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Modified design for the poppet in check valves

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Analysis and modelling

ABSTRACT

Purpose: of this paper: The check valve, which is composed of sleeve, connector and poppet, is the one direction valve that blocks fluid flow. The sleeve and connector are constrained and fixed. But the position of the poppet is swiftly moved by the direction of the fluid pressure. In this check valve, water hammer is applied to the poppet by rapid pressure change. Impact of the water is a reason why the fracture of the poppet is occurred. Using computational fluid dynamics (CFD) and finite element method (FEM), the design of the poppet was verified and modified to avoid the fracture. The diameter of the flow path in the poppet decreased from 6.0 mm to 5.0mm. By CFD, differential pressure of the modified design was compared with differential pressure of the initial design. So, safety for the structure of the poppet was analyzed and verified using available commercial software MSC.MARC. Based on the numerical results, differential pressure increased about 8.7 %. However, Von Mises stress of the old poppet with 6.0 mm was two times that of the new poppet. It is verified and disclosed from the experiment results that the newly modified poppet had no problem being used in a practical product.
Design/methodology/approach: In this paper, pressure loss was calculated by CFD. As such, safety for the structure of the poppet was analyzed and verified using available commercial software MSC.MARC
Findings: Safety and pressure loss of the modified design are obtained from CFD and FEM.
Research limitations/implications: CFD is very complicated in regards to boundary and surface condition of the wall such as surface roughness. Therefore, calculated results using CFD are definitely verified by practical experimentation.
Practical implications: When the design is modified, the number and expense of the experiment is reduced.
Originality/value: The new design for the poppet was analyzed and modified by CFD and FEM. So the modified poppet was verified through the real experiment and is available in a practical product.
Keywords: Computational mechanics; Computational Fluid Dynamics (CFD); Finite Element Method (FEM); Water hammer

1. Introduction

The direction of the fluid flow is defined by the position of the poppet in the check valve, which is composed of sleeve, connector and poppet. The position of the poppet is swiftly moved by the direction of the pressure according to the fluid flow. Such swiftly changing direction of the pressure affects water hammer to the poppet. Pressure by water hammer conveys greater impact to the poppet than static pressure. The fracture occurred to the poppet by water hammer [1-7].

In this paper, design of the poppet is modified for avoiding the fracture. Having the poppet in the check valve allows the valve to come into play like an orifice or venture tube.

There is a differential area in the flow path. In this part, the pressure is changeable [1-3]. Pressure change is the main cause of pressure loss. Therefore, two factors were taken into consideration during design of the poppet. First, safety for the structure of the poppet was checked. If the flow path diameter changes in the poppet, the flow path diameter, which connects with the flow path of the valve exterior, will also change. Therefore, the flow path diameter is selected as one of the design variables.

The flow path diameter of the present poppet is 6.0mm. At first, using CFD, the state of the present poppet was analyzed [3, 4]. Then the newly designed poppet, having a value of 5.0mm for the flow path diameter, was analyzed and compared with the present poppet.

Pressure loss and minor loss were then compared. Because the check valve plays the role of deciding the direction of the fluid flow, pressure loss and minor loss is minimized. Therefore, the loss of the newly designed poppet was confirmed. If the loss of the newly designed poppet is within the permissible level of loss, safety for the structure of the newly designed poppet that considers water hammer is analyzed. The result of the analysis is expressed by Von Mises criteria. Von Mises stress that occurred to the poppet is compared with safety stress [8-15].

Normally, the safety factor is 2. However, 4 is used when repetitive impact is applied. Figure 1 shows the fracture that occurred to the poppet during the practical experiment.

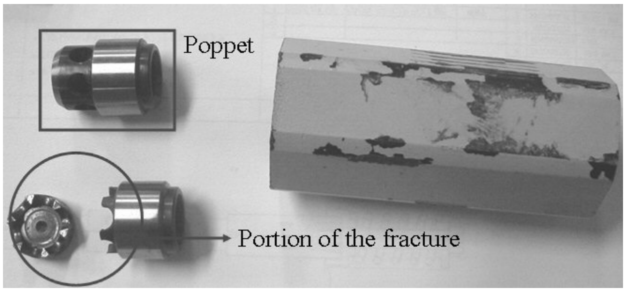

Fig. 1. The poppet and portion of the fracture

2. Loss of the valve

2.1. Pressure loss in valve

Bernoulli's equation about incompressible fluid is expressed by Equation (1). The equation is composed of driving head, potential energy, major loss, minor loss and pressure loss. Each loss is called to head of which dimension is equal to length. Major loss is the equation which is expressed by friction coefficient and diameter of the tube. It is the energy loss generated with the viscosity of the fluid and roughness of the pipeline, etc. Equation (2) is minor loss. Minor loss is energy loss by connected tube or changing direction (elbow, tee and returns etc.). K_m is minor loss coefficient which is achieved by the experiment.

$$H_p + Z_2 - Z_1 + \frac{P_2 - P_1}{\rho g} + \frac{V_2^2 - V_1^2}{2g} = h_f + h_m \tag{1}$$

$$h_m = K_m \frac{V^2}{2g} \tag{2}$$

2.2. Von Mises Criterion

When various loads acted on structure, the strain energy occured in an arbitrary portion of the structure. When the distortion component of the strain energy equals the fracture distortion energy, fracture occured to the structure. This criterion assumes that the strain energy component, which is caused by volume change, does not affect the fracture by yielding of the material. In the experiment, homogeneous material was able to endure very high hydrostatic stress without yielding. This yield criteria is defined by Equation (3).

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2Y^2 \tag{3}$$

3. Modelling for CFD and FEM

3.1. Preparing for CFD and FEM

The fluid part of the valve needs to be modelled for CFD. There are two models. One has a 6.0mm diameter of the flow path in the poppet, the other has 5.0mm. The model of the newly modified poppet has a node of 121404. The other has a node of 120617. The numbers of elements of each model are 669513 and 666171.

Figures 2 and 3 show the boundary condition for CFD and FEM. Properties for numerical analysis are indicated in Table 1.

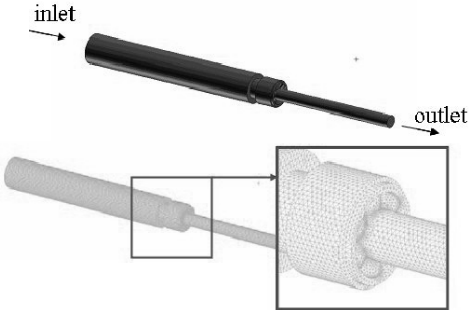

Fig. 2. Model and mesh for CFD

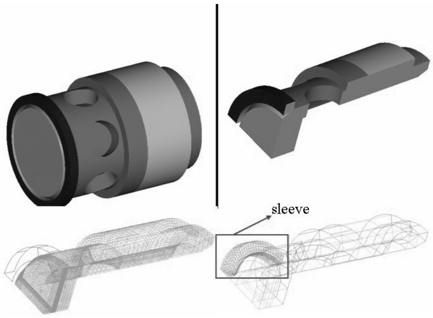

Fig. 3. Model and mesh for FEM

Table. 1 Property for CFD and FEM

Properties of the oil		Mechanical properties		
ρ (kg/m^3)	c (m/sec)	E (GPa)	σ_U (MPa)	Poisson's ratio
850	1270	205	1572	0.29

3.2. Water hammer

If the valve that is in outlet of the pipeline to be filled with fluid is closed swiftly, kinetic energy of the fluid is turned into potential energy when fluid flow is rapidly reduced. Such changing energy gets for elastic wave reciprocate inner pipeline. Also, when closed valve is opened swiftly, the same phenomenon occurs. At this time, water hammer occurred which was bigger than static pressure.

The fluid near the valve which is rapidly opened or closed is stopped in the early stages, and a pressure wave reverses to the fluid source.

$$c = \left(\frac{\beta_e}{\rho}\right)^2 \tag{4}$$

β_e is the effective bulk modulus of the fluid. When the pressure wave arrives at the end of a pipeline, the kinetic energy by flow is saved in the elastic domain of a pipeline at potential energy. At the same time, the pressure of the compressed fluid (P_{IC}) has maximum value. Therefore, the kinetic energy of the fluid in the moment that a valve is closed is as in the following Equation (5). A is the area of the pipeline and v_0 is initial velocity of the fluid. Equation (6) is the potential energy which is saved in compress wave.

$$KE = \frac{1}{2} M_f v_0^2 = \frac{1}{2} \rho L A v_0^2 \tag{5}$$

$$PE = \frac{1}{2} \frac{LA}{\beta_e} P_{IC}^2 \tag{6}$$

$$P_{IC} = \rho\, c\, v_0 \tag{7}$$

$$T \le T_C = \frac{2L}{c} \tag{8}$$

P_{IC} is the pressure that is increased by imprimis of the valve, expressed by Equation (7). P_{IC} is suitable when the return time of the pressure wave is shorter than the valve charge time which is expressed in Equation (8). P_{IC} is a safety value that is a basis for design of the pipeline. Table 2 shows the properties of the driving oil that are used.

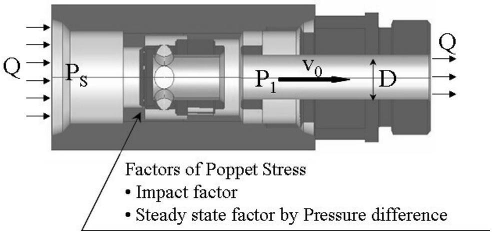

Fig. 4. Fluid flow in the check valve

Table 2. Initial pressures by water hammer

Properties of the oil		Valve		Properties of the fluid flow		
ρ (kg/m^3)	C (m/s)	D (mm)	A (m^2)	Q (l/min)	V_0 (m/s)	P_{IC} (Pa)
850	1270	12	1.1e-4	280	41.3	4.5e+7

4. Results of CFD and FEM

4.1. Results of the CFD

Distribution of the velocity and pressure, which are the results by CFD, are presented in Figure 4, 5 and table 3. Comparing the loss of the diameter with a value of 5.0mm and 6.0mm, loss of the 6.0mm diameter is smaller than 5.0mm. It means that the efficiency of the poppet with 6.0mm diameter is higher than 5.0mm. It is caused because the changing area and velocity in the 6.0mm diameter is small. differetial pressure increased by about 3MPa.

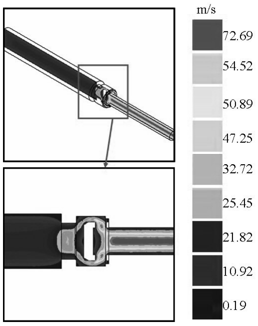

Fig. 5. Distribution of the Velocity

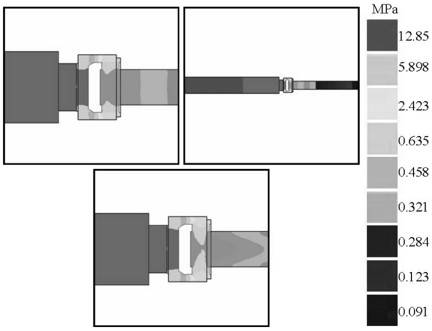

Fig. 6. Distribution of the pressure

Table 3. Comparing result between 5mm and 6mm

D (mm)	5.0	6.0
ΔP^S (MPa)	37.1	34.1
h_m	3.72e+3	3.42e+3
K_m	137.54	127.38
V_D	2.3e+1	2.29e+1
L_{eq}	2.08e+1	2.44e+1

4.2. Results of the FEM

Using FEM, safety for the structure of the poppet, which is in high pressure by water hammer, is taken into consideration.

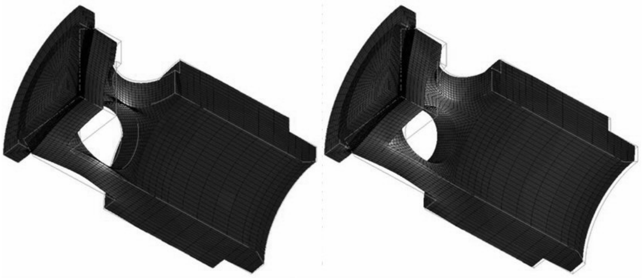

Fig. 7. Distribution of the Von Mises stress

Figure 6 indicates the stress distribution by the structure analysis. The maximum Von Mises stress by stress concentration occurred at the same portion of the figure 1.

5. Conclusions

Table 4 and 5 show the results by FEM. According to the change inner pressure, the maximum Von Mises stress that occurred in the poppet is changed. The newly modified poppet has the maximum Von Mises stress less than the other. Therefore, the newly modified poppet can ensure safety for the structure than the present poppet.

The design of the poppet in a check valve, which can control the direction of the fluid flow, considers safety of the structure and loss of the fluid flow. Furthermore, water hammer also considers safety for the structure of the poppet. Therefore, these problems are disposed by CFD and FEM. Loss of the newly modified poppet is greater than the present poppet by about 8.7%. However, the maximum Von Mises stress of the newly modified poppet is less than the present poppet. Hence, the newly designed poppet is more suitable because the water hammer is applied continuously. According to the verified results of the analysis using CFD and FEM by the experiment of the real condition, the reliability of the newly modified poppet is higher than the present poppet.

Table 4.
Result of the poppet (6.0mm)

Index	Applied Pressure (MPa)	ΔP (MPa)	Maximum Von Mises (MPa)
1	33	0.00	0
2	62.25	29.25	525.8
3	91.5	58.50	815.5
4	120.75	87.75	1099
5	1500	117.00	1383

Table 5.
Result of the poppet (5.0mm)

Index	Applied Pressure (MPa)	ΔP (MPa)	Maximum Von Mises (MPa)
1	33	0.00	0
2	62.25	29.25	277.7
3	91.5	58.50	422.5
4	120.75	87.75	586.9
5	1500	117.00	717.1

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