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Cavitation Heat Effect and Noise of Hydraulic Cone Throttle Valve

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In order to study the thermal effect and noise of cavitation in hydraulic cone type throttle valve, a cone type throttle valve cavitation experiment platform is built. With the organic glass having a better transparency as the material, the model valve was made. The pressure characteristics of five kinds of spool case cone type throttle valves were analyzed through simulation and experimental study, and the main production parts of cone type throttle valve cavitation bubble were obtained. The results show that the frequency of cone type throttle valve noise is above 8kHz. On this basis, we can determine whether the cone type throttle valve noise is the main source of noise in hydraulic system by measurement of noise spectrum. Based on the above findings, it is concluded that it is helpful for fault diagnosis of hydraulic system. The cavitation has relatively great impact on the hydraulic oil temperature flowing through the throttle valve, and its impact cannot be ignored.

1. Introduction

Cone type throttle valve, due to its large gain of flow and fast response, as well as the advantages of certain good linearity and good sealing, as the hydraulic basic element, is widely used in hydraulic master system and pilot hydraulic valve, playing the role of pressure and flow regulation (Vengosh et al., 2014). But because the flow section of throttle valve is narrowed, pressure increases and flow rate increases, it is easy to cause the pressure at the valve port drops to lower than the saturated steam pressure and produce the cavitation (Yao et al., 2014). Cavitation causes a series of effects on throttling valve performance. Due to the structural characteristics of the cone throttle valve, it will inevitably produce noise at work. The fluid noise and cavitation noise are the main noise sources of cone throttle valve (Boudet et al., 2017), and their noise level has a great influence on their performance. Cavitation is a common physical phenomenon in fluid machinery, fuel injector, ship propeller, nozzle, and underwater object (Yao et al., 2016). In the hydraulic system, cavitation usually results in a great reduction in system performance, such as the reduction of flow of the hydraulic pump, causing the vibration and noise of hydraulic pump and hydraulic valve, as well as cavitation. When the cavitation is serious, the hydraulic components will eventually fail (Jorda et al., 2015). The noise of hydraulic system can be divided into fluid noise, cavitation noise and mechanical noise (Gleason et al., 2016), the fluid noise is caused by the vibration of fluid particle, and the cavitation noise is caused by cavitation.
In that the cavitation phenomenon has many adverse effects on the hydraulic system, especially the adverse effects of the thermal characteristics after cavitation generated on the performance of hydraulic system (Musselman et al., 2016), the noise has a great influence on the performance of the cone type throttle valve. We made an in-depth study of cavitation thermal effect and noise problems of cone type throttle valve (Lester et al., 2017). It provides theoretical basis for the suppression of cavitation, the improvement of performance of the cone type throttle valve, and the reduction of the noise level of cone type throttle valve, which has very important practical significance.

2. Cavitation thermal effect of cone throttle valve

2.1 Hydraulic oil temperature during bubble expansion stage

According to the research results of cavitation problems, there is a small free gas core in oil, which is one of the necessary conditions for cavitation in oil (Stringfellow et al., 2014). In order to simplify the problem and

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combine the necessary conditions for the existence of free gas core in the oil, this paper makes the following hypothesis for the free gas core:
The bubbles remain spherical when the bubbles expand;
The wall thickness remains unchanged when the bubbles expand;
Keep the force balance after the formation of bubbles;
The gas pressure in the bubble is uniformly distributed along the radial direction;
The free gas core contains vapor and gas of the oil;
There is no chemical reaction occurring in the bubble;
The hydraulic oil cannot be compressed.
The cavitation bubble expansion and compression experience two different thermodynamic processes (Barbot, et al., 2017). This section mainly studies the effect of bubble expansion on the hydraulic oil temperature. Combined with the Rayleigh-Plesset equation and considering the hydraulic oil viscosity change and compressibility, the Rayleigh-Plesset equation was improved (Delzon and Cochard, 2014). Then we get mathematical model between the oil temperature and bubble hydraulic expansion movement:

$$R\frac{d^2R}{dt^2}+\frac{3}{2}\left(\frac{dR}{dt}\right)^2+\frac{4\times 0.0457\exp\left\{6.58\times\left[\left(1+5.1\times10^{-9}p_\infty\right)2.3\times10^{-8}\left(\frac{T_1-138}{303-138}\right)^{-1.16}-1\right]\right\}}{\dfrac{\rho_*}{1\text{-}(p_\infty-p_*)/K}R}\frac{dR}{dt}+\frac{2\sigma}{\dfrac{\rho_0}{1\text{-}(p_\infty-p_0)/K}R}=\frac{p_v-p_\infty}{\dfrac{\rho_0}{1\text{-}(p_\infty-p_0)/K}}+\frac{p_{g_0}}{\dfrac{\rho_0}{1\text{-}(p_\infty-p_0)/K}}\left(\frac{R_0}{R}\right)^{3\gamma} \quad (1)$$

In this section, numerical calculations are performed for polytropic index γ=1.1, 1.15, 1.2, 1.24, 1.25 and 1.3, respectively. Figure 1 shows the change of hydraulic oil temperature with time after cavitation occurs, where γ is 1.1. From the total analysis, it can be obtained that although the polytropic index γ is different, the variation of hydraulic oil temperature has a similar law. It can be seen from Figure 1 that with the increase of polytropic index value, the decrease trend of temperature of hydraulic oil will become more and more obvious. Theoretical analysis shows that (Peirce and Bunger, 2014), hydraulic oil in the vaporization process, because the bubble needs to overcome the surface tension of oil, it will absorb heat from the hydraulic oil, resulting in reduction of hydraulic oil temperature, which shows that the trend of hydraulic oil shown in figure is consistent with the theory.

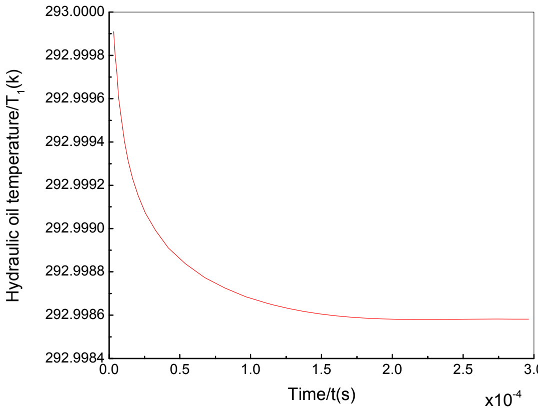

Figure 1: The change of oil temperature with time

2.2 Hydraulic oil temperature during the bubble compression stage

In this section, the hypothesis of free gas core is consistent with what described in 2.1. When the bubble is compressed, because the bubble is compressed very fast, some researchers think that this process is an adiabatic process, but this process is not completely adiabatic. According to the literature (Kassotis et al., 2014) research results, we take the polytropic index γ=1.3, and obtain the improved Rayleigh-Plesset equation:

$$
\begin{aligned}
&R\frac{\mathrm{d}^2R}{dt^2}+\frac{3}{2}\left(\frac{dR}{dt}\right)^2+\\
&\frac{4\times 0.0457\exp\left\{6.58\times\left[\left(1+5.1\times 10^{-9}\mathrm{p}_\infty\right)2.3\times 10^{-8}\left(\frac{T_1-138}{303-138}\right)^{-1.16}-1\right]\right\}}{\rho R}\frac{dR}{dt}\\
&+\frac{2\sigma}{\rho R}=\frac{\mathrm{p_v}(\mathrm{T_0})-p_\infty}{\rho}+\frac{p_{g_0}}{\rho}\left(\frac{\mathrm{R_0}}{\mathrm{R}}\right)^{3\gamma}+\frac{\mathrm{L}}{\rho\mathrm{T_1}\left[\left(p_{\mathrm{v0}}\left(\frac{\mathrm{R_0}}{\mathrm{R}}\right)^3\right)^{-1}-\rho^{-1}\right]}(T-T_0)\\
&+\frac{\mathrm{L}}{\mathrm{T_1}\left[\left(p_{\mathrm{v0}}\left(\frac{\mathrm{R_0}}{\mathrm{R}}\right)^3\right)^{-1}-\rho^{-1}\right]}\frac{2RLp_v}{\rho\lambda(2+0.6\left(\frac{2R\left|v-\mu\right|\rho c_{p1}}{\lambda}\right)^{\frac{1}{2}}\left(\frac{c_{p1}\mu}{\lambda}\right)}\frac{dR}{dt}
\end{aligned}
\tag{2}
$$

Figure 2 shows the temperature of the hydraulic oil during the bubble compression period. From Figure 2, it can be obtained that, the bubble in the initial compressed stage, the hydraulic oil temperature is slightly reduced. This is because in the initial stage of bubble compression, the hydraulic oil acts on the bubble, at the same time, the temperature in the bubble will have a greater decrease after the expansion, and the hydraulic oil needs to transfer heat to air bubbles. Thus it caused the temperature of hydraulic oil in the initial stage of bubble compression to reduce. It can also be obtained from Figure 2 that the liquid temperature around the bubble rises rapidly with the increase of the surrounding liquid pressure. That is to say, in the hydraulic system, the faster the hydraulic oil pressure recovers around the bubble, the faster the temperature of the hydraulic oil will rise.

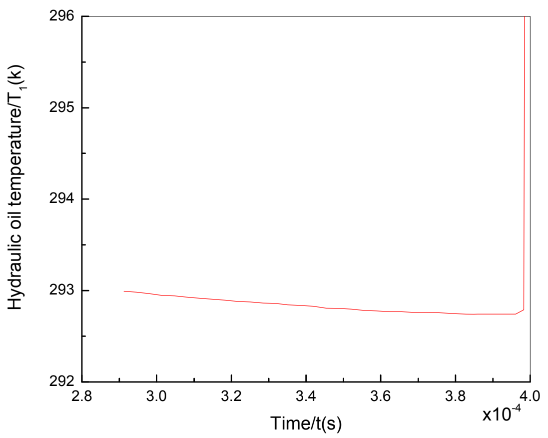

Figure 2: The change of hydraulic oil temperature during bubble compression

3. Experimental research on the noise of cone throttle valve

3.1 Research on relationship between noise and flow channel pressure distribution

The experimental principle of the relationship between noise and back pressure is shown in Figure 3:

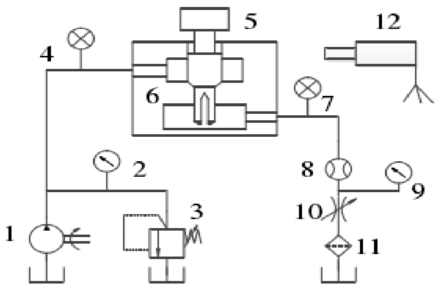

Figure 3: Schematic diagram of experimental system

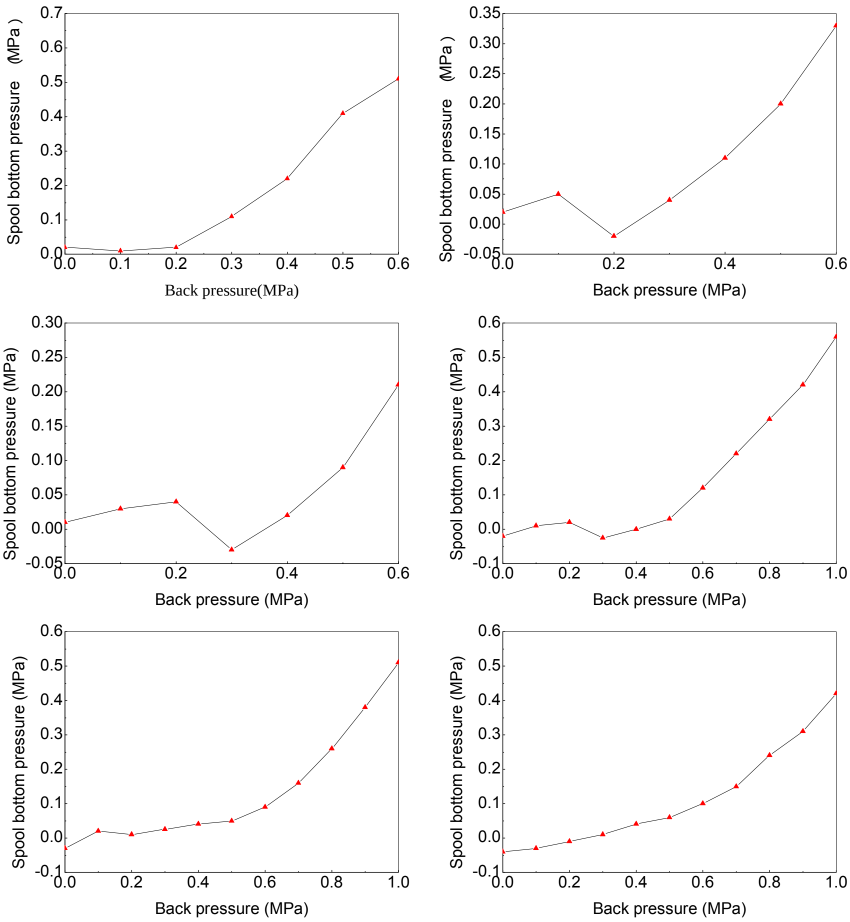

Figure 4: The change of the pressure at the bottom of valve core with back-pressure

Figure 4 shows the change of the bottom pressure of the spool with the back pressure under different system pressures. From Figure 4, we can see that, when the system pressure is between 2.5~4MPa, with the increase of the back pressure, the valve bottom pressure will have an obvious decrease. This means the system pressure of 2.5~4MPa, regulating back pressure can really make the cavitation intensity increase, and produce more bubbles. There will be more bubbles compressed until the collapse in the downstream pressure recovery, so the cavitation noise was increased (Wolfe et al., 2016). While the system pressure is 4.5MPa and 5MPa, the pressure of measuring point is always increasing with the increase of the back pressure, while the noise is increased slightly. This result may be because the pressure point is fixed, while the pressure distribution of valve port will change with the change of system pressure. The pressure measuring point is not the most severe position for cavitation generation. Based on the simulation results and the change of noise value, it can be considered that the law of the back pressure relationship is consistent with cavitation noise (Wu et al., 2017).

3.2 Noise spectrum of conical throttle valve

In subjective sense, the difference between noise and musical sound is whether the sensation is pleasant or not. But in actual physical measurement, it is necessary to analyze the spectrum of the noise and distinguish it according to its frequency composition and intensity distribution. Some scholars analyzed the spectrum of slide valve orifice cavitation noise (Anderegg et al., 2015). In this paper, the noise spectrum of the cone type throttle valve is analyzed. The noise spectrum measurement platform is the same as described in 3.1. We can know that the noise of 60 degree triangle spool in the noise of several openings takes 500~1000Hz as the frequency division. The noise lower than the frequency range of 500~1000Hz has little change, while the noise higher than the frequency range of 500~1000Hz has greater volatility. The higher the frequency is, the greater the fluctuation of noise is (Merouani et al., 2014), and especially in 8k Hz, the noise frequency fluctuation is the largest. In the meanwhile, with the increase of frequency, noise value is gradually close to the weighted noise A, C, and Z, which suggests that, under the condition of the 60 degree triangle spool, the noise is the high frequency more than 8k Hz.

In summary, the noise frequency generated by cone type throttle valve is the high frequency noise, which has obvious stimulation for the human ear and will have a very big impact on the overall performance of the cone type throttle valve. As a result, the research on how to reduce the cone type throttle valve cavitation intensity is quite necessary for the reduction of the overall noise level of cone type throttle valve. At the same time, by measuring the noise frequency of the hydraulic system, we can judge whether the noise of the hydraulic system is the main source of the noise of the hydraulic system, which is beneficial for the fault diagnosis of the hydraulic system (Çakir et al., 2015). After the fly ash is mixed with 0.9Kg/m^3 fiber, compressive strength of alkali slag concrete 7d ago is similar to that of alkali activated slag concrete mixed with fly ash, but the strength 28d later is lower than that of single mixture of fly ash. After the fly ash is mixed with 1.8Kg/m^3 fiber, 7d ago, it is lower than the strength of single fly ash, but 28d later, it is higher than that of single fly ash.

4. Conclusion

Cavitation is a typical defect for the hydraulic system, it has a variety of adverse effects on the hydraulic system, and the cavitation mechanism is quite complicated. Although it has been more than a century since the cavitation was found, there were a large number of in-depth studies on the research of cavitation. The study on cavitation mechanism has been greatly developed, but due to the complexity of the cavitation mechanism, it is necessary to make in-depth researches on cavitation. Cone type throttle valve is widely used in industry, but due to its structural characteristics, in the course of its operation, it will inevitably produce cavitation, and cavitation will have a great impact on the performance of cone type throttle valve. Therefore, taking the cone type throttle valve as the research object, we study the thermal effect of the cone type throttle valve as well as the pressure, flow and noise problems. It has very important practical significance in providing theoretical and data support for the optimization of cone type throttle valve structure.

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