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STUDY ON LIQUID CRYSTAL PUMP

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ABSTRACT

This paper is concerning to a small pump for liquid crystal, which is called liquid crystal pump in the present paper. The mechanism of the induced flow of liquid crystal by application of electric fields on the liquid crystal is used to generate the rotational flow in the present pump. Liquid crystal pump has a channel to change rotational flow into one way flow from inlet to outlet of the pump. Rotational electric fields are used in the present study.

In our researches, a previous pump was cylindrical type with a long length in the axial direction. On the other hand, this paper presents plate type pumps with planar electrode, so it is short in the axial direction. The rotational electric fields are generated by circle-electrode structure fabricated on planar surface, which are applied three-phase alternating currents. Using integrated electrode plate, connection of pumps with plate type is easier than cylindrical one.

The pressure-flow rate characteristics of the pump were measured. In addition the relation between non-dimensional flow rate and pressure of the pump were obtained. In order to obtain a high pressure and high flow rate, various shapes of electrode and channel were investigated and the measured results were compared each other. Besides connecting pumps with integrated circle electrode plate were designed to get the required pressure and flow rate. The structure of liquid crystal pump is simple and the size can be decreased by further researches. So this pump has the advantage of small source of actuator by changing electric power into fluid power. In addition our pump has a good possibility of the cooling system's source because this pump makes no noise and no mechanical vibration.

Keywords: Liquid Crystal, Functional Fluid, Unsteady Electric Field, Pressure, Flow Rate

INTRODUCTION

Research has actively been undertaken to provide a better understanding of pump dynamics. Diaphragm- and micro-syringe pumps are typical examples of a mechanical micro-pump and the other mechanical micro-pumps are developed recently. The advantage of these pumps over conventional ones is that they can be used to pump any liquid or gas. However, they are difficult to micro-fabricate and assemble because they contain many parts, so research is currently being conducted to develop low-noise pumps that use functional fluids and have simplified designs with no sliding parts. Such a micro-pump

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would have various applications. For example, it could be used in power sources of equipment that supply liquid, cooling systems, micro machines, and supplying fuel to the ultra-micro gas turbine. For this wide range of applications, various micro-pumps are needed to enable its use in any environment and under any conditions. Therefore, various micro-pumps are being designed and are actively being studied. The system with fluid control type would be used widely in micro fields because of the decreased number of parts and the sliding part using the fluid drive by the characteristic of the functional fluid. The properties of functional fluids can be controlled by electric or magnetic fields. Typical fluid pumps use some flow mechanisms, including ion drag [1], electro hydro dynamics (EHD)[2,3], electro-conjugate fluid (ECF) jets [4,5] and electroosmotic flow[6].

In our previous researches, when three-phase alternating current is applied to the cylinder electrode in order to apply the voltage on the liquid crystal, one of authors found rotational flow of liquid crystal in cylinder electrode. And they reported the cylindrical pump that consists of a spiral flow channel wrapped inside cylinder electrode [7]. As a result, the liquid crystal flows in the axial direction of the pump. On the other hands, when three-phase alternating currents apply the planar electrodes which are placed at the bottom of the cylinder, they found rotational flow of liquid crystal on the bottom electrodes. And one of authors suggested the motors using rotational flow of liquid crystal [8].

In this study, we developed plate type pump with planar electrodes and flow channel which change rotational flow into one way flow. This plate type pump is shorter in the axial direction than the previous cylindrical type one. We designed the plate type pump and measured the pressure and the flow rate. Especially the relation between various shapes of electrode and characteristics of the pump is reported in this paper. Beside connection of this plate type pumps is easier than connection of the cylindrical one, because this is able to use integrated electrode plate. So we designed the pump with integrated electrode plate to get high pressure and high flow rate.

The structure of liquid crystal pump is simple and the size can be decreased by further researches. So this pump has the advantage of small source of actuator by changing electric power into fluid power. In addition our pump has a good possibility of the cooling system's source because this pump makes no noise and no mechanical vibration.

PROPERTIES OF LIQUID CRYSTAL AND ROTATIONAL FLOW

The liquid crystal which is used in our study is MLC6650. This is liquid crystal mixtures mixed with some nematic liquid crystals. The characteristics of MLC6650 are listed in Table.1. ε_{per} is dielectric constant of the vertical direction to longitudinal of the liquid crystal molecule, and ε_{para} is dielectric constant of the parallel direction to longitudinal direction of the liquid crystal molecule.

In previous study, this liquid crystal is confirmed the rotational flow on the plate electrode. The experimental apparatus is shown in Fig.1. In this experiment, the frequency of a voltage wave of three-phase alternating current is 50Hz and the voltage means the effect value. A 50-Hz, 200-V three-phase alternating current is input to a voltage transformer. An output voltage between 0 and 240 V is generated using this voltage transformer. Next, the amplitude of the output voltage is amplified about 15 times using the transformer, and the resulting voltage of three-phase alternating current (named 'r', 's' and 't') are applied to the electrodes. So the rotating electric field is generated. The flow of the liquid crystal in the cylinder is observed in the axial direction using a commercially digital video camera. The surface of the liquid crystal is almost flat.

A picture of a liquid crystal flow in cylinder electrode is shown in Fig.2. The voltage is 1000V. A liquid crystal rotated in same rotation direction of the electric fields. The flow of the liquid crystal is observed by rotating rotor which is floating on liquid crystal.

Table1. Physical properties of MLC6650

Operating Temperature Region(℃)	-44～99
Kinematic viscosity(mm^2/s) (25℃)	59.7
Dielectric constant(F/m) (relative permittivity) ε per（20℃)	9.0×10^{-11}（10.2)
Dielectric constant(F/m) (relative permittivity) ε para（20℃)	55.6×10^{-11}（62.8)
Density(kg/m^3) ρ （25℃）	1099

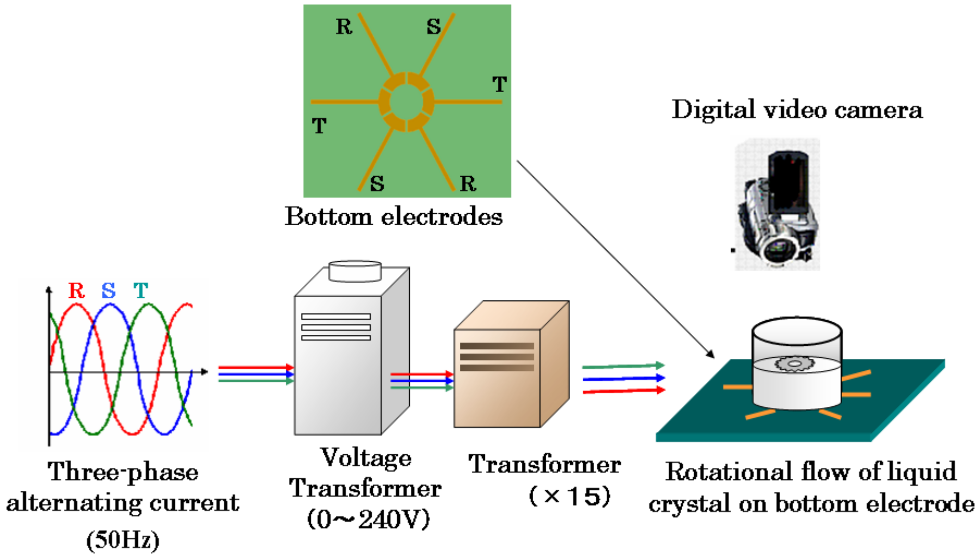


Fig1. Experimental apparatus for visualization

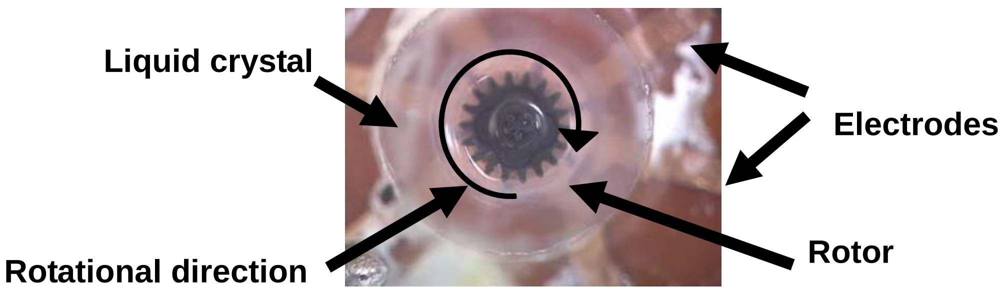


Fig2. Visualization result

EXPERIMENTS OF PUMPS

Electrodes and channels which are used in our research are shown in Fig 3 .This electrode is called 'Circle-electrode'. The diameter of the electrode is 6mm and width of it is 0.5mm, and the inter electrode distance is 0.2mm. The channel is along by electrodes, and the width of the flow channel is 1mm.

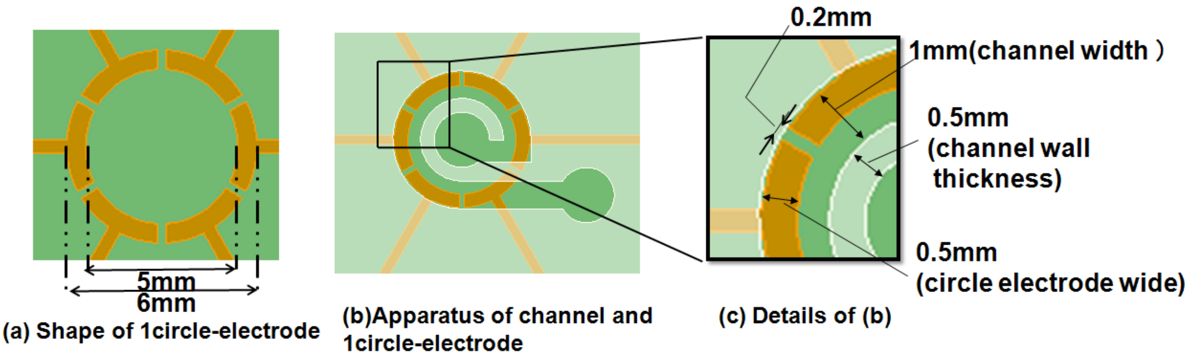


Fig3. Electrode and channel of pump

The principle of this pump is shown in Fig4. Three-phase alternating currents were used as rotational electric fields to generate the rotational flow of liquid crystal , so liquid crystal flows in the way circumferential direction along the channel .The center hall of this pump is inlet ,and outside hall is outlet .

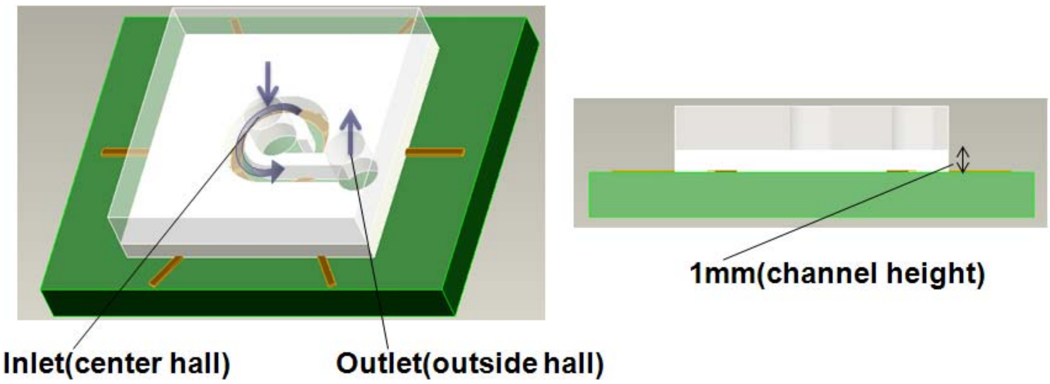


Fig.4 Principal of pump

The experimental apparatus for investigating the characteristics of pump is shown in Fig.5. In this experiment, the frequency of a voltage wave of three-phase alternating current is 50Hz and the voltage means the effect value. A 50-Hz, 200-V three-phase alternating current is input to a voltage transformer (A). An output voltage between 0 and 240 V is generated using this voltage transformer. Next, the amplitude of the output voltage is amplified about 15 times using the transformer (B), and the resulting voltage is applied to the electrodes of tested pump (C).

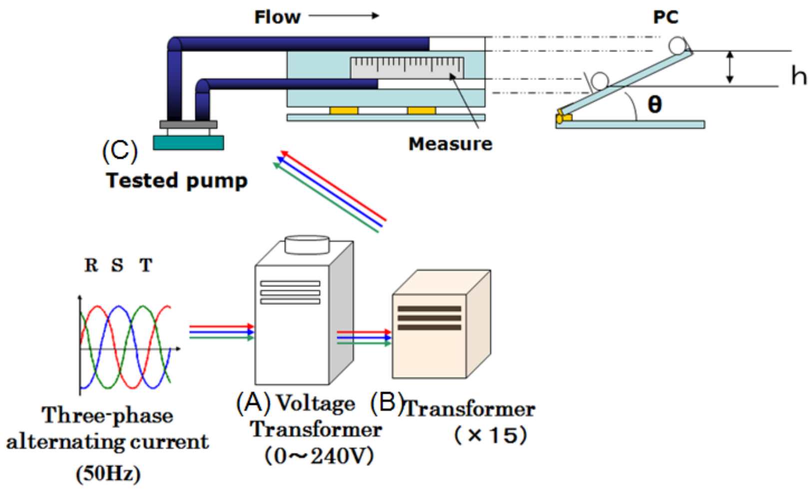


Fig.5 Experimental apparatus

In this experiment, voltages between 0 and 1400 V were applied to the electrodes. The flow rate was measured when the total head, h, was changed. To measure the flow rate, we first took a video of the movement of the free surface of the liquid crystal in a pipe whose inner diameter is 4 mm. The video was taken from the direction vertical to the plate. We then enlarged the images in the video to see the flow clearly. The maximum pressure, p_m, is defined without the flow. The maximum pressure p_m is calculated by $p_m = \rho g h$, where ρ is the density, g is the acceleration due to gravity (9.81 m/s^2), and h is the total head.

RESULTS FOR CHARACTERISTICS OF PUMP

The relation between the flow rate and the pressure are shown in Fig.7 for the pump with 1circle-electrode. The pressure is calculated by $p = \rho g H$. The flow rate increased with the voltage when the pressure was the same. Furthermore, the flow rate was a maximum when the pressure was 0, and the pressure dropped off nearly linearly with flow rate with constant voltage.

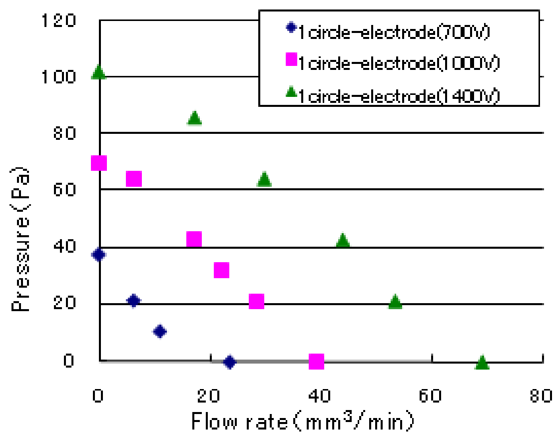


Fig.7 Relationship between flow rate and pressure under constant voltage

The results of the non-dimensional analysis of the pump properties are shown in Fig.8. The relations between $\mu Q/\{D^3(\varepsilon_{per}-\varepsilon_1)E^2\}$ and $p/\{(\varepsilon_{per}-\varepsilon_1)E^2\}$ derived by the π theorem almost become the same line, where μ is the value of viscosity, Q is the value of flow rate, D is the value of channel length , ε_{per} is dielectric constant of the vertical direction to longitudinal of the liquid crystal molecule, ε_1 is dielectric constant of insulating part (Glass epoxy resin) in the electrode, relative permittivity of 4.7 was used, E is electric field intensity, P is the value of pressure. The pressure-flow rate characteristics of the pump can be guessed from this result when the liquid crystals with different properties are used in the present pump. (εper—ε1) means the difference between the dielectric constant of the vertical direction to longitudinal direction of the liquid crystal molecule and the dielectric constant of insulating part. The difference was used for the present non-dimensional analysis because the difference is found to be very important factor, which acts on the characteristics of the liquid crystal under application of the voltage.

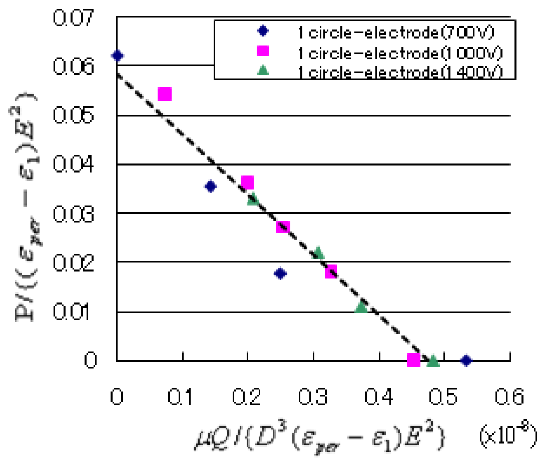


Fig.8 Result of dimensional analysis

In order to increase pressure and flow rate, connecting pumps with integrated circle-electrode plate were shown in Fig.9. Three-phase alternating current applied on the two circle-electrodes respectively as rotations of electric fields are same. So rotations of liquid crystal are same and the liquid crystal flow one way along this channel. The relation between the maximum pressure and voltage for this pump are shown in Fig.10. Using the pump with integrated two circle electrode , the maximum pressure and pressure-flow rate characteristics are almost twice that of a single pump.

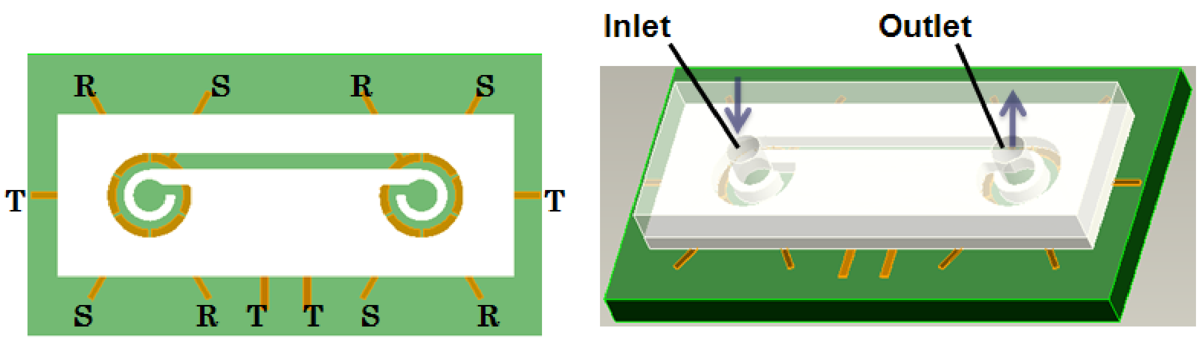
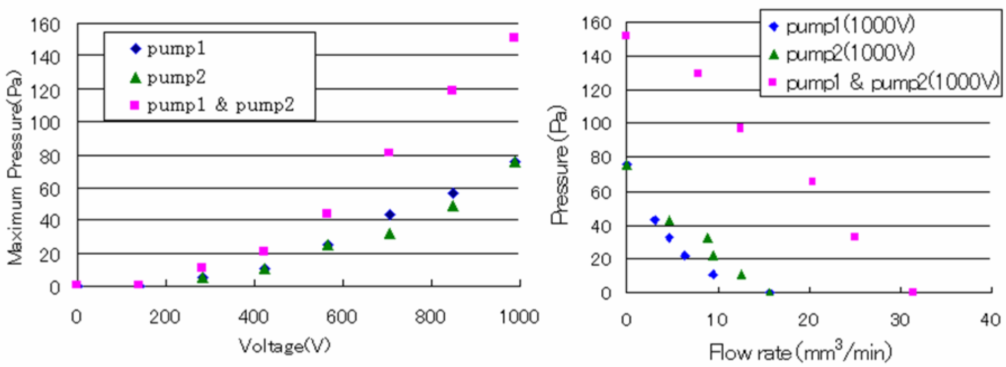


Fig.9 The connecting pump



(a) Relationship between voltage and maximum pressure (single and 2 connecting pumps)

(b) Relationship between the flow rate and pressure (single and 2 connecting pumps)

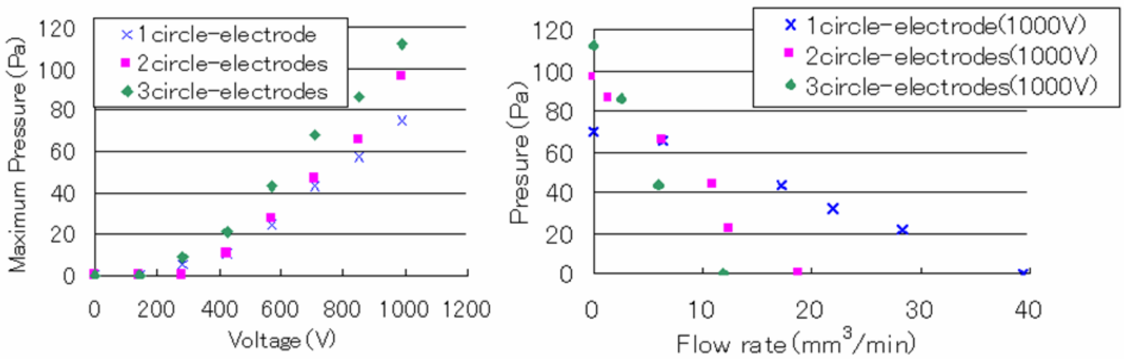
Fig.10 Result of the experiment for connecting pumps

Furthermore, 2,3circle-electrodes are designed in order to get more output power. These electrodes are shown in Fig.6, and channel's scroll number fit the electrode. We investigated the relation between the electrode's circle number and pressure- flow rate characteristics of the pump.

(a) 2circle-electrode **(b)3circle-electrode**

Fig.6 Apparatus of 2,3circle-electrodes

Characteristics of the pumps with 1,2,3circle-electrode are shown in Fig.8 . As circle number is large, the maximum pressure is increased. But circle number is large, the flow rate is decreased.



(a) Relationship between the voltage and the maximum pressure (1,2,3 circle-electrodes)

(b) Relationship between the flow rate and the pressure (1,2,3circle-electrodes)

Fig.8 Result of the experiment for the pumps with 1,2,3circle-electrode

CONCLUSIONS

In the present study, rotation electric fields were applied to the circle-electrodes to add the voltage on the liquid crystal (MLC6650), and flow was induced by the property of the liquid crystal. A pump with the circle-electrode and channel which change rotational flow into one way flow was designed, and the pressure-flow rate characteristics of the pump were measured. We made the following findings.

1. The pressure dropped off nearly linearly with flow rate with constant voltage.
2. For the dimensionless parameters calculated using π theorem, all relations between $\mu Q \big/ \left\{ D^3 (\varepsilon_{per} - \varepsilon_1) E^2 \right\}$ and $p \big/ \left\{ (\varepsilon_{per} - \varepsilon_1) E^2 \right\}$ almost become the same line, where μ is the value of viscosity, Q is the value of flow rate, D is the value of channel length , ε_{per} is dielectric constant of the vertical direction to longitudinal of the liquid crystal molecule, ε_1 is dielectric constant of insulating part (Glass epoxy resin) in the electrode, relative permittivity of 4.7 was used, E is electric field intensity, P is the value of pressure.
3. The connecting pumps are able to increase both pressure and flow rate.
4. As a number of circle-electrode is large, the maximum pressure is increased, but the flow rate is decreased. .

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REFERENCES

1. Yamada, H., Hakama, S., Miyashita, T. and Zhang, N., “An Investigation of an Ion Drag Pump Using a Needle-mesh Electrode Configuration”, Proc. Instn Mecha. Engrs., 216 Part C, J.Mechanical Engineering Science, 2006, pp.325-335.
2. Feng, Y. and Seyed-Yagoobi, J., “Control of Liquid Flow Distribution Utilizing EHD Conduction Pumping Mechanism”, IEEE Transactions on Industry Applications, 2006, 42-2, No.2, pp.369-377.
3. Kano, I., Mizuochi, K. and Takahashi, I., “Micro-Electro Hydrodynamic Pump by Dielectric Fluid. Improvement for Performance of Pressure Using Cylindrical Electrodes”, Proceedings of the Sixth International Symposium on Fluid Power Tsukuba,2005, pp.575-579.
4. Yokota, S., Seo, W., Yoshida, K. and Edamura, K., “A Planar Pump Using Electro-Conjugate Fluids (ECF) (Proposition of an ECF Pump for Liquid Cooling of Electronic Chips)”, Robotics and Mechatronics Division of the Japan Society of Mechanical Engineers, 2004, No.04-4,2P1-L1-61(1-4) (in Japanese).
5. Sakurai, Y., Kadoi, H., Nagata, T. and Edamura, K., “Development of Printed Circuit Board Multi-layered Typed ECF-pump and Its Application to Liquid Colling System”, Transactions of the Japan Society of Mechanical Engineers,2006, C, 72-715, pp.991-996 (in Japanese).
6. Okazaki, T.,Miyazaki, K. and Tsukamoto, H., “Development of an Electroosmotic Flow Driven Liquid Mirco-pump”, The preprint of the Mechanical Engineering Congress in Japan(MECJ-06),2006, No.06-1,No.2, pp.291-294 (in Japanese).
7. Tetsuhiro TSUKIJI and Hiroki SATO,“Basic Characteristics of a Liquid Crystal Pump”, 7th JFPS Intern ational Symposium on Fluid Power Toyama 2008, Toyama International Conference Center, 15-18 Sep tember 2008 Proceedings of the 7th JFPS International Symposium on Fluid Power, pp.545-550
8. Liang CHENG, Tetsuhiro TSUKIJI, Kazunori HAYAKAWA, and Xiao dong RUAN, “Study on Motors Using Liquid Crystal Flow induced by Electric Field”, 7th JFPS International Symposium on Fluid Po wer Toyama 2008, Proceedings of the 7th JFPS International Symposium on Fluid Power, pp.833-836.