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STUDY ON LOW NOISE PRESSURE REDUCING VALVE WITH RADIAL SLIT STRUCTURE

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ABSTRACT

Pressure reducing valves are widely used to maintain the pressure of gas reservoirs to specific values. When highly pressurized air passes through the orifice structure, considerable noise occurs at the downstream side. To solve this problem, we have developed a radial slit structure. The radial slit structure reduces the noise by suppressing the generation of turbulence and shock wave at the downstream. In this paper, we newly develop a pressure reducing valve applied the concept of the slit structure. At the former slit structure, the height of the radial slit was fixed. In the new valve, we proposed an improved slit structure that the height of it is variable. Coned disk springs are installed between the disks and the height of it is controlled from 0 to 50m with a pneumatic cylinder. As a result, the new structure can successfully control the flow rate and control the pressure in a reservoir. The performance of the valve is investigated experimentally and confirmed that noise can be reduced with the radial slit structure.

KEY WORDS

Pressure control valve, Slit structure, Noise

INTRODUCTION

Pneumatic systems are widely used in industrial fields from the viewpoint of low cost and safety. Breather valves are used to maintain the pressure of gas reservoirs to specific values. In a normal valve, supply pressure is depressurized with an orifice plate. When pressurized air passes through the orifice plate, a considerable noise and pressure fluctuation occur at the downstream. Therefore, reduction of noise and pressure fluctuation originating from the valve are required.

These phenomena have been investigated both analytically and experimentally. In addition, several methods, such as the use of diffusers [1], wrapping pipe with sound-damping materials [2], changing the plug structure [3], and the use of silencers [4] have been developed to reduce noise and pressure fluctuation. However, with these methods, when the flow rate increases, the flow might become turbulent. In some cases, sonic flow occurs even when the pressure ratio is lower than 0.528. Turbulent and sonic flow can generate considerable noise and shock waves.

Therefore, the authors have proposed the slit structure that can reduce noise and pressure fluctuation. This reduces the noise by changing orifice into the slit structure.

The flow of the slit structure reduces the noise by suppressing the generation of turbulence and shock wave. In former research, it was found that the slit structure of height 0.05mm has the silencing effect more than about 40dB in comparison with the orifice [5], and the height of the slit was fixed.

In this paper, we proposed an improved slit structure that the height of it is variable by using coned disk springs. The structure of variable slit structure and the flow characteristics of the slit are investigated theoretically and experimentally. And, the effect of the noise reduction is investigated experimentally.

VARIABLE SLIT STRUCTURE

Figure 1 shows a schematic drawing of the variable slit structure. The slit structure consists of three elements, a disk, a guiding bar and coned disk springs. The upper part of Fig. 1 shows the cross section of the structure. The upper disk consists of a flow inlet and an upper surface of the radial slit. The inner diameter of upper disk is 8.5mm. The guiding bar guides the movement of the disk. Coned disk springs are installed between the disk structures and the height of them are precisely controlled.

The compressed air enters from the center of the upper disk and is exhausted outward through the radial slit. The lower part of Fig. 1 shows the top view of the lower disk. The lower disk consists of a lower surface of the radial slit and a groove for holding the disc springs. The outer diameter of upper disk is 50mm, and the depth of groove is 0.5mm.

The structure of the coned disk spring and new valve is shown in Fig. 2. The material of it is SUS304, and the spring constant is 619.5N/mm. The diameter of the coned disk spring is 8mm. The thickness is 0.3mm, and height is 0.55mm. It is located on groove of disk. The height difference of groove and coned disk spring makes the 50μm slit. The height of it is precisely controlled with a control force.

In this study, we produced a new valve which has one layer of slit. The compressed air with supply pressure enters from the center of the disks and is exhausted to atmosphere pressure through the slits. The pneumatic cylinder is set up below the disk, and the piston of it is connected with the disk. The control pressure is supplied to the cylinder, and the cylinder moves the disk. Therefore, the height of slits is controlled with the pneumatic cylinder by changing the control pressure.

ANALYSIS OF THE SLIT STRUCTURE

The height of slit is measured by a microscope.

The flow rate characteristics of the slit structure are investigated theoretically under the assumptions that the flow is laminar and passes through the slit under isothermal conditions.

The relationship between the pressure drop and the average flow velocity is given by the next equation

$$dP_r = -\frac{12\mu \bar{u}_r}{h^2}\,dr \qquad (1)$$

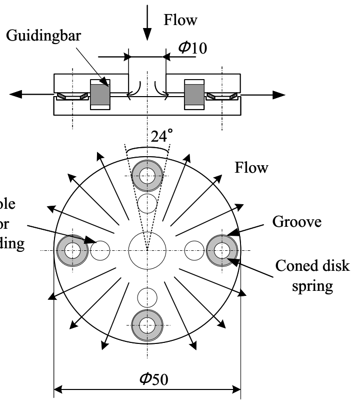

Figure 1 Schematic of variable slit structure

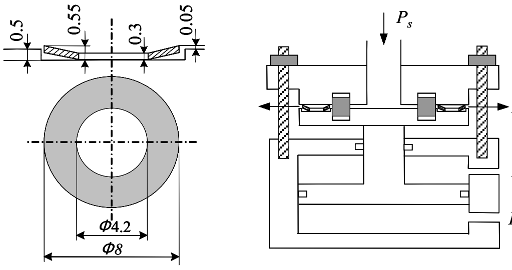

Figure 2 Structure of coned disk spring and new valve

which comes from the Navier-Stokes equation of steady state laminar flow between parallel plates . In Eq. (1), stands for the viscosity of the air and *h* is the height of the parallel slit. The following equation is obtained from the continuity equation:

$$(\bar{u}A\rho)_{r_2} = (\bar{u}A\rho)_r \qquad r_1 \le r \le r_2 \qquad (2)$$

Using the state equation of gases

$$P = \rho R\theta \qquad (3)$$

where R and θ are the gas constant and average temperature of air, respectively. The following equation is obtained From Eq. (2) and Eq. (3).

$$\bar{u}_r = \frac{A_{r_2}\rho_{r_2}}{A_r\rho_r}u_{r_2} = \frac{A_{r_2}P_{r_2}}{A_rP_r}u_{r_2} = \frac{r_2P_{r_2}}{rP_r}u_{r_2} \qquad (4)$$

The effective area of the slit A_r at radius r is given by the following equation:

$$A_r = 2\pi rh\frac{264\,°}{360\,°} \qquad (5)$$

It is assumed that the degree of cross-sectional area is

264°as shown in fig. 2. Substituting Eq. (4) into Eq. (1) yields the following equation:

$$dP_r = -\frac{12\mu r_2 P_{r_2} \bar{u}_{r_2}}{h^2 r P_r} dr \tag{6}$$

When Eq. (6) is integrated, and the boundary condition of is substituted, the following equation is obtained.

$$P_r = \sqrt{\frac{24\mu \bar{u}_2 r_2 P_2}{h^2} ln\frac{r_2}{r} + P_a^2} \tag{7}$$

Substituting $\bar{u}_2 = Q/A_{r_2}$ into Eq. (7), the following equation is obtained.

$$P_r = \sqrt{\frac{24\mu Q_{r_2} P_a}{h^2 A_{r_2}} ln\frac{r_2}{r} + P_a^2} \tag{8}$$

If the flow rate is given, the pressure at r is obtained from Eq. (8). The extra pressure drop must be considered in the inlet region [6]. This is evaluated using the following equation:

$$\Delta P_i = \xi \frac{\rho \bar{u}_{r_1}^2}{2} \tag{9}$$

where ξ is the friction coefficient.

If the flow rate is given, the inlet average velocity is obtained from the equation. As a result, the supply pressure is given by adding the losses in the slit and the losses in the inlet region.

$$P_s = P_{r_1} + \Delta P_i \tag{10}$$

FLOW CHARACTERISTICS

The flow characteristics were measured experimentally using the experimental apparatus shown in Fig. 3. Buffer tank and two regulators are set up on the upstream side. Supply and control pressures were regulated by each regulator. The pressure and the flow rate were measured using a bourdon tube pressure gauge and a float-type area flow meter, respectively.

The measured flow characteristic is shown in Fig. 4. The vertical axis is flow rate and the horizontal axis is a radius. The triangular symbols show the experimental result, and the solid line is the theoretical result. The theoretical result is calculated by Eq. 10 using the parameters listed in Table 1. The friction coefficient was chosen to approximately match the experimental results. The supply pressure is set constant at 500kPa. The control pressure was varied from atmospheric pressure to 580kPa, and the height of slit is varied from 50μm to 0μm. It is thought that from the fact that theoretical analysis and experimental result agree well the flow by the viscosity is dominant.

The pressure distribution along r direction is examined with Eq. 8 and Eq. 9. The result is shown in Fig. 5. The vertical axis is pressure distribution and the horizontal axis is a radius. The pressure loss is almost linear line when the height of slit is 10μm . However, the pressure loss in the inlet region is getting large when the height of slit increases. It means the inlet length effect is greater when the height of slit in-creases.

Table 1 parameters of the slit structure

(m)	(m)	(μ m)	ξ
0.05	0.025	0 ～ 50	0.45

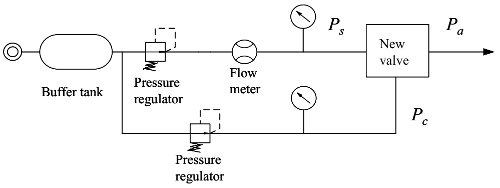

Figure 3 Experimental apparatus

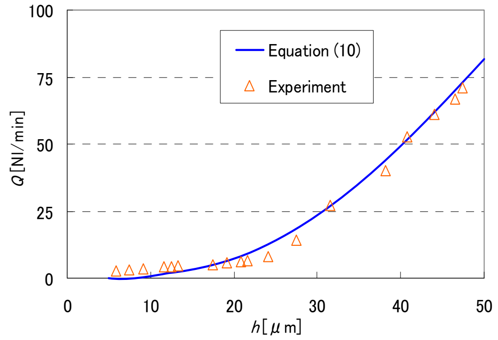

Figure 4 Flow characteristics of the slit structure

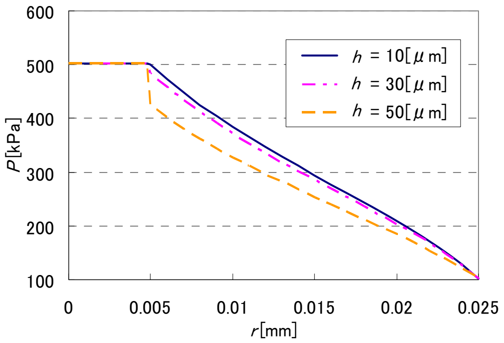

Figure 5 Pressure distribution along r direction

REYNOLDS NUMBER

The Reynolds number is examined from the result by the theoretical analysis. The Reynolds number is calculated by Eq. (11).

$$Re = \frac{\rho_r \bar{u}_r D_h}{\mu} = \frac{\rho_a Q D_h}{\mu A_r} \tag{11}$$

Here,

$$D_h = 4\frac{2\pi r h}{2(2\pi r + h)} \cong 2h \tag{12}$$

Reynolds number along r direction is shown in Fig. 6. The vertical axis is Reynolds number and the horizontal axis is a radius. When the height of the slit rises, the Reynolds number rises because flow rate increases. Because the Reynolds number is a function of the cross-sectional area, the flow on the radial shape has the effect of reducing the Reynolds number. Because the area ratio of the inlet for the outlet is 0.2, the Reynolds number of the outlet becomes 20% of the inlet. The Reynolds number at the outlet is 2000 or less as a result.

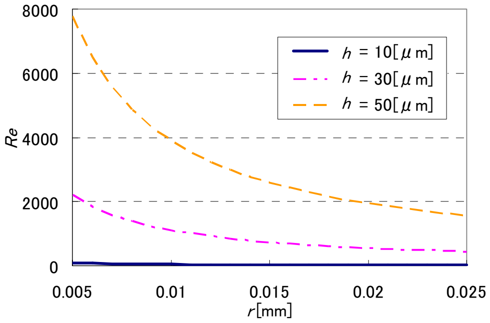

Figure 6 Reynolds number along r direction

NOISE LEVEL

The noise level of the valve was measured using a microphone sensor (Custom corp. ; SL-1370), according to the Japanese Industrial Standards[7]. The background noise level of the room is at 30dB. Microphone was placed in the room at an angle of 45 degree from the center axis of the valve. The distance from the valve to the microphone was 1.0m.

The noise levels of the orifice and the newly developed valve with the variable slit structure were compared. The experimental results are shown in Fig.7. The horizontal axis is flow rate, and the vertical axis is the noise level. We confirmed in advance that the flow characteristics of the orifice and the new valve were approximately the same. The results indicated that the noise level decreased approximately 40dB in the new valve.

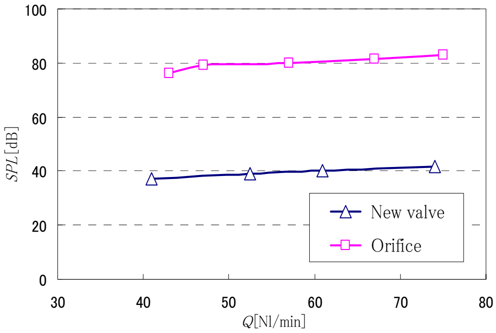

Figure 7 Noise level of orifice and new valve

CONCLUSION

This paper proposed variable slit structures instead of orifice structures. The height of slit is variable by using coned disk springs. The coned disk springs, which diameter is 8mm, are installed between the slit structures and the height of them is precisely con-trolled with control pressure.

The flow characteristics of the slit are investigated theoretically and experimentally. The pressure distribution and Reynolds number is examined. The experimental results indicated that the noise level decreased by approximately 40dB.

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