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Master Thesis

Influence of Particles on Ball Seat Valve Leakage

by

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Aachen, February 5, 2023

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2 State of the Art

By definition, valves are mechanical devices specifically designed to direct, start, stop, mix, or regulate the flow,pressure,or temperature of a process fluid. Valves can be designed to handle either liquid or gas applications [1].

Its seals can be classified as static or dynamic seals. The surfaces in contact with a seal determine what type to use. Static seals are usually used when there is no relative motion between mating surfaces. Dynamic seals are the opposite. They are used when there is motion between surfaces. This can be either reciprocating or oscillating motions [2].

Metallic seals and polymer seals are two different types of seals. Metallic seals are typically made from metals such as stainless steel, brass, bronze, and others. They are commonly used in high-pressure and high-temperature applications due to their durability, strength, and resistance to wear and corrosion. Polymer seals are made from materials such as elastomers, thermoplastics, and composites. They are lighter, more flexible, and often less expensive than metallic seals. Polymer seals are commonly used in low-pressure and low-temperature applications and are ideal for applications where high flexibility and conformability are required.

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 [3].

The metallic ball seat valve used in this study is a check valve, which restricts the flow of fluid to only one particular direction. Normally, a spring is used to provide a normal force to the ball, but in this case, it is the weight of the ball itself and the pressure of the fluid or gas that exert a downward 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 importantrole in hydraulic and pneumatic systems, for example, as pressure relief valves.

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 [4]. 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 [5]. 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 [6]. 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 [7]. In addition, the sealing is also influenced by 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. Table 2.1 provides an overview of the most important influential factors [8].

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

Table 2.1: The most important influencing factors to valve leakage [8].

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 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. According to a search of the scholarly literature, there are limited discussions of the effect of particles in fluids and their concentration on the seal ability of metal valves. For the investigation of these factors' effects on the sealing of metal valves, the improvement of the test rig and the reasonable assessment of leakage under varying experimental settings are therefore imperative.

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.

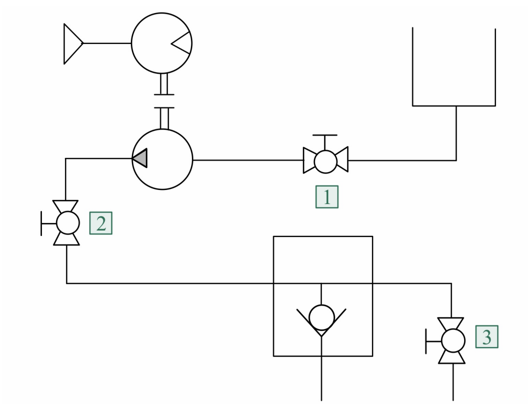

Figure 3.1: Sketch of a original available test rig.

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 analyzed in the work, which is depicted in Fig.3.2, 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.

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 [5].

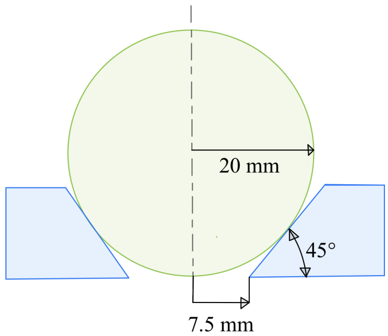

Figure 3.2: Sketch of ball seat valve.

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 pressure is defined to be 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.

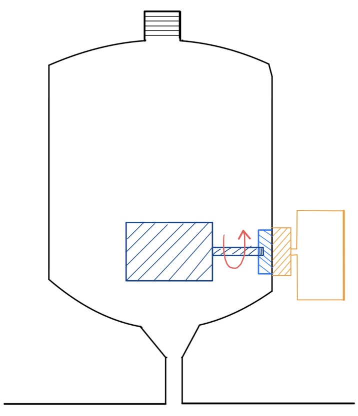

Figure 3.3: Sketch of method 1 for improving the test rig. The water tank and pipes are in black colored, the stirrer is in dark blue colored, the internal magnet is in light blue colored and the external handle with magnet is in orange colored.

To avoid the issue described above, three methods have been tried to improve the test rig. The first approach is depicted in Figure 3.3: a stirrer is placed in the water tank, and a magnet enables it to be connected to an external magnetic handle across the tank's wall. The stirrer is then rotated by turning this external handle manually, allowing the particles and distilled water to mix uniformly. However, there are two considerations with this method: first, how to place a stirrer with large enough blades inside a tank with a 31-cm-diameter entrance; and second, the manual turning of the handle is too slow to achieve homogenous mixing. Therefore this improvement is not considered.

The second approach envisaged is depicted in Figure 3.4; a small water pump is connected to the side of the tank in order to increase the energy of the mixing solution in the tank, thereby achieving a more effective mixing effect. As the existing small pump has a maximum suction pressure of only 7 m of water column, which corresponds to approximately 0.7 bar, the suction side cannot be connected to the high pressure side. So this method is also not suitable.

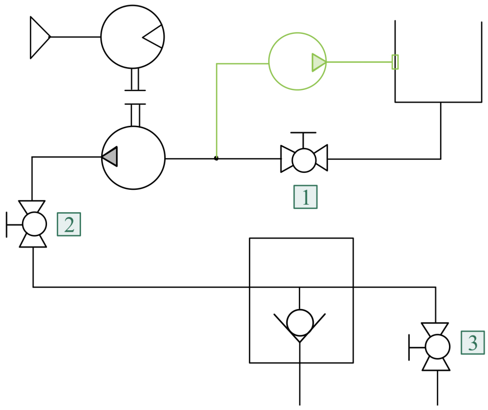

Figure 3.4: Sketch of method 2 for improving the test rig. The small added water pump and pipes are in green colored.

Finally, the test rig was improved by connecting the end of the original pipe to the tank with a new section of pipe and a new ball valve No. 4, as illustrated in Figure 3.5. 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, it looks like a resistor or orifice.

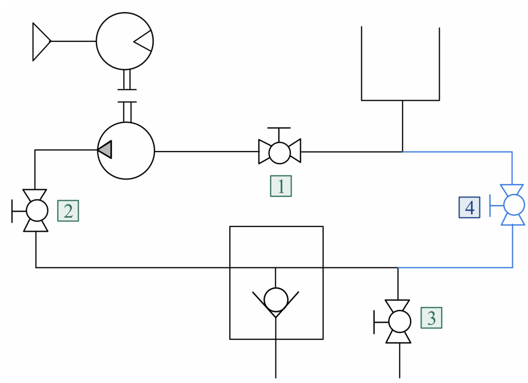

Figure 3.5: Sketch of a improved test rig.

3.2 Qualification

The purpose of this paper is to investigate the effect of the type of particles in the medium and their content on the sealing of ball seat valves. Reducing the interference of irrelevant factors in the experiment is key to obtaining accurate results. Therefore, the experimental conditions must be rationally designed. In accordance with this objective, the concentration of various particles in the mixed solution, the fluid pressure, the cleanliness of the sealing surface, and the degree of opening of the ball valve No. 4 are all subject to experimental environment restrictions.

This experiment is planned to use three particle size gradients with copper powder, molybdenum disulfide powder, and stainless steel powder as particle types. Their information is displayed in Table 3.1. It should be mentioned separately that, according to the supplier, the sieve size distribution for stainless steel powders is >250 µm: 0 %, >150 µm: 10 %, and >45 µm: 90 %; hence, 45 µm is considered the average particle size for stainless steel powders. Besides, two particle concentration levels have been designed. The low concentration is 5 grams of particles per liter of distilled water, while the high concentration is 10 grams per liter.

Powder	Average Particle Size [µm]	Concentration[g/L]	
		low	high
Molybdenum disulfide	5		
Copper	38	5	10
Stainless steel	45		

Table 3.1: Average particle size and concentration of powders.

Additionally, the fluid pressure in the experiment was set at 3 bars; however, due to the previously described issue with the ball seat valve not being entirely sealed, the pressure cannot be continuously maintained at the specified value. The hydraulic pump will begin to raise the pressure as soon as the pressure falls below 3 bars. When the set pressure value is reached, the hydraulic pump will cease pressurization, but it cannot do so immediately upon reaching this crucial point of the set pressure. Therefore, the actual pressure of the fluid is not constant at 3 bars during experiment but fluctuates around this value. System errors due to the instability of the hydraulic system can decrease the reliability of the experimental data. Therefore, in order to reduce this error, the hydraulic pump needs to be adjusted appropriately during the experiment to minimize the difference between the actual pressure and the set pressure.

Leaks occur in the microscopic channels formed by the two contact surfaces, as discussed in the section 2.2. When impurities are present on the contact surfaces, the distance between them will increase, widening the leak path and causing more leakage. To ensure the accuracy of the results, the surfaces of the ball and seat valve must be cleaned before each experiment.

The other variable that must also be managed is the degree of opening of ball valve No. 4. As discussed previously, it is also necessary to guarantee that the hydraulic system can reach and maintain the desired pressure level while establishing a circuit in the pipeline. For this reason, the ball valve No. 4 needs to be opened, but only partially. To reduce the error in the experimental results, the degree of opening should be as consistent as possible.

In addition to the rational design of the experimental settings, many methods will be employed to ensure the precision of the results. For instance, the equipment is checked for proper operation, variables is meticulously recorded, human interference is avoided, and the data is rigorously processed so that valid information can be extracted regarding the effect of particle type and concentration on the seal ability of ball seat valves.

4 Result and Discussionn

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