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Master Thesis

Influence of Particles on Ball Seat Valve Leakage

by

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2.1 Ball Seat Valve

Check valves are one of the most widely utilized piping components in industrial metal piping systems. According to the classification of kinetics, a check valve is an automatically operated valve that relies on its own weight and the pressure of the medium itself to prevent the backflow of the medium.[1]

The metallic ball seat valve used in this study is a check valve, which restricts the flow of fluid to only one particular direction. The principle of action is to rely on the weight of the ball itself and the pressure of the medium, such as fluid or gas, to produce a downward normal force on the ball so that the ball is tightly pressed against the seat to stop the flow of the medium and thus prevent the fluid from flowing in the other direction. These seat valves play an important role in hydraulic and pneumatic systems.

Only the most fundamental components of the ball seat valve that play a critical role in its sealing are going to be covered in this article. The ball seat valve, which is depicted in Fig.2.1, is made up of a ball with a radius of 20 millimeters and a seat that has an inner radius of 7.5 millimeters and a slope angle of 45 degrees. Both of these components are made of stainless steel.
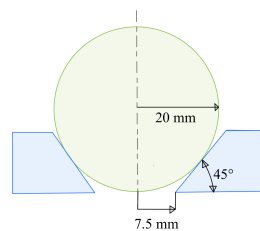

Figure 2.1: Sketch of ball seat valve.

2.2 Sealing and Leakage

The sealing performance of a valve is the ability of the valve's sealing component to prevent the leakage of medium. In order to control the flow of the fluids through a pipeline, valves must be installed, and the pipeline must be sealed to prevent leakage of the fluids it conveys. In the industrial manufacturing process, leaks from valves can have a detrimental influence on economic costs, safety, and environment, and can lead to significant production accidents; therefore, valves must have reliable sealing performance and meet the operating conditions' requirements for leakage. Therefore, it is necessary to investigate the sealing performance and leakage of valves.

In theory, the sealing principle of a ball seat valve is that the ball and the seat, both having perfectly smooth surfaces, are pressed against each other under load, and the two contact surfaces are entirely bonded together to prevent the passage of fluid from the valve in the pipeline, thereby achieving a seal. In fact, however, it is not possible to obtain a theoretically smooth surface with modern machining technology.[2] Consequently, it is common knowledge that there is no perfectly sealed valve in the world and that fluid leakage is bound to occur when the ball and seat are not fully bonded.

The sealing of a ball seat valve is determined by a large range of different factors.[3] For example, it is influenced by the roughness of the contact surfaces. Metallic surfaces are rough on a microscopic level.It must have uneven grooves and convex peaks. Due to the surface roughness, two rough planes which are apparently at full contact have a reduced real contact area if they are investigated using a higher resolution.[4] This means that when two rough sealing surfaces come into contact with each other, their highest peaks meet and microscopic channels are formed between the valleys, resulting in a leak.

The sealing is also influenced by the applied forces and pressures on the system. When the load is increased, the two convex peaks in contact will be elastoplastically deformed to effectively increase the real contact area, thereby reducing the size of the microscopic channel. However, the space between the two corresponding valleys cannot be entirely eliminated, therefore a perfect seal is not achieved.[5] In addition, the sealing is also influenced by temperature, the viscosity of the fluid in the pipe, etc. In summary, the most important influencing factors that affect leakage can be divided into two main categories: mechanical and hydraulic. Mechanical factors include those that act directly on the sealing position through the valve. In contrast, hydraulic factors are introduced into the system by the fluid. The Table 2.1 provides an overview of the most important influential factors. [6]

Mechanical influencing factor	Hydraulic influencing factors
Contact pressure	Pressure difference
Macroscopic contact geometry	Temperature
Microscopic contact geometry	Viscosity
Material hardness	Pollution
Various material influences	Additive influences
Geometric tolerance	Pressure pulsations

Table 2.1: The most important influencing factors to valve leakage.[6]

It is impractical to discuss all the influencing factors simultaneously to analyze the leakage of the ball seat valve. By controlling variables, the purpose of this study is to investigate the effect of the type and the concentration of particles contained in the fluid on the leakage of the ball seat valve.

3 Experiment

As has already been shown, the sealing of valves is essential for the reliability of pipeline transport in hydraulic and pneumatic systems. Leakage can impact the efficiency of industrial production and contribute to the occurrence of potential dangers. Due to these factors, it is crucial to investigate leaks in metal valves.

3.1 Test Rig

Figure 3.1 depicts a developed experimental platform that was available before this study was carried out. A ball seat valve, a water tank, pipelines, an air motor, a hydraulic pump, and ball valves are its primary components. The medium passing through the pipeline consists of distilled water and various types of microscopic particles. Distilled water was chosen for two primary reasons. First, it comprises a negligible amount of particles, which has the least potential impact on the particles being analyzed and reduces the errors caused in the test results. Also, water has a smaller viscosity as compared to hydraulic oil, which is usually used in industrial applications. The smaller viscosity leads to a higher leakage, which is easier to measure. [3]
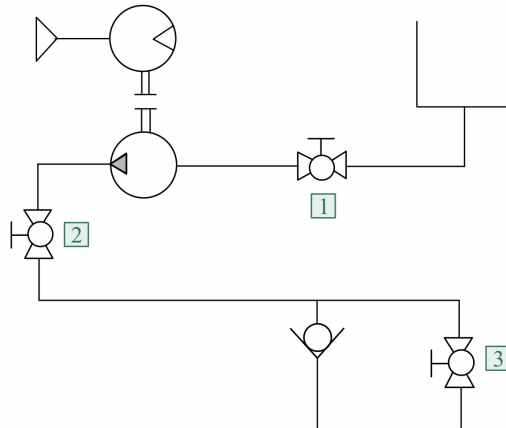

Figure 3.1: Sketch of a original available test rig.

Distilled water and particles will be mixed in a specific proportion. Through the water tank, the mixture is pumped into the pipeline, where it is transformed into a hydraulic medium and delivered on to the valve. Due to the imperfect sealing of the ball seat valve, distilled water can leak from a high-pressure environment to a low-pressure environment, i.e., to the atmosphere where the relative pressure is zero. This facilitates the detection of leaks, and the sealing of the ball seat valve can be analyzed by measuring the amount of leakage.

The initial testing platform will be upgraded in order to keep the distilled water and microscopic particles in the pipeline as uniformly mixed as feasible. As illustrated in Figure 3.1, the medium entering the pipe from the tank either leaks into the atmosphere through the valve or flows out as wastewater at the end of the experiment through the opened drain ball valve No. 3 at the pipe's end, indicating that the pipe is not a closed circuit. During the process of measuring the leakage of the ball seat valve, the No. 3 drain valve always remains closed. When the sealing of the ball seat valve is not particularly poor, the amount of leaking fluid will be small, resulting in the mixture entering the pipe only being dynamic when it is just flowing into the pipe. As the mixture fills the pipe, its state gradually becomes static, which is likely to cause tiny particles to settle downwards due to their own weight, thus accumulating in the pipe and failing to mix evenly with the distilled water, resulting in the actual concentration of particles in the mixture passing through the ball seat valve deviating too greatly from the initial set concentration added to the water tank.

The test rig was improved by connecting the end of the original pipe to the tank with a new section of pipe and a ball valve No. 4, as illustrated in Figure 3.2. With the ball valve No. 4 partially open, the entire pipe forms a closed circuit, and the mixture is able to circulate through the pipe under the action of the hydraulic pump. The microscopic particles also gain more kinetic energy, decreasing the probability of deposition in the pipe and thus increasing the degree of mixing with distilled water. Special consideration should also be given to the fact that the ball valve No. 4 should only be partially opened and not entirely opened; otherwise, it will be challenging for the hydraulic system to attain and maintain the desired pressure level.
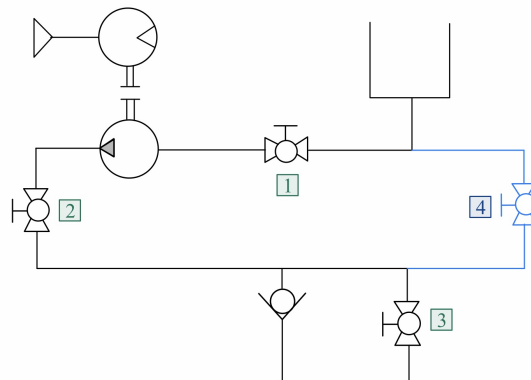

Figure 3.2: Sketch of a improved test rig.

4 Methodology

4.1 Experiment and Analysis

4.2 Experiment and Analysis

4.3 AI-based Implementation

5   Result and Conclusion

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