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Soft Mechanism by using a Sponge-Core-Soft-Rubber Actuator for Welfare Machines

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ABSTRACT

In care activity or rescue activity, hands that can grasp creatures are sometimes needed. Therefore, it is considered that the soft mechanism that uses pneumatic elements is useful to realize such hands. In this paper, we propose a new type of soft actuator (Sponge-Core-Soft Rubber Actuator) in which a sponge rubber is covered with silicon rubber. The structure of the sponge rubber is divided into two types. One is single-layer type and the other is two-layer type (a flat type and a clipping type). In order to clarify the differences in characteristics of each actuator, we examine the basic characteristics of the actuators. Further, the control performances of both position and force are studied to realize a hybrid element. From some experimental results, the control performance of the two layers type actuator is illustrated.

KEY WORDS

Key words, Sponge Rubber, Soft mechanism, Force Estimation, Force Control

NOMENCLATURE

F: Output force,
Fr: Desired force
F_r: Desired Force
K_P, K_I, K: Gain
P: Inner Pressure in the Actuator
P_0: Initial Pressure in the Actuator
Pr: Desired Pressure
V: Input Voltage to Valve
V_0: Neutral Voltage

INTRODUCTION

Recently, many types of robots have been used in factory automation. Since these robots usually grasp hard material objects in these tasks, the robot hand has a mechanical structure. However, when the robot grasps a soft material object such as foods and creatures, the hand needs a force sensor to control the grasping force. In this case, it takes much time and effort to control the grasping force.

Therefore, when the hand grasps the soft material object, it is considered that a pneumatic element that is used at the grasping parts is useful to realize a flexible hand by making use of pneumatic compressibility. Further, by pressure measurement in the element, it is possible to estimate the external force. As a result, there is no need to use a force sensor to measure the external force. Moreover, by controlling the inner pressure of the pneumatic element, the shape of the grasping part can be changed.

That is to say, by making use of pneumatic components, it is possible to realize a hybrid element that has both a position control function and a force control function.

Therefore, an actuator that has both active elements (position control and force control) and passive elements(compressibility) can be used to develop a soft mechanical interface between a robot hand and an object. Thus, since pneumatic actuators have flexibility because of compressibility of air[1], it is considered that pneumatic systems are very useful to realize the above soft mechanical system. In order to realize the system, some kinds of pneumatic actuator such as Flexible Micro Actuator[2] and Rubber Actuator have been proposed in literature. However, when these actuators are burst by some accidents, the rapid deformation of the actuator is caused by air release. As a results, user has some trouble in operating them. Therefore, in order to eliminate these problems, we propose a new type of pneumatic soft actuator in which a sponge rubber is covered with silicon rubber.

In this paper, the structure of the actuator is explained in Section 2. Further, in Section 3, basic characteristics of the proposed element are clarified from some experimental results. Moreover, position and force control performances are examined in section 4. Finally, in Section 5, force sensing performance is illustrated.

SOFT MECHANISM

In factory, many kinds of robots are used to operate many objects. At this time, when the robot hand operates a hard object as shown in Fig.1, the grasping force F is dependent on a weight of the grasping object. On the other hand, when the robot operates a soft material that is shown in Fig.1, the hand has to be realize a force control to operate the object. Further, since the shape of the object is changed by the grasping force, the tip of the hands part have to be moved to grasp the object. However, when the hand grasps a creature,

Moreover, Furthermore, in recent years, human support machines are needed. In this case, we have to investigate the structure of hand part that contacts with human body. So, in order to realize the hand mechanism with human compatibility, we propose a new type of pneumatic rubber actuator. As you know, by making use of both rubber elasticity and pneumatic compressibility, the actuator can realize a passive motion. Moreover, the pneumatic actuator is easy to control generation force by adjusting the inner pressure of the actuator. Thus, the actuator can be used as an active element that is constructed with position and force control. So, in this study, we propose a new type of hybrid element by using pneumatic power.

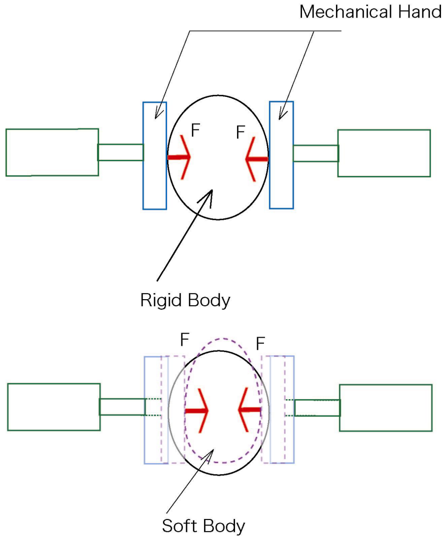


Fig.1 Mechanical Hand

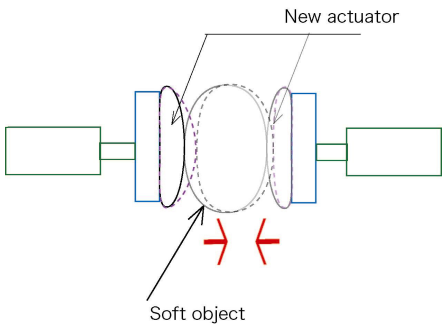


Fig.2 Soft Mechanical Hand

SPONGE-CORE-SOFT RUBBER ACTUATOR[3]~[8]

Structure of Actuator

In order to develop a soft mechanism actuator whose inherent stiffness is controllable, we apply pneumatic system to the actuator. The structure of the actuator is shown in Fig.3. The actuator is constructed with two materials. One is a silicon rubber and the other is sponge rubber. Furthermore, since the sponge is coated with silicon rubber, air can be charged into the sponge chamber. In this study, the number of sponge layer is two. As this time, the actuator expands when air is charged into the sponge chamber.

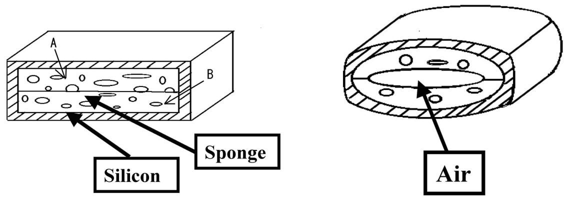
The actuator has sponge layer inside the silicon rubber. Therefore, when the actuator is made to burst by some accidents, the sponge material can support the object by its inherent stiffness. As the results, the actuator can ensure safe operation.

Furthermore, in order to improve the two layers type actuator, a clipping type actuator is proposed. The structure of the sponge is shown in Fig.4. In Fig.4, the two layers type actuator is divided into four structures(Type1 (Standard Type), Type2(Clipping Type), Type3(Outer Coat One Layer Type) and Type4(Outer Coat One Layer and Clipping Type)).

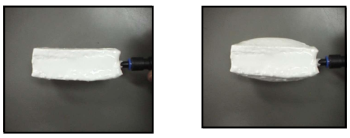
Experimental Setup

We investigate dynamics of the actuator when air is charged into the sponge chamber. In the experiment, two types of sponge are used. One is ECZ type whose density is 16 ± 1.5kg/m^3 and the other is EMM type whose density is 52 ± 3 kg/m^3. The size of the actuator is 80*80*20mm. The experimental set up is shown in Fig.5. The pressure in the sponge chamber is measured by a pressure transducer. Further, we use a laser sensor to measure the displacement of the actuator.

Pressurized State

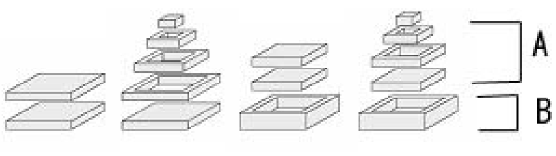


Two Layers Structure



(b-1) Initial State (b-2) Pressurized State

Fig.3 Schematic View of Pneumatic Sponge-Core-Soft Rubber Actuator



(a) Type1 (b) Type2 (c) Type3 (d) Type4

Fig.4 Structure of Sponge Plate

FORCE CONTROL PERFORMANCE

Step Response

In this section, we consider force control performance of the actuator with respect to each sponge type as shown in Fig.4. At first, we investigate the step response of force control. In the experiment, each type sponge structure (Type1-Type4) is investigated with respect to each sponge material (ECZ and EMM).

In the experiment, hierarchical feedback control scheme[9] is applied to the force control of the actuator. The control equations are as follows. Thus, at the first step, the desired pressure is derived from Eq(1). And input volt to the valve is calculated from Eq(2).

$$Pr = K_P(Fr - F) + K_I\int(Fr - F)dt \tag{1}$$

$$V = V_0 + K(Pr - P) \tag{2}$$

The experimental results are shown in Fig.6. From the results, it is considered that the response time is slow because of both low pressure level and rubber elastic force. Further, settling time and steady state error of each sponge type are shown in Table 1 and Table 2. In this experiment, the desired force is 5[N].

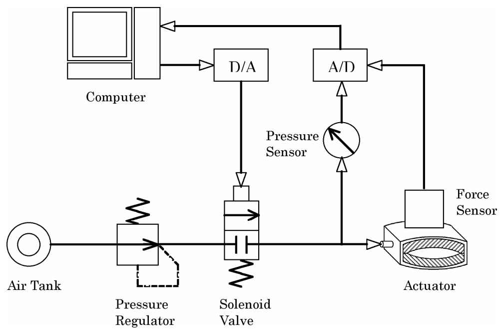


Fig.5 Experimental Setup

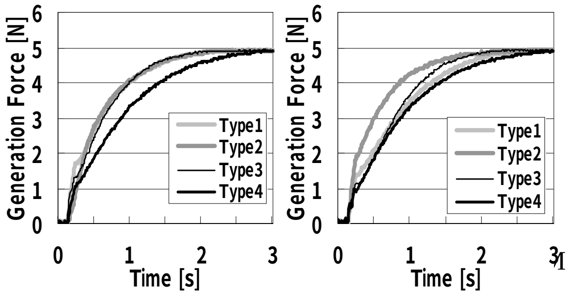


Fig.6 Experimental Results of Force Control

Table1 Settling Time

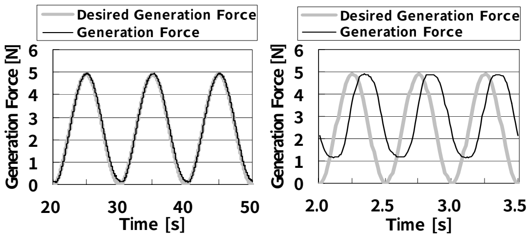
(unit:[s])

	ECZ	EMM
Type1	2.16	2.61
Type2	2.23	2.25
Type3	2.14	2.11
Type4	2.90	2.92

Table2 Steady State Error

(unit:10^{-3}×[N])

	ECZ	EMM
Type1	1.96	5.35
Type2	3.64	1.47
Type3	0.51	2.89
Type4	4.05	3.43



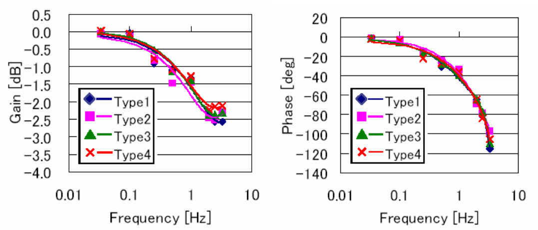
(a) f=0.1Hz (b) f=2.0Hz

Fig.7 Experimental Results of Frequency Response with Force Control (ECZ-Type3)

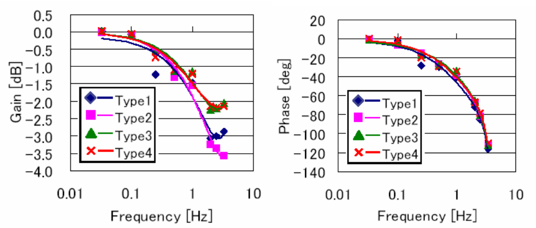
From experimental results, it is seen that the result of Type3 (Sponge material is ECZ) is much better than the other types. Further, in the case of Type3, it is considered that the deformation of the element is easier than the case of Type1 because of their structure.

Frequency Response

In order to ascertain the frequency characteristics of the actuator, we measure the output force as a function of the sinusoid pressure fluctuation. The sample response of the experimental result with respect to Type3(ECZ) is shown in Fig.7.



(a) ECZ



(b) EMM

Fig.8 Bode Diagram

Furthermore, the Bode diagram with [F/Fr] is shown in Fig.8.

From these experimental results, it is cleared that with respect to the ECZ, there is almost no difference between each sponge structure (Type1 – Type4). On the other hand, in the case of EMM the gains of Type3 and Type4 are much larger than that of Type1 and Type2. Furthermore, when we use Type3 and Type4, it is better to use these sponge types in the high frequency region (over 1Hz). As a result, it is cleared that Type3 is useful to realize a good performance of force control from the result of both step pressure and frequency response.

FORCE SENSING PERFORMANCE

Force Estimation

To understand the performance of external force estimation we use the Type3 sponge structure as shown in Fig.4. Here, the sponge material is ECZ and the size of the actuator is 80*80*20mm. The experimental setup is shown in Fig.9. In the experiment, an initial pressure P_0 is charged into the actuator. Next, a force sensor is attached to the plate on the element(Actuator) under the condition that the actuator is sealed up. At this time, we measure both inner pressure and compression force of the force sensor. The relation between the pressure in the actuator and force with respect to each initial pressure is shown in Fig.10. In the experiment, the initial pressure is increased from 0 to 9kPa. From the experimental result, an external force estimation equation is derived as follows.

$$F = \frac{P - P_0}{\alpha_1 P_0^3 + \alpha_2 P_0^2 + \alpha_3 P_0 + \alpha_4} \quad \begin{pmatrix} \alpha_1 = -0.00008 \\ \alpha_2 = 0.0006 \\ \alpha_3 = 0.001 \\ \alpha_4 = 0.3004 \end{pmatrix} \tag{3}$$

Here, F is an external force.

In order to indicate the usefulness of the Eq.(3), we measure the pressure in the actuator under the condition that a mass is placed on the plate of the element. At this time, the external force is calculated from Eq.(3). The result of external force estimation is shown in Fig.11. Here, the initial pressure is 6kPa. From this result, it is clear that the average error is 0.44N and maximum error is 1.03N. Thus, the estimation equation is useful to estimate external forces.

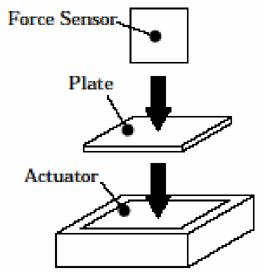


Fig .9 Experimental Setup

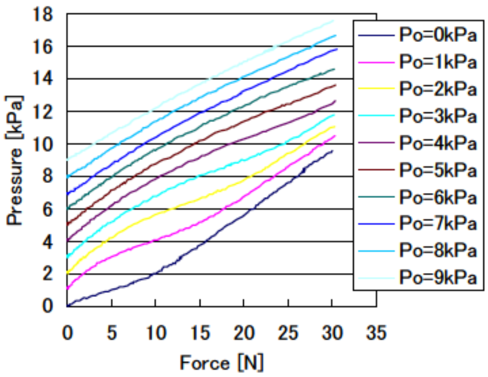


Fig.10 Experimental Result of Force Measurement

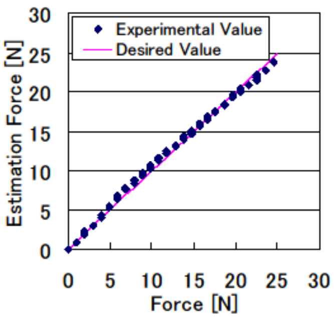


Fig.11 Experimental Result of External Estimation Force

CONCLUSIONS

In this paper, we have proposed a new type of hybrid element by using sponge-core-soft rubber actuator in which a sponge rubber is covered with silicon rubber in order to realize a soft mechanism of a hand. Through several experimental results, the force control characteristics of the proposed element were clarified. Furthermore, we verified the external force estimation capability of the element.

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