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MECHANISM OF WHISTLE-LIKE TONE OF THE CONTROL VALVE

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1. INTRODUCTION

Industrial control valves sometimes cause a peculiar noise under low pressure in addition to the case of high pressure. The noise generated under low pressure is similar to whistle tone and its frequency is about 4 kHz. We call it a peculiar noise or a whistle-like tone. The mechanism of the phenomenon has not been very well known. However once it occurs, it causes people quite a bit annoyance. Recently, papers about similar noise of this phenomenon have been published. One of them treated a whistle-like tone generated by a jet from a rectangular slit[1] . The other discussed a subsonic-jet noise with discrete tones issued from a nozzle with exit divergent angle[2]. The purpose of the present study is to clarify the mechanism of the whistle-like tone and to design a control valve that dose not generate the tone. We set up a model pipe line by using a variety of globe type valves with a characteristic of Equal percentage type. The experiment has been carried out by using clean and cold air,at pressures raging from 10 to 100kPa . Flow direction in the body of a valve was adjusted both ways, forward and backward. Experimental results showed that the noise is generated in limited ranges of the length of a seat-ring, the stroke of a valve or gap width between a plug and a seat-ring and the velocity at the gap. We established empirical formula between lower frequency of this tone and the seat-ring length.

2. EXPERIMENTAL

Apparatus.

The experimental apparatus for testing control valve characteristics consisted of a compressor, plenum chambers, a settling chamber, a test section and a back pressure loading section (Fig. 1). The test section was composed of a plug, a seat-ring and a box containing them. Acrylic resin was utilized as the panel of the box to make optical observation of the internal flow. The used valve was a globe type. We have studied geometrical effects of a plug and a seat-ring on fluid dynamic and acoustic characteristics of the globe valve. Especially, we addressed ourselves to the change by the length of a seat-ring. We also made investigation of flow past the used plug. For the measurement of static pressure around the surface of the plug, we perforated holes of 0.2mm in diameter at a point on six generatrices beside one at the apex of the plug which was used for measuring a stagnation pressure.

The angle between each generatrix was 60deg. The plug was turned by 60deg to obtain a static pressure distribution along a generatrix. The pressure taps were connected to water manometer with acrylic tube (Fig.2). The length of used seat-ring are listed in Fig.3. Actually, the type of 20mm long seat-ring is an article of practical use. Since we have used a model of practical pipe line, careful attention was paid to prevent an unwanted noise from any part of the pipe line other than test section. Then the air was conducted to the section from a plenum chamber through a silencer and a settling chamber. A gauge pressure at the settling chamber was regulated from 10 to 100kPa at the step of 10kPa through a motor-driven control valve. It was confirmed by preliminary experiment that this type of control valve dose not generate any noise under the present test condition. A 1/4 in B&K microphone was set 0.5m apart from the test section facing normal to the flow direction and downward by 30deg from the horizontal. Acoustic measurement was made on linear scale followed by spectrum analysis. The stroke of the tested plug was manually controlled at the step of 1. 0mm at each tested pressure condition. When the port of the valve was full open, the plug stroke was 16mm . When the stroke became shorter than 10mm, no noise was generated. Thus the stroke length ranged from 16 to 10mm. The flow direction was set both way, namely from seat-ring to plug and vice versa. Let us call the former direction FTO (Flow to Open) and the later FTC (Flow to Close). In the present paper, the tested plug was of Equal percentage type. For each length of a seat-ring, fluid dynamic and acoustic investigations were carried out for a variety of plug stroke and inflow stagnation pressure.

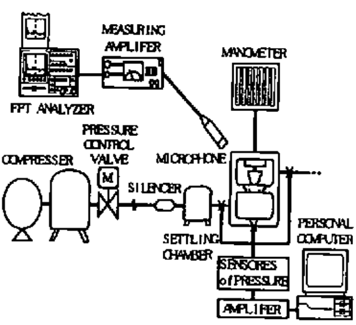


Fig.1 Experimental apparatus

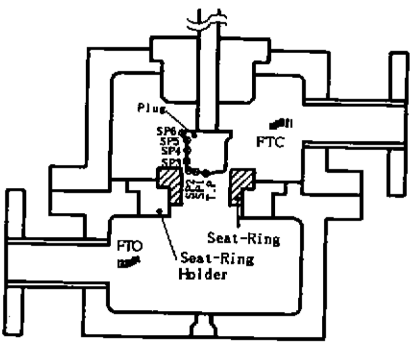


Fig.2 Apparatus of testing valve

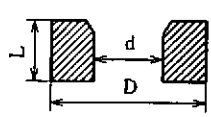
Symbol	L(mm)	D(mm)	d(mm)	Shape of Seat-Ring
L-20	20.0	51.5	28	
L-25	24.5			
L-30	29.5			
L-45	44.5			
L-60	59.0			

Fig.3 Shape & size of seat-ring

3. RESULTS AND DISCUSSIONS

Velocity Profile Over a Plug in a Globe Valve

A flow over a plug in a globe valve is considered as a kind of an annular wall jet. It was observed that the fluid dynamic features depended on the length of a seat-ring and a plug stroke besides the stagnation pressure of the inflow. Furthermore, the flow profile over the plug is changed by the direction of valve flow, seat-ring to plug (FTO) or plug to seat-ring (FTC). For example, in case of FTO, seat-ring L-20 gave the fastest flow among all tested ones, while seat-ring L-45 generated the slowest flow (Fig. 4).The cited values were averaged velocities measured at SP2 and SP3. In other three cases, flow profiles were almost the same. The velocity difference may be caused by the difference of pressure drop through each seat-ring. Remarkable distinction was noticed at the points SP-2 and SP-3. Those points were probably located near vena-contracta of an initial jet issued from a seat-ring of the valve. The variation depended most on the length of a seat-ring and the flow profile for each seat-ring shaped similar even when the inflow pressure was changed while keeping the plug stroke constant. For FTO at a constant plug stroke, relative velocity at SP-2 to one at SP-3 decreased as the seat-ring became longer. In case of the longest seat-ring, 60mm, the velocity at SP3 became greater than one at SP2. Otherwise, the flow was fastest at SP2. On the other hand, for FTC at a constant plug stroke, relative velocity at SP2 to one at SP3 increased as the seat-ring length increased. A higher relative velocity at SP3 to one at SP2 may correspond to a flow being accelerated as shed downstream. The phenomenon may occur when the flow is attached to the surface of the plug.

Spectrum and Sound Pressure Level of Whistle-Like Tone

Valve noise contains variable frequency components(Fig. 5). In the present experiment, a used valve caused a whistle-like tone (WLT) of frequency about 4 kHz (less than 4kHz) and other high frequency components of 10kHz. We classified those two groups as Low-Frequency -Tone (LF) and High-Frequency-Tone (HF). The former has frequently been noticed when a plug stroke was set close to full opening. Sound pressure level of WLT seemed not to depend on the velocity but on the seat-ring length. It seems to be lowered as the seat-ring gets longer.

The mechanism of Whistle - Like Tone

For FTO and FTC case, we studied the wave length of WLT as a function of seat-ring length. The obtained result is shown in Fig. 6. Apparently, the wave length depends on seat-ring length. Then the WLT may be caused by a disturbance at the annular slit between a plug and a seat-ring. Generated noise propagates upstream to reach the end of the seat-ring. Due to the difference of impedance, the noise propagating up to the end of the seat-ring is reflected there and propagate back to the original annular slit where it excites disturbances. Hence a particular frequency is amplified. The frequency should correspond to WLT.

4. CONCLUSIONS

(1) Whistle-like tone (WHT) is generated within a limited range governed by conditions about seat-ring length, width of annual exit and exit velocity at the port of a valve.
(2) Wave length of WLT is proportional to seat-ring length.
(3) Seat-ring length influences not only the frequency of WLT, but also sound pressure level and velocity profile over a plug of a control valve of Equal percentage type.

References
[1] I Kouno, JSME paper 93-0385 (1994-1) (in Japanese)
[2] T Kojima, JSME paper 94-1663(1995-5) (in Japanese)

The authors wish to thank M. Matuoka and for his assistance in the experiment.

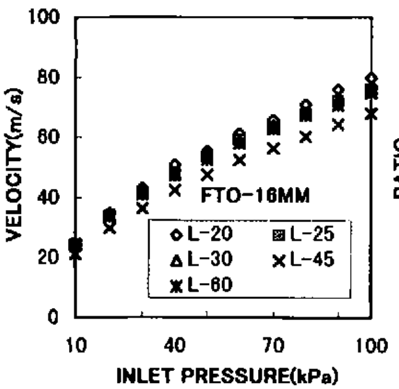


Fig.4 Velocity profile obtained from averaged value of measurements at SP2 and SP3.

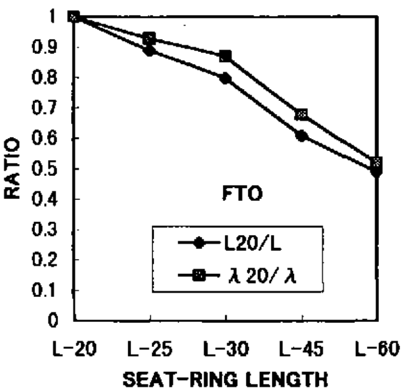


Fig.5 Comparison between ratios of seat-rings length and acoustic wave length in case of FTO.

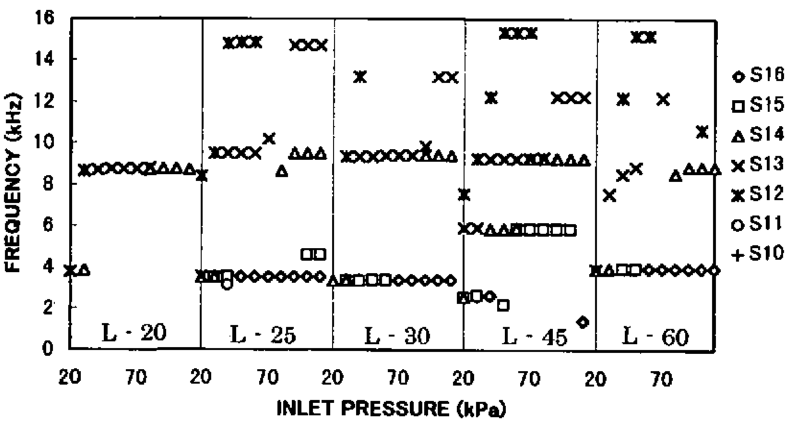


Fig.6 Measured WLT frequencies emitted from five different seat-rings. Each strip corresponds to frequencies of a seat-ring noted at the bottom.