FABRICATION OF AN INCH-WORM TYPE MOBILE MICROROBOT MOVABLE IN DIFFERENT DIAMETER AND LONG PIPES

Sigeo KATO, Manabu ONO,
Yoshiaki AIZAWA and Hisashi NAKAMURA

Nippon Institute of Technology
Miyashiro, Saitama 345-8501, JAPAN
E-mail: kato@nit.ac.jp

1. Introduction

We have many small diameter pipes which are cooling pipes for atomic power stations, boiler pipes for industries, gas and water pipe lines for individual or corporate houses. They must be periodically inspected in order to protect the accident previously. Some of these pipes are long and their diameters are different at the place where pipes change from the main to the branch. The inspection robot for these pipes must move different diameter and long distance.

A step comes where the pipe changes its diameter. The in-pipe robot driven by wheels is very difficult to cross the step [1]. We have used cone-shape friction rings for the driving legs of the in-pipe robot. However, the robot driven by friction rings is also difficult to move in the pipe where diameter changes more than 3 mm [2].

Now, we propose a mobile robot that can surely move in a long pipe whose diameter changes. We are needed to hold the different diameter pipe to the radius direction and to drive the robot to longitudinal direction using the friction force by the holding the pipe, in order to move surely in the different diameter pipe. In order to achieve this motion, we developed a new mechanism which is made of three rubber bellows in series. In the mechanism, 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 different diameter pipe. Then the spread bulging rubber sheets surely hold the different diameter 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 different diameter pipe are canceled. The rubber bellows are stretched by air pressure and shrank by vacuum pressure. The stretching and shrinking of the rubber bellows are controlled by a computer and electromagnetic valves.

The inspection robot is required to move long distance in the pipe. However, large time is needed to send air pressure pulse to the air actuators which are laid at the end of long air-feeding tube because of the compressibility of air, if the electromagnetic valve is laid near at the air pressure generators. Robots whose electromagnetic valves are laid near at the air pressure generators could not move long distance[3], [4]. So, we arranged electromagnetic valves, which make air pressure pulse, near the air actuator in the case of the fabricated mobile robot. We confirmed that the new mobile robot can move in the long and different diameter pipes.

2. Structure of fabricated robot and characteristics of elements

An in-pipe mobile robot which is able to move in pipes whose inner diameters are among 64 mm and 90 mm is shown in Fig. 1. The robot consists of two holding elements and a driving element. The holding elements are driven by bellows which are 33 mm in outer diameter, 23 mm in inner diameter, 55 mm long. The driving element is driven by bellows which is 100 mm long. They are made of nytrile butyl rubber (NBR). Each bellows is an independent vessel. Three electromagnetic valves are arranged near three bellows of the holding elements and the driving element. Consequently, these three electromagnetic valves move with the mobile robot. Two air-feeding tubes which supply air pressure and vacuum pressure and 4 mm in outer diameter, 2 mm in inner diameter are connected to the three electromagnetic valves. The rubber bellows are stretched by the supply of the air 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 10 mm wide, 2 mm thick, 80 mm long and made of NBR. The length of the braking mechanism is 80 mm and the outer diameter of the bulging brake is 40 mm in the condition where the pressure in the bellows is +80 kPa. The length of the braking mechanism is 31 mm and the outer diameter of the bulging brake is 100 mm in the condition where the pressure in the bellows is vacuum of -80 kPa. Then the bulging rubber sheets are strongly pressed to the pipe whose diameter is less than 100 mm. The friction force in the pipe are made by the radial force of the bulging rubber sheets.

3. Mobile robot system

An experimental apparatus for measuring the characteristics of the mobile robot 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 driving element of the mobile robot. These electromagnetic valves move with the mobile robot. An entrance ports of the electromagnetic valves through long air-feeding tubes and

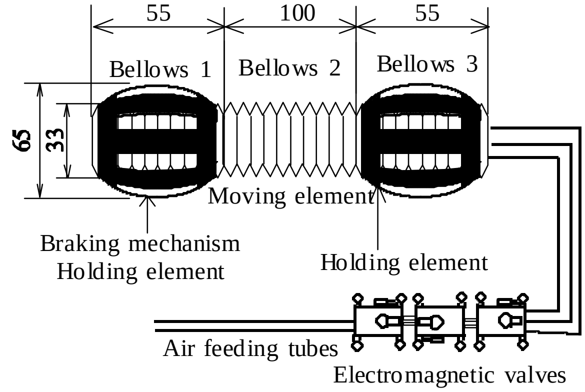

Fig. 1 Structure of the fabricated mobile robot movable in different diameter pipes

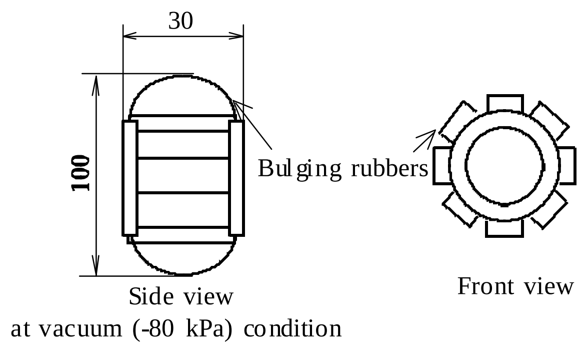

Fig. 2 Structure of the braking mechanism of the holding element

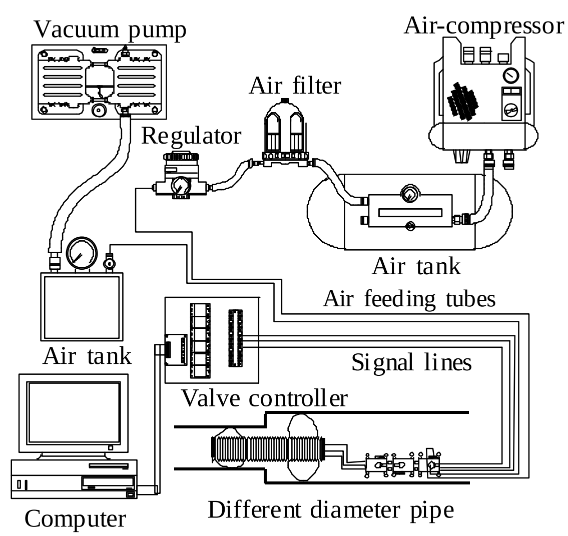

Fig. 3 Experimental apparatus of the mobile robot system

air-compressor is connected to the feeds air 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. Principle of the moving of the mobile robot

The air 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 air 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 air 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 air supplying time among the front holding element, the central driving element and the rear holing element. The mobile moving motion is shown as Fig. 5, when the air 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 pipe.

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

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

(4) The air 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 driving element and the mobile robot is shrinking. Then the rear part of the mobile robot 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 pipe. It is same as the initial condition and one cycle is over. The mobile robot moves the stretching displacement of the driving element. Consequently the speed is shown by (stretching displacement) / (cycle time).

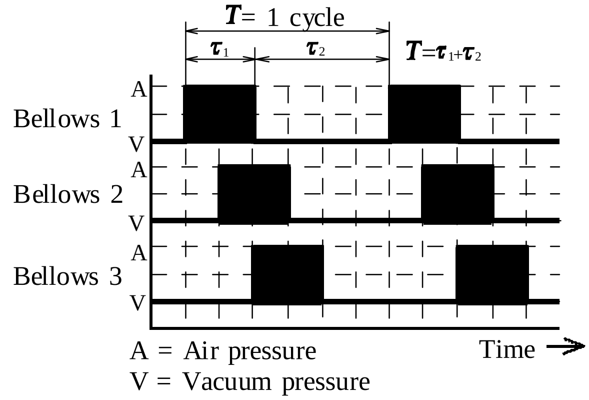

Fig. 4 Time chart of air and vacuum pressure for each bellows

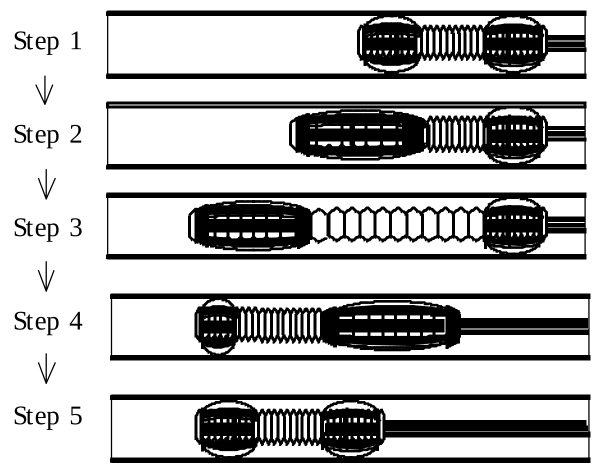

Fig. 5 Principle of the moving of the mobile robot

5. Experiments

5.1 Measurement of the traction force

We measured the generated traction force of the microrobot which moves to perpendicular direction. Relationship between the cycle time and the tractionforce is shown in Fig. 6. The maximum traction force is obtained at the cycle time of 4.2 seconds. The traction force is confirmed to be nearly equal to the friction force of the braking mechanism. Consequently, The mobile microrobot can move distance of 25 m in the case of 90 mm diameter pipe and distance of 45 m in the case of 74 mm diameter pipe.

5.2 Measurement of the speed

We measured the speed of the mobile microrobot supplying their pressure of 0.08 [MPa] and the vacuum pressure of -0.08 [MPa]. The diameters of the pipe are 90 mm, 74 mm and 64 mm. The combinations of the diameter are as follows; 90 mm and 74 mm, 90 mm and 64 mm, 74 mm and 64 mm. Moving is done from larger diameter to smaller diameter pipe. We have steps of 5 mm in minimum and 13 mm in maximum between two pipes. However, the fabricated mobile microrobot could move the steps. Relationship between the cycle time and the speed is shown in Fig. 7. The mobile microrobot was confirmed to move different diameter pipes at the speed of 20 or 27 [mm/s].

6. Conclusions

(1) We proposed a new mobile microrobot that can surely move in long and different diameter pipes. The microrobot consists of two holding elements and a driving element. The holding element has a braking mechanism which consists of eight bulging rubber sheets.

(2) The friction force between the holding element and the pipe was measured. Friction force of 9 N is obtained at the large diameter pipe of 90 mm and 20 N is obtained at the small diameter pipe of 64 mm.

(3) The mobile microrobot was confirmed to move in different diameter pipes whose combinations of the diameter are 90 mm and 74 mm, 90 mm and 64 mm, 74 mm and 64 mm. Its speeds were 20 or 27 [mm/s].

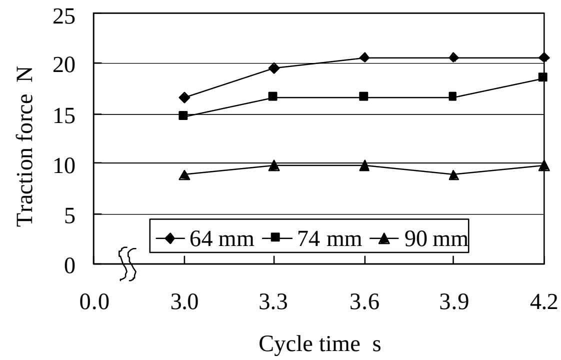

Fig. 6 Relationship between the traction force and cycle time

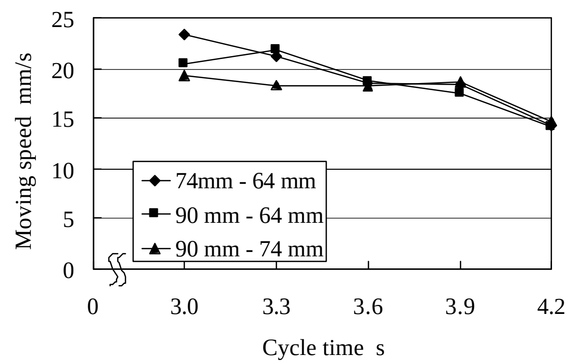

Fig. 7 Relationship between the moving speed and cycle time

References

[1] K. Kawaguti, O. Yoshida, K. Iwao and T. Kikuta, Journal of the Robotics Society of Japan, Vol 15, No. 3 (1997), 387.

[2] S. Kato and T. Hirayama, Proceedings of the Japan Society of Mechanical Engineers, Centennial Grand Congress, Intelligent Motion-control, Power transmission and Tribology, (1997), 661.

[3] M. Takahashi, I. Hayashi, N. Iwatsuki, K. Suzumori and N. Ohki, Journal of the Japan Society for Precision Engineering, Vol. 61, No. 1 (1995), 90.

[4] T. Noritugu and M. Kubota, Journal of the Robotics Society of Japan, Vol 18, No. 6 (2000), 831.