

FABRICATION OF AN ARTIFICIAL EARTHWORM TYPE MOBILE INSPECTION ROBOT MOVABLE IN 100 M LONG PIPES

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1. Introduction

We had an accident that radioactive cooling-water flowed out from the first cooling-water pipe of an atomic power plant, a few years ago. If we can insert an inspection robot and inspect the pipe, we are avoidable from the difficult removal of the heat insulating materials and radioactivity of the flowed water. The cooling-water pipe is long and 76 mm in inner diameter and has vertical parts. Robots driven by electric motor are difficult to move in the vertical pipes, because the ratio between the power and the weight of the electric motor is not large [1]. Authors have researched a new inspection robot which is able to move in the long pipe which has vertical parts and driven by pneumatic actuators, because the pneumatic actuators are advantageous concerning the ratio between the power and the weight. However, they could not move the long distance [2],[3],[4]. This is due to the compressibility of the air. We fabricated an artificial earthworm type robot in which we use three rubber bellows as pneumatic actuators. Twenty rubber friction rings are used to get friction force between bellows and the pipe. Three electromagnetic valves which control pneumatic pressure to the three bellows are attached direct behind of the robot in order to evade the flowing-lag of the pneumatic pressure. The electromagnetic valves and air-feeding tubes are carried on trolleys in order to decrease friction force

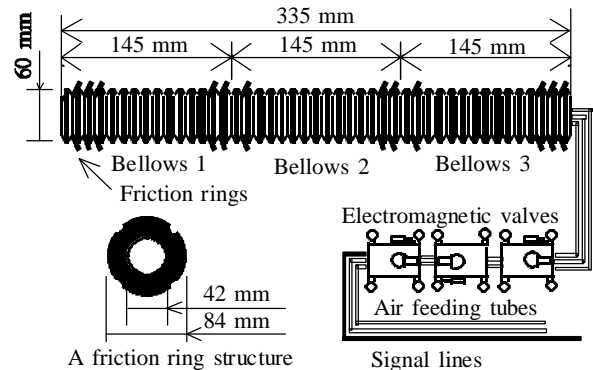


Fig. 1 Structure of the fabricated mobile inspection robot

between the pipe and them. The robot was confirmed to move in the pipe which is 100 m long.

2. Structure of the fabricated microrobot

An in-pipe mobile robot which is able to move in pipes whose inner diameter is 3 inch is shown in Fig. 1. An actual diameter of the pipe is 79 mm. The robot is constructed by three bellows for the pneumatic actuators, friction rings and three electromagnetic valves. Outer diameter, inner diameter and natural length of the bellows are 60 mm, 43 mm and 145 mm, respectively. The bellows are made of Nitrile Butyl Rubber. Total 20 friction rings are attached at the end of the three bellows as moving legs of robot. The friction rings are 84 mm in outer diameter, 42 mm in inner diameter and 1.5 mm thick. When the friction ring is attached at the bellows, the inner diameter is enlarged,

because the inner diameter of the friction ring is 3 mm smaller than the inner diameter of the bellows. Then, friction ring comes to the shape of a cone. Three electromagnetic valves which feed pneumatic and vacuum pressure are attached at direct behind of the actuators. Consequently, the electromagnetic valves move with the actuators. An air-feeding tube made of polyurethane (inner diameter is 4 mm) is attached to the electromagnetic valves in order to feed pneumatic pressure. Another air-feeding tube (inner diameters is 4 mm) are attached to the electromagnetic valves in order to feed vacuum pressure. A power line for the electromagnetic valves is bundled with air-feeding tubes. They are 120 m long.

The air-feeding tubes are carried on conveying mechanisms in order to decrease friction force between the pipe and them. The air-feeding tubes conveying mechanism consists of a chassis made of vinyl chloride pipe, 8 legs made of aluminum and 8 wheels made of plastics. The wheels smoothly rotate.

Fabricated robot system is shown in Fig. 2. Moving sequence is programmed in a computer. The computer controls the electromagnetic valves which are 120 m far away through a valve controller, using the air-feeding time schedule program for the actuators. The other ends of air-feeding tubes are attached to the air-compressor and the vacuum pump.

3. Moving principle

The air-feeding time schedule and moving principle of the robot are shown in Fig. 3. The bellows are stretched by positive pressure of 0.1 MPa, and shrunk by negative pressure of -0.08 MPa.

Step 0: All the bellows are in the shrunk condition, because the negative pressure is supplied.

Step 1: The positive pressure is supplied to the bellows 1 and the bellows 1 is stretched. Front end of the bellows 1 moves to the forward direction, because the friction

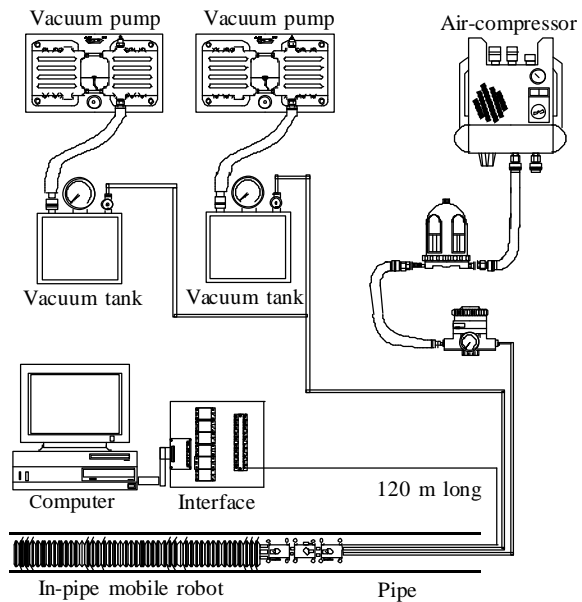


Fig. 2 Experimental apparatus of the mobile robot system

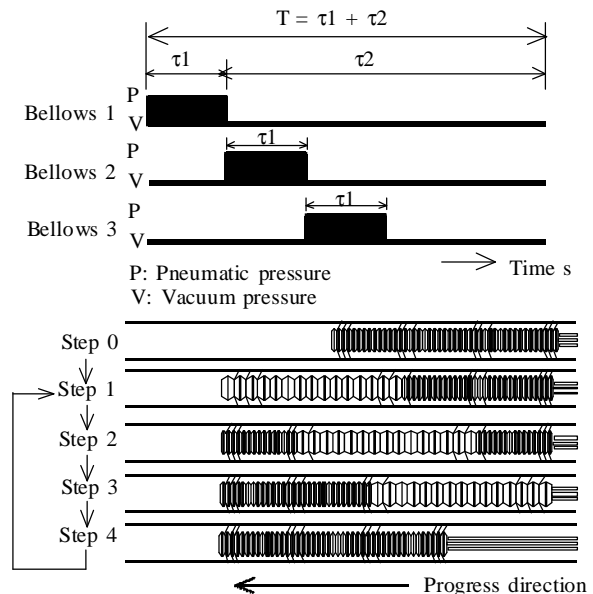


Fig. 3 Principle of the moving of the mobile inspection robot

force of the friction rings at the front end of the bellows 1 is smaller than friction force of the friction rings at the junction between bellows 1 and bellows 2.

Step 2: The negative pressure is supplied to the bellows 1 and the bellows 1

is shrunk. At the same time, the positive pressure is supplied to the bellows 2 and the bellows 2 is stretched. The junction between bellows 1 and bellows 2 moves to the forward direction, because the friction force of the friction rings at the front end of the bellows 1 is larger than friction force of the friction rings at the junction between bellows 1 and bellows 2, beside the friction force of the friction rings at the junction between bellows 1 and bellows 2 is smaller than the friction force of the friction rings at the junction between bellows 2 and bellows 3.

Step 3: The negative pressure is supplied to the bellows 2 and the bellows 2 is shrunk. At the same time, the positive pressure is supplied to the bellows 3 and the bellows 3 is stretched. The junction between bellows 2 and bellows 3 moves to the forward direction, because the friction force of the friction rings at the junction between bellows 1 and bellows 2 is larger than friction force of the friction rings at the junction between bellows 2 and bellows 3, beside the friction force of the friction rings at the junction between bellows 2 and bellows 3 is smaller than the friction force of the friction rings at the end of bellows 3.

Step 4: The negative pressure is supplied to the bellows 3 and the bellows 3 is shrunk. The end of bellows 3 moves to the forward direction, because the friction force of the friction rings at the junction between bellows 2 and bellows 3 is larger than the friction force of the friction rings at the end of bellows 3. One cycle of stretching and shrinking motion of the robot becomes end. The robot can move a stretching distance in the cycle time.

4. Moving experiment

Traction force generated at the friction ring is measured and shown in Fig. 4. The traction force of 52 N is generated at the number of 20 friction rings. Friction force of the air-feeding tubes conveying mechanism in the pipe is measured. Space between each

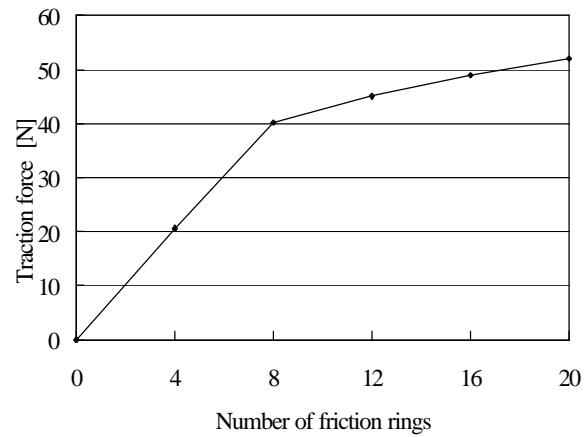


Fig. 4 Relationship between number of friction rings and generated traction force

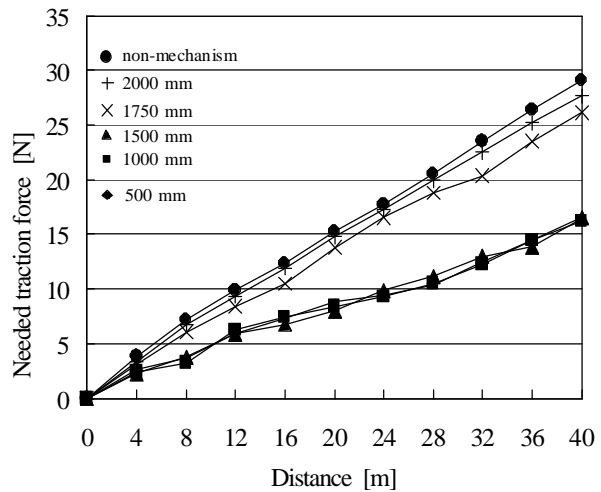


Fig. 5 Relationship between moving distance and needed traction force

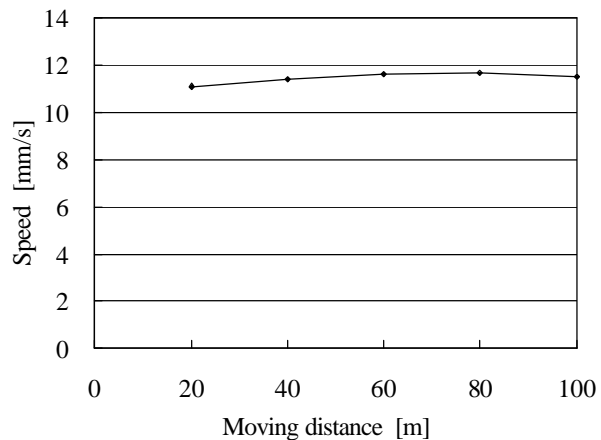


Fig. 6 Relationship between moving distance and speed

mechanism is selected as 500 mm, 1000 mm, 1500 mm, 1750 mm and 2000 mm. Friction force is shown in Fig. 5.

The friction force of the group in 1750 mm, 2000 mm and infinite (non-mechanism) is about 0.7 N/m, because the air-feeding tubes touch the pipe. The other hands, the friction force of the group in 500 mm, 1000 mm and 1500 mm is about 0.4 N/m, because the air-feeding tubes do not touch the pipe.

So, the space between each mechanism is selected as 500 mm. Then, the friction force of 40 N may be occurred for the moving distance of 100 m. However, the robot equipped 20 friction rings can generate 52 N. Moving speed and moving distance of the robot is shown in Fig. 6. The moving speed increases according to the moving distance. Finally, the moving of 100 m distance was confirmed.

5. Conclusions

(1) We fabricated an artificial earthworm type mobile inspection robot which is constructed by three bellows, 20 friction rings and three electromagnetic valves.

(2) The robot was confirmed to move in the pipe which has 79 mm in inner diameter

and 100 m long.

(3) The traction force depends on the number of friction rings. The inspection robot equipped with 20 friction rings may be able to move more than 130 m. We obtained feasibility on an in-pipe inspection robot of the first cooling-water pipe of atomic power plant.

References

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