

Design and Analysis of the Instrumentation Check Valve

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ABSTRACT: The objective of this paper is to study function, working, design and analysis of the check valve. In the present technological advancement, check valves are used for variety of applications. 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. This kind of function is essential for a variety of safety instruments. The check valve has been designed according to ASME standards. The check valve consists of merely six parts which are spring, poppet, body, end coupling, 'O' ring and backup washer. The experimentation has been carried out for cracking pressure, coefficient of valve and equivalent stress and these values are compared with theoretical values and testing results. The valve shows cracking pressure of 0.03-0.045 MPa, coefficient of valve (C_v) 0.652, and equivalent stress 418.736. The results shows values within permissible limits, which ensures safe and sustainable operation.

KEYWORDS: check valve, reverse flow, overflow, ASME, cracking pressure, coefficient of valve (C_v)

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. 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.

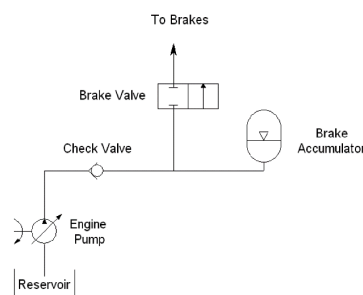


Fig. 1 Application of Check Valve in Emergency Braking

1.1 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

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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.

1.2 Working of Check Valve:

If $P_1A_1 > P_2A_2 + \text{spring force} + \text{friction}$, then the seal breaks and poppet pushed towards left and flow occurs, i.e. check valve opens. But if $P_1A_1 < P_2A_2 + \text{spring force} + \text{friction}$, 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. Check valves commonly use a poppet and light spring to control flow as shown in the fig 2.

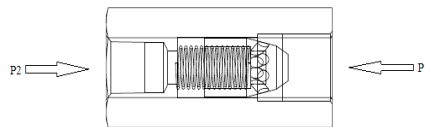


Fig.2 Working Mechanism of Check Valve

II. RELATED WORK

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. McElhanev 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.

K.G. Sarvanan, N. M. Raju, in their paper Structural analysis of check valve, shows static structural analysis of swing check valve. [14] S. S. Thakar, M. L. Thorat, Tansen Chaudhari, briefly reviews check valve with some design considerations. [15]

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,

3.1 Flow Medium

3.2 Flow Regulation

3.3 Sealing ability

3.4 Line Pressure vs. Valve Pressure Drop

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IV. CALCULATIONS FOR DESIGN OF VARIOUS COMPONENTS OF CHECK VALVE

The check valve is a simple piece of instrumentation device, these are designed according to ASME standards, Section VIII Division 1 for the pressure of 280 Kg/cm² i.e. pressure class of 300. The modelling of the check valves are done with the help of standard formulae according to ASME and the solid modelling of the same is done in Solidworks 2014 x 64 Edition.

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

4.1 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

$$t_m = 0.0677 \cdot ID + 2.54$$

$$t_m = 0.0677 \cdot 9 + 2.54$$

$$t_m = 3.08 \text{ mm}$$

$$T_s = t_m + C_A,$$

C_A is corrosion allowance, 2 mm per side,

$$T_s = 7 \text{ mm}$$

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

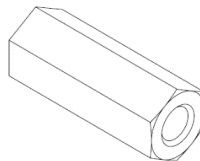


Fig. 3 Threaded End Coupling of the Check Valve

4.2 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.

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

$$\tau = 0.5 \times 880 = 440 \text{ MPa}$$

The Shear Stress in the spring can be given as,

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

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

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

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,

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

$$\delta = 23.175 \text{ mm}$$

Solid Length of the coil can be given using,

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$$N_s = N \times d$$

$$N_s = 8.54 \text{ mm}$$



Fig. 4 Spring of the Check Valve

4.3 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,

$$D_b = \text{Outer diameter of spring} + \text{clearance (0.1- 1 mm)}$$

$$D_b = 9 \text{ mm}$$

Diameter for the holding or locking of plain end spring,

$$D_i = \text{Inner diameter of spring} - \text{Clearance (0.1- 1 mm)}$$

$$D_i = 7 \text{ mm}$$

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

$$N = 4$$

$$D_h = 2.5 \text{ mm}$$



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

4.4 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.

$$d = \text{Major diameter of threads} = 16 \text{ mm}$$

$$d_p = \text{Pitch diameter of threads} = 15.026 \text{ mm}$$

$$p = \text{pitch of threads} = 1.5$$

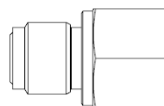


Fig. 6 Threaded End Coupling of the Check Valve

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4.5 '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.

$$D_o = 9.2 \text{ mm}$$



Fig. 7 'O' Ring of the Check Valve

4.6 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 Delrin. The backup washer should have tapered geometry.

$$D_o = \text{Outer diameter of washer} = 14.1 \text{ mm}$$

$$D_i = \text{Inner diameter of washer} = 10.8 \text{ mm}$$

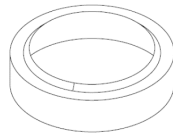


Fig. 8 Back up washer of the Check Valve

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

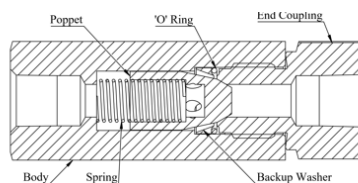


Fig. 9 Cross-Section of Assembly of Check Valve

V. EXPERIMENTATION AND VALIDATION OF MODEL

The vital parameters of the check are the cracking pressure and the coefficient of valve, so the experimentation are carried out to check these parameters. Further with the help of finite element method (FEM), the behaviour of the entire model is observed with the help of various simulations and boundary conditions.

5.1 Cracking Pressure

Cracking pressure of the check valve is the pressure at which a component starts to open. When the cracking pressure is reached the check valve will open. When the pressure drops below the cracking pressure and/or back pressure occurs the valve closes.

Force required to fully close is the product of initial displacement and spring constant.

$$F_{\text{valve closed}} = K \times S_{\text{initial}} = 25.60 \text{ N}$$

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Now we can calculate the cracking pressure knowing the cracking force,

$$P_{\text{cracking}} A_{\text{poppet}} = 25.60 \text{ N}$$

$$P_{\text{cracking}} (5.12 \text{ mm}^2) = 25.6 \text{ N}$$

$$P_{\text{cracking}} = 0.46 \text{ MPa}$$

5.2 Coefficient of Valve (C_v)

The flow coefficient of a device is a relative measure of its efficiency at allowing fluid flow. It describes the relationship between the pressure drop across an orifice, valve or other assembly and the corresponding flow rate.

$$C_v = \frac{1.16 q_v}{F_p \sqrt{\Delta p} / p_r}$$

By calculating,

$$C_v = 0.783$$

5.3 Finite Element Analysis (FEA)

Finite element analysis (FEA) is a numerical method that models a region by dividing it into small discrete elements composed of interconnecting nodes. Finite element analysis obtains the solution to the model by determining the behaviour of each element separately, then combining the individual effects to predict the behaviour of the entire model.

5.3.1 Model Geometry

In Fig. 10, Finite element analysis used with 3-D models as these models generally offers a more accurate analysis because they include all three planes of the physical work. A 3-D model is also composed of a great deal more nodes and elements as well, drastically increasing solution time. In this work, the 3D model of the check valve has been created using Solidworks 2014.

5.3.2 Pre-processing

IN Fig. 11, FEA package ANSYS 16.0 is used in this analysis. Meshing has been done by using the method of hex-dominant mesh. These types of mesh control create a free hex dominant mesh. It is useful for meshing bodies that cannot be swept. It is highly recommended for meshing bodies with large interior volumes.

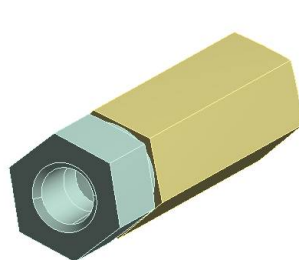


Fig 10 Geometry of valve

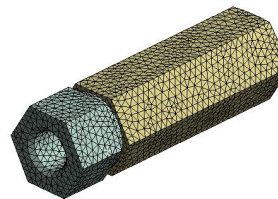


Fig 11 Meshed geometry of valve

5.3.3 Boundary Conditions

In Fig. 12, the check valve is fixed on both the side as shown in Figure, because the valve flanges are fastened with the pipe flanges. Thus all the degrees of freedom of the valve housing are arrested. Normally during working condition, the maximum allowable working pressure is 32.7 MPa, room temperature.

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5.3.4 Result

After applying the boundary conditions, the structural analysis is carried out. The results of analysis are shown in below figure Fig. 13 and Fig. 14.

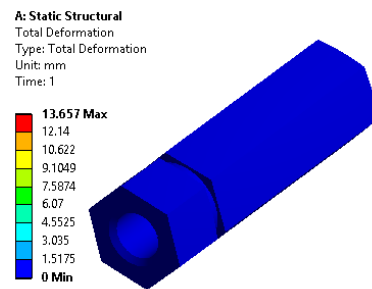
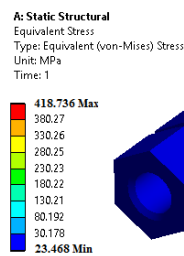
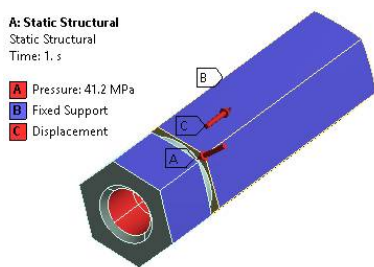


Fig 12 Boundary conditions in valve

Fig 13 equivalent stress in valve

Fig 14 Total deformation of valve

VI. TESTING OF THE CHECK VALVE FOR VARIOUS PARAMETERS AND LEAKAGE ON TEST RIG

As the analysis of the check valve yields the results on safer side, the check valve is fabricated according to the model and material. The check valve is tested on the test rig for the below parameters,

6.1 Cracking pressure

By attaching valve to the pneumatic cylinder carrying nitrogen, the first bubble passes at the pressure of 0.03-0.045 MPa



Fig 16 Test rig of check valve

6.2 Coefficient of Valve (C_v)

By following the above procedure for the known time, at fully open position valve the and calculating various parameters associated to coefficient of valve, it gives C_v of valve as 0.652

6.3 Hydrostatic body testing

In this testing the body the valve attached to the test rig, and the pressure 420 Kg/cm² exerted through the inlet and it's trapped in the body and for the 1 minute, testing is carried out for the leakages and the failures.

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6.4 Hydrostatic seat testing

This method is similar as the hydrostatic body testing, instead of the body the seat is exposed to the pressure of 280 Kg/cm².

VII. RESULTS AND DISCUSSION

As per the ASME B16.34 calculated wall thickness is 7mm i.e. internal diameter of valve is 15.026mm and external diameter of valve is 22 mm with M16×1.5 threads.

By experimenting on FEM design is safe and withstand the maximum hydrostatic test pressure for body of 420 Kg/cm² and seat of 280 Kg/cm² efficiently. The wall thickness of 7 mm is an optimized value per the standards and the theoretical calculations as well as structural analysis. The check valve is safe with the high degree of structural stability. The cracking pressure of the valve is 0.03-0.045 MPa i.e. the valve will open between this pressures with coefficient of 0.652.

Table No. 1 Comparison of results

Sr. No.	Parameter	Theoretical Value	Experimental Value	Error (%)
1	Cracking Pressure (MPa)	0.046	0.03-0.045	13.04
2	Coefficient of Valve (C _v)	0.783	0.652	16.73
3	Equivalent Stress (MPa)	469	418.736	10.71

VIII. 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 explains the various detailed operation, function and applications of check 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 and coefficient of valve by testing are 0.035-0.045 MPa and 0.652 respectively, which are very close to the theoretical values. The analysis of check valve on FEA shows that it is safe with the equivalent stress of 418.736 MPa and deformation of 13 mm. 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 check valves.

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