HIGH-SPEED METAL-BELLOWS EARTHWORM TYPE IN-PIPE MICROROBOT

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Abstract

We fabricated a prototype of a new earthworm type microrobot which is able to move in the thin pipe with very high-speed. The microrobot is made by three flexible metal-bellows which is 6.8 mm in diameter and 20 mm long. The material for the bellows is nickel. The microrobot is driven by the pneumatic pressure and vacuum pressure. The maximum speed of 21 mm/s was obtained in the acrylic pipe of 9 mm in inner diameter. The maximum speed of 18 mm/s was obtained in the small intestine of a sheep held in an acrylic pipe.

Keywords**:** High-speed, Metal-bellows, Earthworm, In-pipe, Microrobot

1. Introduction

In-pipe mobile microrobots which inspect or repair thin pipes in the atomic plants, pipelines, intestines or blood vessels have been developed. Kato et al. have presented an inchworm type and an earthworm type microrobot [1], [2]. Pneumatic pressure and vacuum pressure were used to drive these microrobots.

We fabricated a prototype of a new earthworm type microrobot which is able to move in the thin pipe with very high-speed. The microrobot is made by three flexible metal-bellows which is 6.8 mm in diameter and 20 mm long. The material for the bellows is nickel. The microrobot is connected with three thin tubes which are 1 mm in inner diameter, 1000 mm long and feed pneumatic and vacuum pressure to the microrobot. The air-feeding tubes are 2 times larger than the microrobot which we fabricated last years in their length and inner diameters. The pneumatic pressure of +0.035 MPa and the vacuum pressure of –0.085 MPa are used to drive the microrobot. These two pressures are switched by three electromagnetic valves. First, the vacuum pressures are supplied to the three metal-bellows. The microrobot is shrunk at that time. Then, the pneumatic pressure pulses are sequentially supplied to the top, the second and the third bellows. A tractile wave generated by the stretching and shrinking motion goes to the backward direction in the metal-bellows. The microrobot repeats such stretching and shrinking motion which leads to go forward direction. If we want to reverse the microrobot, the pneumatic pressure must be supplied from the third to the top bellows.

The microrobot is equipped with four friction-rings which are located at the joint of the metal-bellows. The rings are 9 mm in outer diameter and 0.3 mm thin made of vinyl chloride. These rings make friction force between the pipe and the microrobot. A ring makes the force of 0.08 N for the forward direction and 0.13 N for the backward direction in acrylic pipe of 9 mm in inner diameter. A ring also makes the force of 1.02 N for the forward direction and 1.21 N for the backward direction in the small intestine of sheep held in acrylic pipe of 9 mm in inner diameter.

The maximum speed of 21 mm/s was obtained in the acrylic pipe of 9 mm in inner diameter. The cycle time was 0.09 s. This speed is 1.2 times of former fastest speed of 18.2 mm/s The maximum speed of 18 mm/s was obtained in the small intestine of a sheep held in an acrylic pipe. The cycle time was 0.09 s. The intestine of a sheep is almost same as the large intestine of human child. This robot is also effective for inspect in the intestine of human child.

2. Structure of the fabricated microrobot

We fabricated a prototype of a new earthworm type microrobot which is able to move in the thin pipe with very high-speed. The microrobot is structured by a flexible metal-bellows. The cross section of the microrobot is shown in Fig. 1. The material for the bellows is nickel. The microrobot is 6.8 mm in inner diameter and 60 mm long. Three silicon air-tubes which feed pneumatic and vacuum pressure to the microrobot. The air-tubes are 0.5 mm in inner diameter, 1 mm in outer diameter which is put within inside of the metal-bellows. The air-tubes are put within outside of the metal-bellows which are 1 mm in inner diameter and 2 mm in outer diameter and 1000 mm long, because these thick tubes are easy to supply the air. Four friction-rings which are 9 mm in outer diameter, 4 mm in inner diameter and 0.3 mm thin are fixed at all ends of the bellows. The friction-rings are made of vinyl chloride These rings make friction force between the pipe and the microrobot.

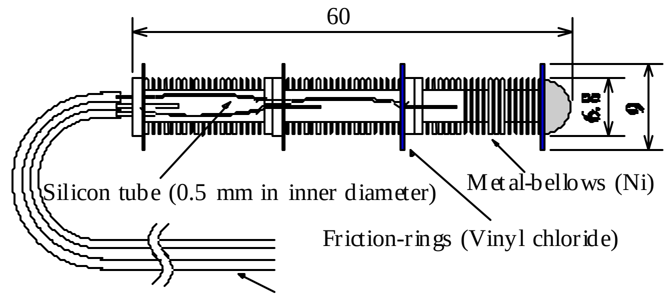

FIg. 1 Structure of the earthworm type microrobot

The moving principle of microrobot shown in Fig. 2.

1) The vacuum pressures are supplied to the three metal-bellows. The microrobot shrinks at that time.
2) The pneumatic pressure is supplied to the top bellows, the top bellows stretches.
3) The pneumatic pressure is supplied to the second bellows, and vacuum pressure in supplied to the top bellows, the second bellows stretches and the top bellows shrinks.
4) The pneumatic pressure is supplied to the third bellows, and vacuum pressure is supplied to the second bellows, the third bellows stretches and the second bellows shrinks.

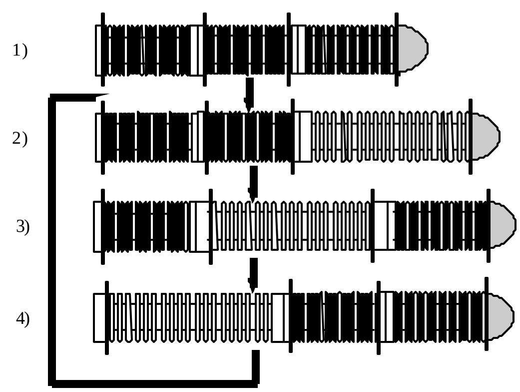

Fig. 2 Movement of tne earthworm type microrobot

A tractile wave generated by the stretching and shrinking motion goes to the backward direction in the metal-bellows. The microrobot repeats such stretching and shrinking motion which leads to go forward direction. If we want to reverse the microrobot, the pneumatic pressure must be supplied from the third to the top bellows.

3. Frictional force

Four friction-rings which fixed at ends of the bellows. The friction-rings made of vinyl chloride. These rings make friction force between the pipe and the microrobot. The friction forces made by the friction-rings are shown in Table. 1. A ring makes the force of 0.08 N for the forward direction and 0.13 N for the backward direction in acrylic pipe of 9 mm in inner diameter. A ring also makes the force of 1.02 N for the forward direction and 1.21 N for the backward direction in the small intestine of sheep held in acrylic pipe of 9 mm in inner diameter. The friction force is backward direction larger than forward direction. Consequently, the microrobot is able to go forward by these differences.

Table. 1 Frictional force

	Forward direction (N)	Backward direction (N)	Difference of both forces (N)
Acrylic pipe	0.08	0.14	0.06
Sheep's small intestine	1.03	1.21	0.18

4. Moving speed

An experimental apparatus for measuring the speed of the microrobot is shown in Fig. 3. A computer controls three electromagnetic valves through a valve controller. Three feeding air-tubes are connected from the electromagnetic valves to three metal-bellows and independently feed the pneumatic and the vacuum pressure to each metal-bellows. The vacuum pressure is –0.085 MPa and the pneumatic pressure is +0.03 MPa. The pulse width time is changed from 0.03 seconds to 0.3 second. The displacement of the metal-bellows is measured by the laser displacement indicator to calculate the virtual speed.

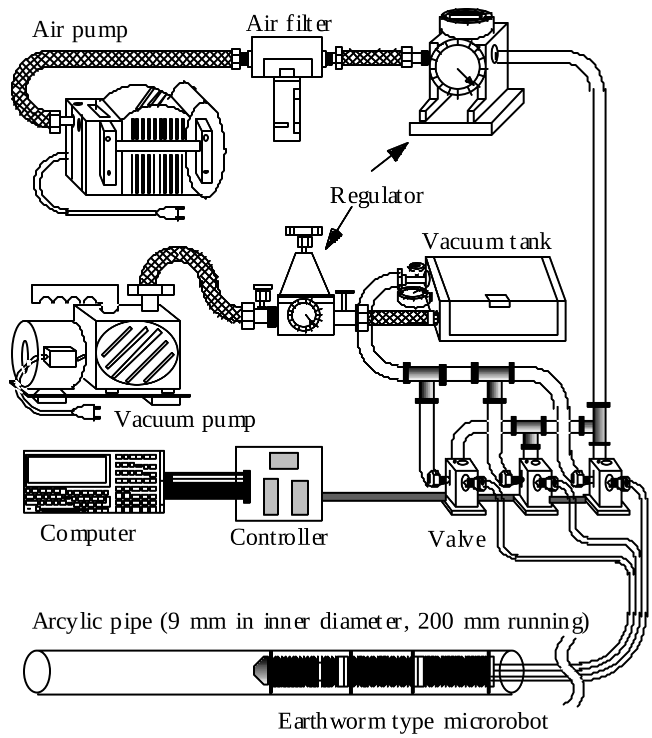

Fig. 3 Exprementa l apparatus

The speed of the microrobot is shown in Fig. 4. The maximum speed of 21 mm/s was obtained in the acrylic pipe of 9 mm in inner diameter. The cycle time was 0.09 s. The maximum speed of 18 mm/s was obtained in the small intestine of a sheep held in an acrylic pipe. The cycle time was 0.09 s. The virtual speed of 25 mm/s was obtained in this cycle time was 0.06 s. The vertical traction force of 15 N was obtained in acrylic pipe.

5. Speed coefficient

The speed coefficient is shown in Fig. 5. The speed coefficient is a ratio of the real speed and the virtual speed. The speed coefficient of 0.8 was obtained in the acrylic pipe. The speed coefficient of 0.6 was obtained in the small intestine of a sheep held in an acrylic pipe. The speed coefficient of 0.8 in the acrylic pipe was higher than the small intestine of a sheep of 0.6, because the small intestine of a sheep are more flexible than metal-bellows. As a result, the real speed can be predicted by the virtual speed.

6. Conclusions

Fabrication of a prototype of a new earthworm type microrobot to inspect or to repair thin pipes in the human body or pipelines was performed. The followings are the conclusions of the fabrication.

(1) We fabricated a new earthworm type microrobot which is constructed by a metal-bellows which is 6.8 mm in outer diameter and 60 mm long. A plastic air feeding tubes which feeds pneumatic and vacuum pressure to the microrobot is 1 mm in inner diameter and vacuum pressure to the microrobot is 2 mm in inner diameter and 1000 mm long.

(2) Four friction-rings of vinyl chloride 9 mm in outer diameter are fixed at the metal-bellows. These friction-rings make friction force between the pipe and the microrobot. A ring makes the force of 0.08 N for the forward direction and 0.13 N for the backward direction in acrylic pipe of 9 mm in inner diameter. The ring makes the force of 1.02 N for the forward direction and 1.21 N for the backward direction in the small intestine of sheep held in acrylic pipe of 9 mm in inner diameter.

(3) The microrobot is able to move in an acrylic pipe of 9 mm in diameter. The maximum speed of 21 mm/s was obtained in the acrylic pipe of 9 mm in inner diameter. The cycle time was 0.09 s. The maximum speed of 18 mm/s was obtained in the small intestine of a sheep held in an acrylic pipe. The cycle time was 0.09 s. The virtual speed of 25 mm/s was obtained in the cycle time was 0.06 s. The vacuum pressure of –0.085 MPa and the pneumatic pressure of +0.03 MPa were used.

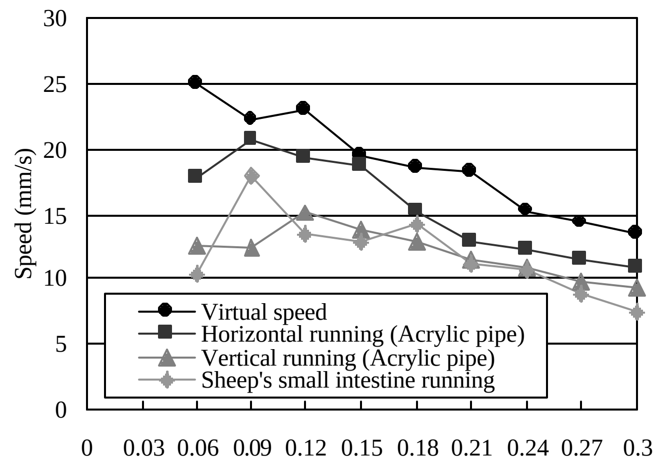

Fig. 4 Speed of the microrobot

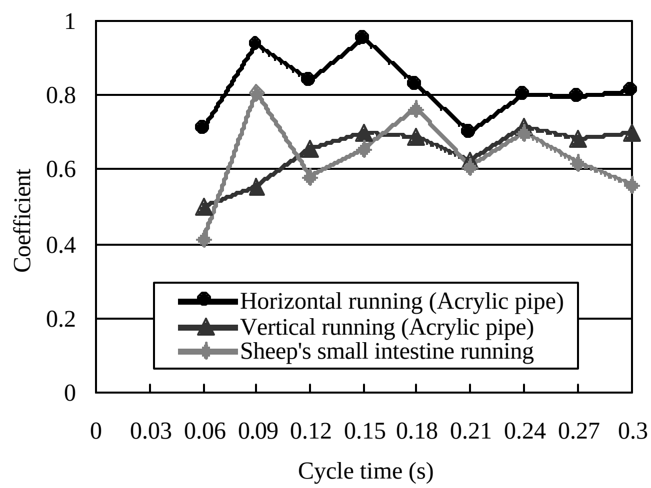

Fig. 5 Speed coefficient

(4) The speed coefficient of 0.8 and 0.6 were obtained in the acrylic pipe and in the small intestine of a sheep held in an acrylic pipe respectively. The acrylic pipe's speed coefficient was higher than the small intestine of a sheep's speed coefficient.

References:

[1] S. Kato, M. Shirakawa, M. Ohno and S. Fukumoto, *Proceedings from ASPE 1999 Annual Meeting* (1999), 37-40.

[2] S. Kato, M. Shirakawa, M. Ohno and M. Tabata, *Proceedings from ASPE 1999 Annual Meeting* (1999), 204-208.