Design and Development of Pressure-Operated Sprinkler

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Abstract – *In this project, we conducted research to design, develop a Pressure-operated sprinkler, which consists of Pressure relieving valve. The pressure-operated sprinkler has a header piping system where pressure should be maintained at 2-Bar. The bypass valve remains open and releases water to the surroundings, but if the sensors attached to the system detect fire, the valve closes automatically, and the system is activated. The pressure in the pipeline system is raised to the range of 4 to 6 Bar. Main application of the pressure-operated sprinkler is in fire suppression.*

Key Words: Valve optimization, Valve, Operation analysis, Pressure-operated sprinkler.

1. INTRODUCTION

a. What is a Pressure relieving valve?

A relief valve or pressure relief valve (PRV) is a type of safety valve used to control or limit the pressure in a system; pressure might otherwise build up and create a process upset, instrument or equipment failure, or fire. The pressure is relieved by allowing the pressurized fluid to flow from an auxiliary passage out of the system.

b. Importance of Pressure relieving valve:

The relief valve is designed or set to open at a predetermined set pressure to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits. When the set pressure is exceeded, the relief valve becomes the "path of least resistance" as the valve is forced open and a portion of the fluid is diverted through the auxiliary route. In systems containing flammable fluids, the diverted fluid (liquid, gas or liquid-gas mixture) is usually routed through a piping system known as a flare header or relief header to a central, elevated gas flare where it is usually burned, and the resulting combustion gases are released to the atmosphere.

In non-hazardous systems, the fluid is often discharged to the atmosphere by a suitable discharge pipework designed to prevent rainwater ingress, which can affect the set lift pressure, and positioned not to cause a hazard to personnel. As the fluid is diverted, the pressure inside the vessel will stop rising. Once it reaches the valve's resetting pressure, the valve will close. The blowdown is usually stated as a percentage of set pressure and refers to how much the pressure needs to drop before the valve resets. The blowdown can vary roughly 2–20%, and some valves have adjustable blowdowns. [1] These characteristics of pressure valve will be utilized in the system to open and close at predetermined pressure points.

c. The Pressure-operated sprinkler:

In contrast to the conventional systems, the pressure-operated system is developed in a mechanical way, as it is highly reliable in case of fire outbreaks. The pressure is maintained at 2 Bar in the pipeline to have a faster reaction time. (< 3 seconds)

Hence, the pressure relieving valve was to be developed for which, the cracking pressure is 2.5 bar and resealing pressure is 2.3 bar.

2. PROBLEM STATEMENT:

- Optimizing response rate of spring.
- Calculating the opposing force required by spring to optimize the spring selection and preset load & spring deviation.
- Maintaining cracking pressure of valve between 2.3-2.5 bar.

3. WORKING METHODOLOGY

I. Numerical calculations.

II. Preliminary CAD model of the valve.

III. Finite Elements Analysis.

IV. Sealing Selection.

V. Prototype Manufacturing and testing

I. Numerical calculations.

Valve cracking pressure & closing pressure are defined by the spring stiffness & preset load.

Hence, for proper operation tuning of the spring is required.

Given conditions:

Cracking pressure= 2.5 bar

Resealing pressure= 2.3 bar

Hence, calculation opening & closing forces required

For cracking pressure of 2.5 bar,

$F_{Cracking} = P_{cracking}$ x a ……… (1)

Where,

$F_{Cracking}$ = Force exerted on poppet surface by water pressure.

$P_{cracking}$ = Cracking pressure on valve=2.5 bar = 0.25 N/mm^2

A= Area of poppet in contact with water= π x $(9.25)^2$

Putting values in equation 1, we get,

$F_{Cracking}$ = 67.20 N

For resealing pressure at 2.3 bar,

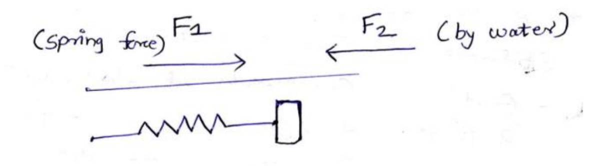
$F_{reseal} = P_{reseal}$ x a …. (2)

P_{reseal} = 2.3 bar.

Putting values in equation (2), we get,

F_{reseal} = 57.7 N

$F_{Cracking}$> K (spring stiffness) x X (deviation of spring)> F_{reseal} (3)



Standard spring available in the market was selected,

Sr. No.	Specification	Remark
1	Spring type	Helical Spring
2	Material	Inconel X-750
3	Outside diameter	18.8 mm
4	Inside diameter	13.8 mm
5	Spring wire dia.	2.5 mm
6	Free length	53 mm

As per the calculations given below,

Spring stiffness is defined as following,

$K = G.D^4 / 8\ D^3n$… (4)

Where,

G= Modules of elasticity= (for Inconel X-750) = 75.8 KN/mm^2

d= wire dia. =2.5mm

D=mean spring dia. =16.3 mm

n=No. of active coils. =9

Putting values in equation. 3, we get,

K= 9.49 N/mm (Numerical value)

Force exerted by spring under preset compression is,

F=K x X

Where,

F = Force exerted by spring in opposite direction of compression.

K= spring stiffness.

X= Deviation

Hence, as per equation (3)

$F_{Cracking}$ > K (spring stiffness) x X (deviation of spring) > F_{Reseal}

67.2 > KX > 57.7

Now, taking value of K=9.29,

Value of X is,

7.2 > X > 6.2.

As the spring stiffness differs in each material due to its properties, value of the spring stiffness was measured.

Spring stiffness of the sample spring is measured practically by loading spring under the weight and measuring deformation in spring while under load.

Hence, the test was carried out where bar stock of weigh 5.19 Kg was kept over spring.

Recorded data as per below,

Weight of bar = 5.19 weight of collar = 0.1kg kg

F=ma = (5.19+0.1) x 9.8 = 50.96 N

Spring length (without load) = 53mm, spring length (with load) = 46 mm

Deviation = 53-46 = 7 mm.

F=K x X

F = Force exerted by spring in opposite direction of compression.

K= spring stiffness.

X= Deviation

Hence,

50.96 = K x 7,

K= 7.28 N/mm (Actual stiffness)

Hence, it is observed that the actual spring stiffness is less than theoretical value. Possibly due to deviation in material properties.

Hence, putting the actual value of spring stiffness in equation (3),

$F_{Cracking}$ > K (spring stiffness) x X (deviation of spring) > F_{Reseal}.

67.2 > KX > 57.7

As K=7.28,

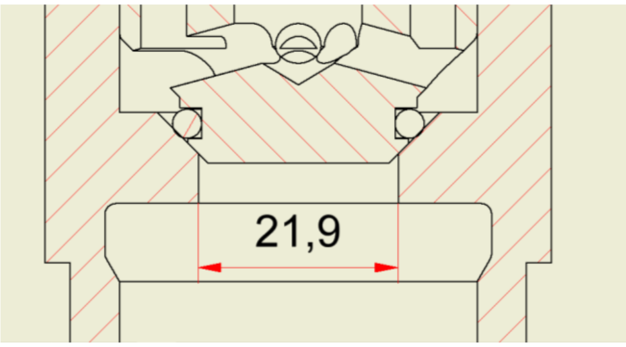
Value of X is,

9.23 > X >7.92

Hence, spring deviation to be maintained 7.9-9.2 mm to satisfy the equation 3.

Trial to be taken to validate the numerical calculations.

II. Preliminary CAD model of the valve:



Proper O-ring is selected as per groove width & groove height such that seal is formed without excessive forces on O-ring and extra threading length is provided for spring tuning.

III. Finite Elements Analysis:

As with water hammering, and poppet material being Brass, FEA is done to check if there is any chip-off during the operation.

Design Objective	Single Point
Study Type	Static Analysis
Detect and Eliminate Rigid Body Modes	No

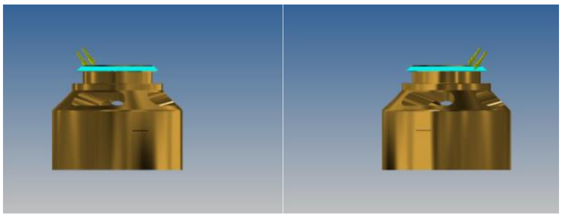
Material(s):

Name	Brass	
General	Mass Density	8.49 g/cm^3
	Yield Strength	124 MPa
	Ultimate Tensile Strength	338 MPa
Stress	Young's Modulus	97 GPa
	Poisson's Ratio	0.31 ul
	Shear Modulus	37.0229 GPa
Part Name(s)	holder 2. ipt	

Operating conditions:

Load Type	**Pressure**
Magnitude	0.700 MPa

Selected Face(s):



Result Summary:

Name	**Minimum**	**Maximum**
Volume	15496.5 mm^3	
Mass	0.131565 kg	
Von Mises Stress	0.00308738 MPa	4.34453 MPa
1st Principal Stress	-1.69577 MPa	1.01132 MPa
3rd Principal Stress	-5.67681 MPa	0.299134 MPa
Displacement	0 mm	0.000176621 mm
Safety Factor	15	15

IV. Sealing selection:

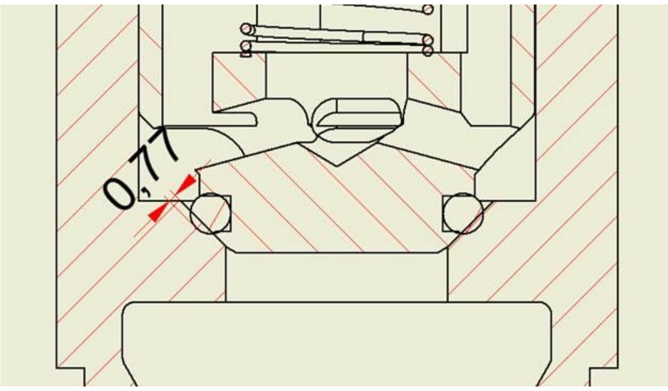


Figure 1

Optimum range of compression is typically 8%-35%. [2]

As it can be observed in the design, it was ensured that metal-to-metal contact would be there, compression on the O-ring will be 0.7 mm, which is 17%, which lies in the optimum range as mentioned above.

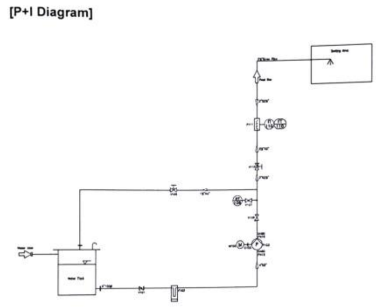
V. Prototype manufacturing and testing:

Test stand:

Test Rig

A Test rig is a piece of machinery that is primarily used to test and assess the capability and performance of components for industrial use. The term test rig is sometimes also referred to as test bay, test bench, pressure test facility and testing station but they all refer to equipment that carry out component testing.[3]

The test rig machine used for testing the prototype has the range of 750 lpm maximum. It can bear maximum pressure until the range of 5 Bar and maximum usable flow rate is 500 lpm. While some test rigs have pump without motor, this one comes with an inbuilt one.



Pipe and Instrumentation diagram

The pipe and instrumentation diagram of this test rig machine describes the workflow of the machine. Water inlet on the far-left side conducts water to the water tank. The water from the water tank flows to the basket filter through butterfly valve, which are used for opening and closing the pipeline. The water is then filtered in the basket filter to supply it to the pump, which has an inbuilt motor. The pump and motor assembly pushes the water, and it passes through a non-returning valve which provides a direction to the water and a needle valve in the line to regulate the flow of the fluid.

Further, globe valve is attached which provides manual control followed by the flow meter by sensing the flow. Water is then sent to the tester and tests are carried out on the prototype.

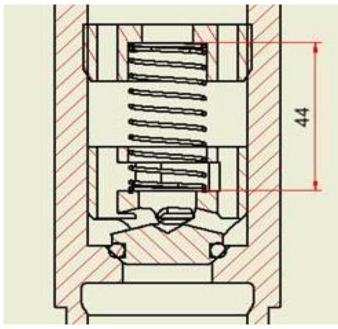


Figure 2

As seen in the theoretical calculations, value of the spring deviation was 9 mm as it is observed in the figure 2. (Free size: 53 mm, Spring length: 44 mm, thus, 9mm spring deviation.) But it was observed that cracking pressure of the valve was 2.3 bar

Resealing pressure was observed to be 1.98 bar,

Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.3	75.4
Cut out Value	1.98	

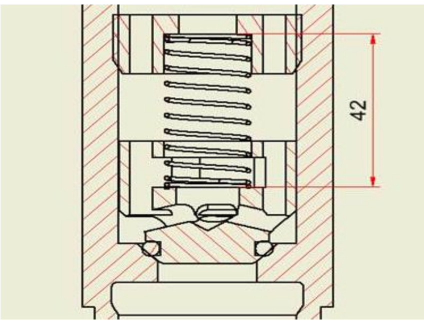


Figure 3

Value of the preset was increased to increase the preset load and 2nd trial was conducted with spring deviation of 11 mm.

Valve was tested once again to ensure proper working,

Test parameters:

Deviation in spring maintained at 11 mm

Rest of the parameters were unchanged,

Observations as per following,

Valve cracking pressure: 2.5-2.52 Bar

Valve reseal pressure: 2.27-2.23 Bar

Cyclic test was conducted for 10 cycles.

Table -1: Performance Trial of Pressure operated valve

Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.52	75.4
Cut out Value	2.25	
Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.52	74.9
Cut out Value	2.27	
Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.52	75.2
Cut out Value	2.26	
Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.52	74.8
Cut out Value	2.27	
Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.52	75.2
Cut out Value	2.26	
Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.52	74.8
Cut out Value	2.27	
Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.51	75.2
Cut out Value	2.27	
Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.51	75.4
Cut out Value	2.27	
Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.51	74.8
Cut out Value	2.27	
Valve with Nozzle	**Pressure (Bar)**	**Flow in LPM@ 4 bar.**
Cut in Value	2.51	74.8
Cut out Value	2.27	

Hence, as depicted from the observations table, cyclic tests ensured the repeatability of the performance of the valve.

4. CONCLUSIONS

The check valves are the most important part of the instrumentation tube fittings. They must be designed carefully to cope with precise working requirements.

The paper explains the various detailed operation, function and applications of relief valve with the design considerations and various materials used for the check valves. The paper also presents the thoughts on design of the check valve and analysis of the same. Spring plays main role in specific cracking pressure and it is also more prone to failure, due to shear by applied compression loading. The cracking pressure of valve by testing is 2.3-2.5 bar respectively, which are very close to the required values. The analysis of check valve on FEA shows that it is safe with the equivalent stress of 4.34 MPa and no deformation. The theoretical values and experimentation values shows very small percentage of error. In the future scope we

May lead to optimization by using various size of relief valve.

5. REFERENCES

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