ECF Micro Artificial Muscle Actuator and its Application to Micro Robot Arm

Kenjiro TAKEMURA†, Shinichi YOKOTA† and Kazuya EDAMURA‡
† Precision and Intelligence Laboratory, Tokyo Institute of Technology, Japan
‡New Technology Management, Japan
Tel: +81(45)924 5034 – Fax: +81(45)924 5097 – e-mail: takemura@pi.titech.ac.jp

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1. Introduction

Robotic technology is now widely used not only in industrial field but in various fields, for instance, many researchers are developing medical robots, welfare robots, domestic robots, rescue robots etc. This fact means robots become much closer to people who are not in mechanical/electrical engineering. In such a case, a physical flexibility or softness becomes having much importance. For this reason, soft actuators or artificial muscle actuators are widely studied.

There have already been developed several types of artificial muscle actuators. Pneumatic artificial muscle actuators, or McKibben type actuators [1], shape memory alloy actuators [2], polymer actuators [3], and electroactive polymer artificial muscles (EPAMs) [4]. However, they have some problems to be solved for practical applications.

The authors also developed a new type of artificial muscle actuator [5] using electro-conjugate fluid. The electro-conjugate fluid is a kind of dielectric fluid, which generates a powerful jet flow when subjected to high DC voltage. This means, with this attractive fluid, we can develop tiny fluid-driven mechanical components without any bulky pumps [6].

In this paper, we propose a novel McKibben type micro artificial muscle actuator using electro-conjugate fluid and apply the actuator to a micro robot arm. The main contribution of this research is to introduce the electro-conjugate fluid to the McKibben type artificial muscle, resulting in using no bulky mechanical pumping system.

2. Electro-conjugate Fluid

The electro-conjugate fluid is a kind of dielectric fluid, which works here as a smart fluid. When it is subjected to high voltage with electrodes inserted into the fluid with interelectrode gap of several hundred micrometers, we can observe a powerful jet flow (an ECF jet) between the electrodes (Fig. 1). Although a high voltage is needed to generate the jet flow, the current is quite low at several μA, resulting in total power consumption is around several milliwatts.

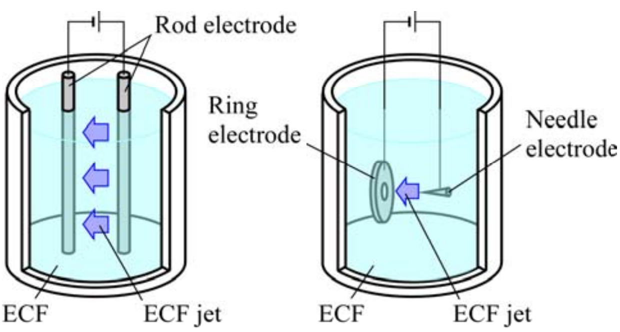


Figure 1: Schematics of ECF jet

3. Concept

As proved in our previous studies, the electro-conjugate fluid is suitable for micro actuation because (1) with ECF, we do not need any bulky pumping system apart from actuators, and (2) power density of the ECF jet is higher when the electrodes pair is smaller. Consequently, we propose a new type of micro artificial muscle actuator using electro-conjugate fluid. Fig. 2 illustrates a configuration of the ECF micro artificial muscle actuator. The actuator has a tank, a jet generator with an electrode pair, a silicone rubber tube covered with a fiber sleeve. The inner pressure of the silicone rubber tube is controlled by the ECF jet pressure. When the inner pressure of the silicone rubber tube is increased, the tube contracts because of the restraint due to the fiber sleeve. The main contribution of this artificial muscle actuator is making the system tiny even using a fluid power for actuation.

4. Design and Fabrication

Fig. 3 shows designed components of ECF micro artificial muscle actuator. Fig. 3(a) is a detailed configuration of the jet generator. We located two pairs of needle and ring electrodes in the jet generator in order to test the effect of arranging the pairs in series/parallel. The needle electrode (tungsten) has a diameter of 0.13 mm, and the ring electrode (brass) has a ϕ0.3 mm hole at its

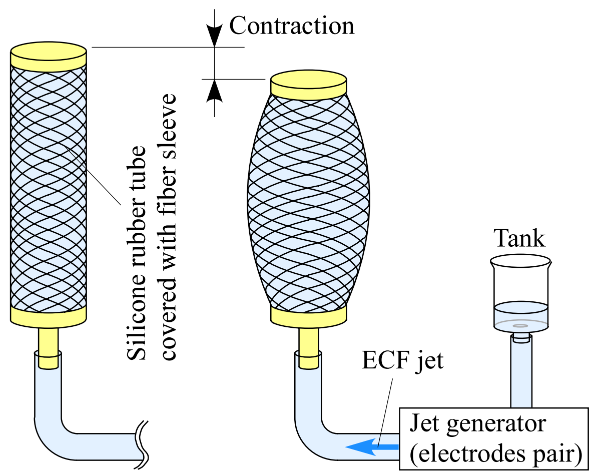
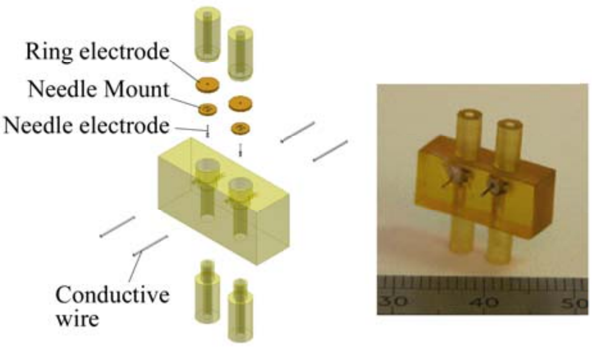


Figure 2: Concept of ECF micro artificial muscle actuator



(a) Jet generator


(b) Silicone rubber tube covered with sleeve

Figure 3: Components of ECF micro artificial muscle actuator

center. The interelectroe gap between them is 0.2 mm. Fig. 3(b) is the silicone rubber tube covered with the fiber sleeve. The effective diameter and length of the tube is 3 mm and 10 mm, respectively. The thickness of the tube is 45 μm. The fiber sleeve is made using 16 spindles.

5. Experiments

5.1 Characteristics of Jet Generator

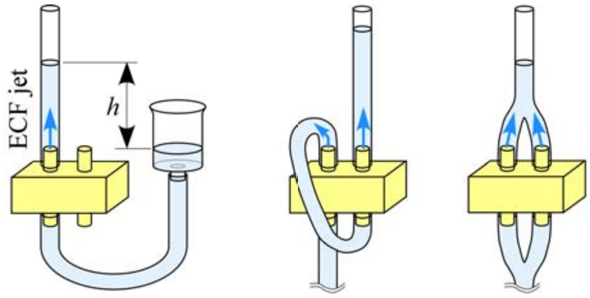
Here measures characteristics of the jet generator. As mentioned above, we put two pairs of needle and ring electrode in the jet generator. Hence, we measured characteristics of generated pressure and flow rate with (1) a single electrode pair, (2) two electrode pair in series, and (3) two electrode pairs in parallel. However, we used FF-1$_{EHA2}$ (New Technology Management, Japan) as a working fluid.

First we measured the applied voltage vs. maximum pressure relation with an experimental setup shown in Fig. 4. The pressure P due to ECF jet is calculated using the following equation,

$$P = \rho gh \quad (1)$$

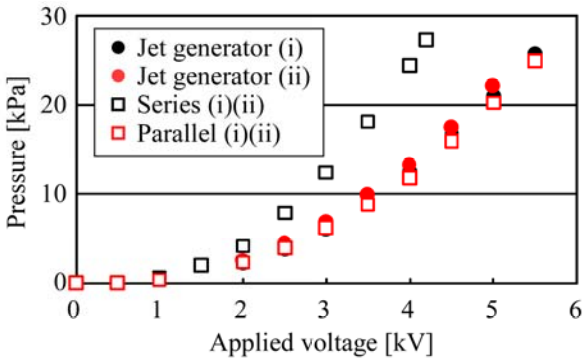
however, ρ: relative density of working fluid (1.68), g: gravity acceleration, h: fluid column head. Fig. 5 (a) shows the experimental results. The currents during the experiments are also shown in Fig. 5 (b). Note that, because of the limit of the experimental setup, the maximum voltage when the electrode pair was arranged in series was 4.2 kV, which is smaller than those in other cases. Fig. 5 denotes each electrode pair has almost the same characteristics. When the pairs are arranged in series, the ECF jet pressure becomes double of that by a single electrode pair. At the same time, the current also becomes double. On the other hand, when the pairs are arranged in parallel, although the current becomes double, the ECF jet pressure does not increase.

Second we measured the pressure vs. flow rate relation. Fig. 6 shows the experimental results when the applied voltage is (a) 5 kV, (b) 4 kV, (c) 3 kV, and (d) 2 kV,

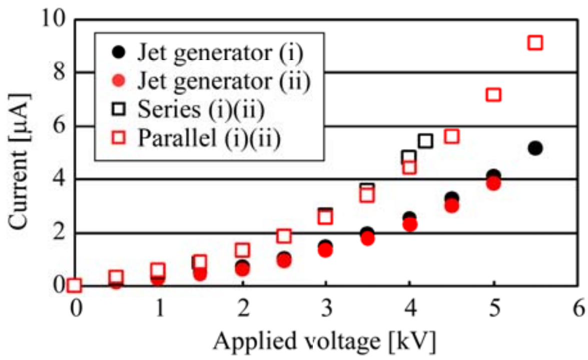


(a) Single electrode pair (b) Two pairs in series (c) Two pairs in parallel

Figure 4: Experimental setup for jet generator



(a) ECF jet pressure



(b) Consumption current

Figure 5: ECF jet pressure and consumption current

however range of axis is common in each graph for being easily compared. However, because of the limitation of experimental setup, we could not obtain the results when the electrode pairs in series with 5 kV and a single electrode pair/pairs in parallel with 2 kV. Each jet generator has a little different characteristic due to the production error. From the view point of flow rate, the electrode pairs arranged in parallel clearly have an advantage. On the other hand, when considering the generated pressure, those in series must be the best choice. Fig. 7 is the pressure vs. output power relation calculated from Fig. 6. It is clear that the electrode pairs arranged in series have the best performance from the view point of output power.

5.2 Static Contraction of ECF Micro Artificial Muscle Actuator

From the experiments mentioned above, the electrode

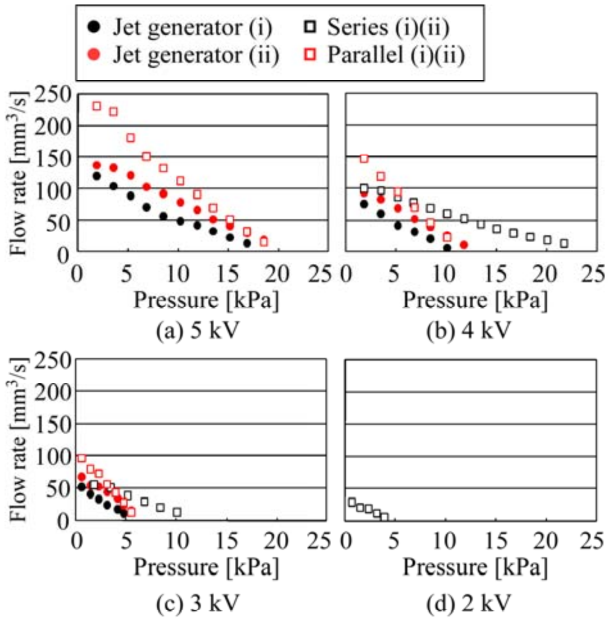


Figure 6: Pressure vs. flow rate relation

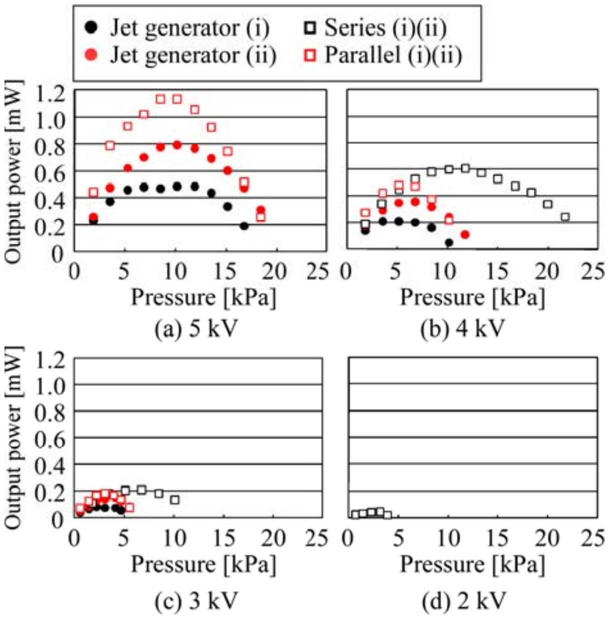


Figure 7: Pressure vs. output power relation

pairs arranged in series is clearly having the best pumping performance. Consequently, using this ECF jet generator, we construct the ECF micro artificial muscle actuator as shown in Fig. 8. The figure also illustrates an experimental setup for measuring driving performance of the ECF micro artificial muscle actuator.

In this section, we measure the static contraction of the ECF micro artificial muscle actuator when the applied voltage to the jet generator is up to 3.75 kV. Fig. 9 shows the experimental results. The contraction rate here means the contraction ration with regard to the original length of the silicone rubber tube, 10 mm. The effective contraction occurs at 2.25 kV or higher, which means, with lower than 2.25 kV, the inner pressure is used to initialize the tube shape to be straight. Namely, there must be slack of silicone rubber tube and fiber sleeve when no voltage is applied because of a possible production error. However,

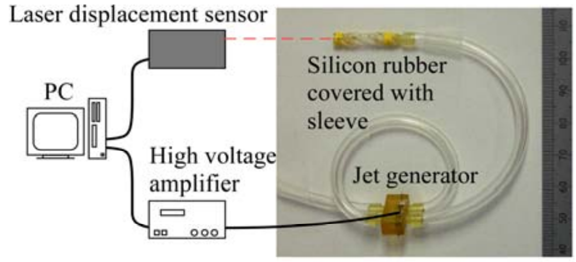


Figure 8: Produced ECF micro artificial muscle actuator

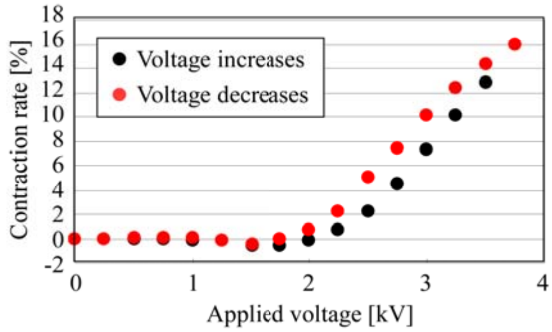


Figure 9: Static contraction of ECF micro artificial muscle

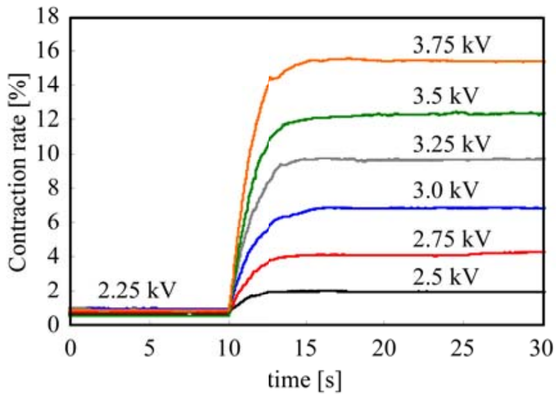


Figure 10: Dynamic contraction of ECF micro artificial muscle

the contraction rate increases as the voltage increases with a little hysteresis. The maximum contraction rate measured was 16 %.

5.3 Dynamic Contraction of ECF Micro Artificial Muscle Actuator

This section describes the dynamic contraction of the ECF micro artificial muscle actuator driven with electrode pairs arranged in series. From the static characteristics mentioned above, we applied step inputs to the jet generator from 2.25 kV to 2.5 kV, 2.75 kV, 3.0 kV, 3.25 kV, 3.5 kV and 3.75 kV, respectively. Fig. 10 shows the experimental results. The convergence time of each response is nearly the same as can be seen in the results and the contraction rate smoothly saturates to the steady state. The rise time of each response is 1.9 s, 1.6 s, 3.1 s, 2.6 s, 2.7 s and 2.3 s.

6. Micro Robot Arm Application

We develop a micro robot arm driven by two ECF micro artificial muscle actuators as shown in Fig. 11. When one artificial muscle actuator contract, the arm bends. On the other hand, the arm translates as both artificial muscle actuators are driven. The ECF micro

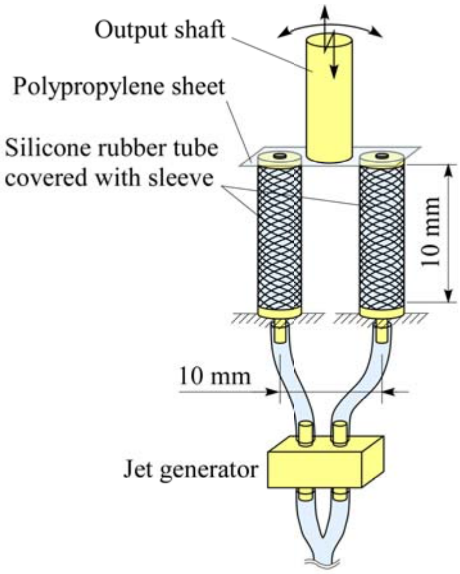
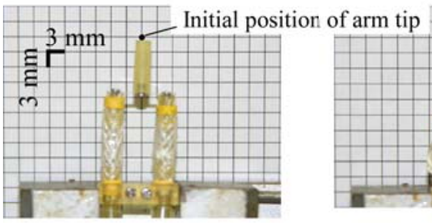
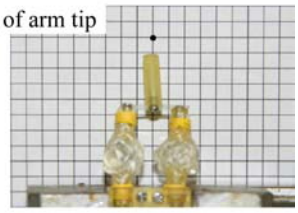


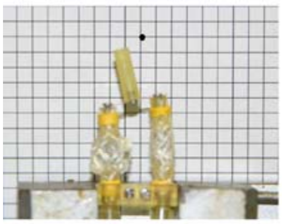
Figure 11: Micro robot arm driven by ECF micro artificial muscle actuators



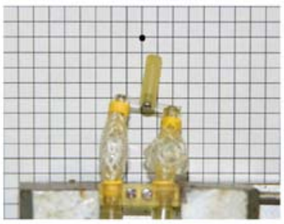
(a) Initial state



(b) 5.0 kV - 5.0 kV



(c) 5.5 kV - 0 kV



(d) 0 kV - 5.5 kV

Figure 12: Driving status of micro robot arm

artificial muscle actuators in this application work not only as actuators but also as elastic hinges, because the actuator itself has flexibility. Fig. 12 shows a driving status. From the figure, we confirm the effectiveness of the proposed micro robot arm.

7. Conclusion

A new type of artificial muscle actuator using electro-conjugate fluid (ECF) is proposed in this study. The actuator is mainly composed of an ECF jet generator and a silicone rubber tube covered with a fiber sleeve. The experimental results confirm the concept of the ECF micro artificial muscle actuator. In addition, we applied the actuator to a simple micro robot arm.

Our future work focuses on integrating the jet generator with the silicone rubber tube (artificial muscle actuator), and on a dexterous robot arm/hand driven by the ECF micro artificial muscle actuators.

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