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INVESTIGATION INTO PRESSURE DISTRIBUTION OF SPOOL VALVE WITH NOTCHES

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ABSTRACT

A novel test apparatus used to measure the pressure distribution of spool valve with notches has been designed, thus the mechanism of the noise differences related to the different notches can be investigated. Some small holes used to detecting pressure were arranged on a sleeve that can be shifted and rotated in preset locations. Several ways are introduced to minimize the internal leakage, which include the hydraulic force used to close the gaps between the sleeve and valve body, the large distance between the small holes and a high requirement of small clearances between the body, the spool and the sleeve. The effect of this test apparatus on the flow field inside the valve is limited to the minimum to improve the accuracy of the method proposed. The experimental results of pressure distribution are agreed well with the CFD results as a whole, particularly in diverging flow direction in notch (called 'FLOW-OUT'). In converging flow (call 'FLOW-IN'), the correspondence between the experiment and CFD results is not good as the former due to the numerical errors in CFD. The CFD and experimental results of two typical notches, the sloping notch (V-notch) and the notch with a passage of same cross-section areas (U-notch), was presented in this paper. As a result, it is revealed that the U-notch has a two-stage orifice characteristic that can be helpful to suppress the cavitation noise.

KEY WORDS

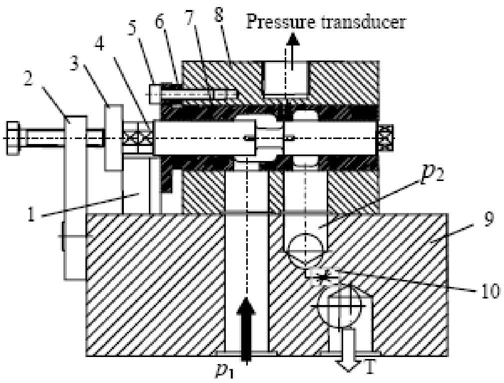
Notch, Spool valve, Pressure distribution measurement, CFD, Cavitation noise

INTRODUCTION

The notches in spool valve are one of main configurations of orifice in fluid power systems. It is widely used in spool valves to throttle flow. The notch with different geometry has different noise level in practical applications. However, there has been few works concerning the noise characteristics on the notch. Shigeru Oshima (1994-2003) used a unique half cut model of poppet valve, had studied the pressure distribution and cavitation in a poppet valve in detail. Hisanori (1994) reported the noise measurement and numerical simulation of a relief valve. These works show that the flow passage and the orifice geometry have a great effect on the valve noise. It is necessary to understand exactly the relationship between the geometry of a notch and the noise. Though the CFD approach has popularly adopted to investigate the flow in hydraulic components, papers including the pressure distribution obtained by CFD and experiment are still lack.

In this paper, for the purpose of understanding the effects of the geometry of notch on the noise characteristic in spool valve, a method and a test apparatus to measure the pressure distribution and to detect noise is proposed. The pressure distribution results of two typical notches obtained by experiment and CFD was presented.

EXPERIMENTAL APPARATUS



(a) Schematic diagram of test apparatus

(b) Picture of the test apparatus

Fig.1 The test apparatus

1.Gauge blocks for spool location, 2.Screw, 3.Measurement plate, 4.Spool, 5.Screw for sleeve location, 6.Gauge block for sleeve location, 7.sleeve, 8.valve body, 9.Manifold, 10. Backpressure valve

The apparatus to measure the pressure distribution are shown in figure 1 - figure 3. Four notchs with the same size and configuration are symmetrically placed on each spool. In figure 2, the nineteen small holes are placed on the sleeve, five of which are used to measure the wall pressure distribution between high-pressure regions and return pressure area, the others are placed on both sides of the sleeve to detect the return chamber pressure. In order to stop the leakage among the holes, the small holes are arranged in three rows with the distance between the adjacent holes fixed at 4 mm. Several ways have been introduced in the test apparatus to stop leakage, which include the hydraulic force used to close the gaps between the sleeve and valve body (see the figure 1a), a high requirement of small clearances (5 μm in radial) among the body, the spool and the sleeve.

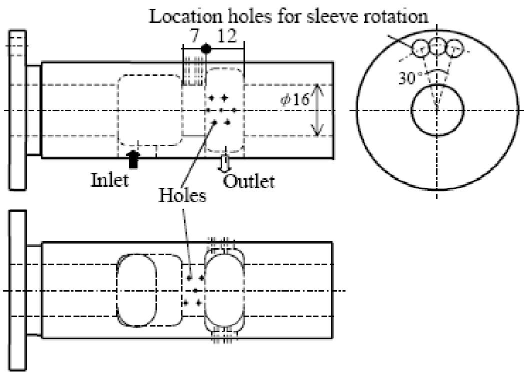


Fig.2 diagram of sleeve

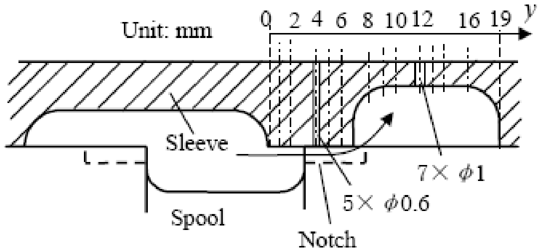


Fig.3 Holes location in axial direction for measuring pressure distribution

The sleeve is movable and rotatable which makes it able to connect each small hole with the pressure transducer. Holes to be selected to connect the transducer are determined by the thickness of the gauge blocks for sleeve location and the selection of location holes for sleeve rotation. The thickness of gauge blocks for the spool location determines the valve opening. When a point in the low-pressure area is detected, the transducer with a narrow range is selected to improve measurement accuracy. In figure 3, it is shown the holes location in spool axial direction, the distance between two adjacent holes is 1 mm or 2 mm.

Sound noise was measured using a noise spectrum analyzer with the microphone 90 mm away from the test valve body.

TYPICAL NOTCHS

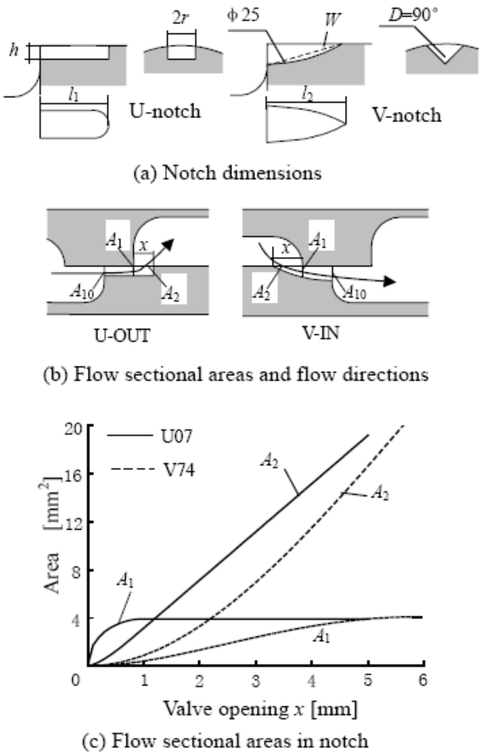


Fig. 4 notch configuration and flow areas

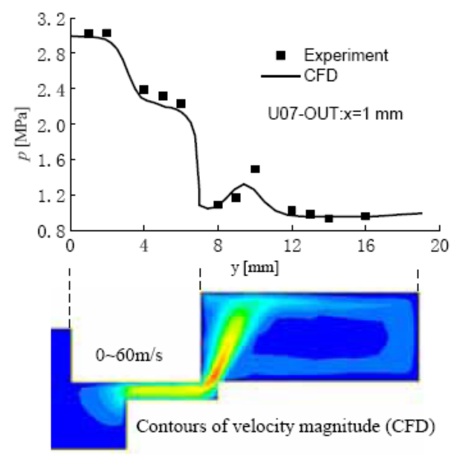
The flow areas and main dimensions of two types of typical notchs are shown in figure 4. The two types of notchs are named as U-shape and V-shape notch (simply called U and V), the numbers followed the U or V indicating the different size notchs in the paper, the followed letters IN or OUT to indicate the flow direction in the notch passage in this paper. U-notch and V-notch have typical difference in flow areas and profiles. The profile of U-notch has a passage of same cross-section area, its length being the function of the opening x. while the feature of the V-notch profile is slope along the flow direction. The actual orifice area of V-notch is determined by the flow area A1 because of the valve of A2 being larger than the A1 in all range of opening. The orifice location of the U-notch is not fixed in one position. When the opening is equal to a certain value (for example, 1.2 mm in fig.4c), the flow areas A1 and A2 of U-notch is equal, thus the two-stage orifice is formed in U-notch. When the opening is less than the certain value (1.2 mm), the actual orifice area of U-notch is determined by A2. On the other hand, when the opening is larger than this certain value, the actual orifice area is determined by A1. This change of the orifice location is called the shift of orifice location in this paper.

RESULTS OF PRESSURE DISTRIBUTION

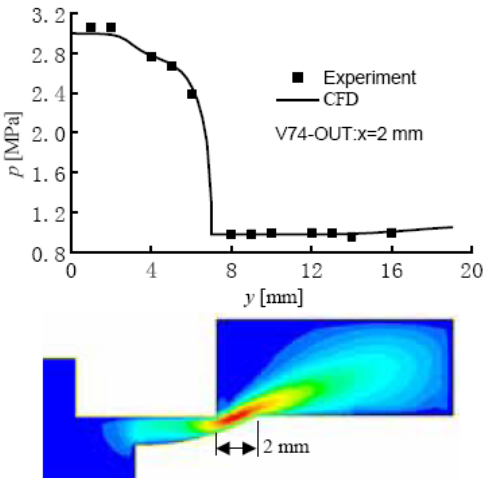
Figure 5-figure 6 show the pressure distribution of the sleeve internal surface in FLOW-OUT state and in FLOW-IN on the two typical notches described in the previous section. The results in figure 5 and figure 6 are obtained with the inlet pressure fixed at 3.0 MPa and the pressure in valve chamber at 0.98 MPa. In that condition, no cavitation occurs in the valve and the state of flow in the valve can be thought single-phase flow. Both the experimental result and the CFD result are showed in these figures with the experimental result showed in scattered dots and the CFD result in continued solid lines. The CFD results are obtained on FLUENT software adopted RNG k-ε turbulence model. The oil density ρ is 889 kg/m3,the kinetic viscosity is 4×10－5 m2/s.

Case of FLOW-OUT

Figure 5 shows the pressure distribution measured along the sleeve surface at one opening in FLOW-OUT. It is known from the figure that the CFD result agrees with the experimental result very well. The pressure drop steeply at the position of y=7 mm. Since the pressure within the notch remains considerable value, there is no cavitation occurrence in this restriction part. On the other hand, since the pressure reduction due to the flow contraction close to the valve chamber is remarkable, the minimum pressure appears at the corner between the notch and the valve chamber (around y=8 mm). Cavitations tend to occur at this low-pressure area in FLOW-OUT.



(a) U-OUT



(b) V-OUT

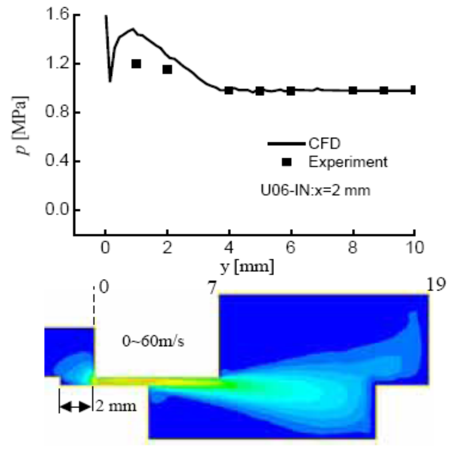
Fig.5 pressure distribution in FLOW-OUT

Figure 5a shows the pressure distribution in the opening x=1 mm of U07 model. The pressure difference drops on two positions (y=3 mm, y=7 mm) and the pressure within the notch decrease slowly because of the resistance in the notch passage with a length of same sectional area, which can be understood in Figure 4. It is revealed that the U-NOTCH has a characteristic of two-stage orifice. The curve of pressure distribution in the return chamber has one peak at the position of y=10 mm due to the impact of the high-speed flow stream to the surface of the valve chamber. As the valve opening increases, the pressure peak tends to occur in the rear of the valve chamber due to the smaller flow spray angle, and the pressure value in peak decreases due to the momentum loss caused by the longer distance between the point of spray and the valve chamber surface along the flow stream.

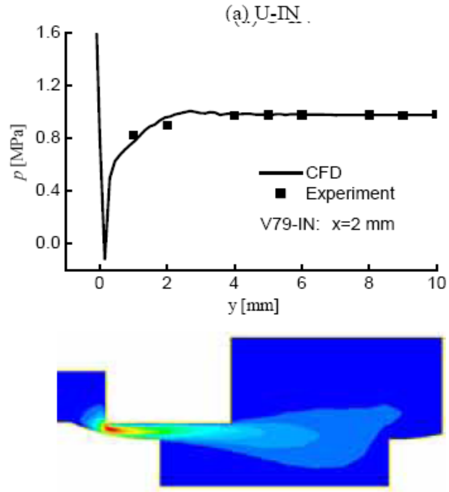
As to the notch of V74, the pressure in the notch drops gently when the valve opening is small. The pressure mainly drops to the return pressure steeply in the fixed position of y=7 mm. Compared with the U-NOTCH, the pressure in the wall of the return chamber almost keeps constant, and increases only in the rear of the chamber for the flow spray angle under different openings is small and changes little.

Case of FLOW-IN

Figure 6 shows the pressure distribution measured along the sleeve wall in FLOW-IN state. Since no small holes for detecting the pressure are arranged within the region between y=0 mm and y=1mm for the difficulty of small machining, the experimental results do not show the pressure distribution in this region. However, the pressure distribution in this region can be conceived from the CFD result. Because the flow detaches from the sleeve wall at the entrance corner, the pressure drops deeply within the region between 0 mm and 0.3 mm. After passing the detaching area, the flow is decelerated and reattaches to the sleeve wall, thus the pressure regains and approaches the pressure value near to the return chamber of the valve.



(a) U-IN



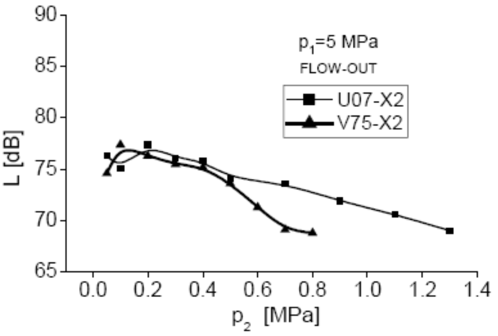
(a) V-IN

Fig.6 pressure distribution in FLOW-IN

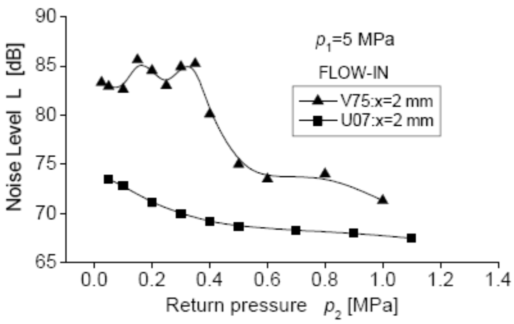
Compared the pressure distribution of U-notch with that of V-notch, the pressure at the restriction of U06 regains more quickly and more easily than that in V79. As to the notch of U06, when the valve opening is 2 mm, there exists a length of 3 mm flow passage with same sectional area behind the notch orifice to resist the flow from the notch orifice again. Thus a higher pressure at the position of y=1mm than the pressure of the next position occurs. Two factors, the flow rate from the orifice ahead and the length of passage mainly determine the resistance of the same sectional passage. In turbulence flow state, the resistance (or pressure drop) is proportional to the square of flow rate and the length of passage.

SOUND NOISE LEVELS

Figure 7 shows the change of the sound noise level with the increase of pressure in the return chamber at the inlet pressure fixed at 5 MPa and oil temperature kept in the range between 46C°and 50C°. Since the environmental noise level is comparatively low (65dB) and steady in the test environment, the measurement results of noise showed in the figures contains the environmental noise. The flow rate of the U07 and V75 in an opening of 2 mm is 15 l/min and 12.5 l/min at the return pressure p2 0.2 MPa.



(b) The noise of FLOW-OUT



(a) The noise of FLOW-IN

Fig.7 the noise level difference

In FLOW-IN shown in figure 7a, the noise characteristics between the U-notch and V-notch are remarkable difference. Compared with the V75-notch, the noise level of the U07 is much lower. When the return pressure p2 is less than 0.4 MPa, the noise level of V75 reaches 85 dB, whereas the noise level of U07 is less than 75 dB. When the return pressure is gradually increasing, the noise level of V75 decreases steeply. The noise of U07 decreases steadily. Compared with V75, the noise of U07 drops more slowly with the increase of return pressure.

The noise level In FLOW-OUT is shown in figure 7b, there is not marked difference between the noise levels of two notches. Their noise characteristics are similar and there is no high squeal noise as FLOW-IN state. When the return pressure increase beyond 0.5 MPa, the noise level of V75 is lower than that of U07 due to the flow rate of the former being lower.

CONCLUSIONS

The pressure distribution of spool valve with notches was investigated by a novel apparatus. The experimental results agree with that of CFD as a whole. Particularly, in flow direction of FLOW-OUT, the correspondence between experiment and CFD is very good. The pattern of pressure distribution in typical notches can be concluded. In FLOW-OUT state, the pressure within notches has a high value to restrain the occurrence of cavitations, and the area of low pressure lies in the return chamber due to the flow contraction. In FLOW-IN, the pressure distribution has remarked difference between the typical notches. The pressure of U-notch regains quickly, and the pressure of V-notch has a slow and long process to regain the pressure value of the return chamber.

The noise characteristics in FLOW-OUT are similar. The noise of FLOW-OUT is low and no squeal noise occurs. There exists a critical return pressure where the maximum noise level appears. When the return pressure exceeds the critical return pressure, the noise level decreases gradually with the increase of the return pressure because the location of the flow stream contraction lies near to the return chamber. As the return pressure rises, it enhances directly the pressure of the flow contraction. The occurrence of cavitations is restrained and the noise level drops down.

There are remarkable differences in noise between U-IN and V-IN. The differences are almost due to the difference of the pressure distribution determined by the notch configurations. The squeal noise appears at middle openings in V notch.

ACKNOWLEDGMENTS

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REFERENCES

1.Shigeru Oshima, Tsuneo Ichikawa. Cavitation phenomena and performance of oil hydraulic poppet valve. Bulletin of JSME, 1985, 28(244): 2264-2271.

2.Shigeru Oshima,Timo leino, Matti Linjama,etc. Effect of cavitation in water hydraulic poppet valves. International journal of fluid power, 2001, 2(3):5-13.

3.Hisanori UENO, Noise measurement and numerical simulation of oil flow in pressure control valves, JSME International Journal, series b, V.37, N.2, 1994.

4.Frank R., Siegfried H., Basic investigation of characteristics of flow and noise for oil-hydraulic valves, Proceedings of the 8th SICFP’03, May 7-9, 2003, Tampere, Finland, 565~575.