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DRIVING CHARACTERISTICS OF A MICRO ARTIFICIAL MUSCLE ACTUATOR USING ELECTRO-CONJUGATE FLUID

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ABSTRACT

Soft robot inspired from natural systems is one of keywords in the robotic field in last decade. Accordingly, many types of artificial muscle actuators are developed. On the other hand, using an electro-conjugate fluid (ECF), which generates a powerful jet flow when subjected to a high voltage, we can construct a tiny pressure source. This paper proposes a novel micro artificial muscle actuator (< 1 cm^3) utilizing the fluid. The essence of this study is to develop the micro artificial muscle integrated with micro pressure source, which enables us to construct an autonomous system and/or artificial muscle array. The contraction characteristics and normal force characteristics of the actuator were measured. The maximum contraction rate was around 16 % and the force generated was about 0.2 N with applied voltage of 6 kV. The experimental results confirmed the effectiveness of the proposed actuator.

KEY WORDS

Soft actuator, Micro actuator, Soft Robot, Functional fluid, Electro-conjugate fluid

INTRODUCTION

As robots are becoming widely used in many fields, a soft robot inspired from natural systems becomes one of the main research topics in the field of robotics and mechatronics, especially in the application requiring closer and safer interactions between humans and machines. The authors think the muscle of natural systems which potentially has flexibility is worthy of note, and that to create a new type of artificial muscle actuator might be a great research topic. As artificial muscle actuators, for example, several types of actuators have been developed. The artificial muscle actuator which has the longest history is a pneumatic actuator such as Mckibben type actuator. The constructions, numerical models, and applications of pneumatic actuators were widely studied [1][2]. It generates an extend-contract motion, however, there needs a bulky pressure source outside the actuator. Shape memory alloys are another example of artificial muscle [3][4]. They have great features as high power density, however, they suffer from slow response and heat problems. Polymer materials [5][6] might be a recent research trend on artificial muscle actuator, however, they are still not suitable for robotic application because they must be used in particular environments. A most

promising research of artificial muscle actuator in robotic field is electrically actuated dielectric elastomer films [7]. Although there reported several types of actuators as mentioned above, artificial muscle actuators are still being developed.
On the other hand, there is an interesting smart fluid or an electro-conjugate fluid (ECF) [8]. The fluid generates a powerful jet flow when subjected to a high voltage (~ kV). This kind of phenomenon is known as an EHD (electrohydrodynamics) effect [9]. In our previous studies, the authors clarified the necessary condition for showing the effect, and the fluids meeting the condition are called ECFs. Although the mechanism of the effect has not been clarified yet, the ECFs are attractive for constructing new actuators. Hence, the authors applied the ECF effect on micro motors [10-12] and micro manipulators [13]. According to our previous studies on the ECF, the jet flow becomes more powerful with smaller electrode pair, which means, the ECF effect is suitable for micro actuation. Therefore, this paper proposes a new type of micro artificial muscle actuator using the ECF and clarifies its characteristics.

DRIVING PLINCIPLE

Our previous studies proved the ECF effect is suitable for micro actuation [10-13], which means, it is easy to construct a micro pressure source using the ECF. Therefore, a new type of micro artificial muscle actuator can be realized as shown in Fig. 1. As the inner pressure of a fiber-reinforced flexible tube increases by a jet flow, which is generated at the pressure source using ECF, the tube contracts along the actuator axis because the fiber cannot extend.
One of the main accomplishments of this research is the incorporation of the pump (pressure source) in the actuator. This results in a very compact actuation system and therefore, we can place the actuator in an array just like natural muscles. This kind of design solution cannot be realized by pneumatic artificial muscle actuators previously developed because they need bulky pressure sources outside the actuator.

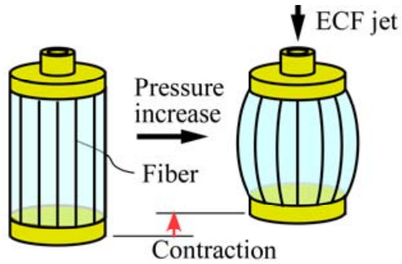
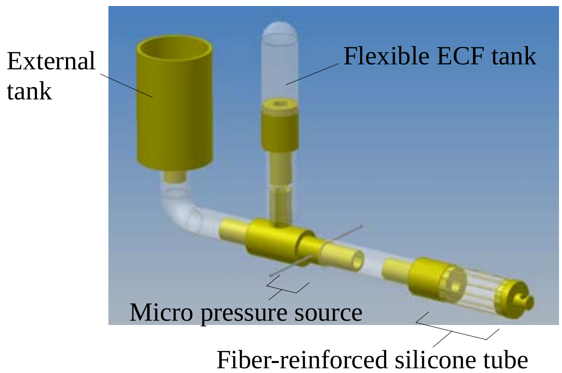


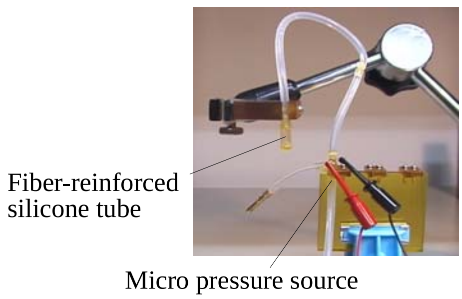
Figure 1 Concept of ECF micro artificial muscle

DESIGN AND MANUFACTURING

Here we briefly introduce a prototype of novel micro artificial muscle actuator. Fig. 2 shows a schematic illustration and actual view of the prototype. The prototype is composed of a fiber-reinforced silicone rubber tube, a micro pressure source using electro-conjugate fluid, a flexible ECF tank, and an external tank. This prototype is designed to confirm the driving principle of the micro artificial muscle actuator, so that each component is individually designed and produced. The fiber-reinforced silicone rubber tube is made of silicone rubber and aramid fibers with thickness of 35 μm and 12 fibers. The design parameters, tube thickness and number of fibers, are experimentally determined [14]. The outer dimension of the tube, $\phi 5 \times 10$ mm, is determined so as the tube volume to be less than 1 cm^3. The maximum contraction rate and force along tube axis measured at inner pressure of 10 kPa were 16 % and 0.18 N, respectively.
The micro pressure source using the electro-conjugate fluid includes a tiny electrode pair, consisting of a needle and ring electrodes as shown in Fig. 3 (the needle is connected to the GND, and the ring is to the positive). The diameter of the needle is 0.13 mm, and the inner diameter of the ring is 0.3 mm. An electrode spacer located between the electrodes keeps the



(a) Schematic illustration



(b) Actual view

Figure 2 Prototype of micro artificial muscle actuator

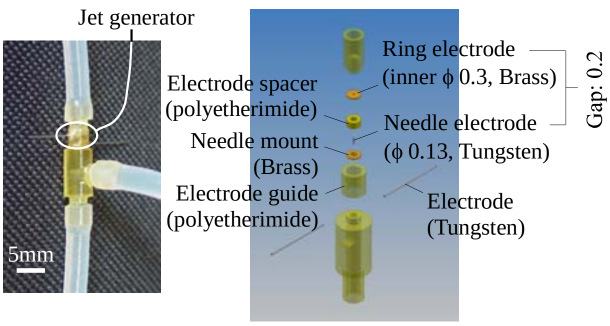


Figure 3 Micro pressure source (Jet generator)

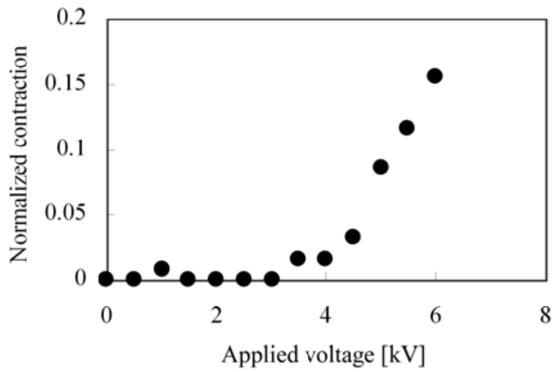


Figure 4 Static contraction

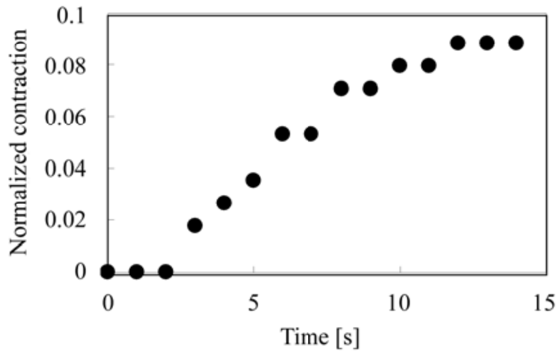


Figure 5 Step response of contraction

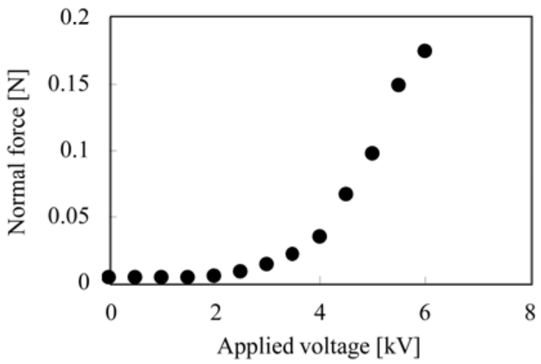


Figure 6 Static normal force

electrode gap to be 0.2 mm. The micro pressure source generates up to around 10 kPa with applied voltage of 6 kV when dibutyl decanedioate , one of the electro-conjugate fluids, is used as a working fluid [14]. The flexible ECF tank and the external tank are filled with the ECF. A bulky external ECF tank was connected to the micro pressure source so that we could easily regulate the pre-pressure of the tube. In case of practical use, the external ECF tank should be removed (the actuator only needs the flexible ECF tank for drive).

EXPERIMENTS

Contraction Characteristics

The contraction characteristics of the prototype were measured. Fig. 4 shows the experimental result of static contraction with input voltages up to 6 kV. The contraction rate showed a quadratic curve against the input voltage. The maximum contraction rate was 0.16 at the input voltage of 6 kV. From the maximum contraction rate, the inner pressure of the actuator is expected to be around 8 kPa.

Fig. 5 shows the experimental results of dynamic contraction when the step input of 5 kV was applied. No overshoot was observed and the rise time was around 7.9 s. The dead region of 2 s shown in Fig. 9 is caused by the following phenomenon: The initial shape of fiber-reinforced silicone rubber tube had a hyperbolical cross-section, which means, narrow in the middle, because of the surface tension. Consequently, the pressure increase at the early phase was used to deform the initial shape to be a straight column.

Force Characteristics

The normal force generated by the prototype was measured. Fig. 6 shows the experimental result of static normal force. The static force measured here is that of so to say isometric contraction of natural muscle. The normal force showed a quadratic curve as the contraction rate did. This kind of characteristics is caused by the pressure characteristics, i.e., the pressure generated at the micro pressure source showed a quadratic relation against the applied voltage. The maximum normal force obtained was 0.18 N at the input voltage of 6 kV. The inner pressure of 9 kPa might generate the normal force of 0.18 N, although it is expected to be 8 kPa from the contraction characteristic. The generative force of the actuator may seem to be small, however, note that the actuator with pressure source is extremely small. This means that higher actuation forces can easily be obtained by arranging several artificial muscle actuators in parallel.

Fig. 7 shows the experimental result of dynamic normal force with the step input of 5 kV. No overshoot was observed and the rise time was around 7.5 s. The response of the micro artificial muscle actuator was not so high, however, it can be improved by placing several electrode pairs in series-parallel in order to accelerate

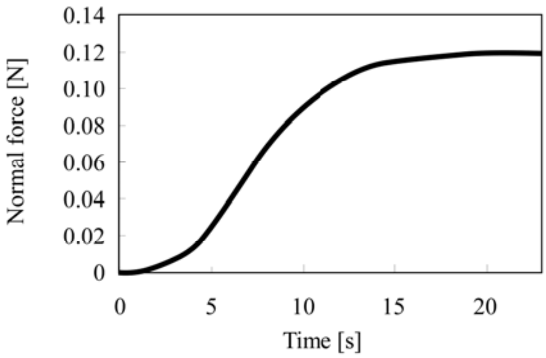


Figure 7 Step response of normal force

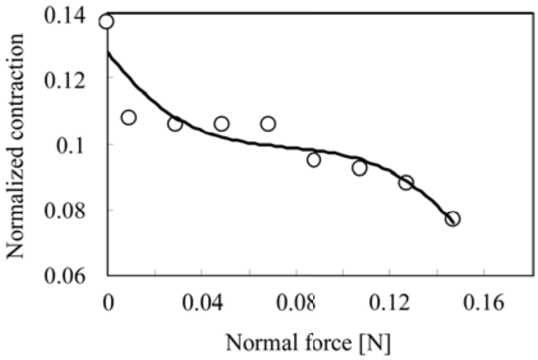


Figure 8 Isotonic normal force

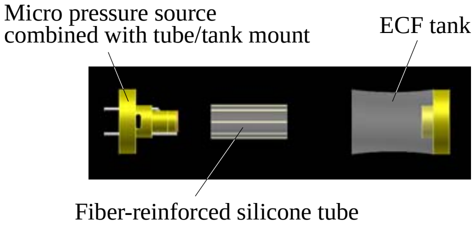
the flow velocity of the ECF jet. Note that, the electrode pair required was extremely compact.

Finally, the normal force of so to say isotonic contraction of natural muscle was measured when the input voltage was 5 kV. Fig. 8 shows the experimental result. The relation between normal force and contraction rate showed non-linear characteristic as that of natural muscles do.

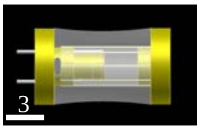
PRACTICAL DESIGN SOLUTION

The prototype was for confirming the driving principle and for clarifying the basic driving characteristics of the micro artificial muscle actuator we proposed. It has the fiber-reinforced silicone rubber tube, the micro pressure source, the flexible ECF tank and the external tank, independently. For practical use, we have to integrate the components together.

Fig. 9 shows a practical design solution of the micro artificial muscle actuator. The flexible ECF tank is located around the fiber-reinforced silicone tube in order to maximize the space efficiency. To realize this purpose, the micro pressure source is combined with a tube/tank mount. With this design solution, the pressure source and tank are incorporated in the actuator. Hence, it is easy to be applied for actual systems and to be arranged in an array to obtain lager stroke and force.



(a) Exploded view



(b) Assemble view

Figure 9 Practical design solution

CONCLUSIONS

A new type of micro artificial muscle actuator using electro-conjugate fluid was developed in this study. The main contribution of this research is the incorporation of the pressure source in the actuator, utilizing the ECF. This enables us to construct a compact artificial muscle actuator, and then, it is easy to apply the actuator to autonomous systems or to micro systems. Furthermore, we can arrange the artificial muscle actuators in an array just as natural systems do.

Our future study focuses on controlling the micro artificial muscle actuator. Also, we will be focusing on applications.

ACKNOWLEDGMENT

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