

# FABRICATION OF IN-PIPE MOBILE MICROMACHINES DRIVEN BY PNEUMATIC AND VACUUM PRESSURE

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## Abstract

This paper presents two in-pipe mobile micromachines which are driven by pneumatic and vacuum pressure. The one earthworm type micromachine is made by three flexible metal bellows which are 6.8 mm in diameter and total length of 48 mm. The another inchworm type micromachine is structured by only two parallel arrayed rubber bellows which are 5 mm in outer diameter and 20 mm long. The pneumatic pressure is used to stretch and the vacuum pressure is used to shrink the bellows. It is confirmed that the former micromachine is able to move with the maximum speed of 18.2 mm/s, and the latter micromachine can pass freely through the junction with the angle of 120 degree.

**Keywords:** In-pipe, Mobile, Micromachine, Inchworm, Earthworm

## 1. Introduction

New micromachines to inspect or to repair thin pipes in the the human body or pipelines have been developed. Takahashi et al. have presented a flexible inching micromachine which is 20 mm in diameter and able to inch in pipes by imitating the creeping motion of an earthworm [1]. Kato et al. also have presented an earthworm type micromachine which is 16 mm in diameter and moves in a speed of 77 mm/s [2]. However, these micromachines are suitable for the pipes of diameter more than 20 mm but not suitable for the thin pipes less than 12.7 mm diameter.

Yoshida et al. a new micromachine which is made of a rubber tube and a spring of 3 mm in diameter and driven by water pressure [3]. However, moving speeds of this micromachine is not sufficient for the micromachines to inspect or to repair thin pipes in the the human body or pipelines, because the speed of the micromachine is 7 mm/s. Moreover, the blood vessel has many junctions. The former micromachines are not able to pass freely the junctions.

We fabricated new small size micromachines which are able to move in the pipes of 12.7 mm in diameter with the medium speed. The one micromachine is earthworm type and the another micromachine is inchworm type. These micromachines are made of metal and rubber bellows, respectively. The stroke of the micromachines are enlarged, because the pneumatic pressure is used to stretch and the vacuum pressure is used to shrink the bellows of the micromachines. Consequently, the earthworm type micromachine is able to move with the speed of 18 mm/s in the pipe of 9 mm in diameter and the inchworm type micromachine is able to move with the speed of 32 mm/s in the pipe of 11 mm in diameter and pass freely the junction of 120 degree.

## 2. Earthworm type micromachine

### 2.1 Structure of the fabricated micromachine

The section of the fabricated micromachine is shown in Fig. 1. The micromachine is able to move in pipes by imitating the motion of an earthworm. The micromachine is structured by three flexible Ni metal bellows. A bellows-cell is 6.8 mm in outer diameter and 15 mm (18 mm only front one) long. The total length of the micromachine is 48 mm. Three plastic air-tubes which feed

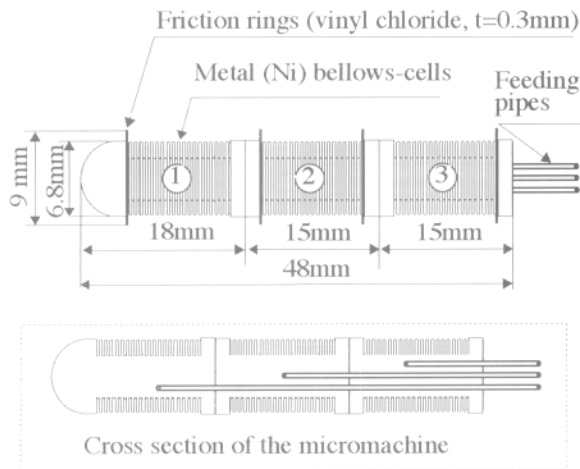


Fig. 1 Structure of the fabricated earthworm type micromachine

pneumatic pressure to the micromachine are 0.5 mm in inner diameter, 1 mm in outer diameter and 500 mm long. Four friction rings which are 9 mm in outer diameter, 3.5 mm in inner diameter and 0.3 thick are fixed at the ends of the three bellows. These rings make friction force between the pipe and the micromachine. The rings make cones, because the inner diameter of the rings is a little smaller than the diameter of the bellows. A ring makes the force of 0.03 N for the forward direction and 0.12 N for the backward direction.

An experimental apparatus for measuring the speed of the micromachine is shown in Fig. 2. In the figure two electromagnetic valves are shown, but in the earthworm type micromachine, a computer controls three electromagnetic valves through a valve controller. Three feeding air-tubes are connected from the electromagnetic valves to three bellows-cells and independently feed the pneumatic and the vacuum pressure to each bellows-cell.

The time-chart of the pneumatic pressure for the micromachine is shown in Fig. 3. First, the all bellows-cells are shrunk by the vacuum pressure. Then the pneumatic pressure pulses are sequentially supplied to the cell-1, the cell-2, and the cell-3. A tractile wave generated by the stretching and shrinking motion goes to the backward direction in the flexible bellows. Consequently, the in-pipe mobile micromachine is able to move to the forward direction.

## 2.2 Moving characteristics of the fabricated micromachine

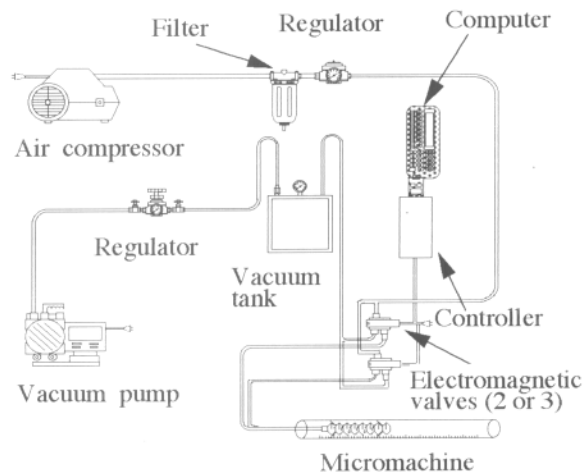


Fig. 2 Experimental apparatus for measuring speed of the micromachines

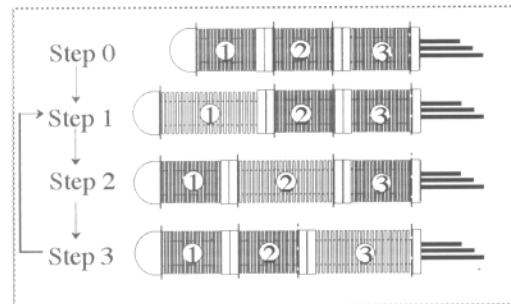
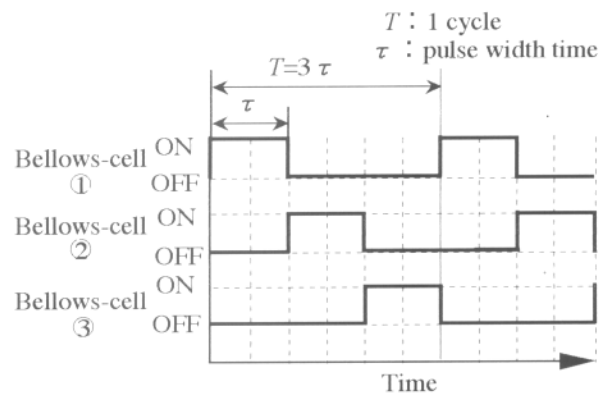


Fig. 3 Time chart of pneumatic pressure for the earthworm type micromachine

The moving speed is measured. The vacuum pressure is  $-0.095$  MPa and the pneumatic pressure is  $+0.08$  MPa. The pulse width time is changed from 0.02 seconds to 1 second. The relationship between moving speed of the micromachine in an acrylic pipe of 9 mm in diameter and the pulse width time is shown in Fig. 4. The maximum speed of 18.2 mm/s was obtained at the pulse width time of 0.07 seconds.

### 3. Inchworm type micromachine with a steering mechanism

#### 3.1 Structure of the micromachine

The fabricated new in-pipe mobile micromachine with a very simple steering mechanism is shown in Fig. 5. The micromachine is structured by only two parallel arrayed rubber bellows which are 5 mm in outer diameter, 2 mm in inner diameter and 20 mm long. The two bellows are fixed at double ends by nylon-strings. The bellows are connected with a thin tube which is 1 mm in inner diameter, 500 mm long and feeds pneumatic and vacuum pressure to the bellows. Four friction rings which are 9 mm in diameter, 1.5 mm in inner diameter made of vinyl chloride are fixed at the ends of the two bellows. The rings make cones because the inner diameter of the rings is a little smaller than the diameter of the bellows. The rings make friction force of 0.14 N for forward direction and 0.35 N for the backward direction. The backward force is greater than the forward force. Consequently the micromachine can move in the pipes.

#### 3.2 Straight movement of the fabricated micromachine

First, the vacuum pressure is supplied to the two bellows, the bellows are shrunk. Then, the pneumatic and vacuum pressure are alternately supplied in the pulse width time of  $\tau$  seconds. The two bellows reciprocally moves in parallel. The chart of the pressure and the movement is shown in Fig. 6. The moving speed is measured. The vacuum pressure is  $-0.08$  MPa and the pneumatic pressure is  $+0.1$  MPa. The pulse width time is changed from 0.03 seconds to 0.2 seconds. The maximum speed of 39 mm/s was obtained at the pulse width time

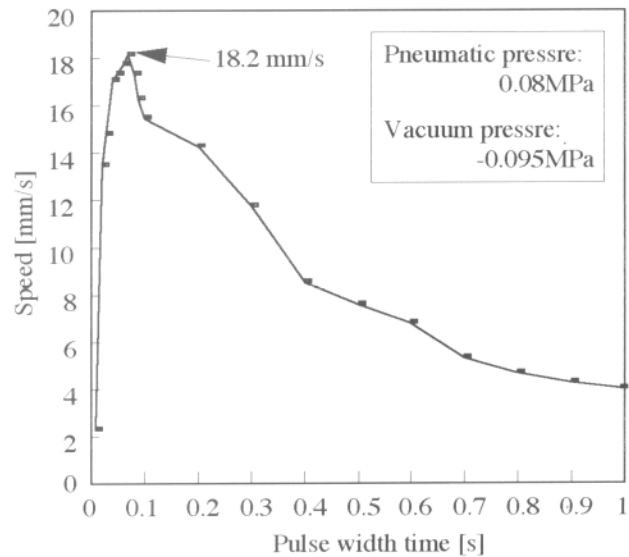


Fig. 4 Relationship between speed of the micromachine and the pulse width time

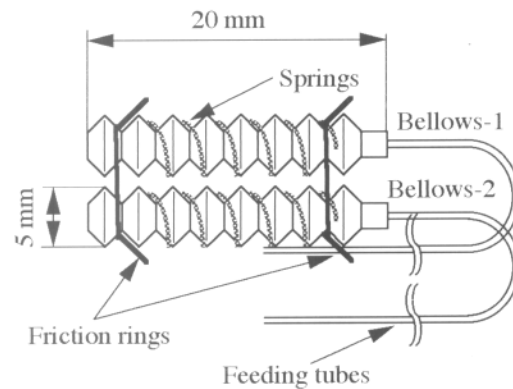


Fig. 5 A new in-pipe mobile micromachine with a very simple steering mechanism

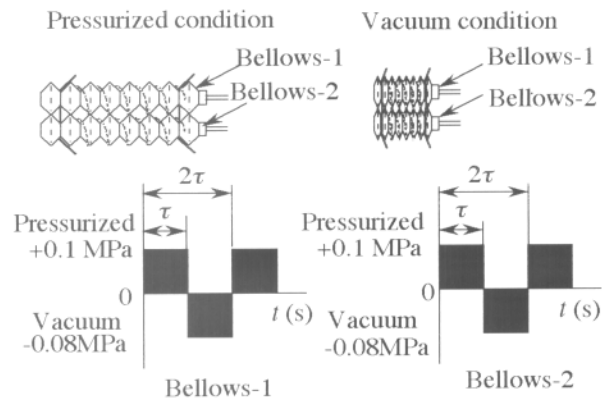


Fig. 6 The chart of the pressure and the movement of the bellows (at straight pipe)

of 0.08 seconds.

### 3.3 Steering movement of the fabricated micromachine

In order to steer, the micromachine must bend its head. Therefore, the pneumatic and vacuum pressure are supplied shown as Fig. 7. That is, bellows-2 is shrinking in all the time, because the pneumatic pressure is not supplied to the bellows-2. The other hand, the bellows-1 reciprocates by the alternate supply of the pneumatic and vacuum pressure. The double ends of the bellows-1 and bellows-2 are fixed. Consequently, the micromachine move to the forward bending its head and can pass the junction to the desired direction. The speed is good to be slow at the junction. When the micromachine moves at the slow speed of 29 mm/s, the micromachine is confirmed to pass easily the junction with the angle of 120 degrees to the desired direction. This movement is shown in Fig. 8.

### 4. Conclusions

A fabrication of prototypes of new micromachines to inspect or to repair thin pipes in the the human body or pipelines was performed. The followings are the conclusions of the fabrication.

1) We fabricated a new earthworm type micromachine which is constructed by three flexible Ni metal bellows 6.8 mm in outer diameter and 48 mm long. The micromachine is able to move in an acrylic pipe of 9 mm in diameter. The maximum speed of 18.2 mm/s was obtained at the pulse width time of 0.07 seconds, the vacuum pressure is -0.095 MPa and the pneumatic pressure is 0.08 MPa.

2) We fabricated a new in-pipe mobile micromachine with a very simple steering mechanism. The micromachine is structured by only two parallel arrayed rubber bellows which are 5 mm in outer diameter and 20 mm long. The two bellows are fixed at double ends by nylon-strings. When the vacuum pressure is -0.08 MPa and the pneumatic pressure is 0.1 MPa, the maximum speed of 39 mm/s was obtained at the pulse width time of 0.08 seconds. The micromachine was confirmed to pass easily the junction with the angle of 120 degrees to the desired direction.

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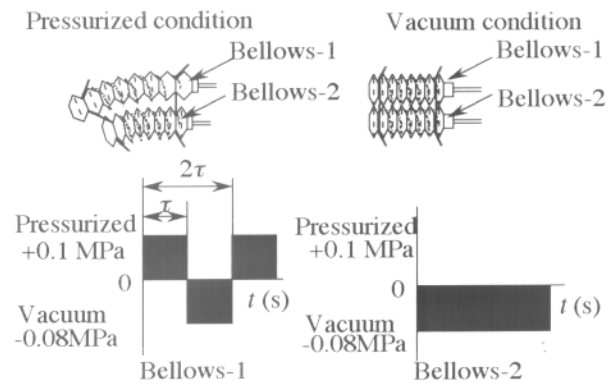


Fig. 7 The chart of the pressure and the movement of the bellows (at the junction)

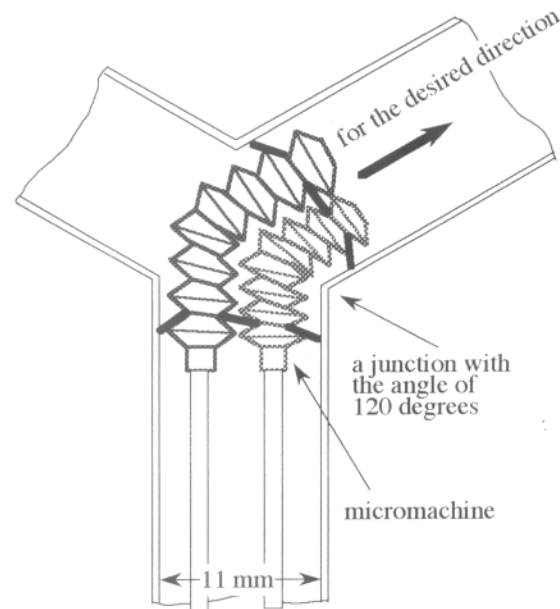


Fig. 8 The movement of the micromachine at the junction with the angle of 120 degrees