Development of a Throw & Collect Type Rescue Inspector

- 6th Report: Control of the Throwing Distance by a Magnetic Brake Cylinder -

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Abstract: For an effective search for survivors over debris in collapsed buildings, the authors have been developing the Throw and Collect type rescue inspector. The performance of this rescue robot is based on the parent robot throwing the child machine, equipped with cameras and sensors over high debris for inspection of the area and for searching for survivors, and then to draw it back, which should be better than trying to roll over, or jump over obstacles, as usual robots do. The throwing mechanism consists of a magnetic brake cylinder, which was developed to overcome the problems of the internal pressure fall of the pneumatic cylinder when moving light loads. However, the first magnetic brake cylinder designed does not have the necessary structure and mechanism to provide control over the child machine's throwing distance. This paper describes the design and the controlling method of a new magnetic brake cylinder, which allows control of the throwing distance of the child machine.

Key Words: Rescue Robot, Fluid Energy

1. Introduction

As terrorism and natural disasters occur with more frequency these days, the demand for robots with high efficiency for searching survivors inside collapsed buildings has been increasing. These kinds of robots are desired to be: i) light and small sized, so they can be transported and inserted easily inside the collapsed building; ii) designed to have high performance in getting over debris and furniture inside the building; iii) able to be manipulated remotely, without looking directly at the robot.

To attend to these demands, the authors developed a new rescue robot, capable of searching for survivors in a rubble environment: the Throw and Collect Mobile Robot.^[1] This robot is composed of a child machine, equipped with camera, microphone and speaker, and it is attached by a tube to the parent robot, which has locomotion ability (Fig.1). Its actions to perform the search are as follows: ①The parent robot is inserted inside the collapsed building; ②The robot moves in while the area offers the possibility; ③The child machine is thrown over any high obstacle by the parent robot; ④The parent robot draws the tube, performing the search with the child machine

Fig. 1 Rescue operation by a throw and collect type with a mobile parent robot

The Leg-in-Rotor-V mobile robot^[2], also developed by the authors, can be seen in Fig. 2, equipped with the throwing and drawing mechanisms and performing a search beyond a 2 meters high obstacle.

Fig. 2 Throwing of a child machine over a 2m high obstacle

Furthermore, the parent robot can be classified as a mobile robot as in Fig. 1, or as a debris penetrating robot as in Fig. 3, differing one from another by the accessing method into the building. What these parent robots would have in common are the throwing mechanism and the child machine.

Fig. 3 Throw and collect type with a telescopic parent robot

Figure 4 shows an experiment of a rescue operation in a train station using the Throw and Collect type rescue inspector. This rescue inspector is composed of a telescopic type parent robot, equipped with the throwing mechanism, the drawing mechanism, and a child machine.

Fig. 4 Rescue operation in a train station

2. Developed Elements Up to Now

2.1 Developed Child Machine

The child machine (Fig.5) was developed with mechanisms to avoid getting stuck in the obstacles while being drawn back by the parent robot. Its weight is 350 grams and it is equipped with a wireless camera with microphone, magnetic brake cylinder, and with active and passive wheels.^[3]

Fig. 5 Developed child machine

2.2 The Drawing Mechanism

The drawing mechanism is composed of a taper case and an active pinch-roller (Fig. 6). After throwing the child machine, the pinch-roller pinches the tube that attaches the child machine to the parent robot, and the roller is driven by a motor in order to pull back the tube into the taper case.

Using the tube's elasticity, the pinch-roller pushes the tube into the taper case, and the tube winds up by itself. This allows the structure to be simple, without extra actuators and reel.

Fig. 6 Drawing mechanism

2.3 The Throwing Mechanism

The throwing mechanism consists basically of a cylinder, which differs from common ones with a magnet inside (Fig.7). With this structure, the piston-rod starts to move only when the pressure is high enough, making the moving force of the piston higher than the magnet's attractive force. This structure was used to avoid the pressure fall inside the cylinder when moving light loads.

Fig. 7 Magnetic brake cylinder

Although this structure solves the problem of internal pressure fall in the cylinder, it only enables it to perform throws of a great distance. It is impossible to throw the child machine short or middle distances, which is desired when inspecting areas nearer to the parent robot. To do so, the child machine should be thrown and collected until the desired area is reached, taking too much time in the process.

This paper demonstrates the design and controlling methods of a new magnetic brake cylinder, capable of throwing the child machine into desired bands of distances. In section 2, the ideas and the development of a new magnetic brake cylinder is shown, and the controlling methods for this cylinder is described in section 4.

3. Structure Aimed to Control the Throwing Height

As seen in the previous section, the structure of the cylinder should be changed in order to allow the control of the throwing height. Therefore, the authors came up with three ideas, and since the cylinder should be restructured, the aim was also to make it lighter and able to throw the child machine farther. Although three ideas were proposed, only one of them allowed achieving the above objectives. This section shows the three ideas and the developed new magnetic cylinder.

3.1 Method 1: Drive of a Permanent Magnet

The first idea was to change the attracting force by inclining the magnet. By deviating the magnet's angle position θ (Fig.8), it changes the contact area between the magnet and the piston, altering the magnetic circuit.

Fig. 8 Deviation of the magnet's position

As the angle θ increases, the air gap between the magnet and the piston increases, and the attractive force decreases. Thus, this method consists of altering the attractive force by changing the air gap between the magnet and the piston.

Although the idea is simple, to implement it inside the cylinder would require more space, since there is need of using a servo-motor to alter the magnet's position. In addition, the mechanical structure necessary to move the magnet would be complex and to control the piston's output wouldn't be a simple task.

3.2 Method 2: Combination With an Electromagnet

Still with the idea of changing the magnetic circuit, another possibility is to use an electromagnet. With an electromagnet, it is possible to control the magnet's attractive force easily by altering the magnetic circuit as shown in Fig.9. In order to make it possible, the new structure would require a pole piece and a yoke, used to complete the magnetic circuit.

Fig. 9 Cylinder's lower part with an electromagnet

With the electromagnet, it is possible to increase or to decrease the magnet's attractive force by controlling the current's amplitude in the coils, creating a coupled drive (magnet + solenoid).

This would be the easiest controlling method,

needing only a device to change the inputted current into the solenoid. However, the problem with using this structure is that the weight of the cylinder would increase in 90% to more, because of the yoke and the coil's size. If the coil is small, it requires high currents in order to change the attractive force, and high currents in a small sized robot are not desired because it needs powerful batteries. But the coil being large, it would need space and the cylinder's weight would increase.

Another issue would be the cost to construct the yoke. As known, the best materials to make a yoke are expensive, and it is difficult to process it to the desired shape without losing its properties.

3.3 Method 3: Separation of Two Chambers

As seen in section 1, to make the piston move, it is necessary that the pressure rises until it gains enough force to overcome the magnet's attractive force. So, when the piston is attached to the magnet, if the piston's area that receives the air pressure is small, this pressure needs to be high to move the piston. By altering this initial area, it is possible to control the piston's outcome.

To alter the piston's initial area, the lower part of the cylinder was divided into two chambers, as in Fig.10. Fig. 11 shows the actual lower part of the cylinder. When the piston is attached to the magnet (initial position) the two chambers become separated. The central area, which is called the main chamber, is pressurized by a main valve. In this case, the piston's area is small and a high pressure is necessary to detach the piston from the magnet, and the piston's final velocity is high.

Fig. 10 Main chamber and secondary chamber (half-cut model of the cylinder's lower part)

Fig. 11 Cylinder's lower part

To reduce this velocity the secondary chamber is used. Combining the pressure in the main and in the

secondary chamber, the piston's total area is used in the initial position. The area being larger than when just using the main chamber, the piston detaches with a lower pressure and its final velocity becomes lower than in the other case. To pressurize the secondary chamber, a micro valve is used, since it does not need great flows of air.

Furthermore, this structure enables the cylinder to be lighter. Instead of using one powerful magnet, which is big in size, two small magnets are used, one in the cylinder's lower part and another one in the piston. This increases the attractive force that would be weak if using only one in the cylinder's lower part. Of course, it is possible to use only one magnet and restructure the main chamber to be very small, but then the effective sectional area would be too small for a great flow of air, causing the undesired pressure fall inside the cylinder. Table 1 shows the comparison between the first cylinder and the new one.

Table 1. Comparison between cylinders

Cylinder	Pressure necessary to release the piston	Weight
Magnetic Brake Cylinder	0.42MPa (absolute)	380g
New Magnetic Brake Cylinder	0.3MPa~0.5MPa (absolute)	196g

Another issue with the cylinder was the tank, occupying too much space in the robot. Thinking in minimizing the structure, the tank now involves the cylinder (Fig.9).

Fig. 12 Tank involving the new magnetic brake cylinder

4. Controlling Methods of the Cylinder

To control the throwing distance of the child machine, it is necessary to use the main and secondary chambers in order to change the initial pressure with which the piston starts to move. Altering the initial pressure and using the internal pressure fall affect the piston's velocity. The piston's final velocity (i.e. the velocity of the piston used as initial velocity of the child machine) determines how high the child machine will be thrown.

There are two methods to control the throwing distance, which will be explained in the coming subsections.

4.1 Controlling with PWM

One of the methods to control the throwing distance is by altering the pulse length of the micro valve's input current. The process of this control would be as

follows: i) send a pulse to the micro valve, in order to pressurize the secondary room; ii) open the main valve to pressurize the tank, and moving the piston.

The pulse determines the quantity of air that enters the secondary chamber, therefore its internal pressure. When this chamber is pressurized, the pressure necessary in the main room to make the piston move is lower than when it isn't pressurized. By altering the pulse width, it alters the pressure in the secondary room, and the piston would start moving with a different initial pressure. The lower the necessary pressure to move the piston is, the nearer or lower the throw becomes. This means that the pulse is wide. On the other hand, when the pulse is too little the necessary initial pressure would be high and the piston moves faster.

However, to adjust the pulse width with the throwing distance isn't a simple task, since the variables for this control method are the opening time and the quantity of air introduced by the micro valve, the pressure dynamics of the secondary chamber and the pressure dynamics of the tank and cylinder.

4.2 Controlling by Time Triggering

This method consists in opening the main valve and the micro valve in different instants of time. As known in [4], there is an interval of time to pressurize the tank when the main valve is opened. Using this interval of time, it is possible to make the piston move with the desired initial pressure.

Without opening the micro valve, the tank usually achieves 0.35MPa, the pressure necessary to move the piston. But if the micro valve opens during the process of pressurizing, the piston starts to move before the internal pressure of the tank is high. This causes the piston to move with a lower velocity due to the pressure fall of the cylinder while it increases in volume. Fig. 13 shows the graph of the internal pressure of the tank by time, and it also shows the interval of the opening time of the micro valve.

Fig. 13 Internal pressure of the tank x time

Compared to the previous method, this is simpler to adjust. The variables for this control method are the pressure dynamics of the tank and the cylinder, and the opening time of the micro valve.

Table 2 shows the results of three opening times of the micro valve. This experiment was done by setting

the cylinder to throw the child machine vertically, which has a weight of 350 grams. Figure 14 shows pictures of these results, in which the child machine is represented by a red ball with the same mass.

Table 2. Throwing height

Opening time of main valve	Opening time of micro valve	Child machine's height
1000 ms	2500 ms	450 cm
1000 ms	1500 ms	279 cm
1000 ms	1000 ms	170 cm

Fig. 14 Throwing heights: 450cm (a), 279cm (b), 170cm (c)

Fig. 15 shows an experiment of a rescue operation. The child machine is thrown into a second floor balcony to inspect the area's situation.

Fig. 15 Throw of the child machine into a second floor balcony

All these experiments were done using a child machine, or a dummy child machine. Fig. 16 shows the shooting of the piston-rod 10m high, and it is seen that the more the child machine's weight is lighter, the higher becomes the throw.

Fig. 16 Shooting the piston-rod 10m high

5. Conclusions

This paper has demonstrated the design and the controlling methods of a new magnetic brake pneumatic cylinder.

Dividing the lower part of the cylinder into two chambers allows controlling the throwing distance of the child machine as proposed. It also showed that this structure is lighter and more effective than the first magnetic brake cylinder. The control can be done by PWM or by time triggering, however the simplest method is the second, as proposed. It has been demonstrated experimentally that the throwing distance of the child machine can be controlled easily.

To enhance the throwing height and to perform a better inspection in a disastrous site, the next steps of this research are as follows: i) propose a designing method of the pneumatic magnetic brake cylinder; ii) development of a new child machine; iii) improve the access technology of the parent robot into the disastrous site.

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