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Preliminary Design of Flexible Linear Stepping Actuator Driven by Pneumatic Balloons and Brakes

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Abstract. Recently, the requirement for development of soft actuator for the rehabilitation device and power assisting devices is increasing. However, development of a flexible actuator that has both larger force and longer stroke has not been carried out. In addition, it is also difficult to realize a flexible displacement sensor with long stroke while deforming its form according to the actuator's shape. In this paper, development of the flexible actuator with larger force and longer stroke that can adjust its stroke by giving stepping motion using pneumatic balloons and brakes is described. The fundamental performance of tested actuator is also investigated.

1 Introduction

According to aging society and decreasing birth rate in Japan[1], the requirement using soft actuator for the rehabilitation device and power assisting devices is rapidly increasing[2-5]. As a soft actuator, a rubber artificial muscle is well-known and actively used because of its larger generated force. However, the muscle cannot realize longer displacement, that is, the maximum stroke is limited until one fourth of its original length [6]. In addition, the generated force decreases according to the increase of the displacement of the muscle. In the previous study, as a long stroke flexible actuator, a flexible pneumatic cylinder that can be used even if the cylinder bends was developed [7]. Stroke of the cylinder is possible to be set longer. However, the generated force depends on sectional area of the cylinder and it is not so large. Therefore, a flexible actuator that can generate both larger force and longer stroke has been strongly desired. On the other hand, it is difficult to realize a flexible displacement sensor with long stroke while deforming its form according to the actuator's shape. In other words, the flexible actuator with larger force and longer stroke that can adjust its stroke without sensor is ideal. In this paper, to satisfy such a greedy demand, a flexible linear stepping actuator driven by pneumatic balloons and brakes is proposed and tested. The experiment for investigating the performance of the tested actuator is also carried out.

2 Previous flexible pneumatic cylinder

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Figure 1 shows the flexible pneumatic cylinder that was developed in our previous study[7]. The cylinder consists of a flexible tube (SMC Co. Ltd., TSU1208) as a cylinder, the steel ball with the outer diameter of 9 mm as a cylinder head, and a slide stage. The slide stage has two brass rollers with diamter of 4 mm set on the inner bore of the stage to press and deform the tube. The steel ball is held by two slide stages from both sides of the ball. When the supply pressure is applied to one side of the cylinder, the tube is moved forward and backward while holding the slide stage. The cylinder can move even if the cylinder bends. The cylinder also realize a longer stroke such as a more than 10 m. However, the frictional force of the cylinder is relatively large, that is about 10 N. The generated force of the cylinder is about 15 N when the supply pressure of 500 kPa is applied. The generated force of the cylinder depends on the sectional area of the cylinder. However, the frictional force increases according to increasing the diameter of the cylinder because of the sliding mechanism between the inner ball and rollers. In addition, it is difficult to realize a displacement sensor that can measure a longer stroke and deform the shape of the sensor according to deformation of the cylinder.

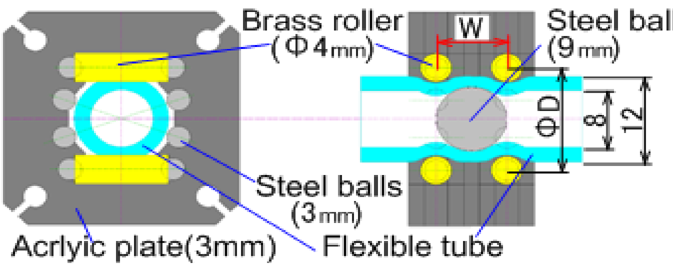

Figure 1. Construction of flexible pneumatic cylinder.

3 Construction of flexible linear stepping actuator

Therefore, in this study a novel pneumatic actuator with larger force and longer stroke that can adjust the displacement without sensor is proposed. Figure 2 shows the schematic diagram and view of the tested flexible linear stepping actuator driven by pneumatic balloons and brakes. The actuator consists of two pneumatic driven brakes set on both sides of actuator, a moving round stage with a pnematic driven brake, two doughnut-shaped balloons such as a diaphragm and a flexible tube as a rod. Figure 3 shows the pneumatic brake. The brake consists of silicone rubber tube with outer diameter of 4 mm surrounded by acrylic cover. When the supply pressure is applied to the brake, the tube in the rubber brake expands. At a same time, the rubber tube hold the flexible tube. The moving stage with a brake in the center is sandwiched by two balloons. The doughnut-shaped balloon that is made of silicone rubber film with thickness of 0.5 mm has the outer diameter of 48 mm and the inner diameter of 26 mm. The theoretical generated force from the sectional area of the balloon with the supply pressure of 500 kPa is about 639 N. The size of the actuator is small, it has the outer diameter of 60 mm and the length of 50 mm. The mass of the actuator without tube is about 180 g.

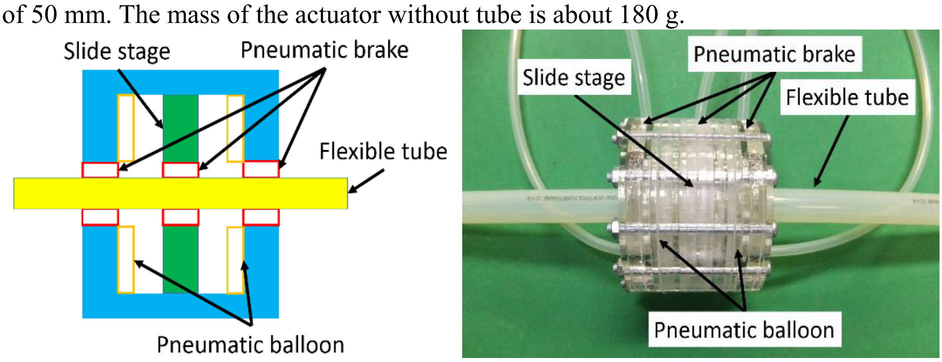

Figure 2. Construction and view of tested flexible linear stepping actuator.

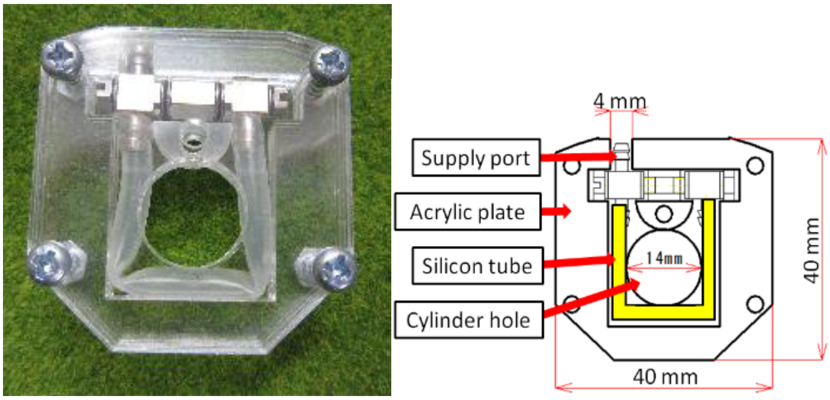

Figure 3. View and construction of pneumatic driven brake

4 Operating principle of flexible linear stepping actuator

Figure 4 shows the operating principle of the tested actuator. The operating principle is as follows: First, the both side brakes are driven to hold the tube for 0.2 s as shown in Fig.4 (1). In the condition, the left side balloon is driven for 0.15 s and the moving stage moves toward right as shown in Fig.4 (2). When the moving stage reaches at the right wall (input pressre is given for 0.15 s), the brake on the stage is driven to hold the tube as shown in Fig.4 (3). After that, the left balloon and both side brakes are released. At the same time, the right side balloon is driven for 0.15 s, the tube that is held by the brake on the moving stage is pushed toward left as shown in Fig.4 (4). By repeating this procedure, the tube can move toward left every a certain stroke ; the width of the balloon chamber(5mm).

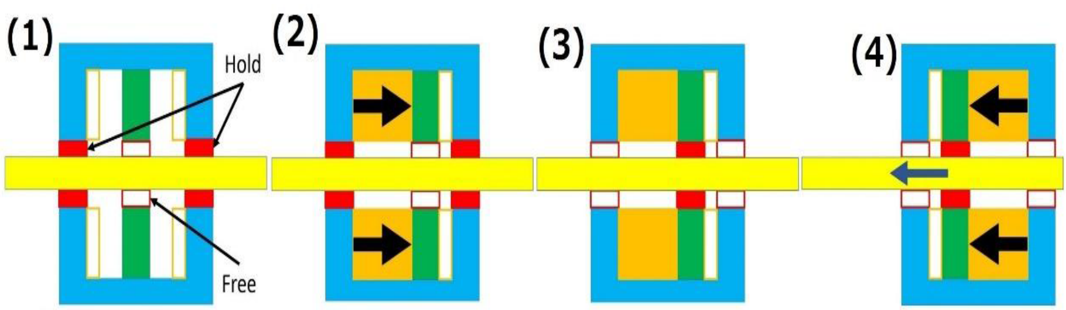

Figure 4. Operating principle of tested linear stepping actuator.

5 Control system and experimental result

Figure 5 shows the schematic diagram of the driving control system of the tested actuator. The system consists of the tested flexible linear stepping actuator, an embedded controller (Renesas Co. Ltd., SH7125) and four on/off control valves (Koganei Co. Ltd., G010E1). Valves 1 and 2 are used to drive both side balloons, respectively. Valve 3 is used to drive the brake on the moving stage. Valve 4 can drive both side brakes. These valves are controlled by the embedded controller through I/O ports.

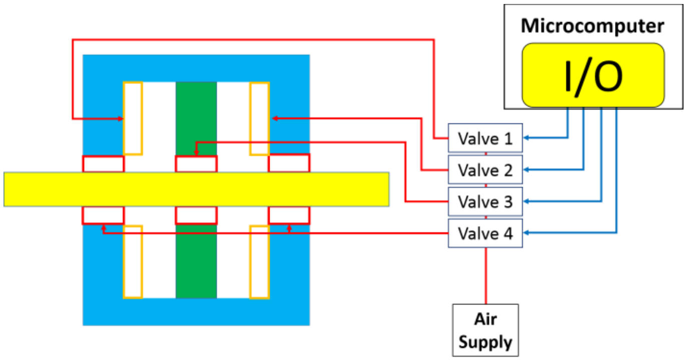

Figure 5. Schematic diagram of control system of tested linear stepping actuator.

Figure 6 shows the transient view of the movement of the tested actuator when the moving pattern of the brakes and balloons are given mentioned above. From Fig.6, it can be seen that the actuator can push the tube with step stroke of 5 mm every 0.7 s. The speed of the tested actuator is about 5.4 mm/s. The improvement of the moving speed is our future work.

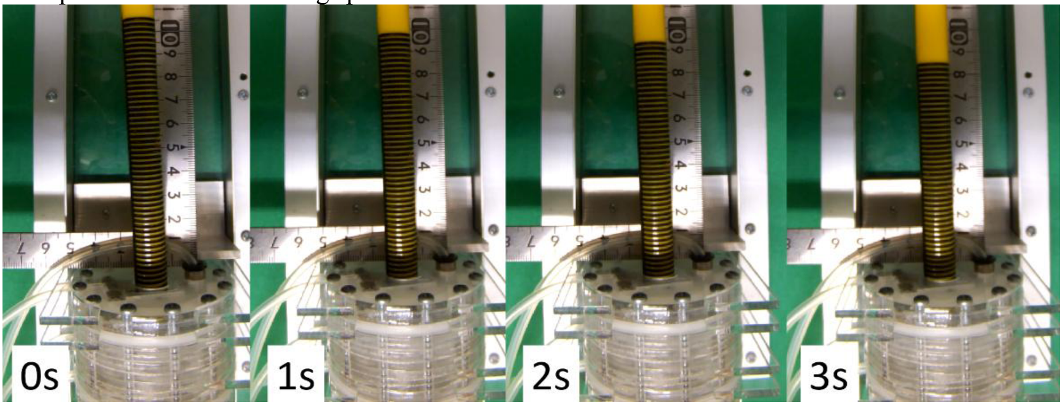

Figure 6. Transient view of movement of the tested actuator.

6 Conclusions

As a flexible actuator with larger force and longer stroke, the flexible linear stepping actuator driven by pneumatic balloons and brakes was proposed and tested. The moving test using various moving pattern was carried out. As a result, it can be found that the tested actuator can move with maximum speed of 5.4 mm/s in experiment. It can be confirmed that the actuator can move every step that is about 5 mm.

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