Design of the Instrumentation Check Valve

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***Abstract*: The objective of this paper is to study and design of the check valve. In the present technological advancement, check valves are used for variety of applications such as industrial processes in chemical and nuclear plants, petroleum, hydraulics, pumps and compressors etc. The check valves are a common piece of instrumentation fittings which allows flow in solely direction. The most vital function of check valves is to prevent or minimize the development of reverse flow, as well as for preventing overflow which helps to protect systems from damage caused by reverse flow or overflow. This kind of function is essential for a variety of safety instruments. The critical components of check valves are spring, poppet and body, spring plays critical role to decide life of the check valve. The wall thickness of the body should be optimum. Based on the ASME standards, check valve body is categorised as a pressure vessel which is having only internal pressure. The check valve consists of merely six parts which ensures a required range of cracking pressure and performance characteristics with smooth and safe operation.**

Keywords: check valve, reverse flow, overflow, ASME, cracking pressure, performance characteristics

I Introduction

Instrumentation valves and tube fittings are used for the many demanding applications such as chemical, petroleum, power generating, textile and various types of manufacturing industries. They, in combination provide a highly reliable, leak proof and torque free seal on all tubing connections. Check valves are also known as non-return or one-way valves. Check valves are designed to allow fluid to flow one way i.e. ability to pass fluid in solely one direction. Check valves are often used with positive displacement machines such as pumps and compressors to prevent reverse flow. For the fluctuating and cyclic loadings, check valves usually avoided.

In some of the high end automobiles, In Fig. 1, check valves plays important role in emergency braking of the vehicle i.e. check valves can be used to trap pressure in a given volume and maintain the charge pressure for a specified time interval. A pump is used to charge an emergency brake accumulator through a check valve. In this case, when the pump is turned off pressure is maintained downstream of the check valve and this pressure is available for emergency braking conditions with improved overall efficiency.

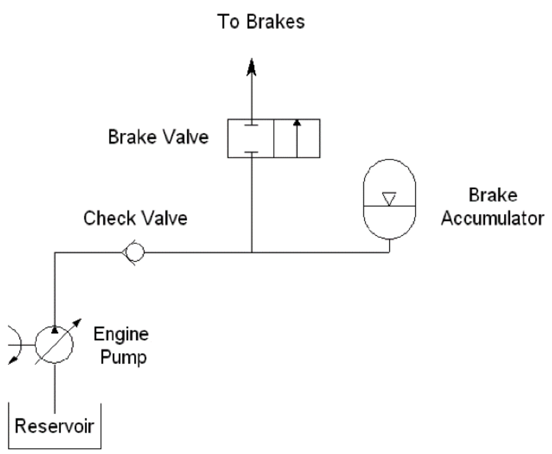

Fig. 1 Application of Check Valve in Emergency Braking

Functional Expectations of Check Valve:

The check valve should be sustainable, i.e. it should sustain high working pressure and environmental conditions. The check valve should have minimum number of parts and its size should be as small as possible. The design of valve should be simple, so that the complexity such as difficulty to operate under routine conditions, failure under shock loads, and difficulty of fixing when broken can be avoided.

Depending on design, there may be other items such as a stem, hinge pin, disc arm, spring, ball, elastomers, and bearings. Internal sealing of the check valve poppet and seat relies on fluid back-pressure. Metal sealing surfaces generally will allow some leakage while elastomers provide bubble-tight shutoff (zero leakage). Because of their simple design, check valves generally operate without automation or human interaction. According to the application and construction check valves are divided in various types as ball check valve, lift check valve, poppet check valve, butterfly check valve etc. An important concept in check valves is the cracking pressure which is the minimum upstream pressure at which the valve will operate. Typically the check valve is designed for and can therefore be specified for a specific cracking pressure.

Working of Check Valve:

Check valves commonly use a poppet and light spring to control flow as shown in the fig 2.

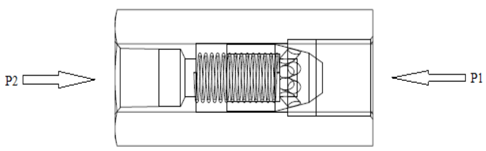

Fig. 2 Working Mechanism of Check Valve

If $P_1A_1 > P_2A_2$ + spring force + friction, then the seal breaks and poppet pushed towards left and flow occurs, i.e. check valve opens.

But if $P_1A_1 < P_2A_2$ + spring force + friction, then the poppet would be pushed to the right, against the stop which forms the seal, prohibiting flow in the reverse direction, i.e. check valve closes.

II Review of Literature

Anthony Esposito from his book Fluid Power with Applications explained the function and modern application of check valve and its advantages over other types of valves. [1] William Orthwein and V.B. Bhandari from his books explains the design of various components with their analysis. These books also suggests the materials for the various components with their composition and material properties. [2][3]

K.S. Sriranjini, Abhishek H.V., Mandara Yograj, Dr. S. Nagaraja, explained design and analysis of check valve under static and thermal load conditions with material selection and geometric modelling of check valve. [4] The Daerospace Hydraulic Systems explains the working poppet check valve with mathematical relations having variables like pressure, area, spring force, friction, etc. evaluation of like spring force, friction, Pressure Rating, Regulation Range, Pressure Drop across the Valve, Temperature Rating, Valve Materials, Seals/Clearances, Leakage and Failure Modes. [5]

K.L. McElhaney shows the analysis of check valve performance characteristics based on valve design. It also tells that the performance of check valve depends on the check valve type and operating conditions. [6] S-LOK Tube Fittings journal and Parker Instrument Tube Fitting Installation Manual talks about the various applications of instrumentation tube fittings and their reliability and advantages over traditional method of pipe fittings. [7][8] DeZuric's APCO Check Valve Guide, Martin Lohse via Check Valves also proposed the characteristics of ideal check valve with reference of parameters like coefficient of valve, flow sensitivity, flow path, line size, open position, pressure drop etc. and it also talks about different types of check. [9][10]

Fevisa Check Valves explains about the different materials used for manufacturing check valves. Parker Hannifin Corporation Check Valve catalogue shows the performance curve of check valve i.e. Pressure vs. Flow parameters. [11][12] Val-Matic Design and Selection Criteria of Check Valve overviews the design considerations of various types of check valves. [13] Val-Matic Dynamic Characteristics of Check Valve talks about parameters like wave velocity, reverse velocity, pressure. It also talks about testing circuit of check valve. Flowserve Edward Valves explains application, installation, check valve flow performance, sizing of check valve. [14][15]

K.G. Sarvanan, N. M. Raju, in there paper Structural analysis of check valve, shows static structural analysis of swing check valve. [16] S. S. Thakar, M. L. Thorat, Tansen Chaudhari, briefly reviews check valve with some design considerations. [17]

III Important Design Considerations

Designing check valves depends upon so many factors which are analysed to get design inputs for the check valves. These factors are listed below,

Flow Medium:

For the various types of fluids like fibrous, highly erosive, solid particle suspended, etc. different types of check valves can be used.

Flow Regulation:

Flow rate and velocity closely relates with the pressure drop. Increased flow rate or velocity may leads to lowering C_v of valve.

Sealing ability:

In general, there are two types of sealing materials - resilient or soft seat seals and metal-to-metal seat seals.

Line Pressure vs. Valve Pressure Drop:

The valve pressure is subjected to full line pressure (upstream pressure) whereas the pressure drop ΔP is difference between the valve upstream and pressure exists that just downstream. Both pressure are equally important when selecting check valve. The line pressure determines the valve body rating whereas pressure drop determines valve trim or seat rating.

Materials of Construction:

Selection of variety of materials of construction is generally based on their corrosion resistance to the line medium. Both metallic and non-metallic components must be considered. Concentration of material in fluid is very important. Most chemicals are easier to handle in dilute concentration. Temperature is an important factor in choice of materials because high temperature increase corrosion.

IV Design of Components

The check valve is a simple piece of instrumentation device, these are designed according to ASME standards, Section VIII Division 1.

By considering higher safety factor, we can do away with secondary bending stress. For check valve application thick wall pressure vessel is considered.

Material Properties of Check Valve:

Material of the valve body: A276SS316

Tensile strength (S_{ut}) = 550-1140 N/mm^2

Yield Strength (S_{yt}) = 220-820 N/mm^2

Poison's ratio (υ) = 0.30

Young's modulus (E) = 1.90×10^6 N/mm^2

Body:

Body is the outermost part of the valve. Body has internal threads which are similar to the threaded end coupling.

As per the ASME B16 [9] Table A-1, The minimum diameter of 1/4" valve is 8.45 mm, let's consider 9 mm. The wall thickness according to ASME B16.34 is

$$tm = 0.0677*ID + 2.54$$

$$tm = 0.0677*9 + 2.54$$

$tm = 3.08$ mm

$Ts = tm + CA$

CA is corrosion allowance, 2 mm per side,

$Ts = 7$mm

The body also have internal threads, for check valve application ISO metric threads are preferred.

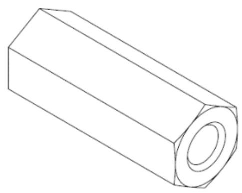

Fig. 3 Threaded End Coupling of the Check Valve

Spring:

A spring is a flexible elastic element used to exert a force or a torque and, at the same time, to store the energy. In other words we may say that the resilient member of valve. In check valve spring ensures the contact between poppet and 'O' ring when there is back flow.

The Indian Standard has recommended much higher value of permissible shear stress.

i.e. $\tau = 0.5\ S_{ut}$

Therefore,

$\tau = 0.5\ S_{ut}$

$\tau = 0.5 \times 880$

$= 440$ MPa

The Shear Stress in the spring can be given as,

$$\tau = K\,\frac{8\,PD}{\pi(d*d*d)}$$

But we have, $(D/d) = C$

$$\tau = K\,\frac{8\,PC}{\pi(d*d)}$$

Considering the suitable Wahl factor (Between 8-14 for valves),

D_o= Outer diameter of coil = 8.6 mm

D_i= Outer diameter of coil = 8.0 mm

D = Wire diameter of spring = 0.61 mm

For the deflection of spring,

$$\delta = \frac{8 \times P \times (D*D*D) \times N}{G \times (d*d*d*d)}$$

$\delta = 23.175$ mm

Solid Length of the coil can be given using,

$N_s = N \times d$

$N_s = 8.54$ mm

Compressed length of coil can be given using,

$N_c = (N - 1) \times$(Gap between adjacent coils)

$N_c = 7.5$ mm

Free length of coil can be given using,

N_f = Compressed length (N_c) + Deflection of spring (δ)

$N_f \cong 30$ mm

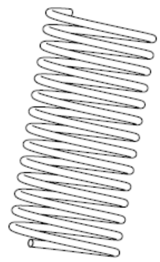

Fig. 4 Spring of the Check Valve

Poppet:

A poppet is a valve component which covers an integral passage and is held in a space by a material flow pressure and spring. Poppet also ensures closed crossover and less wear of internal seal.

For the blank diameter,

D_b = Outer diameter of spring + clearance (0.1- 1 mm)

$D_b = 9$ mm

Diameter for the holding or locking of plain end spring,

D_l = Inner diameter of spring – Clearance (0.1- 1 mm)

$D_l = 7$ mm

The poppet should have sufficient opening for the material to flow through the poppet, Consider the four holes equally spaced at the surface between D_l and D_t . The diameter of the hole should be selected such as there should not be any large change in pressure and velocity of the flow, Therefore considering diameter of the holes as 2.5 mm

N = 4

D_h = 2.5 mm

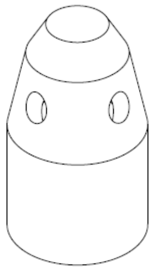

Fig. 5 Poppet of the Check Valve with a circular holes on surface

Threaded End Coupling:

Threaded couplings are self-locking and it also provides protection against overloads. Threaded couplings have small overall dimensions which leads to compact design. The material used for thread are same as poppet. And ISO Metric Thread Designation of M16×1.5.

d = Major diameter of threads = 16 mm

d_p = Pitch diameter of threads = 15.026mm

p = pitch of threads = 1.5

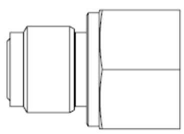

Fig. 6 Threaded End Coupling of the Check Valve

'O' Ring:

'O' Ring is the non-metal ring which forms the tight seal with the poppet. As it is metal to non-metal contact it forms resilient joints. When the inlet pressure raises above the cracking pressure the resilient seal breaks and material flows from inlet to outlet.

D_O = 9.2 mm

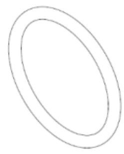

Fig. 7 'O' Ring of the Check Valve

Backup Washer:

Backup washer is placed just behind the 'O' Ring. As the contact between the poppet and 'O' ring is not precise i.e. irregular shaped and slightly oversized backup washer is used to prevent leakage. The material used for backup washer is Derlin. The backup washer should have tapered geometry.

D_O = Outer diameter of washer = 14.1 mm

D_I = Inner diameter of washer = 10.8 mm

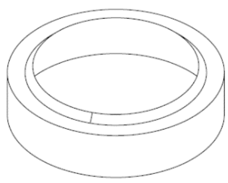

Fig. 8 Back up washer of the Check Valve

The designed check valve must work at given cracking pressure and its coefficient value/efficiency should high.

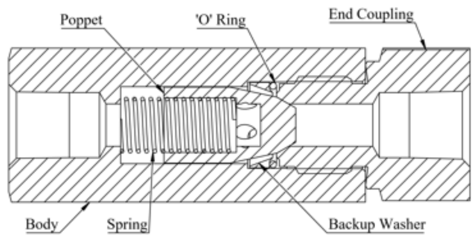

Fig. 9 Cross-Section of Assembly of Check Valve

V Conclusion

The check valves are the most important part of the instrumentation tube fittings. They have to be designed carefully to cope with precise working requirements. The paper presents the thoughts on design of the check valve which ensures the safe and precise operation of the valve. Spring plays main role in specific cracking pressure and it is also more prone to failure, due to shear by applied compression loading. The paper also comments on the rest components, body, poppet, end coupling, back up washer and ‘O’ ring, with the various design details. The Further analysis of check valve on FEA shows whether it is safe or not. If valve sustains in FEA then we may lead to optimization and if it’s not safe then we must redesign the valve. The paper also explains the various detailed operation, function and applications of check valve with the design considerations and various materials used for the check valves.

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