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Development of Hybrid Type Flexible Pneumatic Cylinder for Considering Less Air Consumption

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Abstract. Inexpensive rehabilitation devices that can be used at home are required because of a lack of PT and welfare workers. In the previous study, the low-cost portable rehabilitation device using a flexible spherical actuator that consists of flexible pneumatic cylinder was proposed and tested. However, a compact and high power compressor that supplies air pressure to pneumatic actuator has not been developed yet. In particular, the heat generated by compressing air prevents to miniaturize it. To realize a home rehabilitation, the small-sized compressors or less air consuming flexible actuators are required. In this study, a hybrid type flexible pneumatic cylinder driven by electric motors and air pressure is proposed and tested. The concept, the construction and the operating principle of the proposed actuator were described. The position control using the tested actuator is also carried out.

1 Introduction

In an aging society, it is required to develop a system to aid in nursing care [1-4] and to support the activities of daily life for the elderly and the disabled [5]. Rehabilitation devices help the elderly who is injured temporally to recover their physical ability for keeping Quality of Life (QOL). In the previous study [6], to realize a home rehabilitation using a low-cost device, a flexible spherical actuator using a flexible pneumatic cylinder was proposed and tested. A portable rehabilitation device using the actuator that can be used while handling it with hands was also tested. However, in order to drive pneumatic actuator at home, a compact and high power compressor is necessary. Unfortunately, compact compressors that can generate continuous flow rate for a long period have not been developed yet. It is related to the heat problem caused by compressing air. To realize a home rehabilitation, small-sized compressors or less air consuming flexible actuators are required. In this study, aiming to develop the flexible pneumatic cylinder that consumes less air, a hybrid type flexible pneumatic cylinder utilizing an electric motor is proposed and tested. The position control using the tested cylinder is also carried out.

2 Construction of hybrid type flexible pneumatic cylinder

Figure 1 shows the flexible pneumatic cylinder developed in our previous study [7]. The cylinder consists of a flexible tube as a cylinder and gasket, one steel ball as a cylinder head and a slide stage

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that can move along the outside of the cylinder tube. The steel ball in the tube is pinched by two pairs of brass rollers from both sides of the ball. The operating principle of the cylinder is as follows. When the supply pressure is applied to one side of the cylinder, the inner steel ball is pushed. At the same time, the steel ball pushes the brass rollers and then the slide stage moves toward the opposite side while it deforms the tube. The slide stage is moved forward and backward even if the cylinder bends.

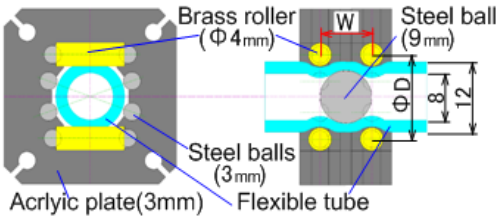

Figure 1. Flexible pneumatic cylinder.

To construct a flexible pneumatic cylinder driven by air and electric motor, the wire winding type motor is applied to the cylinder. Figures 2 and 3 show the view and construction of prototype of hybrid type flexible pneumatic cylinder, respectevely. Compared with a typical flexible pneumatic cylinder, it has a steal ball connected with wire as a cylinder head, a tee connecter for air supply, a tube end connecter for sealing and a wire winding motor. The wire winding motor consists of an acrylic wire spool with diameter of 10 mm and a small-sized geared motor (Seeed Studio Co. Ltd., MOT102A2B). The steel ball with the outer diameter of 9 mm has a hole with the inner diameter of 2 mm as shown in Fig.4. To keep a seal, there are two rubber balls with the outer diameter of 4.6 mm on both side of the steel ball. They are penetrated by a screw connected with a wire hook. The wire is connected to the motor and passed through the tee connecter, thin tubes, and the tube end connecter as shown in Fig.4. The tube end connecter consists of a tube connector, an acrylic cover, and a rubber ball with a thin hole. By adjusting the pushing force acting on the rubber ball using screw in the connecter, it can keep a seal even if the wire slides.

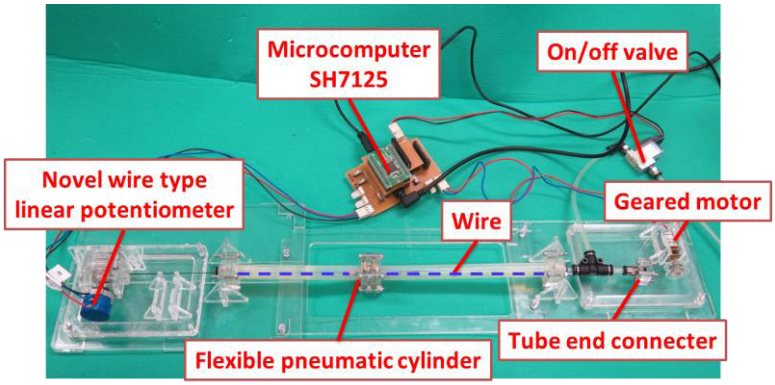

Figure 2. View of the tested hybrid type flexible pneumatic cylinder.

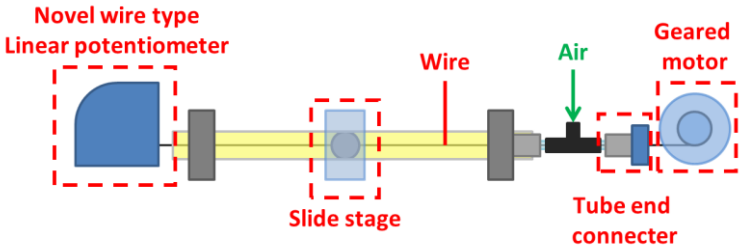

Figure 3. Construction of the tested hybrid type flexible pneumatic cylinder.

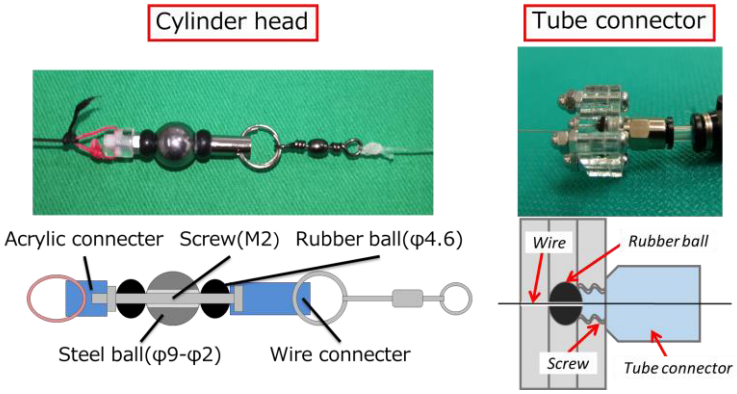

Figure 4. Cylinder head with the wire and inner schematic diagram of the tube end connecter.

3 Operating principle and experimental results

The operating principle of the cylinder is as follows. To drive the slide stage toward motor side, the motor winds up the wire. To drive toward opposite side, the wire is released by motor and an on/off valve is driven to supply the pressurized air to the steel ball. By pushing and pulling the steel ball, the ball pushes the rollers in slide stage while deforming the tube. Then, the slide stage moves. Thus, this method can reduce the consumed air for driving to push toward the motor side. As a result, the consumed pressurized air could be a half compared with the typical pneumatic cylinder. This is a natural phenomenon because the electric energy in partially used instead of pneumatic energy. You may ask what the advantage of the hybrid actuator is. The answer will be given in the following section.

Figure 5 shows the transient response of the controlled displacement of the cylinder for various desired position. In the experiment, the cylinder displacement was measured by a novel wire type linear potentiometer connected with the ball from the opposite side. Figure 6 shows the construction of the tested wire type linear potentiometer [8]. The tested potentiometer consists of a helical potentiometer (BOURNS Co. Ltd., 3590S-A26-104L) that can measure 10 times rotational angle, a clockwork wire spool with diameter of 22 mm and a stainless steel wire with diameter of 0.4 mm. Both shafts of the potentiometer and the wire spool are connected each other. From a rotational angle of the helical potentiometer and the diameter of the wire spool, the maximum length for measurement of approximately 0.7 m can be expected. The resolution of the potentiometer using 10 bit A/D converter is approximately 0.74 mm. The resolution can be improved by using 12 bit A/D converter. The cost of the linear potentiometer except the stainless steel wire is inexpensive, that is 8 US dollars. As a control scheme, simple on/off control scheme was used. In Fig.5, a broken and solid lines shows the desired and controlled displacement. It can be confirmed that the displacement of the tested cylinder can be controlled using both electric and pneumatic power. However, the speed of slide stage in the case when the motor winds the wire is slow, it is 10 mm/s.

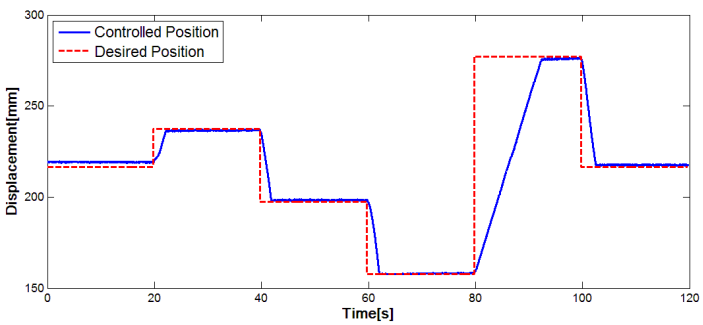

Figure 5. Transient response of the displacement of the tested cylinder.

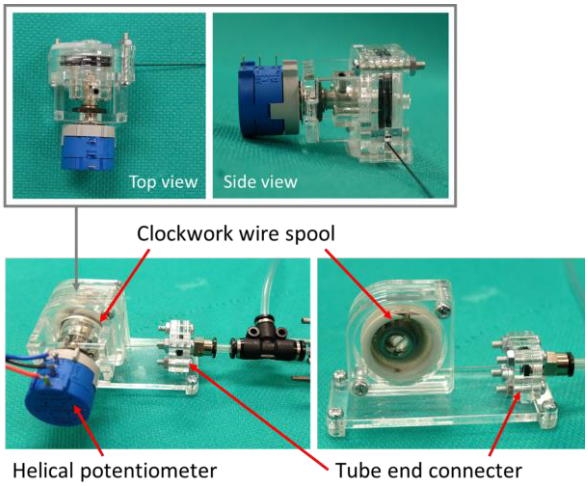

Figure 6. Low-cost wire type linear potentiometer

4 Improvement of hybrid type flexible pneumatic cylinder

The tested cylinder mentioned above needs a compressor to drive it for a long time such as one hour. If the pressurized air is not exhausted, the cylinder can be used for a long time without a compressor. Therefore, the improved type hybrid pneumatic cylinder without consuming pressurized air is proposed and tested. Figure 7 shows the improved hybrid type flexible pneumatic cylinder. Compared with the previous one, the motor was changed from one motor to two motors to increase the winding torque. Two output shafts of two motors are connected with each other through the wire spool. In addition, there is a PET bottle tank with volume of 500 cc and the initial pressure of 400 kPa, that is connected to the input port of motor side in direct. The operating principle of the improved cylinder is almost same as the previous. To drive the slide stage toward motor side, the motor winds up the wire. To drive toward opposite side, the wire is only released by motor. Then, the steel ball is pushed by always applied pressurized air of the tank. By this method, in the condition when the cylinder is always applied by a constant pressure, the slide stage can control the position by only using the motor. It means that the consumed pressurized air is externally decreased, that is zero in ideal, compared with driving by only air pressure. In this method, the cylinder can be driven for relative longer period of 1 or 2 hours by using a small Li-ion battery.

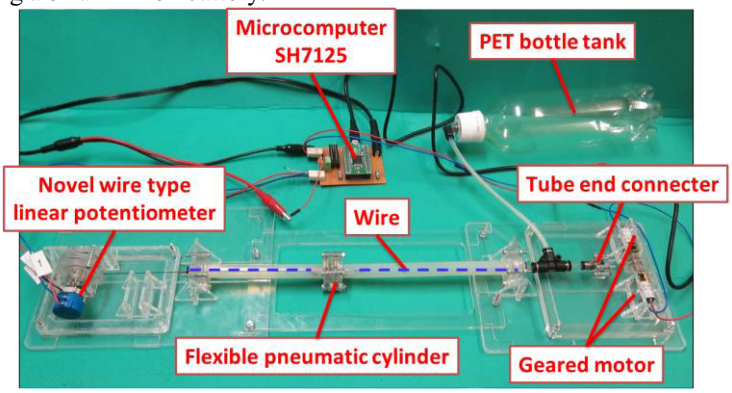

Figure 7. Improved hybrid type flexible pneumatic cylinder with embedded position controller.

The advantage of the proposed hybrid type flexible pneumatic cylinder is as follows. They can consider a similar system using a coil spring instead of air tank. However, the generated force of the coil spring increases according to the displacement. Therefore, the generated force is changed by the position. They can also consider the system using only electric motors. However, it is difficult to keep the wire's tension constant by synchronizing two electric motors. Therefore, the air spring using the pneumatic pressure was used.

Figure 8 shows the transient response of the controlled displacement of the improved cylinder for various desired position. As a control scheme, a simple on/off control scheme of the motor was applied. In the control, electric circuits of two motor connected in series so as to apply same current to both motors. The applied voltage is controlled by the embedded controller (Renesas Co. Ltd. SH7125) through a motor driver IC (Toshiba Co. Ltd. TA7291P). The suppled voltage of 12 V was used. In Fig.8, a broken and solid lines show the desired and controlled displacement, respectively. Compared with the result using the pervious cylinder as shown in Fig.5, the speed of slide stage in the case when the motor winds the wire is increased from 10 mm/s to 22 mm/s. As a result, it can be confirmed that the improved cylinder can be driven for more than one hour without a compressor.

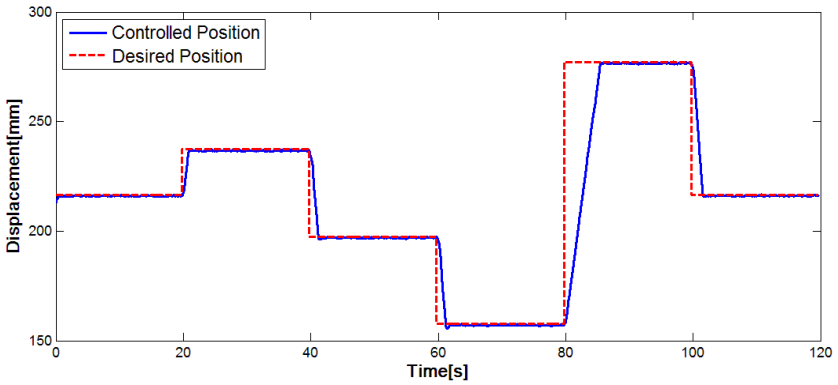

Figure 8. Transient response of the displacement of the improved cylinder.

5 Conclusions and future work

Aiming to develop a home rehabilitation device driven using a small air tank for 1 or 2 hours, the hybrid type flexible pneumatic cylinder for considering less air consumption was proposed and tested. The construction of the cylinder was described. The operating principle of the tested cylinder is also illustrated. The position control of the cylinder was carried out. As a result, the tested cylinder can be driven for more than one hour by using small sized PET tank with initial pressure of 400 kPa. It can be confirmed that the hybrid type flexible pneumatic cylinder with no consumed pressurized air can be realized. As a future work, we develop a more potable rehabilitation device using the hybrid type flexible pneumatic cylinder.

Acknowledgements

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