FABRICATION OF A MICROROBOT MOVABLE IN FLEXIBLE PIPES LIKE THE LARGE INTESTINE

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1. Introduction

An inspection of the large intestine is very effective in order to prevent the large intestine cancer. A fiberscope is excellent for the inspection of the large intestine. However, the inspection by the fiberscope often attends many pains and injuring of the intestine. We are hoping the inspecting method for the intestine with no pain and no injuring of the intestine before the operation by the fiberscope. Some microrobots which can move in the large intestine have been proposed by several research groups [1], [2]. However, the sure moving in the large intestine has not been confirmed, because the actual large intestine in our human body is especially very flexible to the radius direction and the mobile moving in the flexible pipes is very difficult.

Now, we propose a new model of mechanism that can surely move in a flexible pipe like the large intestine. We need holding the flexible pipe to the radius direction and driving the mechanism to longitudinal direction using the friction force by the holding the flexible pipe in order to move surely in the flexible pipe. We use three rubber bellows in series. Two outer rubber bellows are provided eight bulging rubber sheets. These are called as holding elements with braking mechanisms. So, the holding element works as a break of the moving mechanism. The center rubber bellows is called as a driving element, because the rubber bellows drive the moving mechanism by its stretching and shrinking motion.

When the rubber bellows of the holing element shrinks, eight bulging rubber sheets spread to the radius direction and touch the flexible pipe. Then the spread bulging rubber sheets surely hold the flexible pipe. When the rubber bellows of the holing element stretches, spreading to the radius direction of the eight bulging rubber sheets and touching to the large intestine are canceled. The rubber bellows are stretched by pneumatic pressure and shrank by vacuum pressure. The stretching and shrinking of the rubber bellows are controlled by a computer and electromagnetic valves.

We confirmed that the new mobile mechanism, which is equipped two holding elements and a moving element, can move to the forward and backward direction in the flexible pipe like the intestine.

2. Structure of the fabricated mobile moving mechanism

Structure of the fabricated mobile moving mechanism is shown in Fig. 1. The mobile moving mechanism consists of two holding elements and a moving element. These elements are driven by three bellows which are 16 mm in outer diameter, 11 mm in inner diameter, 30 mm long and made of nytrile butyl rubber (NBR). Each bellows is an independent vessel. Three air-feeding tubes, which are 1.2 mm in outer diameter, 0.6 mm in inner diameter and 1.5 m long, are connected to three bellows of the holding elements and the moving element. The rubber bellows are stretched by the supply of the pneumatic pressure and are shrunk by the supply of the vacuum pressure. The stretching and shrinking of the bellows are controlled by three electromagnetic valves and a computer.

A braking mechanism of the holding element is shown in Fig. 2. The braking mechanism consists of eight bulging rubber sheets which are 5 mm wide, 0.5 mm thick, 20 mm long and made of NBR. The length of the braking mechanism is 17 mm in the free condition and 14 mm when the pressure in the bellows is vacuum. The diameter of the braking mechanism becomes to about 26 mm. Then the bulging rubber sheets are strongly pressed to the flexible pipe like the large intestine. The friction force in the flexible pipe are made by the radial force of the bulging rubber sheets.

3. Experimental apparatus

An experimental apparatus for measuring the characteristics of the mobile moving mechanism is shown in Fig. 3. A computer controls three electromagnetic valves through a valve controller. Three air-feeding tubes are connected from the electromagnetic valves to two holding elements and the moving element of the mobile moving mechanism. An air-compressor is connected to the entrance ports of the electromagnetic valves and feeds pneumatic pressure to stretch the bellows. A vacuum pump is connected to the exit ports of the electromagnetic valves and feeds vacuum pressure to shrink the bellows.

4. Moving principle of the microrobot

The pneumatic and vacuum pressure are fed like as a time-chart shown in Fig. 4. The mass flow rate through the electromagnetic valve is proportional to the absolute pressure of the upstream flow, because the electromagnetic valve is a kind of an orifice. The absolute pneumatic pressure at the time of stretching motion is more than two times of the pressure in the bellows in the time of shrinking motion. Then the supplying time of the vacuum pressure in the shrinking motion ($=t_2$) must be more than two times of the supplying time of the pneumatic pressure in the stretching motion ($=t_1$). The sum of t_1 and t_2 is called as the cycle time ($=T$).

As shown in Fig. 4, we make a time difference of $t_1/2$ in the pneumatic supplying time among the front holding element, the

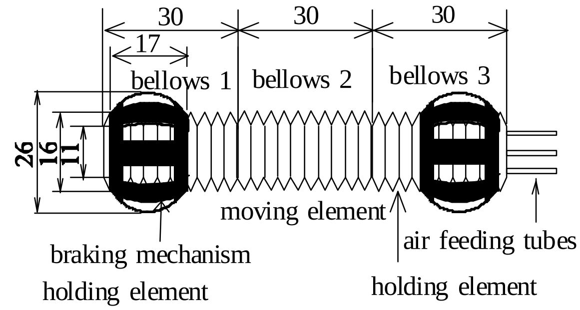

Fig. 1 Structure of the fabricated microrobot

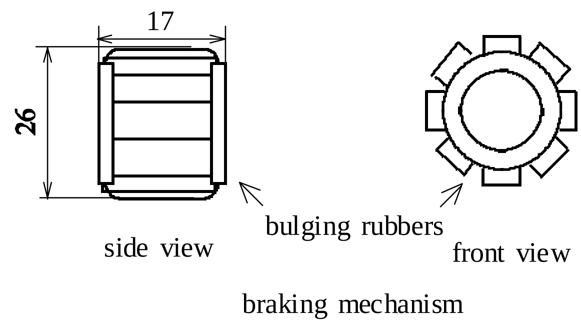

Fig. 2 Structure of a braking mechanism of the hold element

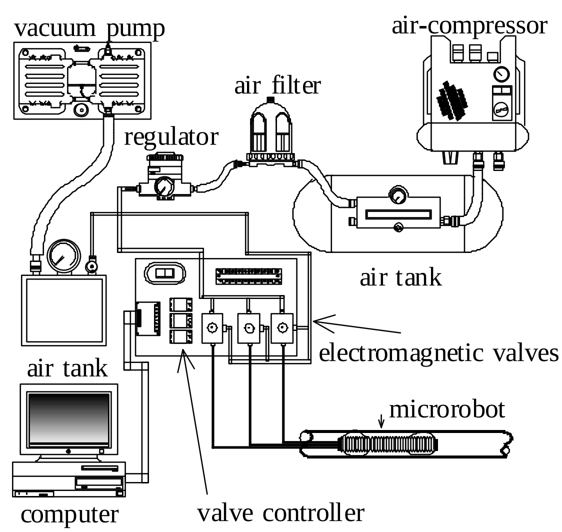

Fig. 3 Experimental apparatus

central moving element and the rear holing element. The mobile moving motion is estimated as Fig. 5, when the pneumatic and vacuum pressure are supplied as shown in Fig. 4.

(1) At initial, all the bellows are shrinking by the vacuum pressure. The braking mechanisms of the front and rear holding element are at the condition of the braking and hold the flexible pipe.

(2) The pneumatic pressure is fed to the front holding element and the braking is free.

(3) The pneumatic pressure is fed to the central moving element and the mobile moving mechanism is stretching. Then the front part of the mobile moving mechanism can move to the forward direction, because the rear holding element is still at the condition of the braking and holds the flexible pipe.

(4) The pneumatic pressure is fed to the rear holding element and the braking is free. At the same time, the vacuum pressure is fed to the front holding element and it is at the condition of the braking. The vacuum pressure is fed to the central moving element and the mobile moving mechanism is shrinking. Then the rear part of the mobile moving mechanism can move to the forward direction, because the braking of the rear holding element is free.

(5) All the bellows are shrunk by the vacuum pressure. The braking mechanisms of the front and rear holding element are in the condition of braking and hold the intestine. It is same as the initial condition and one cycle is over. The mobile moving mechanism moves the stretching displacement of the moving element. Consequently the speed is shown by (stretching displacement) / (cycle time).

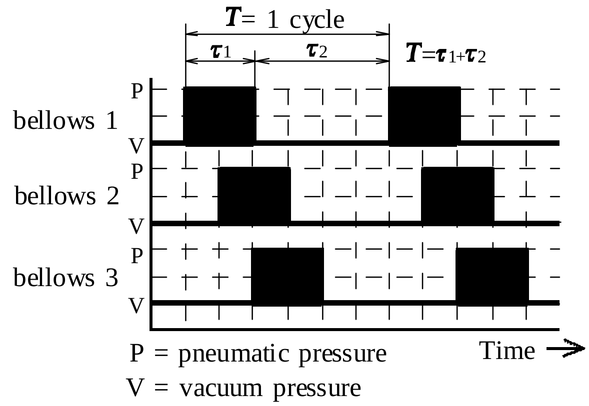

Fig. 4 Time chart of the pneumatic and vacuum pressures for the each bellows

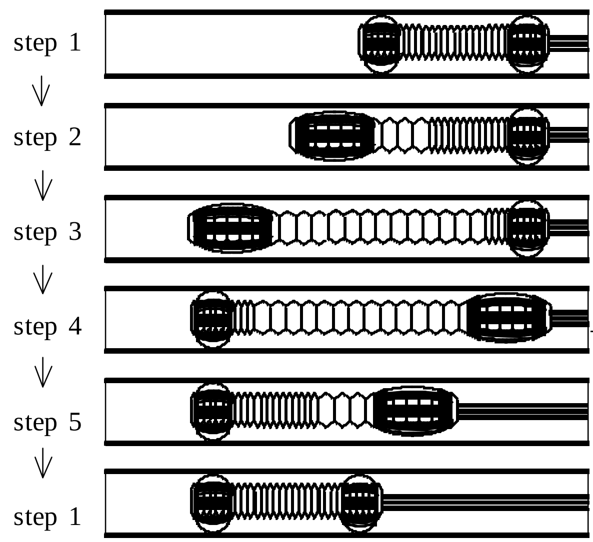

Fig. 5 Moving principle of microrobot

5. Measurement of the speed

We measured the speed of the mobile moving mechanism supplying the pneumatic pressure of 0.08 [MPa] and the vacuum pressure of -0.08 [MPa]. We chose that the supplying time of the pneumatic pressure in the stretching motion ($=t_1$) is 0.2 seconds. The supplying time of the vacuum pressure in the shrinking motion ($=t_2$) was changed. Relationship between the cycle time and the speed is shown in Fig. 6. The mobile moving mechanism was confirmed to move at the speed of 39 [mm/s]. In this experiment, it was also confirmed that the mobile moving mechanism is able to move to the vertical direction and to generate the traction force of 0.8 [N].

6. Conclusions

(1) We fabricated of a new microrobot that can surely move in a flexible pipe like the large intestine. The moving mechanism consists of two holding elements and a moving element. The holding element has a braking mechanism which consists of eight bulging rubber sheets.

(2) We confirmed by the experiment that the moving mechanism can move to the forward and backward direction in the flexible pipe like the intestine. The mobile moving mechanism was confirmed to move at the speed of 39 [mm/s]. It was also confirmed that the mobile moving mechanism is able to move to the vertical direction and to generate the traction force of 0.8 [N].

(3) The mobile moving mechanism may be used to the inspection mobile microrobot for the human large intestine, because the pig's small intestine is very similar to the human large intestine.

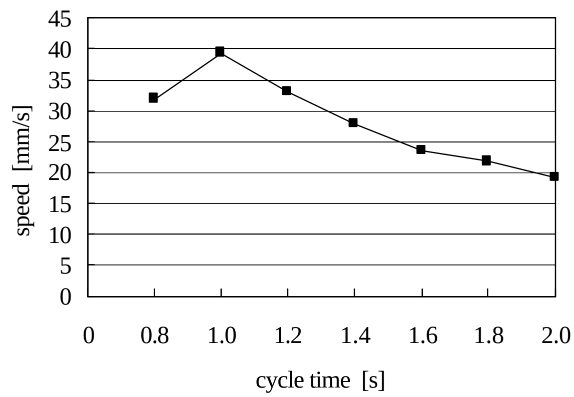

Fig. 6 Relationship between speed and cycle time

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[2] M. Ono, E. Arakawa, S. Kyoumine, S. Kato, Fabrication of a Microrobot Movable in a Freely Held Pig's Small Intestine, Proceedings of the 2nd International Conference of EUSPEN, pp. 806- 809.