealth Edison's interperation of the seperate conclusions arrived at to date by the various investigation teams. In a few months the last testing program (at Wyle Laboratories) will be completed and a final meeting will be held with all investigation teams represented. At this meeting all results will be discussed and final conclusions and recommendations will be made.

II Summary

The investigation of premature actuation mechanisms for safety valves has resulted in seven sources being identified. In the following discussion the seven sources will be evaluated with respect to their contribution to premature actuation. The sources are as follows:

1. Safety valve Spring Relaxation due to temperature effects.
2. Mechanical shock effects on safety valves operation due to electromatic relief valve actuations.
3. Pressure pulse effects on safety valve operation due to electromatic relief valve actuations.
4. Safety Valve Spindle and Spring Washer Design Effects on valve operation.
5. Safety valve body temperature effects on valve operation.
6. Safety Valve Alignment Effects on valve operation.
7. Safety Valve Nozzle seat distortion effects on valve operation.

Also included in this report is a discussion concerning the blowdown settings of the safety valves and its effect on the severity of a safety valve pop occurance.

III Discussion: Mechanisms which can cause premature Safety Valve Actuations

A. Mechanism 1: Safety Valve Spring Relaxation

The safety valves installed on Units 2 and 3 at Dresden Station were designed to operate in an environment whose temperature was not to exceed 150(°F) as per design specifications.

In actuality, these valves are operating in an environment whose temperature is approximately 185 (°F). The safety valves are mounted on the main steam lines whose temperature is approximately 550 (°F). In most applications, these valves are not insulated. The Dresden Valves are insulated up to the second coil of the safety valve spring. See Figure (1).

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Thermocouples installed on a typical insulated safety valve at Dresden indicated a temperature on the spring surface of 250 (°F), near the lower spring washer. Tests have shown that removal of the insulation results in a spring temperature equal to the drywell environmental temperature, about 150 - 180°F. A program of testing safety valve springs at Commonwealth Edison's Technical Center at Maywood was initiated. This program involved testing of these springs under simulated service conditions, and revealed the following.

Initially, a safety valve spring taken from a safety valve which had been in-service at Dresden, was held at 200 (°F) under the normal in service deflection of 1.25" (equivalent to a load of 20,000 pounds of force, initially) and the spring relaxed about 1% after about 20 hours. This relaxation is believed to be due to a spring modulus of elasticity change with temperature. This effect is reversible, so that when the spring is brought back to room temperature, after this high temperature test,the spring can be expected to again exert its full 20,000 pound force.

The 200(°F) temperautre was an approximation since at the time of this test actual in-service spring temperatures had not been measured. It was then decided to test a new spring before it experienced service conditions, to determine if any initial irreversible relaxation effects would be present. A new spring was purchased and held at a constant deflection of 1.25" (equal to the normal deflection in service) and at a temperature of 250 (°F) for a period of about 25 hours. The spring exhibited a 3% relaxation in load,of this 1% was due to the reversible effect discussed above. The 3% relaxation, had this valve been in service, would have resulted in a 36 psi drop in set point pressure; or stated differently, the valve could be expected to pop 36 psi below its setpoint pressure.

The manufacturer's safety valve setting procedure calls for a heat up period of only thirty minutes on the steam test stand before the setting and "popping" of the valve begins; this period is totally inadequate for even the valve body to reach an equilibrium temperature. The effects previously explained require service conditions (temperatures) to be present for at least twenty hours before they are manifest.

It can therefore be stated that for a heat up period of 30 minutes the nameplate popping point of safety valves set at the manufactures plant on steam is not the popping point that the valve will have under service conditions in the drywell. Under in-service conditions it can be expected that the safety valve will "pop" 12 to 36 psi below the nameplate value due to spring relaxation.

B. <u>Mechanism 2:</u> <u>Mechanical Shock Effects</u>

A shock-induced premature actuation of a safety valve was found to be a highly probable explanation for some of the incidents at Dresden. A procedure for testing safety valves at the manufacturers plant included a section on impacting the valve at close to setpoint pressure.

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An operator at the manufacturers plant was asked to impact a small safety valve whose setpoint was 770 psig while it was at 750 psig. The valve repeatedly discharged following a slight tap of the wrench, thus indicating the shock sensitivity of these valves.

The design of this valve was slightly different from that of the Dresden valve in that it had a solid casting up to the spring compressor nut instead of the two yoke rods and yoke configuration (see Figure 2). It is believed that the shock mechanism which caused this valve to discharge was the vibration of the spring and the spindle rod which presses on the disc. (See discussion in section III D).

In the Dresden valve the same type spindle rod is used in addition to the less stable yoke and yoke rod configuration. Thus it can be expected that the Dresden valve would have a greater shock sensitivity.

From the above discussion it can be deduced that shock initiation is a highly probable cause of premature operation of the safety valves. In two actuations (6/5/70 and 5/4/72, at Dresden), the safety valve adjacent to the operating electromatic relief valve has prematurely relieved, on 12/8/72 another actuation occurred but no electromatic valve was involved.

The most sensitive component of the safety valve, with respect to shock, is the spring and spindle system. Due to the nature of the helical spring it cannot exert a uniform loading on the spring washers at each end. The eccentric loading puts a bending force on the spindle in addition to the expected compression force.

When a shock (horizontal acceleration) is imposed on the safety valve, the inertia of the spring will tend to increase this bending load on the spindle. As the spindle deflects under the increased load, the resultant force exerted by the spindle on the valve disc deviates farther than normal from the vertical axis of the disc thus decreasing the downward force on the disc and causing it to pop at a lower pressure than it is set for. See Figure 3 for a graphic representation of this phenonmena.

Recently, during tests were performed at Quad Cities Unit II; accelerations on the order of 30 G's were measured on the top of the valve spindle in the dirdction perpendicular to the plane of the yoke rods, see Figure 2, when an adjacent electromatic relief valve was manually actuated.

It is difficult to calculate the reduction in setpoint during periods when a safety valve is subjected to such accelerations; but from the above discussion it can be stated that this acceleration will reduce the safety valve actuation pressure and will lead to premature actuation.

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General Electric is conducting tests in conjunction with Wyle labs to evaluation the acceleration effects on this type of safety valve.

C. Mechanism 3: Pressure Pulse Effects

Recent tests at Quad Cities Unit II on an instrumented safety valve in service, indicate that actuation of an electromatic valve adjacent to a safety valve on the same main steam line with the reactor isolated (mainsteam isolation valves closed) caused on opening, pressure pulses 125 psi above the main steam line pressure before actuation. This test was performed at 1000 psi. Data at 990 psi where a pulse of approximately 75 psi above operating was measured, indicate that the higher the initial pressure in the main steam line before electromatic valve actuation, the higher the pressure pulse that the safety valve on the same line will experience. These data also indicate that this pressure pulse magnitude is a steeply rising function of initial steam pressure in the main steam line before actuation. Similar results were obtained although smaller in magnitude for the unisolated tests. Figure 6 shows these plots of pulse heights versus operating level.

It is difficult to calculate the energy in the pressure pulse curves and the response of the safety valve to these pulses, but the potential for premature actuation on a high pressure pulse can be readily visualized.

D. Mechanism 4: Spindle and Spring Washer Design Effects

Due to the nature of a helical spring it cannot apply a perfectly axial force on a spindle of this type of safety valve.

There are two ramifications of the eccentric loading that the spring exerts on the spindle and the spring washers. One involves the tilting of the upper and lower spring washers which involves a lowering of the magnitude of the load applied by the valve spring on the spindle. The other involves a bending of the spindle which leads to a reduction in the spring load applied to the valve disc because of the shift of the resultant force applied by the spring through the bent spindle to the valve disc. (See Figure 7) These two ramifications are discussed separately below.

Tilted Spring Washers

When the BK 7155 safety valve (the valve that lifted prematurely on 5/4/72 at Dresden) was examined at the manufacturers Plant, both the upper and lower spring washers appeared to be tilted with respect to a horizontal plane. This tilting is due to the last half turn of the spring pressing on one side of each washer more heavily than on the other side.

The lower spring washers can tilt relative to the spindle to accommodated this uneven force, because there is a spherical seating surface for this washer on the spindle.

The upper spring washer mates with the spring compression nut in the yoke on a conical seating surface. This surface should prohibit tilting of the washer relative to the compression nut, but as previously stated the upper washer, as observed, was tilted. This indicates that the nut material is incapable of sustaining the eccentric load which the spring applies to the washer, See Figure 8.

This tilting of the upper and lower spring washers, when it occurs, results in an effective lengthening of the compressed spring height (See Figure 8). The net effect is a reduction in the magnitude of the spring load on the valve disc.

Eccentric Load Effects On Spindle

The eccentric load that the valve spring exerts on the lower spring washer is transmitted to the safety valve spindle on its spherical bearing surface (See Figure 9)

The design of the spindle is such that at the lower spring washer bearing point the spindle shaft changes diameter from about 2" below the bearing point to about 1" above bearing point. In addition, this transition has a built-in stress concentration point because of the sharp corner formed where the spherical bearing surface for the washer joins the surface of the 1" O.D. section of the spindle. Finally, the spindle material is austenitic stainless which is one of the lower yield point stainless steel alloys.

Under these conditions, it is conceivable that the spindle undergoes a stress relaxation similar to that hypothesized for the spring. In this case, it is known that the spindle is in direct contact with the 550 (°F) steam temperature by way of the path through the valve disc. If indeed the spindle does bend in response to the eccentric load and the high temperature, the effect described below can be readily visualized.

The bending of the spindle further increases the deviation of the resultant force exerted by the spindle on the disc from the perpendicular axis of the disc. Since the resultant force of the steam on the disc is always colinear with the perpendicular axis of the disc, the deviation of the spindle force decreases the opposing force against the disc exerted by the spring.

One possible justification for this hypothesis is the recurring problem of bent spindles. The manufactuere has strict tolerances on spindle straightness (0.003") On the BK 7155 valve a 0.030 inch eccentricity of the spindle was noted on dissembly. Other spindles have been found to be bent up to 0.150 inches. These spindles are always found to be bent at the above transition point.

The bending of the spindle caused a shift in direction of the resultant force which the spring exerts on the valve disc. This shift acts to reduce the popping pressure of the safety valve.

In general, the valves at Dresden are always handled with a special rig to prevent any mistreatment of the spindle, yet it is repeatedly found to be bent on valves dissembled after service.

The above discussion postulates a mechanism which can cause the observed bending of safety valve spindles. Another potential mechanism is related to the accelerations experienced by a safety valve during plant operations as discussed in Section III B.

It has been experimentally determined during the Quad Cities in-service safety valve test that the instrumented safety valve can be subjected to accelerations up to 30 G's in magnitude under certain conditions. These accelerations occur in a direction perpendicular to the plane formed by the two safety valve yoke rods (See Figure 4). (The "weak" bending direction for the yoke and yoke rod configuration above the valve body.)

Since the safety valve is accelerated by means of loadings transferred through the mainsteam line to which it is attached the following mechanism can be readily visualized.

The safety valve spring is connected to the safety valve body at two points, the upper and the lower spring washers. Acceleration of the valve body in the above indicated direction causes an inertial loading of the spring on the valve body components through the two spring washers. The upper washer is connected to the compression nut which is rigidly mounted in the yoke. The lower spring washer however is held by the safety valve spindle. As previously stated the region where the lower spring washer rests on the spindle contains a stress concentration configuration. Considering the spindle to behave as a vertical beam, subjected to a large inertial load at a stress concentration, plastic deformation (bending) is highly probable at this point when the valve body is accelerated, See Figure 9.

E. Mechanism 5: Temperature Effects on Valve Body

When the safety valve is put on the manufacturer's steam test stand, the spindle moves out of the yoke approximately 0.050 inches due to hot steam causing the expansion of the nozzle material; this phenomena occurs within 5 or 10 minutes. When a Dresden valve was tested at the manufacturer's plant on the steam test stand, the body of the valve was found to be close to room temperature. Under these conditions, the valve spring is compressed an additional 0.050 inches and the popping point is increased approximately 50 psi over the nitrogen set point. In practice, dimensional tolerances as well as deviations in the spring constant probably add up and cause the spread of the data on steam versus nitrogen set pressures. Therefore, it can be expected that the valve will pop at higher pressure on the steam test stand than a nitrogen test stand.

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When the valve is installed in the drywell and is at operating temperature, the insulation installed on this valve may cause the body and the yoke rods to expand to such a degree that the popping point could actually be lower than the value determined on the steam test stand. Recent measurements at Quad Cities on the safety valve body temperature for an insulated valve gave a value of 400 (°F). Calculations done by the manufacturer indicate that if the yoke rods are at 400 (°F) inside the valve insulation, they will be responsible for lowering the valve set pressure by about 50 psi. As stated in Section I the spring relaxation can contribute a 36 psi drop, the sum of these two effects gives an 86 psi drop in setpoint pressure, due to thermal effects alone.

F. Mechanism 6: Safety Valve Alignment Effects

A problem which appears to be inherent in the steam setting of safety valves at the manufacturers plant is that the steam pressure of the initial pop on steam is discounted during safety valve setting. This practice of discounting the first steam pop of the valve and only noting the subsequent three values was questioned. The manufacturer responded that the valve needed one pop to assure the various components of the valve were in correct alignment after a disassembly and reassembly had occurred. Under these conditions it is concieveable that this "first pop" would occur with the valve in service and that under these conditions it would not pop at the pressure on its name plate. It was not clear if this "alignment" pop had to be done on nitrogen or on steam. Another question that comes to mind is what happens if this alignment is affected by a bump during installation. The manufacturer further recommend that if possible, the spring should remain compressed by means of its spindle when the valve is disassembled to preserve this "alignment".

Experience with these valves has shown a considerable number of problems with bent spindles. These bent spindles are usually discovered when the valve is disassembled at Dresden. If transportation type problems or the shaking forces due to electromatic valve actuation are causing the spindles to be bent it can also be assumed that the delicate "alignment" mentioned above can be effected by these factors and that possibly the theory that we are getting the "first pop" while the valve is in service can indeed be the case.

Naturally, because the first pop is discounted on the steam test stand at the Dresser Plant, practically no data exists on the first pop pressure relative to the set pressure. The set pressure is determined from the subsequent 3 pops whose averaged valve is called the valve set point pressure. Some data on first pop after reassembly were taken on valve BK 7155 at the manufacturers plant. In this case, the valve first popped at 1245 (the alignment pop) its subsequent 3 pops occurred at about 1210 psig. This unpredictable first pop was a standard occurance during setting of Dresden type valves as per the manufacturer.

As another example of the delicate "alignment" property of this type of valve, the following experience with BK 7155 can be cited. Valve BK 7155 is the Dresden valve that was sent to the manufacturer for testing. After testing, remachining, and resetting the valve, on both nitrogen and steam it was shipped in a manufacturer approved construction crate. When the valve arrived at Quad Cities it was tested on the Dresden nitrogen test stand and pressurized with a regulator. It popped 25 psi low and required a resetting.

Thus it can be concluded that shipment can influence the setpoint of this valve.

G. Mechanism 7: Safety Valve Nozzle Seat Distortion

A recurring problem with the safety valve nozzle seat has been experienced. Valve seats on valves removed from service have elevated and depressed areas a few mills above and/or below the mean seating surface level. These high and low spots, some varying as much as 22 mills from the mean seating surface level, can have serious effects on the valve setpoint and leakage. Any area in the seat region which distorts in such a way as to allow steam to act on a larger surface area of the valve disc causes a decrease in the valve setpoint. Some distortions of the valve seat, as reported by the manufacturer, result in a raised outside diameter of the seating surface. A considerable number of distortions fall into this catagory. See Figure 12. This is the worst possible case, since under these conditions the valve disc seat area exposed to the steam pressure is enough to reduce the setpoint up to 180 psi. This high value has never been found to exist, probably because of the uneven nature of the seat distortion and the fact that the disc of the valve has a slight flexibility built in.

An explanation of the raised outside diameter and lowered inside diameter phenomenon has been suggested.

Consider a safety valve to be tested on a steam test stand. Initially the valve is at room temperature. The 550 (°F) steam is applied to the valve; the valve nozzle inside diameter is exposed to this temperature while the outside diameter of the nozzle is still at room temperature. The inside surface of the nozzle grows axially and elastically; the outside surface is plastically strained by the growth of the inside surface. Thermal equilibrium is eventually established at 550 (°F). The outside surface now has an initial plastic axial strain in addition to the thermal expansion strain; thus the outside diameter of the seating surface is higher than the inside diameter of the seating surface by an amount exactly equal to the plactic strain that the outside surface experienced upon the initial thermal shock. This effect may also be operative during normal temperature cycles of the valve.

A similar effect can occur if a rupture disc on the exhaust of a safety valve in service is broken. A down draft of cool air into the safety valve through the discharge flange will cool the outside surface of the nozzle in an unpredictable manner. These convection currents could be responsible for some of the random seat distortion which has been found in the past.

Another potential cause of this nozzle seat warpage is the possibility of residual stresses in the nozzle generated during their manufacture. The uneven growth of the seat could be due in part to the growth of nozzle regions under service conditions due to relaxation of these residual stresses.

These two potential sources of seat distortion are being presently investigated.

IV Blowdown Range Problems

Once a safety valve has lifted in service, due to whatever cause, the severity of the resulting steam discharge damage is totally dependent on the blowdown range of the valve.

Most safety valve specifications call for a 3-4% blowdown range below the setpoint, including those of the Dresden II valves.

The manufacturer was questioned on how he determined the blowdown setting of the Dresden and Quad Cities valves. The manufacturer stated had no means, theoretical or experimental, of determining the blowdown of these valves.

Since the blowdown setting determines how much steam is relaesed to the drywell following a lift, it was decided to reset all Dresden and Quad Cities valves to give the minimum possible blowdown. This was done as a tentative solution until some means of determining blowdown could be found.

The blowdown setting on the valve responsible for the May 4, 1971 incident at Dresden was "estimated" by the manufacturer to be 200 pounds instead of 40 pounds (which is 3% of the setpoint pressure).

V Conclusions and Recommendations

The insulation on the safety valve bodies at Dresden Units II and III and Quad Cities Units I and II is capable of causing, in the worst case, a reduction of poping pressure by approximately 90 psi due to safety valve spring relaxation and yoke rod expansion.

The safety valves when initially set on steam are not at the equilibrium temperature which they achieve when they are in service in the drywell. This causes a change in setpoint for the valve in the drywell relative to the initial setpoint made by the manufacturer.

The safety valves are presently situated on the four mainsteam lines in the drywell, each of these lines also has one or more electromatic relief valves situated on it. From tests conducted at Quad Cities on Unit II, it has been determined that the operation of an electromatic valve in on a specific main steam line causes a safety valve located on the same line to experience accelerations up to 30 G's and steam pressure pulses on the order of 100 psi above reactor pressure. Because of the valve design it is likely that premature actuation can be induced by either or both of these effects, and indeed a number of incidents of premature safety valve actuation has been directly related to prior operation of an electromatic relief valve on the same main steam line.

The popping point of the safety valve is effected by the design of the spindle and the spring washers. Bending of this spindle, due to the eccentric load of the safety valve spring and/or the inertial loading of the spindle due to horizontal accelerations has occurred. The bending of the spindle causes a reduction in poping point due to lengthing of the compressed length of the spring and also to the shift of the resultant force exerted by the spring on the valve disc. The upper and lower spring washers tilt under load and/or shock conditions. Tilting of these washers can change the compressed length of the spring, and change the popping point of the valve.

The safety valve nozzle seat distorts under service conditions. This distortion appears to be due to thermal expansion and plastic deformation effects. The typical distortion pattern acts to reduce safety valve poping point, in the extreme case this distortion could possibly drop the popping pressure by 180 psi.

In the evant that a safety valve does pop due to whatever the cause, the severity of the resulting steam discharge is dependent on the blowdown range of the valve. Typically a safety valve of this type should reseat after an initial pop at a pressure about 40 psi below the pop pressure. Under a given set of conditions a specific quantity of steam will be released into the drywell while the valve is open. If the blowdown setting is wrong as it has been found to be in certain cases, as set by the manufacturer, the valve will not reseat until the reactor pressure drops say 200 psi.

The quantity of steam released into the drywell and the resulting damage sustained for a valve with a 200 psi blowdown is much greater than for a valve with a 40 psi blowdown, when the respective valves pop. In addition to the problem of getting new valves with wrong blowdown setting (qualitatively determined) the manufacturer states that there is no method experimental on theoretical available at this time to set the blowdown adjustment of these valves. The only solution which is available and which has been used on the respective Dresden and Quad Cities units is to set the blowdown ring to give the minimum blowdown, whatever that value is.

The various problems indicated are now under investigation by the parties involved.

The remaining investigations in progress are briefly summerized below.

Wyle Laboratories

Tests on effects of temperature and vibration on safety valve performance are being carried out initial results reported in agreement with data presented herein.

Operational Analysis Department, Commonwealth Edison Co.

Tests on a safety valve nozzle to determine effects of thermally induced stresses and strains on seat distortion will be carried out shortly.

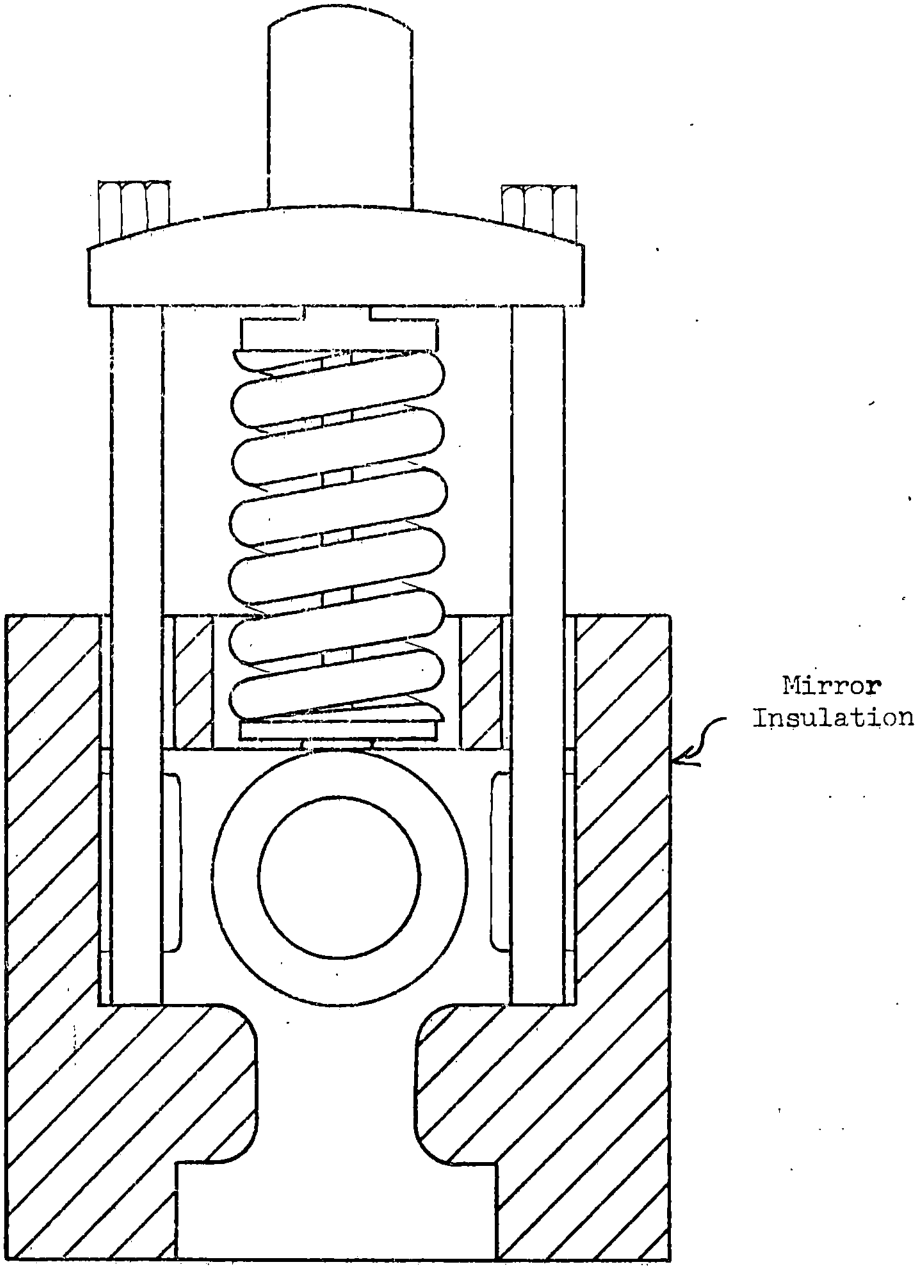

Figure 1

Safety Valve Insulation

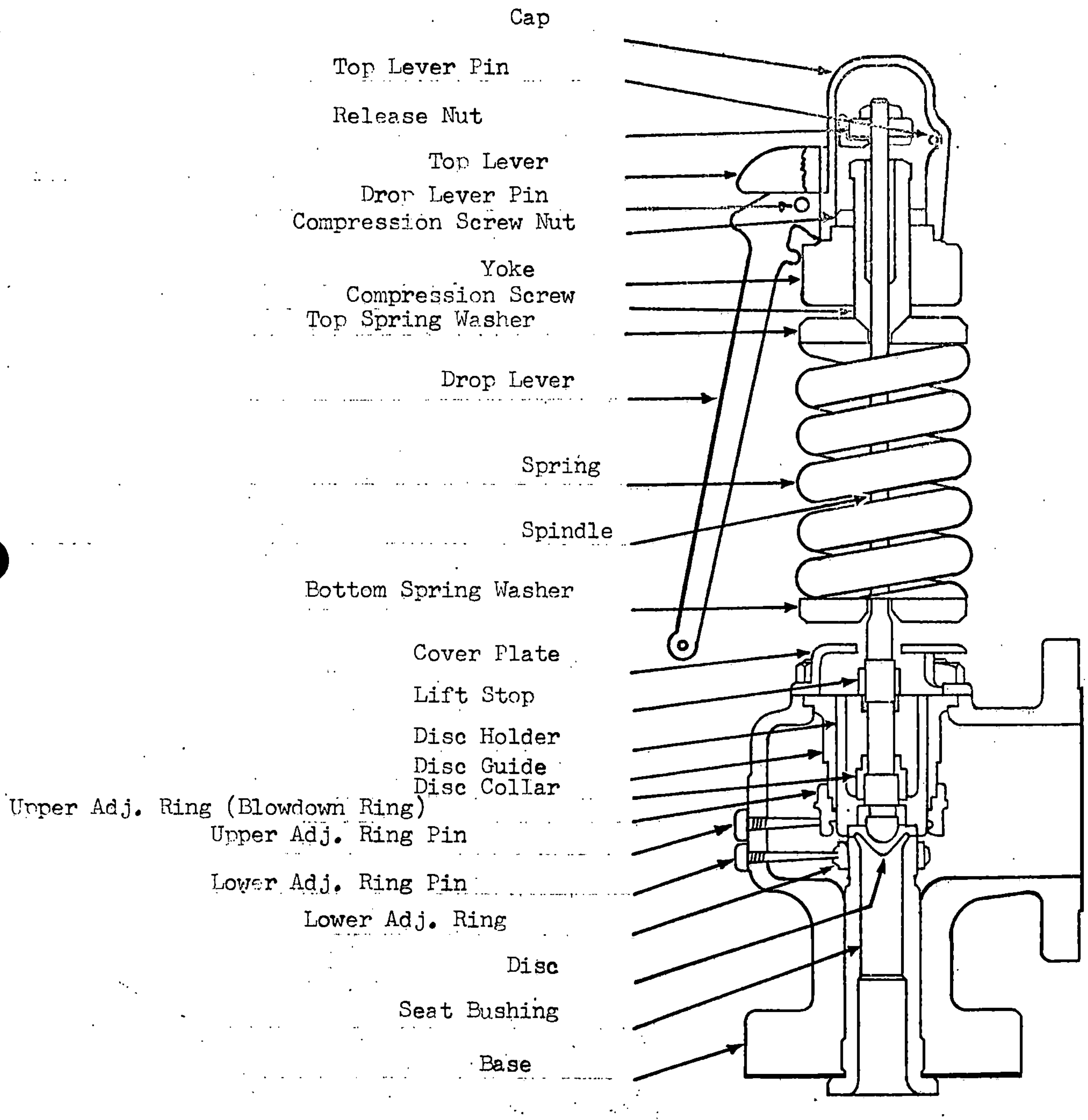

Figure 2

Safety Valve Schematic

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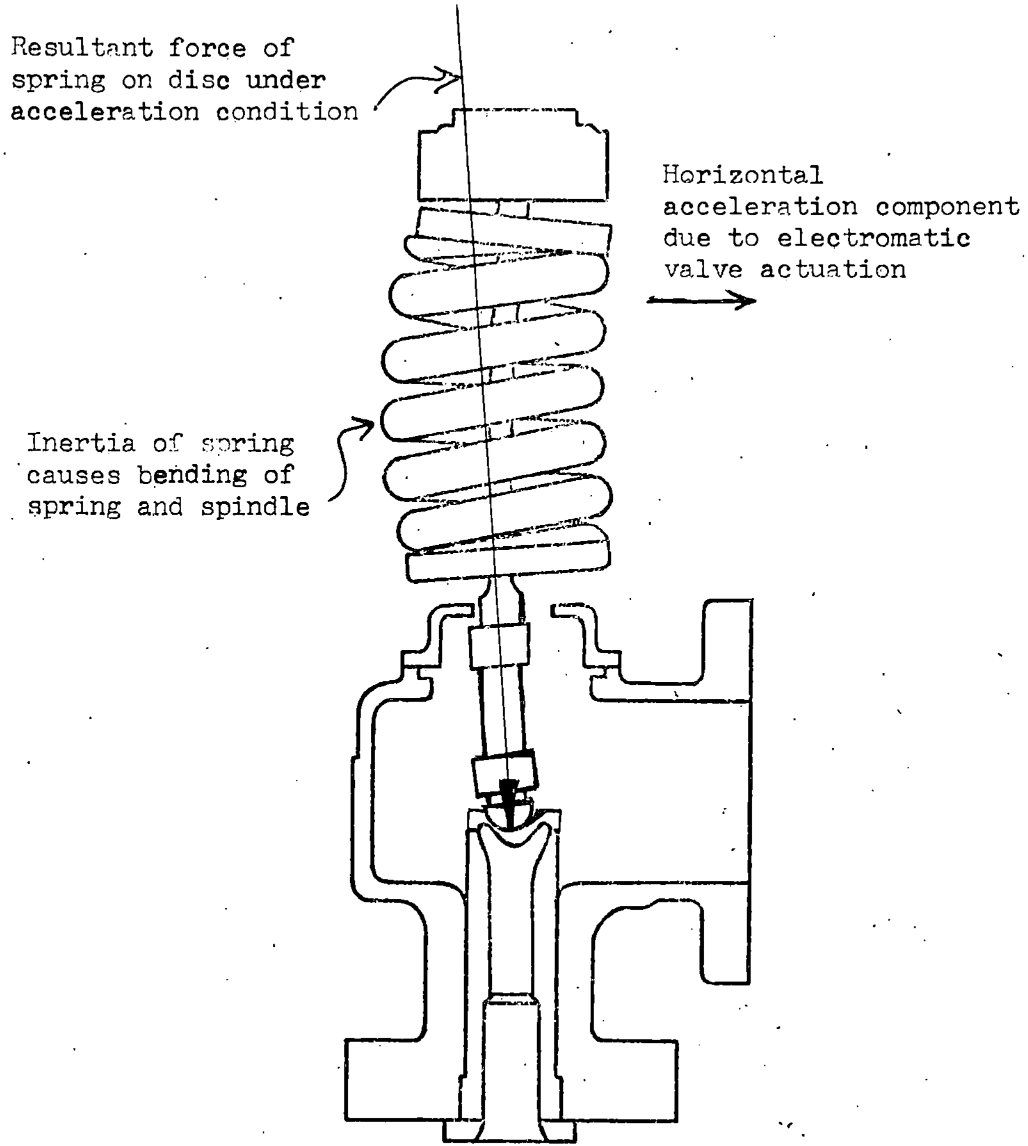

Figure 3

Spring Inertia Effects

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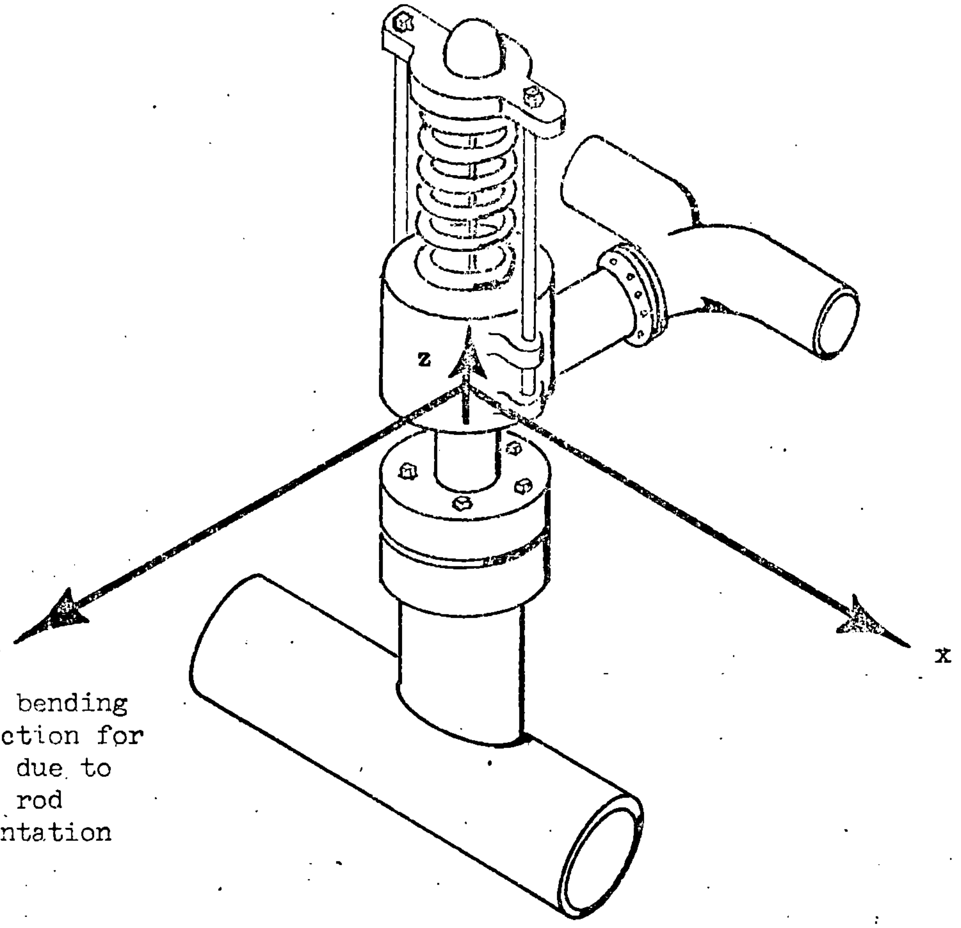
Accelerations Recor ng During Safety Valve Tests at uad Cities

	Valve Body Accelerations in G's			Top Spindle Accelerations in G's		
Test Title	x	y	z	x	y	z
Isolated Reactor (1,000 psi)	-	-1.7	-20	-16	-28.5	-5
Unisolated Reactor (1,000 psi)	-	-2	-25	-17	-31.5	-1.6

Accelerations resulted from operation of an electromatic relief valve adjacent to the safety valve instrumented.



Weak bending direction for yoke due to yoke rod orientation

Figure 4

Safety Valve Accelerations

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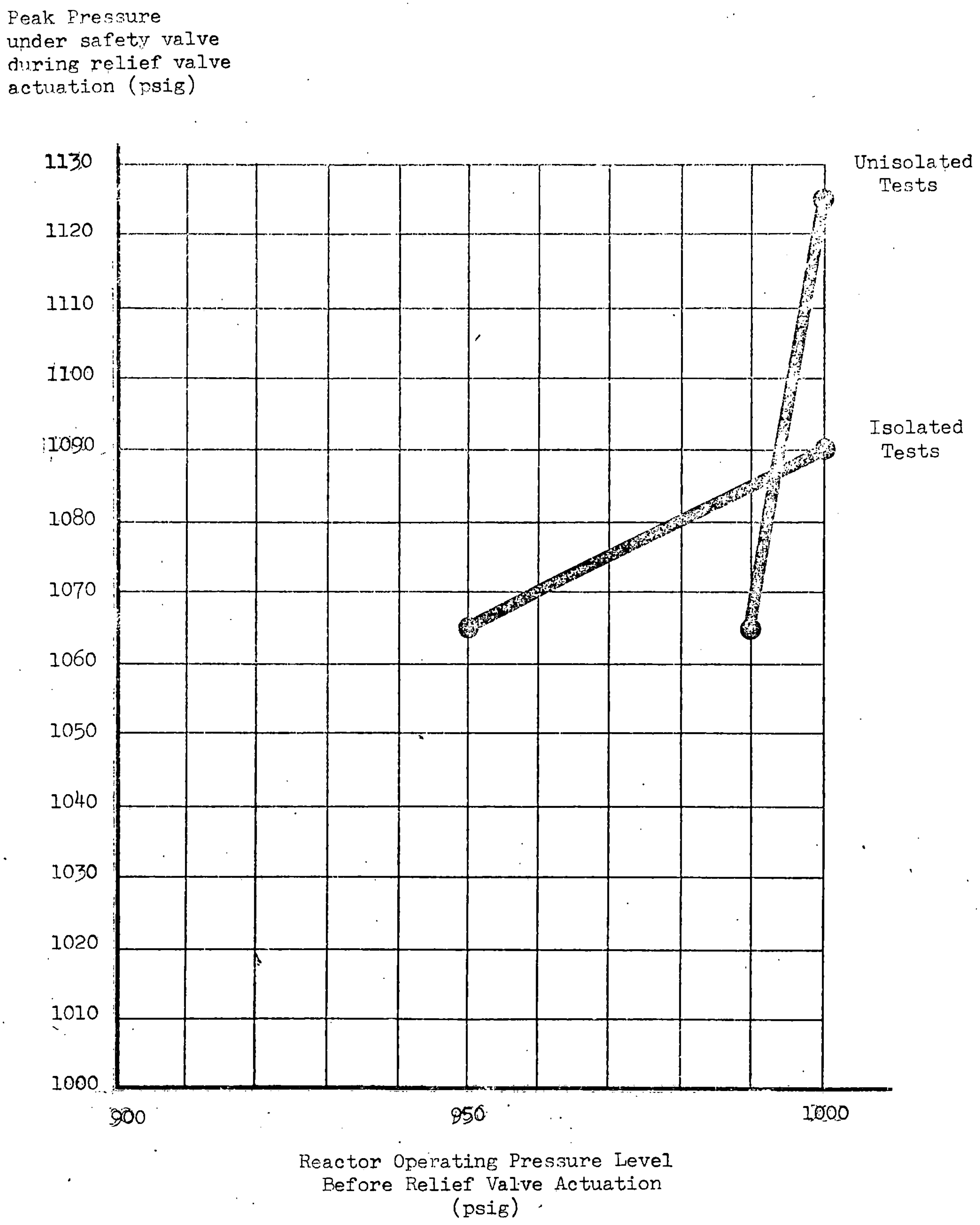
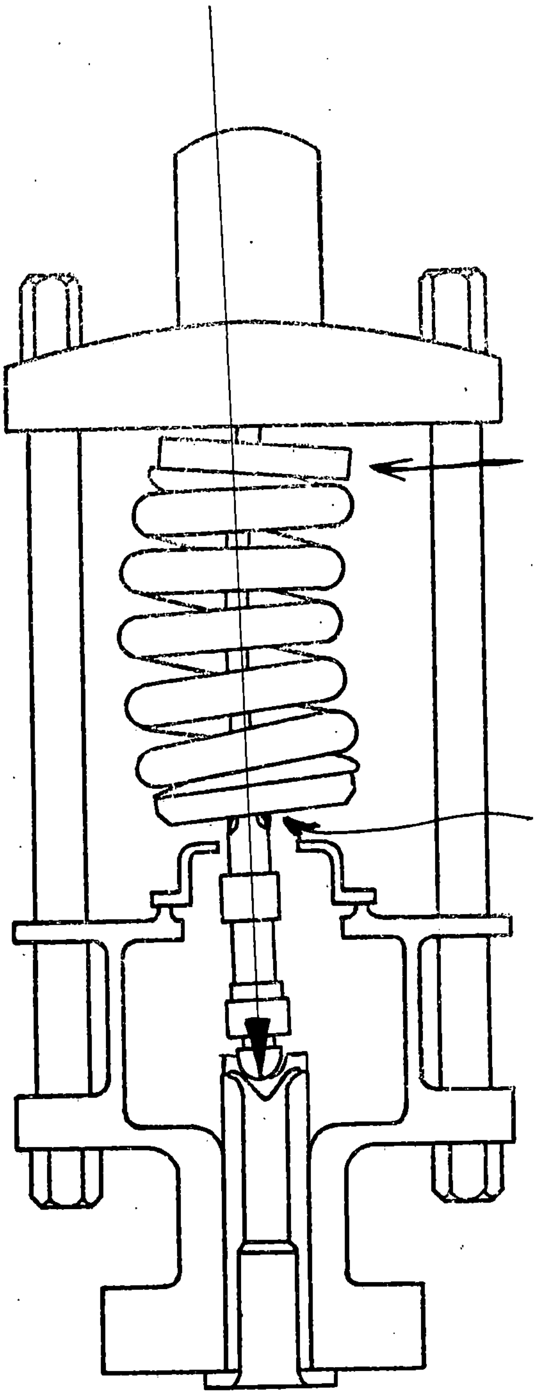


Figure 5

Pressure Pulse Height Versus Reactor Operating Pressure Level During Electromatic Relief Valve Actuation

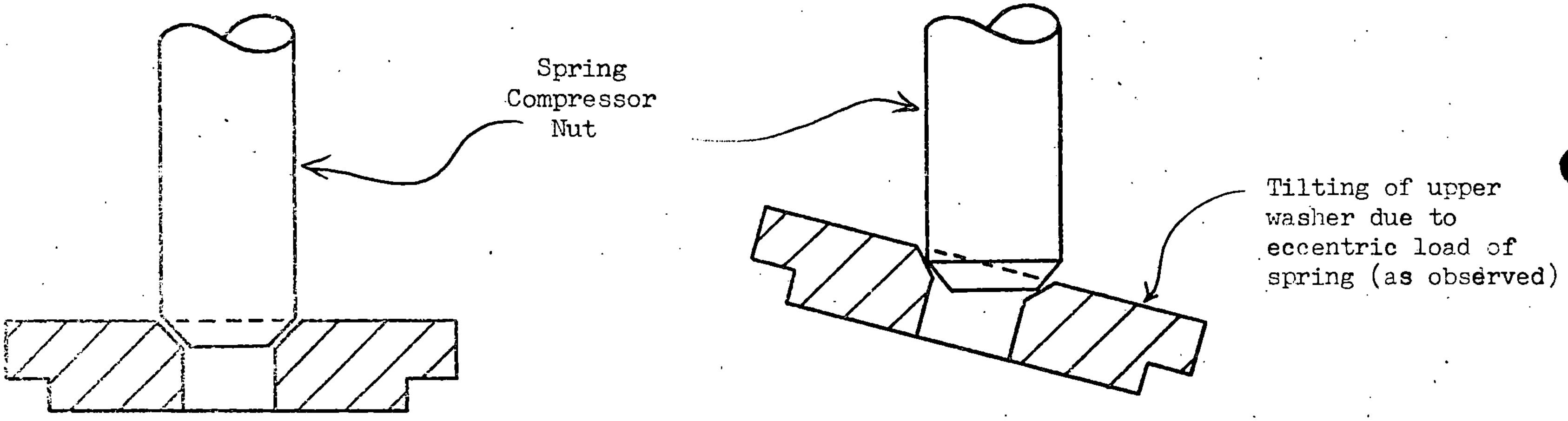


Tilting of upper spring washer

Bending of spindle due to eccentric spring load on lower washer lowers resultant force acting down of valve disc.

Figure 6

Safety Valve Spring Force Components



As Designed

In-service

Figure 7

Spring Compressor Nut and Upper
Spring Washer Configurations

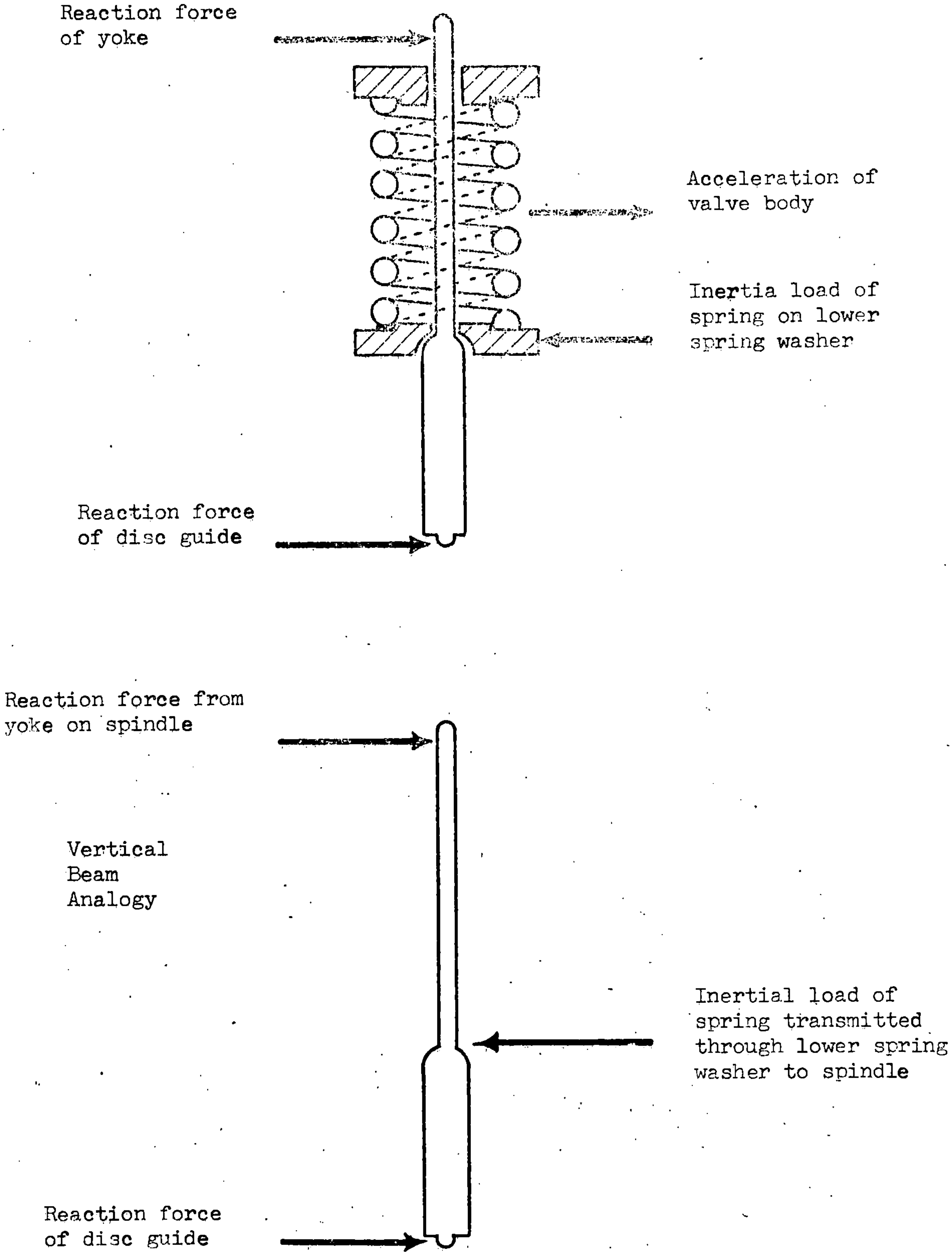


Figure 8

Inertial Bending Load of Valve
Spring on Valve Spindle

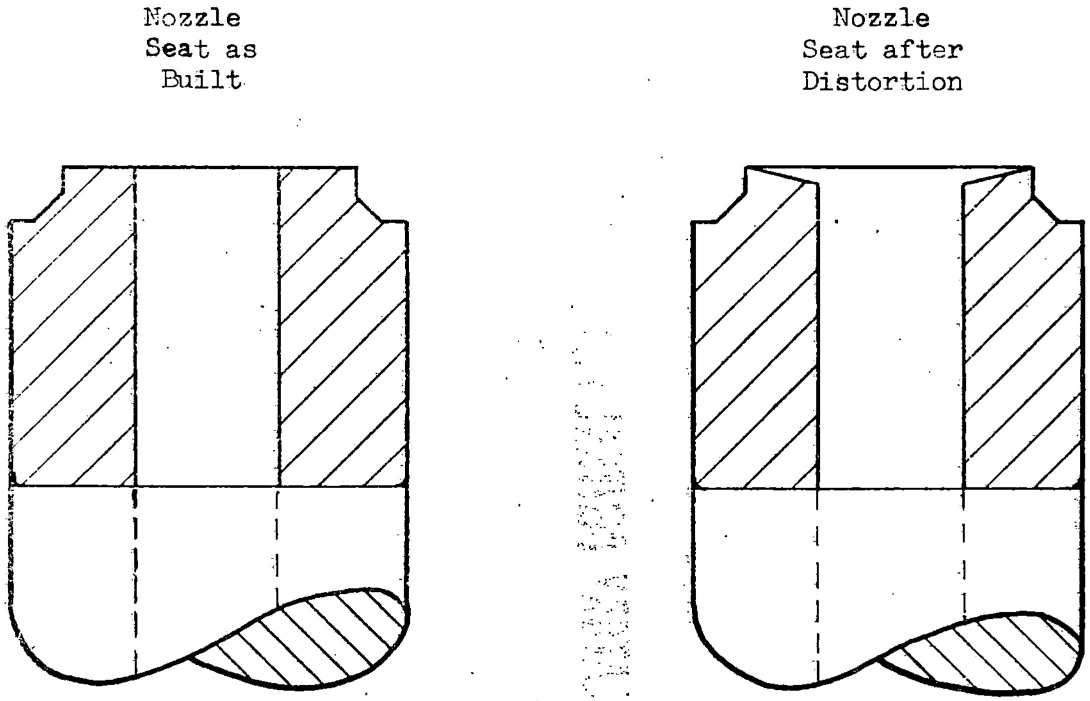


Figure 9

Typical Nozzle Seat Distortion Configuration