

AN INCHWORM TYPE IN-PIPE MOBILE MICROROBOT DRIVEN BY THREE GAS-LIQUID PHASE-CHANGE ACTUATORS

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1. Introduction

New in-pipe microrobot which inspect or repair thin pipes in the human body or pipelines have been searched. Pneumatic pressure or water pressure have been utilized for the power of in-pipe mobile microrobots [1], [2]. However, we noticed the power of the large change in volume that occurs during a phase-change between liquid and gas [3], [4]. When a liquid is vaporized, the volume of phase-changed gas is more than 100 times that the liquid. The gas-liquid phase-change actuator is a kind of thermal engines that need thermal energy. These actuators are suitable for microactuators used in microrobots in thin for thin pipes in the human body or pipelines, because conventional electrical power or laser beams conducted by optical-fibers can be used as the sources of vaporizing energy. We fabricated an inchworm type in-pipe mobile microrobot driven by three gas-liquid phase-change actuators. The actuators are made of welded stainless steel bellows 7.8 mm thick in outer diameter. The operating fluid is a perfluorocarbon, because its vaporizing temperature is higher than the human body and its latent heat for vaporization is only 1/22 that of water. Consequently, the energy needed for vaporization is very low. The fabricated microrobot is confirmed to move stably with the speed of 2.4 mm/s.

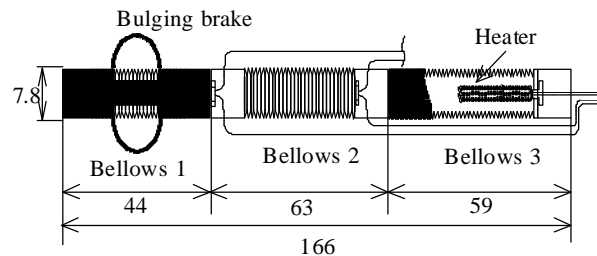


Fig. 1 Structure of the microrobot

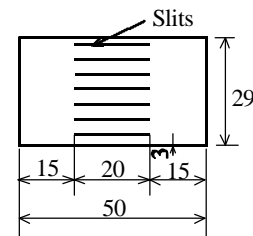


Fig. 2 The bulging brake



Fig. 3 A photograph of the fabricated microrobot

2. Structure of the fabricated microrobot

Structure of the fabricated in-pipe mobile microrobot is shown in Fig. 1. The microrobot consists of 3 gas-liquid phase-change actuators. The actuator is made

of welded stainless steel bellows whose dimension is 7.8 mm in outer diameter, 3.0 mm in inner diameter. The operating fluid and a heater are enclosed in the bellows. The heater to vaporize the operating fluid is made of a coiled constantan wire which is 0.2 mm thick and 320 mm long. Its electrical resistance is 5.2 W. The operating fluid is non-chlorine perfluorocarbon ($C_5F_{11}NO$). Its vaporizing temperature at atmospheric pressure is 325 K (122 degree in Fahrenheit) and the latent heat for vaporization is 104.56 kJ/kg.

The second (center) actuator 31 mm long is called as a driving element, because the actuator drives the inchworm type microrobot by its stretching and shrinking motion. The first (front) and the third (rear) actuators 44 mm long are called as holding elements, because the actuators are provided seven frictional bulging brakes. The frictional bulging brake which is shown in Fig. 2 is made of vinyl chloride or nitrile butyl rubber (NBR). The holding element works as a brake of the inchworm type microrobot. Friction force of vinyl chloride is smaller than that of NBR. When the actuator of the holding element shrinks, the diameter of seven frictional bulging brakes is 18 mm. The spread bulging brakes surely hold the pipe. According to the stretching of the actuator, the diameter of seven frictional bulging breaks decreases. When the actuator of the holding element stretches 3 mm, the diameter of seven frictional bulging brakes is 10 mm. Then the braking is canceled. The photograph of the microrobot at the free condition is shown in Fig. 3. The microrobot control system is shown in Fig. 4. The system consists of a computer, a power supply and an electric power controller. The cycle of the electric power is shown in Fig. 5.

3. Moving principle

Moving principle is shown in Fig. 6.
 (a) Step 0: All actuators are shrinking.

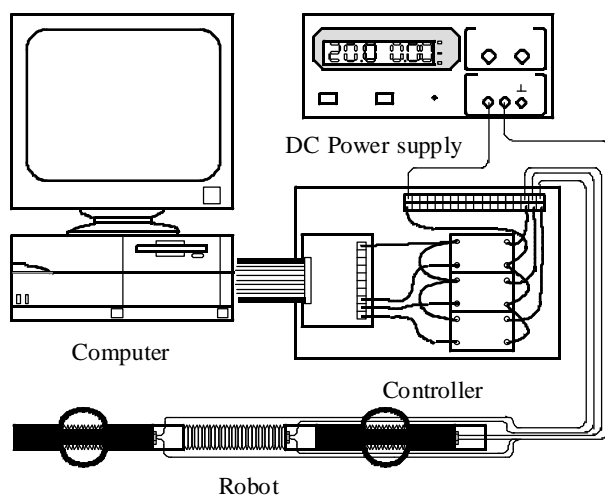


Fig. 4 The control and driving system

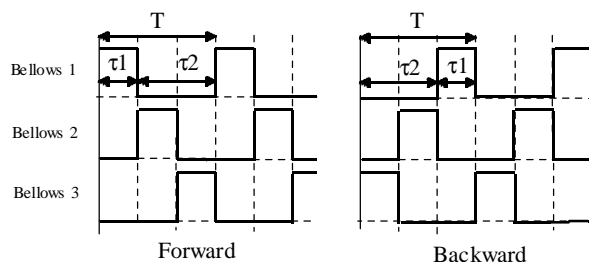


Fig. 5 Cycle time for the microrobot

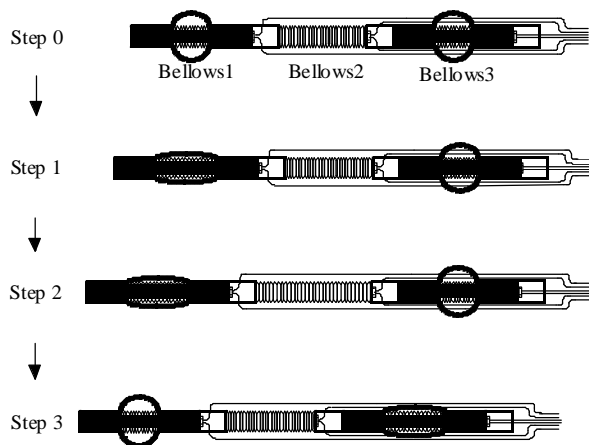


Fig. 6 The principle of microrobot

Consequently, the diameter of frictional bulging brakes of the first and third actuator is large and the braking is done.

(b) Step 1: Electrical power is supplied to the first actuator. Then the actuator

stretches and the frictional bulging brake is released.

(c) Step 2: Electrical power is supplied to the second actuator. The actuator stretches and pushes out the microrobot. At this period, electrical power to the first actuator is cutting off. However, the frictional bulging brake is releasing, because the gas is liquefying and the actuator is stretching. Consequently, the front end of the microrobot is pushed out.

(d) Step 3: Electrical power is supplied to the third actuator. The actuator stretches and the frictional bulging brake is released. At this period, the first actuator already shrinks. The diameter of frictional bulging brakes of the first is large and the braking is done. Electrical power to the second actuator is cut off and the actuator shrinks. Consequently, the rear end of the microrobot is pushed out to the forward direction.

(a) Step 0: All actuators are shrinking. Consequently, one cycle of stretching and shrinking motion of the microrobot is finished. The microrobot is moved to the forward direction in one cycle. If the cycle is reversed, the microrobot can move to the backward direction.

4. Moving experiment

The microrobot is inserted in a 16 mm inner diameter pipe filled with water. The moving characteristics of the microrobot equipped frictional bulging brakes made of vinyl chloride is shown in Fig. 7. When three actuators are stretched in turns from the first to the third, the microrobot moves to the forward direction. When the order of stretching in three actuators is reversed, the microrobot moves to the backward direction. However, the difference of speed between the forward direction and the backward direction is small. Maximum speed of 2.4 mm/s was obtained at the cycle time of 1000 ms.

The moving characteristics of the microrobot equipped frictional bulging brakes made of NBR is shown in Fig. 8. The

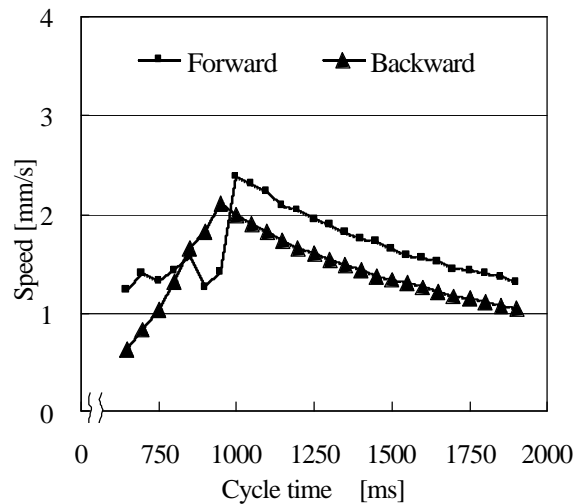


Fig. 7 Moving speed by the vinyl chloride brake

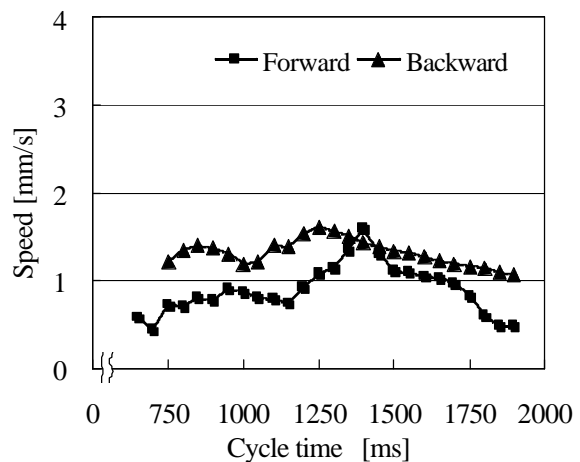


Fig. 8 Moving speed by the NBR brake

difference of speed between the forward direction and the backward direction is also small in this case. Maximum speed of 1.6 mm/s was obtained at the cycle time of 1300 ms. It is confirmed that the speed of microrobot equipped brake of small friction coefficient is larger than the speed of microrobot equipped brake of large friction coefficient.

The speed of the microrobot may be improved by decreasing of the operating fluid and refinement of the frictional brakes. The

microrobot may be used for the heart catheter, if we apply thin bellows actuators less than 1 mm.

5. Conclusions

(1) We fabricated an inchworm type in-pipe mobile microrobot driven by three gas-liquid phase-change actuators.

(2) We confirmed that the microrobot moves to the forward direction when three actuators are stretched in turns from the first to the third and the microrobot moves to the backward direction when the order of stretching in three actuators is reversed.

(3) The microrobot was inserted in a 16 mm inner diameter pipe filled with water. Maximum speed of 2.4 mm/s was obtained by the microrobot equipped frictional bulging brakes made of vinyl chloride.

References

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