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A small water flow control valve using particle excitation by PZT vibrator

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Hydraulic proportional valves generally suffer from their large size and heavy weight due to their complicated structures using large solenoids or motors. Therefore, they have some limitations of design or decrease mobility of hydraulic systems. In this paper, we present a small hydraulic flow control valve using particle excitation by a PZT vibrator. This valve can control the flow rate of water by the applied voltage to the PZT vibrator. The prototype of the proposed valve evaluated the relationship between the applied voltage, the impressed pressure, and the flow rate. This fundamental evaluation successfully indicated the flow-controllability of the proposed valve.

1 Introduction

Hydraulic systems are used in vehicles such as aircrafts or locomotion robots [1], [2]. In these fields, it is required that the entire system is lightweight for improvement of its payload and energy efficiency. While lightweight materials have been actively applied to hydraulic valves for addressing this problem, due consideration was not paid to the driving principle: using large electromagnetic motors and complicated configurations. Therefore, this study aims to miniaturize the control valve by using a new driving method developed for pneumatic systems [3], [4]. This valve is smaller and lighter than conventional flow control valves for pneumatic. Although the valve has a 2-port flow control function, it is possible to realize a higher functionality by a combination of this mechanism. In this paper, we describe these results of a fundamental experiment applying the prototype valve to a water hydraulic system.

2 Working principle and structure

Fig. 1 shows the principle of the proposed proportional control valve. When the voltage is not applied to the PZT, the orifices are sealed by the particles due to the flow of fluid, which carries the particles onto the orifices. In order to move the particles that seal the orifices, an external force is applied to the particles by the excitation at the orifice parts. The orifice parts are excited by the PZT which sinusoidal voltage activates at a resonant frequency. As a result, the particles leave from the orifices, so that flow paths are generated. Since the excitation intensity that the flow paths are generated differs depending on the location of each orifice, it can control the flow rate by adjusting the voltage. The condition for generating the flow path is derived from balance of forces acting on the particle as below [3].

$$a > \frac{\pi r^2 P \pm mg}{m} \qquad (1)$$

Where a represents the acceleration at the orifice part, P is the air flow pressure from the inlet port of the valve, r is the radius of the orifice, m is the particle mass, and g is the acceleration due to gravity.

Fig. 2 shows the structure and the photograph of the valve. It consists of an orifice plate which has some orifices, a PZT vibrator which is stacking four thin PZT and four electrodes, a fixing nut and iron particles which can seal all orifices. Since the vibration at the orifice parts decays with increasing density and viscosity by changing the fluid from air into water, the stacked number of the PZT is modified, though the original design for pneumatic systems is driven by two PZT. This is to improve the relationship between the applied voltage to the PZT and the acceleration at the orifice part. The size of this valve is 10.0 mm in diameter, 9.0 mm in height, and the weight is 2.50 g.

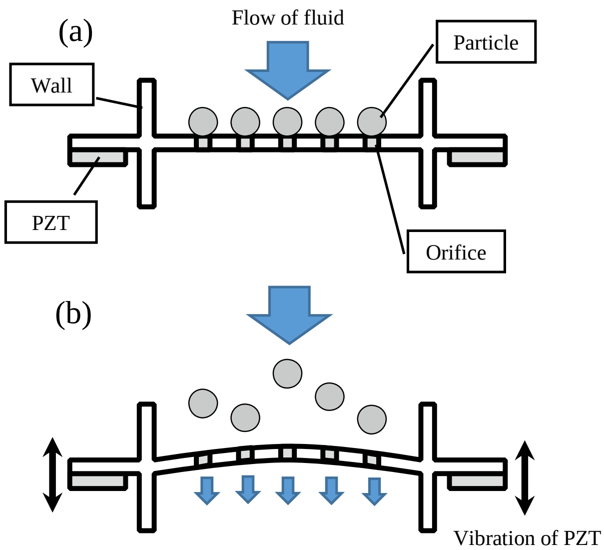

Fig. 1 Working principle of the proposed valve: (a) sealed state, (b) opened state [3].

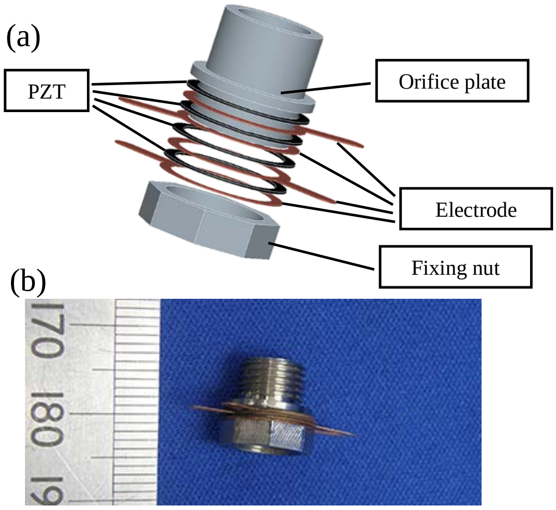

Fig. 2 The proposed proportional control valve: (a) structure of the valve; (b) photograph of the valve

3 Results of experiment

The flow rate and the opening voltage of the orifices were measured, in order to evaluate characteristics of the prototype valve in water system. The experimental system is shown in Fig. 3. In this system, the outlet of the valve was released to the atmosphere.

The result of the relationship between the applied voltage and the flow rate is shown in Fig. 4. The pressure was applied from 0.05 MPa to 0.50 MPa. From the result, this valve achieved a maximum flow rate of 793 ml/min under conditions of 130 $V_{p\text{-}p}$ and 0.50 MPa. In addition, it was found that a range of the flow rate can be controlled in the wider range according to the increase of the impressed pressure. On the other hand, Fig. 5 indicated that the opening voltage of orifices increased, when the impressed pressure becomes higher. It is difficult to operate the valve under high pressure, because the applied voltage for thin PZT vibrator is limited by dielectric strength voltage.

4 Conclusion

A novel hydraulic proportional control valve for water is introduced in this paper. The results of the fundamental experiments verified that the maximum flow rate of this valve is 793 ml/min at 0.50 MPa. On the other hand, the valve was required higher vibration velocity so that it worked at higher pressure. Future work is to develop the valve which can control flow rate under the higher pressure for hydraulic oil systems.

Acknowledgement

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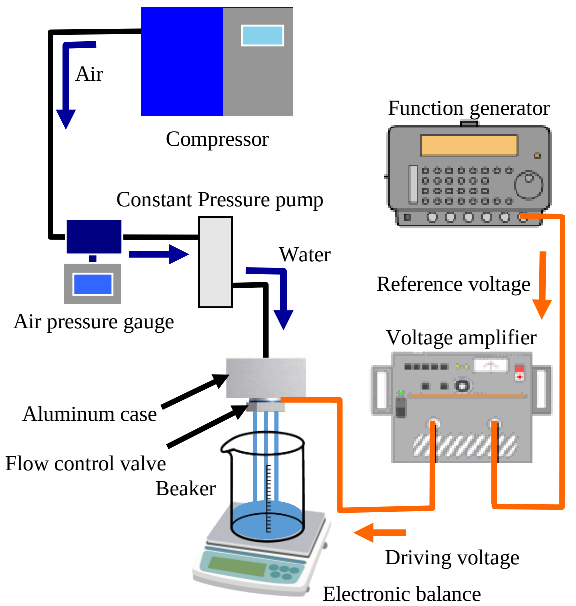

Fig. 3 The experimental system for evaluating characteristics of the valve

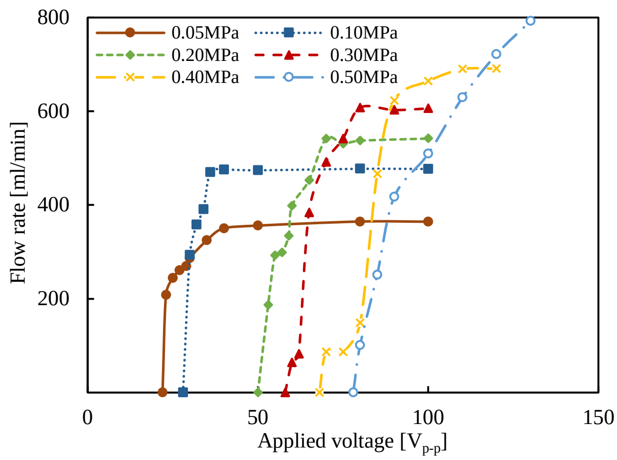

Fig. 4 The relationship of applied voltage, impressed pressure and flow rate

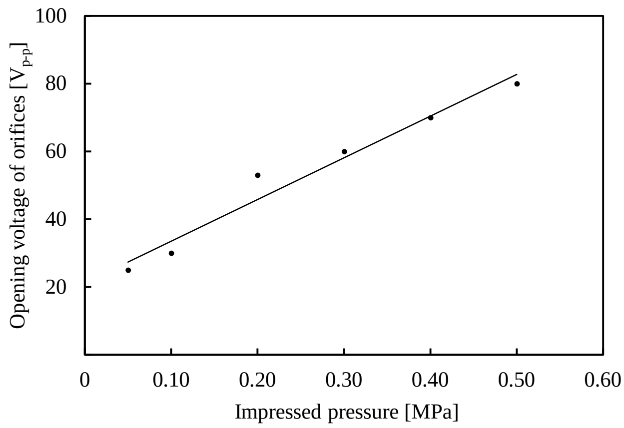

Fig. 5 The relationship between impressed pressure and opening voltage of orifices