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DEVELOPMENT OF SMALL-SIZED FLEXIBLE CONTROL VALVE USING VIBRATION MOTOR

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ABSTRACT

Recently, due to the ageing in Japanese society and the decreasing birthrate, an important problem of providing nursing care for the elderly has occurred. As a result, it is necessary to develop wearable systems to aid in nursing care. To realize the system, we require not only wearable soft actuators, but also compact and flexible control valve that can drive the soft actuator such as a pneumatic artificial muscle. The purpose of our study is to develop a flexible, lightweight and compact control valve which can be safe enough to be attached to the human body.
In this study, we proposed and tested a new type of control valve. The valve consists of a vibration motor and a check valve that made of a steel ball and an orifice in flexible tube. The operating principle of the valve is as follows. The valve is normally closed as a function of check valve. When the vibration is applied, the inner ball in the check valve moves and the valve opens. By giving continuous vibration, the valve can keep open. As a result, we find that the valve can control the relatively larger flow rate compared to their weight and size.

KEY WORDS

Small-sized control valve, Control using vibration, Flexible control valve, Valve using vibration motor

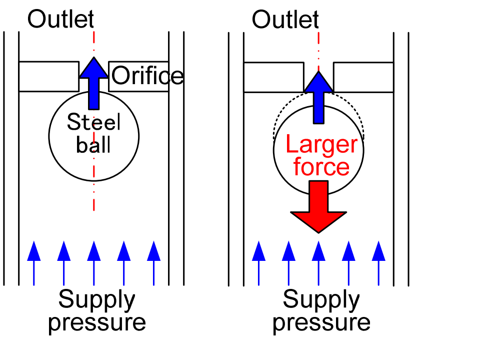
INTRODUCTION

Recently, force feedback devices in virtual reality and power assisted nursing care systems[1-2] have received much attention and active research. In such a control system, an actuator and a driving device such as a control valve are mounted on the human body[3-5]. To consider the development of wearable control valve that can drive pneumatic actuator so as to support the multi degrees of human motion, the size and weight of the valve become serious problems. The usual electro magnetic solenoid valves drive their spools by using larger solenoid to open the valve. The solenoid valves have complex construction to keep a seal while the spool moving. This complex construction makes the miniaturization of the valve and the fabrication of the low cost valve more difficult. The purpose of our study is to develop a small-sized, lightweight and flexible control valve that can be safe enough to mount on human body with a lower cost. In this study, we proposed and tested a new type of control valve that can make it open by using a vibration motor. In addition, we investigated the output flow characteristics of the tested valve.

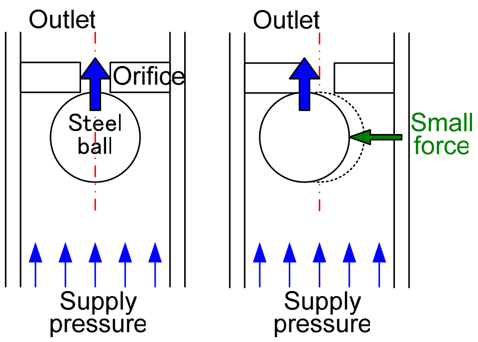
CONTROL VALVE USING VIBRATION MOTOR

Concept of the proposed valve

Figure 1 shows a fundamental concept of a proposed control vale. The figure shows the model of the tested valve using the check valve which is composed of a steel ball and orifice. Figure 1 (a) and (b) illustrate the operational image of a usual electro magnetic on/off control valve and a proposed valve, respectively. In the both valves, the supplied pressure is applied from the lower inlets as shown in Fig.1. From Fig.1, the steel ball is always applied by the upper force according to the differential pressure between inlet and outlet of the orifice and the sectional area of the orifice. In the case using the usual on/off valve as shown in Fig.1 (a), to open the valve, it needs a larger longitudinal directional pulling force that can overcome the pushing force of the ball generated by supplied pressure. Therefore, the usual elector-magnetic solenoid valve needs a relatively larger solenoid coil to open the valve surely. It prevents the miniaturization of the valve. In addition, in order to pull the steel ball while keeping the seal between inside and outside of the valve, it needs some complex mechanisms. It prevents to make the cost of the valve lower.



(a) Image of a usual control valve



(b) Image of proposed valve

Figure 1 Concept of proposed control valve

In case of the proposed valve as shown in Fig.1 (b), to increase the opening of the valve, we apply the steel ball the horizontal direction force to slide the ball. By using this method, it becomes possible to open the valve using smaller force. In the case of closing, when we stop to apply the horizontal direction force, the inner steel ball automatically moves toward the orifice by the generated force of momentum of the flow such as a check valve. Then, the ball closes the orifice as a stable condition of check valve.

Construction and operating principle

Photo.1 shows the construction of the tested control valve. The tested valve consists of a flexible tube whose inner diameter is 2.5 mm and outer diameter is 4 mm, an acrylic orifice with inner diameter of 0.5 mm, a steel ball with outer diameter of 2 mm and a vibration motor (Shicoh Co.Ltd. SE-4C-1E). The acrylic orifice and the steel ball are inserted into the flexible tube. In the opposite side of the orifice and ball, the ball stopper that has inner bore with diameter of 1.5 mm is inserted into the tube. The vibration motor is set on outer side of flexible tube by an acrylic connector. The orifice and the steel ball are inserted into the tube. There is no mechanical connecting part between the both contents of inner and outer of the tube. It means that the tested valve does not need the special sealing such as a gasket between the inner and outer of tube. In addition, the valve has no mechanical sliding moving part in the tube. The volume of the tested valve including the vibration motor is about 1 cc, that is the valve has the length of 20 mm, the width of 5mm and the height of 10mm. The mass of the tested valve is very lightweight, that is only 2 g. The inner mechanism of the valve is very simple. It means that the valve can be fabricated with a lower cost.

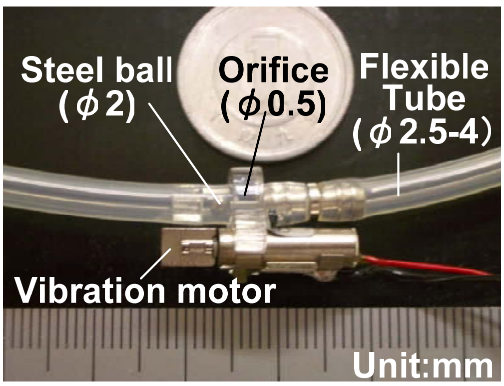
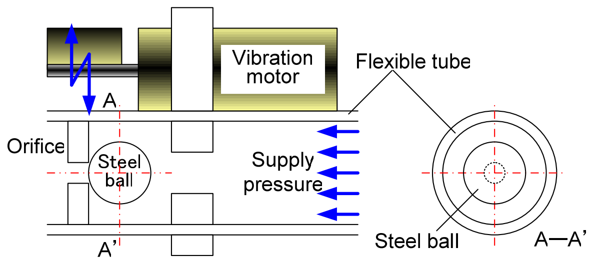


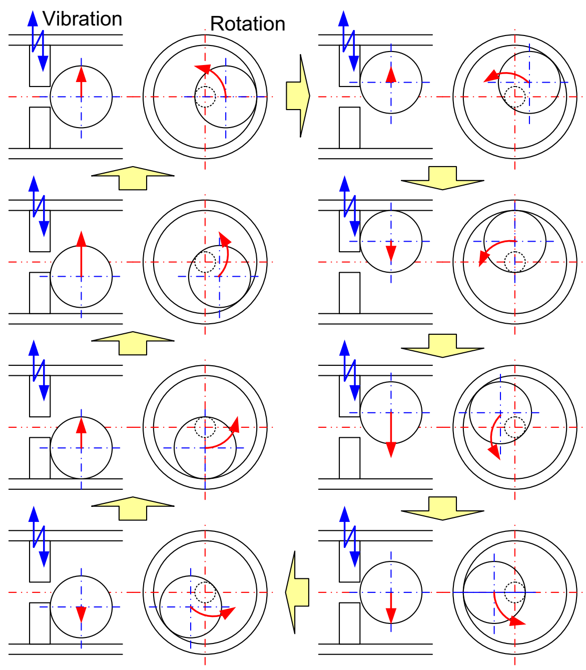
Photo.1 Tested control valve using vibration motor

Figure 2 (a) and (b) show the schematic diagram of the valve and the operation of the valve, respectively. The operating principle of the tested valve is as follows.

When the vibration motor is driven, the tube connected with the vibration motor is oscillated. From the law of inertia, the inner steel ball stays in a certain position of the tube. The inner steel ball contacts to the inner wall of the tube. Then, it gives horizontal direction force to the ball. The inner ball starts to move and rotate along to the inner wall of the tube as shown in Fig. 2(b). By giving the vibration continuously, the ball carries on rotating along to the inner wall of the tube. It is said that the opening of the orifice keeps a certain sectional area while the vibration motor being driven. It means that the tested valve generates the stable flow rate while the valve working. This method is more useful to supply the stable flow rate compared with other way of the valve opening using vibration[6] When the vibration motor is stopped, the steel ball automatically moves toward the orifice by the generated force of momentum of the flow such as a check valve. In the case of giving a large impulse disturbance to the valve such as flipping the valve, the ball moves temporally and a negligibly small leakage occurs. It means that the tested valve does not open when the continuous vibration is applied.



(a) Schematic diagram of the tested valve



(b) Operation of the tested valve

Figure 2 Operating principle of tested valve

CHARACTERISTICS OF THE TESTED VALVE

In order to investigate the characteristics of the tested valve, we measured the output flow rate from the tested valve when the inlet of the valve is connected with the air supply. Figure 3 shows the experimental setup to investigate the characteristics of the tested valve. The equipment consists of the tested valve, float type flow meter, electric power supply and ammeter. In the measurement of output flow rate, the outlet of the valve is connected to the inlet of a float type flow meter whose outlet is released to the atmosphere. While the valve being driven, the current in the vibration motor was also measured by an ammeter. Figure 4 shows the relation between the supply pressure and output flow rate of the tested valve. In Fig.4, each symbol ●, ▲ and ■ show the results using the tested valve and two

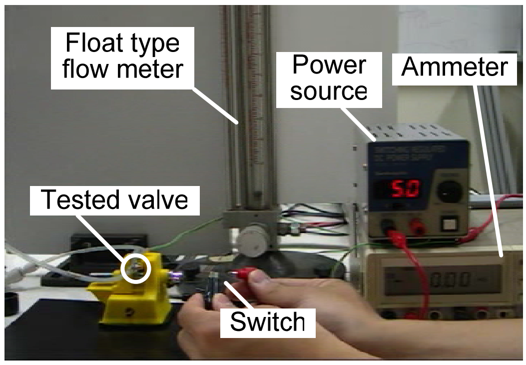


Figure 3 Experimental setup of the tested valve

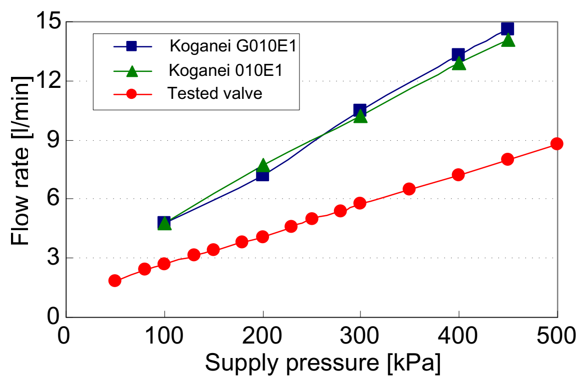


Figure 4 Relation between supply pressure and output flow rate of the tested valve

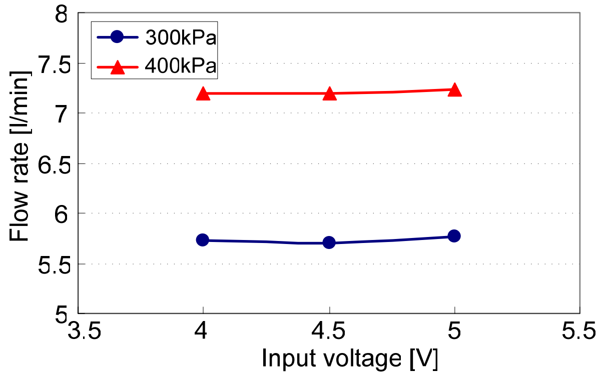


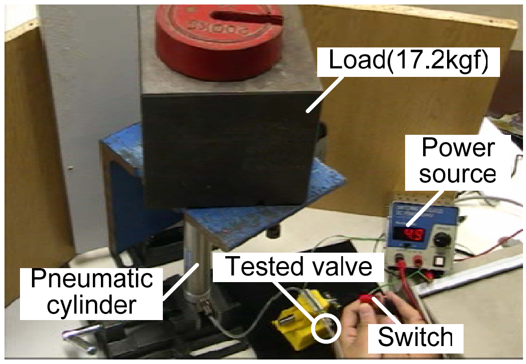
Figure 5 Relation between operating voltage and output flow rate of the tested valve

types of pneumatic on/off control valve on the market (Koganei Co. Ltd. G010E1 and 010E1), respectively. These commercial pneumatic control valves are relatively small-sized valves on the market. In the experiment, the input voltage of 5 volts was applied to the vibration motor in the tested valve and the input voltage of 12 volts was applied to the commercial on/off valves as an operating input. The supply pressure of these valves was changed from 50 kPa to 500 kPa. From Fig.4, it can be seen that the output flow rate of the tested valve has the linear relationship between the supply pressure and the output flow rate. It can be said that the sectional area of the orifice in the tested valve does not change even if the pushing force acted on the inner ball increases according to the supply pressure.

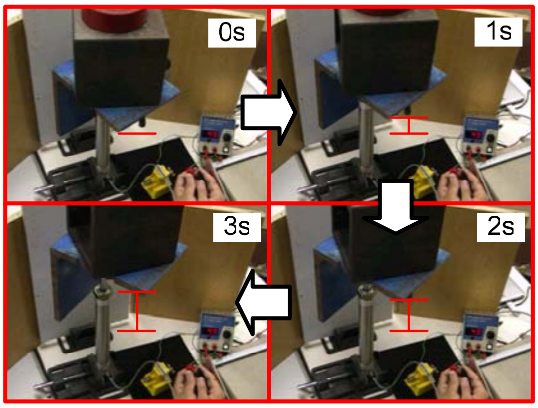
Figure 5 shows the relation between operating voltage and output flow rate of the tested valve. In Fig. 5, symbols ● and ▲ show the results using supply pressure of 300 and 400 kPa, respectively. The vibration motor in the tested valve can be driven by operating voltage of more than 3 volts. Therefore, the tested valve can be driven by a relatively wide range of the operating voltages, that is from 3 to 6 volts. It means that the tested valve does not need higher operating voltages so as to get the generated magnetic force as large as to drive the solenoid. From Fig.4, we can see that the output flow rate does not change according to operating voltage. These results show that the valve can generate a constant flow rate even if an unstable input voltage is given to the valve.

As a dynamic characteristic of the tested valve, we investigated the response of the float type flow meter connected with the tested valve when the input voltage of the valve was turned ON or OFF. In this experiment, we can see that the response of the tested valve for input voltage is almost same as that of the commercial valve using the solenoid. The response time of the valve for stepwise input voltage looks less than 0.1 s even if the length of the connecting pipe between the valve and the flow meter is about 1m.

In addition, it is necessary to confirm the performance of the valve connected to the closed chamber such as a cylinder chamber. Figure 6 (a) shows the experimental setup for driving the pneumatic cylinder whose inner diameter is 20 mm using the tested valve. The end of the cylinder connected to the weight whose mass is 17.2 kg. Figure 6 (b) shows the transient view of the moment of the cylinder driven by the tested valve. It can be seen that the cylinder can be driven smoothly even if the valve is connected to the closed chamber. The valve can work under the both conditions of pressurizing into the closed chamber and releasing from compressed air chamber. It means that the tested valve can be used as both of supply and exhaust valves.



(a) Experimental setup for driving cylinder



(b) Transient view of movement of cylinder

Figure 6 Experiment for driving cylinder with a load of 17.2 kgf(169N) using the tested valve

COMPARISON TO COMMERCIAL VALVE

Figure 7 shows the comparison of the size and weight of the tested valve with the commercial on/off type pneumatic control valves. The upper bar graph shows the comparison of the size of the valves. The lower graph shows the comparison of the mass. From Fig.7, we can see that the size of tested valve is from one 24th to one 16th, the mass is about one 10th compared with the commercial valves that have almost same output flow rate and same supply pressure range. We can confirm that the tested valve is suitable for the wearable control valve because of small size, lightweight and its flexible property.

Figure 8 shows the relation between the electric power consumption and supply voltage of the tested valve. In Fig.8, symbol ● shows the calculated electrical power using the measured current and supply voltage of the vibration motor. The green and blue lines show the power consumption using the commercial valves that can be driven by the input voltage of 12 volts. From Fig.8, it can be seen that the power consumption of the valve decreases according to the decrease of the input voltage to the vibration motor. The minimum power consumption of the valve is about 0.6 W, that is one second of power consumption using the commercial valve. In addition, the power consumption of the valve can be reduced by changing the construction of the valve so as to generate the resonance phenomenon of the beam-structured tube in the valve using lower electric power. Figure 9 (a) and (b) show the comparison of normalized output flow rate between the tested valve and commercial valves. Figure 9 (a) shows the relation between the supply pressure and the output flow rate normalized by the size of the valves. Figure 9 (b) shows the results of output flow rate normalized by the mass of the valves. In Fig.9, each symbol ●, ▲ and ■ show the result using the tested valve and the commercial valves, respectively. From Fig.9 (a), it can be seen that the normalized flow rate of the tested valve is about 10 times as large as those using the commercial valves. From Fig.9 (b), the normalized flow rate by the mass of the tested valve is about 6 times larger than the commercial valves. The both experimental results prove that the tested valve is suitable as a wearable control valve because of relatively larger output flow rate compared to their weight and size.

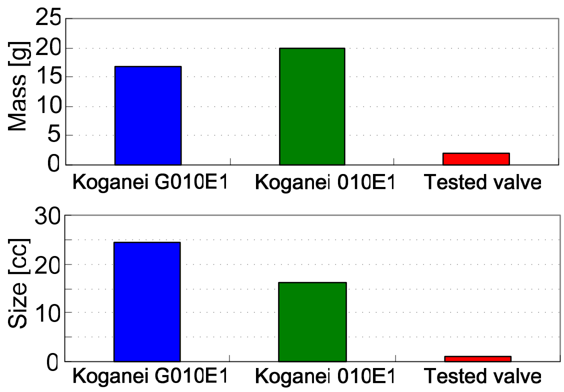


Figure 7 Comparison of size and mass between the tested valve and the commercial valves

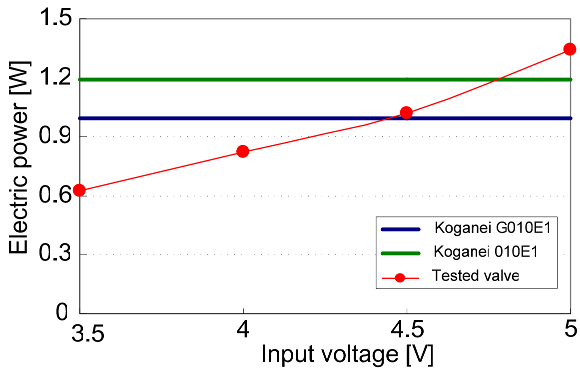
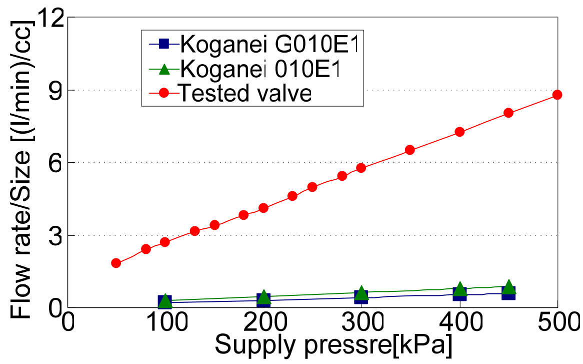
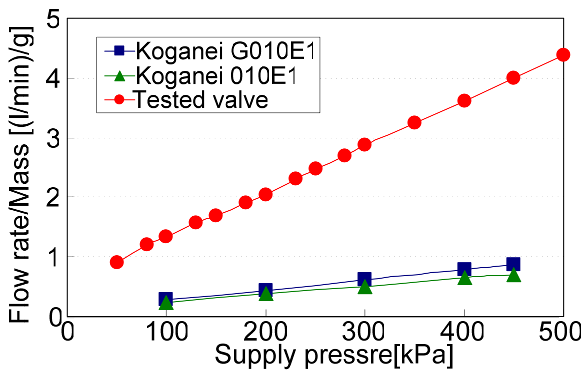


Figure 8 Relation between input voltage and electric power consumption



(a) Output flow rate per size of the valve



(b) Output flow rate per mass of the valve

Figure 9 Comparison of normalized flow rate between the tested valve and commercial valves

CONCLUSIONS

This study that we aim to develop the small sized wearable control valve is summarized as follows.

1) We proposed and tested a flexible control valve that consists of a vibration motor and a check valve composed of a steel ball and an orifice in flexible tube. We also investigated the operating principle of the tested valve. As a result, we found that the inner steel ball of the valve rotated along the inner wall of the tube and the constant opening area of the valve could be opened by ball rotating.
2) The output flow rate of the tested valve for various input voltages of the valve was investigated. As a result, it was found that the proposed valve could generate a constant flow rate even if the input voltage of the vibration motor was changed. As a result of experiment for driving the pneumatic cylinder, we can see that tested valve can be used as both of supply and exhaust valves.
3) As comparing the characteristics of the output flow rate of the valve with the commercial valves on the market, the tested valve is suitable as a wearable control valve because of relatively larger output flow rate for their weight and size.

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