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Mechanism of Cavitation Erosion in a Hydraulic Control Valve

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Abstract: Cavitation erosion often occurs in the hydraulic control valves of construction machinery and shortens product life. Cavitation erosion in the cylindrical spool valve with holes to control the flow rate has been observed by the erosion test. In the present study, to clarify the mechanism of such cavitation erosion, the cavitating flows inside the spool was experimentally visualized. As the results, the amount of cavitation generated in the spool increased as the flow rate increased, then the cavitation bubbles are observed inside the spool holes facing on the block surface. Next, the brightness fluctuation due to the growth and collapse of cavitation was quantitively examined by image analysis. The sharp increase in the averaged brightness value of the spool holes, which indicates the violent collapse of cavitation bubbles, was frequently observed. Therefore, it is considered that the block surface is eroded due to the frequent collapse of cavitation bubbles in the spool hole facing on the block surface. Additionally, the fluctuation intensity of brightness depends on the hole position, which is qualitatively consistent with the position dependency of the amount of erosion in the erosion test.

Keywords: cavitation erosion; hydraulic valve; visualization experiment

1. Introduction

Construction machinery employs various types of hydraulic equipment for transmitting power by fluid. Cavitation is inevitable in hydraulic equipment. Although cavitation itself does not disturb the work of construction machinery, cavitation noise and erosion due to the collapse of cavitation bubbles are problems to be solved [1,2]. Fig.1(a) shows the schematic diagram of a hydraulic control valve. Oil flows from high pressure side through the opening of the spool into the inside of the spool. Cavitation occurs inside the spool due to the high-speed jet flows from the opening. Fig 1(b)shows cavitation erosion of the block surface faced on the closed holes of the spool in an endurance test of the control valve. Such cavitation erosion in the control valve developing in long term operation of construction machinery decreases the controllability of flow in the valve. In the previous work [2], the cavitating flows in the in the control valve was numerically simulated, and the collapse of cavitation bubbles in the spool holes faced on the block surface was observed. However, the cavitating flows in the control valve has not been confirmed experimentally. Therefore, the purpose of the present study is to clarify the mechanism of the cavitation erosion in the control valve by a visualization experiment.

2. Materials and Methods

A visualization experiment equipment of the cavitating flows in the hydraulic control valve is shown in Fig.2. There are two windows for visualization at both ends of the spool, and cavitation was visualized by the shadow graph method. In addition, the spool itself was made of acrylic so that the cavitation not only

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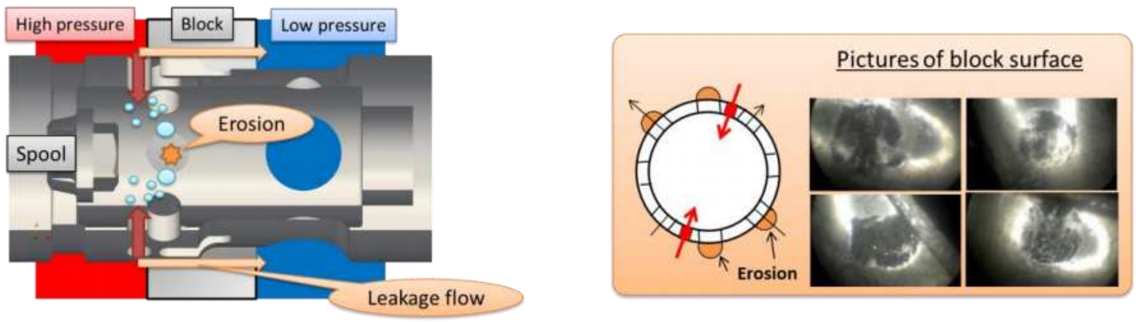

(**a**) (**b**)

Figure 1. Cavitation erosion in a hydraulic control valve: (**a**) Schematic diagram; (**b**) Pictures of eroded block surface.

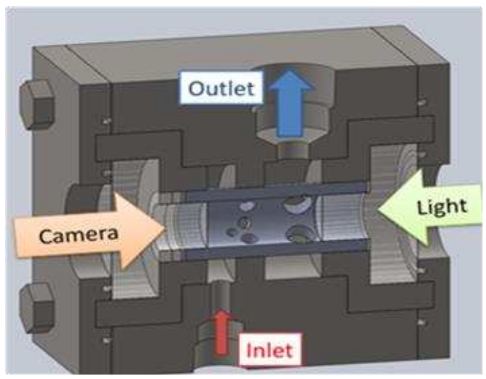

Figure 2. Visualization experiment equipment of cavitating flows in a hydraulic control valve.

inside of the spool but also inside the spool holes could be visualized. In the experiment, oil flows from the pump of the hydraulic unit to the inlet of the visualization experimental device via the accumulator, passes through the spool opening, and returns from the outlet to the tank. A high-speed camera (MEMRICAM HX-7s) and high-brightness LED lighting or laser illumination (CAVILUX Smart) were employed for high-speed photography.

3. Results

Figure 3 shows cavitation in the spool with the opening of 1.0 mm for various flow rates. At the flow rate of 15L/min (Fig.3(a)), two jets from the paired openings collide, and cavitation occurs in the vortexes inside the spool. As the flow rates increases from 15L/min to 18L/min, the amount of the cavitation bubbles increases to fill in the spool, no cavitation bubbles are observed in the spool holes. At the flow rate of 24L/min (Fig.3(c)), the inside of the spool is filled with cavitation bubbles. It was confirmed that small cavitation bubbles and bubble clusters grow and collapse in the spool holes facing on the block surface.

Fig. 4(a) shows the time evolution of the average brightness value in the spool hole surrounded by the white broken line in Fig. 3(c). The brightness gradually dims from (i) to (iv), and the brightness value decreased from 70 to 20 between 0.1ms. This is due to both the growth of small cavitation bubbles and the inflow of cavitation bubbles into the holes as shown in Fig.4(b). Then, due to the collapse of cavitation bubbles, the brightness value increases sharply from 20 to 70 between 0.033ms from (v) to (vi). Such sharp increase in brightness indicates a collapse of cavitation bubbles. It is well known that the collapse of

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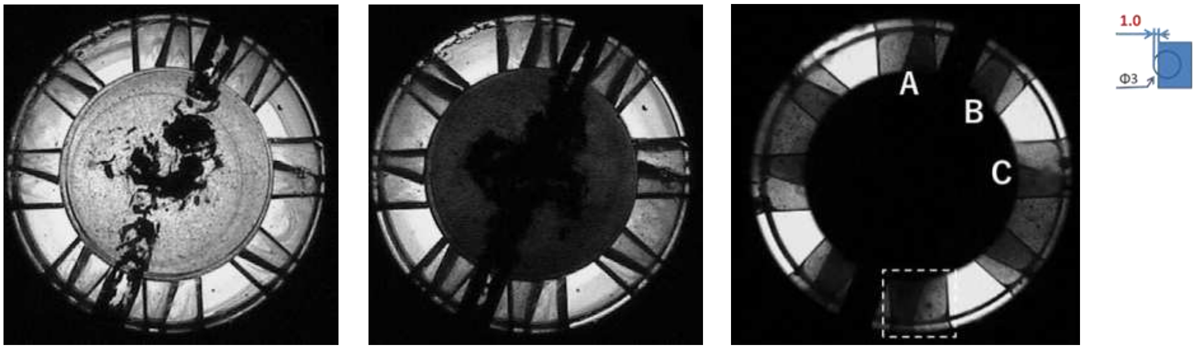
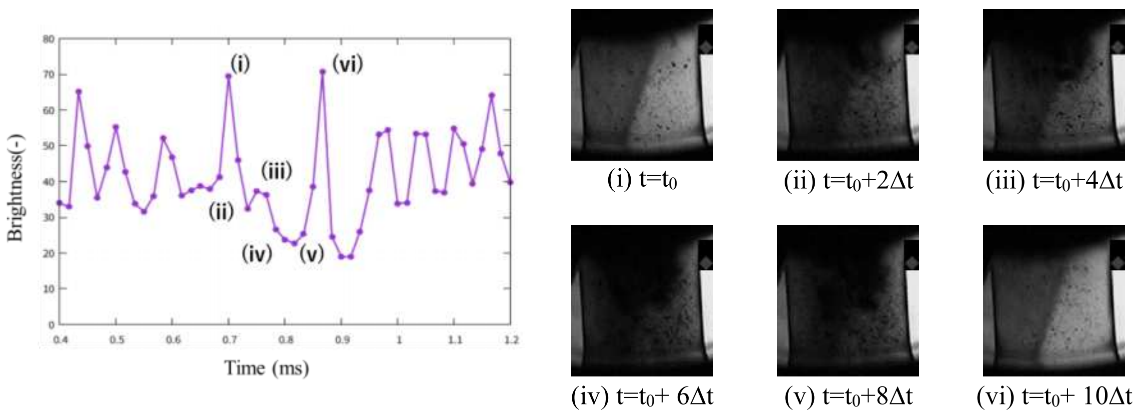


(**a**) (**b**) (**c**)

Figure 3. Cavitation in the spool with the opening of 1.0mm for various flow rates as: (**a**)15L/min; (**b**)18L/min; (**c**)24L/min.



(**a**) (**b**)

Figure 4. Time evolution of (**a**) average brightness value in the spool hole surrounded by the broken line in Fig. 3(c) and (**b**) cavitation corresponding to time from (i) to (vi) (Δt = 1/60,000).

cavitation bubbles near the solid surface erodes [2,3]. Thus, it is considered that the greater the change in brightness over time, the greater the growth and collapse of cavitation, which causes the erosion of block surface.

The amount of erosion depends on the position of the spool hole as shown in Fig.1(b), so the dependence of the blinking intensity on the position of the spool hole was examined. Figure 5 compares the time evolution of the average brightness values at the spool holes A, B, and C in Fig.3(c). The brightness value of hole A varies more than the brightness value of holes B and C. It is considered that the fluctuation of the brightness value differs depending on the position of the spool hole. Here, the standard deviation of the brightness values for all spool holes was calculated as shown in Table 1. The standard deviation of holes A and E is higher than others. In Fig.1(b), the block surfaces faced on holes A and E were severely eroded. Thus, the dependence of the brightness fluctuations on the position of spool holes is qualitatively consistent with the results of erosion test.

4. Conclusions

The cavitation in the hydraulic control valve has visualized, the collapse of cavitation bubbles in the spool holes facing on the block surface was observed by the present study. The average brightness in the

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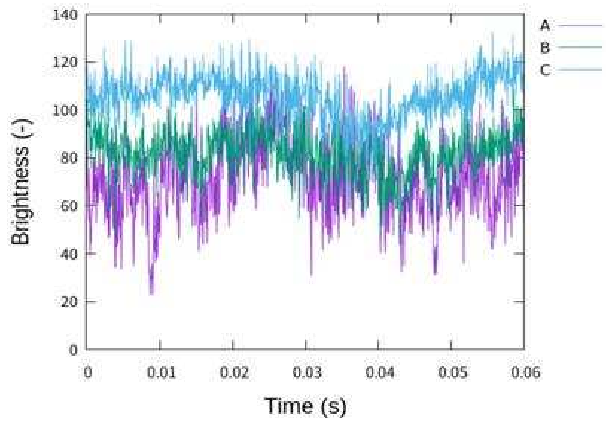
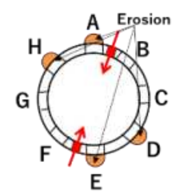


Figure 5. Time evolution of the average brightness values in the spool holes A, B and C in Fig. 3(c).

Table 1. Standard deviation of average brightness values in spool holes.

Hole	A	B	C	D	E	F	G	H
Standard deviation	16.74	10.53	9.94	11.45	14.87	9.58	9.48	9.12



spool holes fluctuates corresponding to the cavitation bubble growth and collapse because of the shadow graph method. The sharp increase in brightness indicates the collapse of cavitation bubbles, which causes the erosion of the block surface. Additionally, the fluctuation intensity of brightness depends on the hole position, which is qualitatively consistent with the position dependency of the amount of erosion in the erosion test. Thus, the growth and collapse of cavitation bubbles differ owing to the position of the spool hole. The asymmetric flows due to the jet flows from the openings is considered to cause the position dependence of cavitation in spool holes. In the future, to design a spool that reduces cavitation erosion, it is necessary to clarify the flow of cavitation in the spool in more detail.

References

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