Microfluidics PZT Pump Control by using High Voltage Controller with Multi-Phase Shifter

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***Abstract-* The high voltage driving system with multi-phase shifter including piezoelectric actuators comprised a driving power unit for outputting the driving power by converting input alternate current into direct current, a frequency shifting unit for supplying the direct current power and shifting or generating a frequency, a high-voltage amplification unit for amplifying the input signal outputted from the driving power unit and the frequency shifting unit into a high-voltage signal, and a phase shifting unit for shifting the phase difference of the amplified signal applied to the high-voltage amplification unit and driving plural piezoelectric actuators sequentially. The results that the operating voltage was stable, the voltage loss ratio was low and the response velocity was fast could be obtained. An experiment on performance of the high voltage driving system with multi-phase shifter designed and manufactured as above described was conducted by using a piezoelectric pump having 3 sheets of round unimorph piezoelectric actuators laminated respectively in a rectangular case. It sucks any fluid by causing the first piezoelectric actuator to shift from the inlet porter side, the phase delay of 60° causes the second piezoelectric actuator to begin to shift, and the phase delay of 120° causes the third piezoelectric actuator to begin to shift. As a result of measuring each change in the outlet flow rate of the piezoelectric pump, it was shown that the frequency-flow rate characteristic, the voltage-flow characteristic, and the load pressure-flow rate characteristic were improved.**

I. Introduction

A pump using a piezoelectric actuator requires a high-voltage control system for obtaining a high force, a large displacement characteristic, precision and an high response velocity[1][2]. If a general operational amplifier is used in a load circuit requiring high power which is not a circuit for low power driving, due to power greater than electric shock, normal operation cannot be done and the element gets to be destroyed[3]. In this study, a circuit was constructed so that high-voltage driving could be available and high-current could be outputted, and the circuit was designed and built so that safe power output could be available even in case the driving voltage was 200V or higher. In order to realize a high precision and a fast response characteristic having a direct effect on enhancement of actuating efficiency in a system comprising one or plural piezoelectric actuators, a phase shifting piezoelectric driving system to enable the output voltage to follow up the input voltage linearly and the frequency shift to be independently and sequentially controlled in the range of 0° to 180° was designed. A high-voltage driving system to amplify and shift an driving signal gets to have a direct effect on actuation of the piezoelectric actuator, and its characteristics, including compensation for a phase delay in a high frequency, prevention of distortion of the sine wave in a high voltage by a high slew rate, shift and stabilization of a voltage gain, improvement of input and output impedance, expansion of a frequency band width are very important[4].

An experiment on performance of the high voltage driving system with multi-phase shifter designed and manufactured was conducted by applying what 3 sheets of circular unimorph piezoelectric actuators were laminated in a rectangular case to a piezoelectric pump making vertical and bending motions by alternate compression and expansion[5]. Such pump using the piezoelectric actuator enables a micro flow controller, a microbial manipulating apparatus and the like to be manufactured so that it is extensively applicable to measuring instruments and apparatus requiring a high precision and treatment apparatus.

II. Design of High Voltage Driving System

The high voltage driving system with multi-phase shifter including piezoelectric actuators comprised a driving power unit for outputting the driving power by converting input alternating current into direct current, a frequency shifting unit for supplying the direct current power and shifting or generating a frequency, a high voltage control unit for amplifying the input signal outputted from the driving power unit and the frequency shifting unit into a high voltage signal, and a phase shifting unit for shifting the phase difference of the amplified signal applied to the high voltage control unit and driving plural piezoelectric actuators sequentially, as shown in Fig. 1. This driving system, including 3 piezoelectric actuators, was designed so that the output voltage could follow up the input voltage linearly and the frequency shift could be independently and sequentially controlled.

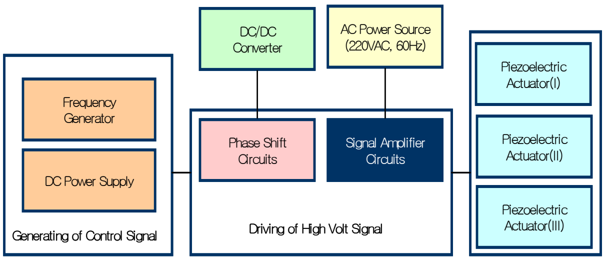

Fig. 1. Schematic diagram of high voltage driving controller with multi-phase shifter.

A circuit enabling a shifted phase response without any change in the amplitude and the phase of the sine wave input signal to be varied and controlled was as shown in Fig. 2. The operational amplifier of the first stage was made to have a circuit function to reverse or non-reverse the output waveform by connecting the one next to the resistance of R_1 with the ground. The operational amplifier circuit of the second stage was varied to phase shift of the waveform to be inputted by the time constant value of C_1 and VR_1 in the range of 0° to180°. If the output of the first operational amplifier is a reversal circuit, the phase shift will be in the range of –180° to 0°. A transfer function for the phase shifting circuit is represented by (1).

$$\frac{V_0}{V_I} = \frac{s - \dfrac{1}{VR_1C_1}}{s + \dfrac{1}{VR_1C_1}} \tag{1}$$

The phase shift by C_1 and VR_1 is represented by (2).

$$Phase(rad) = \tan^{-1}\left| \frac{\dfrac{2\omega}{VR_1C_1}}{\omega^2 - \left[\dfrac{1}{VR_1C_1}\right]^2} \right| \tag{2}$$

Where V_I is the input voltage, V_0 is output voltage, and ω is the frequencies in rad/s, or 2*pi*f, when f is in hertz.

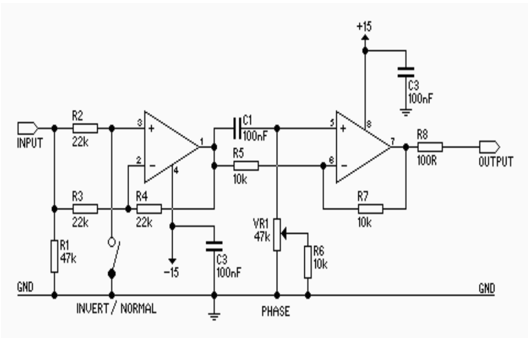

Fig. 2. Schematic of phase shift circuit.

The phase shift could be controlled by the unit of 1°, and the multi-phase shifter with phases of 0°, 60°, 120°, and 180° was as shown in Fig. 3.

Fig. 3. Multi- phase shifter with the range of 0° to 180°.

2.2 Design of Driving System for High-Voltage Control

The driving system for amplifying the multi-phase shift waveform into a high voltage signal was designed so that it could receive the commercial power and output a high voltage power having a frequency and enable 3 piezoelectric actuators to be operated with a phase difference. Its circuit structure was made to be simple by building integrated circuits, and its response time and operational characteristic were improved. The rectified DC power and a variable voltage in the range of 0V to 10V was made to be the input voltage for the high voltage controller, and the output power was controlled so that the frequency could be linearly shifted in the range of 1 Hz to 200 Hz at 200V. An impedance matching circuit was designed so that it could be respectively installed at the input stage and the output stage for prevention of a voltage drop and a signal distortion due to a difference in impedance between the phase shifter, the piezoelectric actuators and the actuating system and improvement in the input/output impedance. A circuit for discharging the electrical charge, with which the piezoelectric actuators were charged, at a high speed when the power was cut off, was designed so that the off time delay was minimized and the response velocity and the operational characteristic were improved. The manufactured high voltage driving system with multi-phase shifter was shown in Fig. 4.

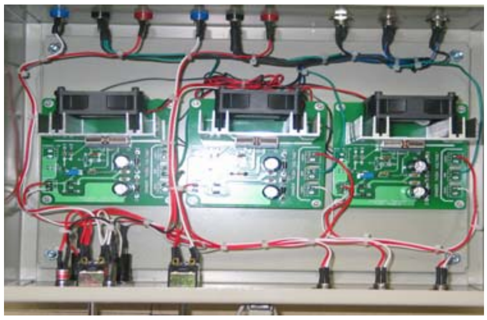

Fig. 4. Driving system for high-voltage control and multi-phase shift.

III. SEQUENCE CONTROL OF PZT PUMP

The piezoelectric actuator's structure was designed in the form that its thickness and diameter were respectively 0.2mm and 40mm, the brass shim's thickness and diameter were respectively 0.15mm and 50mm, piezoelectric ceramics were bonded to side of the brass shim and electrodes were laminated, and it was manufactured in the structure that silicon was molded for prevention of any contact with any fluid, as shown in Fig. 5. Expansion and compression of the piezoelectric actuator gets to take place depending upon the supplied power. When a frequency and a voltage sine wave were respectively applied to the piezoelectric actuator respectively in the range in 1Hz to 200Hz and 20V to 200V, it could be known that there was no change in the displacement in the range of 1Hz to 100Hz and 20V to 200V and in case the frequency was over 100Hz, as the frequency was more and more increased, the displacement was sharply decreased. The maximum displacement was 310 μm and the generating force appeared to be 170 gf at 200V.

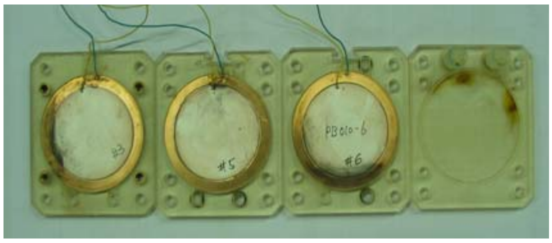

Fig. 5 Unimorph type piezoelectric actuator for PZT pump

The high voltage driving system with multi-phase shifter designed and manufactured, was applied to the piezoelectric pump with what 3 sheets of piezoelectric actuators were respectively laminated in a rectangular case was combined, as shown in Fig. 6. In the rectangular case, a flow channel enabling a fluid to flow in and out was formed, and the last actuator case, a flow channel was formed so that it could be directly connected to the first actuator case, and a suction porter and a discharge porter were made so that they could be arranged in parallel. The piezoelectric pump for carrying a micro quantity of fluid gets to suck the fluid as the piezoelectric actuator gets to be expanded and a chamber gets to be formed so that a cavity gets to be made, if the unimorph piezoelectric actuator is molded with silicon in the diaphragm form so that the sine wave signal is applied, and fit gets to discharge the fluid when the piezoelectric actuator is reinstated. The piezoelectric pump was of a simple structure enabling suction and discharge to be intermitted by sequential-operation of the unimorph piezoelectric actuator even without any check valve, and the number of its components was so small that any failure or any repairing event did not take place frequently. Since it had no noise resulting from operation of any check valve, it had an effect to enable low noise operation to be realized. A method for driving the piezoelectric pump by sequence control is that when the first piezoelectric actuator is caused to be displaced so that a fluid gets to be sucked, the phase shift of 60° causes the second piezoelectric actuator to start to be displaced, and then, the phase shift of 120° causes the third piezoelectric actuator to start to be displaced, and then, the fluid gets to flow into the cavity as formed by such displacement resulting from the phase shift of the piezoelectric actuator and the fluid gets to be pushed toward the outlet and discharged through it. Fig. 7 shows the principle of driving the piezoelectric pump by 6 phases.

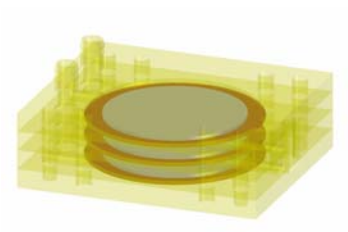

Fig. 6. Schematic of pump with laminated PZT Actuator.

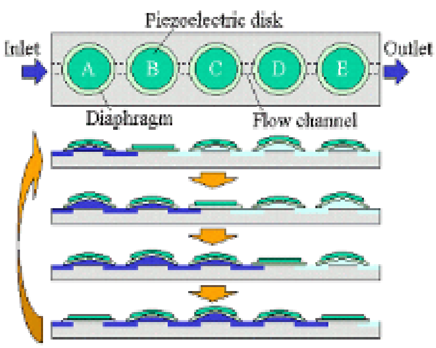

Fig. 7. Principle of sequence control for pumping.

IV. Experiment and Discussion on Results

For evaluating the performance of the high voltage driving system with multi-phase shifter, a test was conducted on the performance of the controller by voltage and a frequency, displacement and the generating force characteristic was conducted, the flow rate of the piezoelectric pump was measured and the condition for the maximum flow rate was obtained. For evaluating the performance of the multi-phase shifter, the phase shift by the unit of 1° was simulated as resistance was changed under the condition that the input signal was the sine wave with 60Hz, the amplitude was 3V and the offset was 3V by using the circuit as shown in Fig. 2.

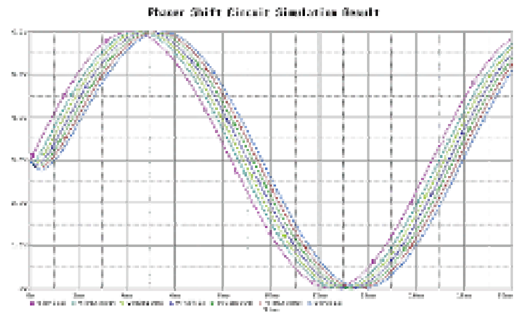

Fig. 9 Result of phase shift simulation with resolution of 1°.

As a result of conducting an experiment on characteristics of the output voltage of the high voltage driving system with multi-phase shifter, showed characteristics that the voltage gain value was 19.24 and the offset value was 0.186, and the range of controlling the frequency appeared to be 1Hz to 200Hz, and the output voltage appeared to be 20V to 200V. In the consumed power test, the power output of about 3.3W and the consumed current of about 20mA were measured. Fig. 10 shows the results of conducting an experiment on each phase shift of 0°, 60°, 120° and 180° under the condition that the voltage was varied in the range of 0V to 10V and the frequency was 60Hz.

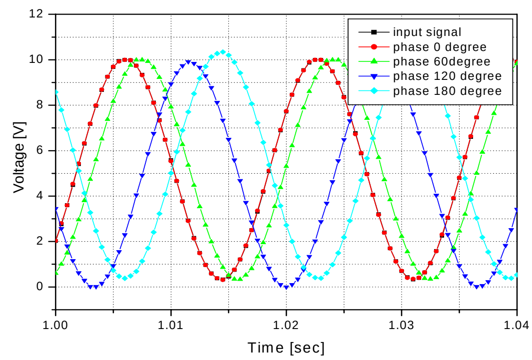

Fig. 10 Result of phase shift test at 60Hz, and 10Vp-p.

As a result of measuring a displacement of the piezoelectric actuator installed in the pump by using the high-voltage amplification actuating system, the maximum displacement was 202.4 ㎛ and the hysteresis was within 5.2%. The results of conducting a test to measure a displacement by each changed voltage were shown in Fig. 11.

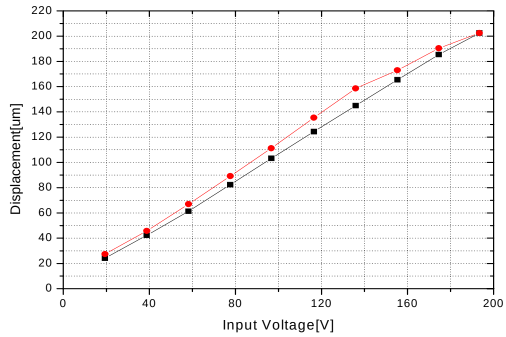

Fig. 11 Result of displacement for PZT actuator.

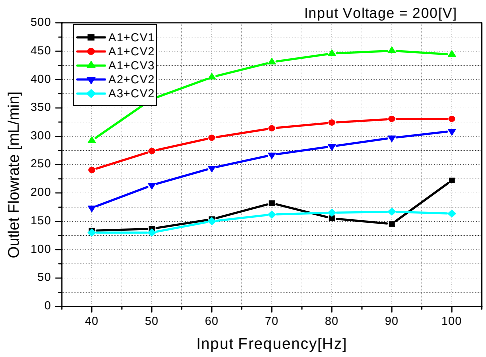

Fig. 12 Result of input frequency versus outlet flow rate test

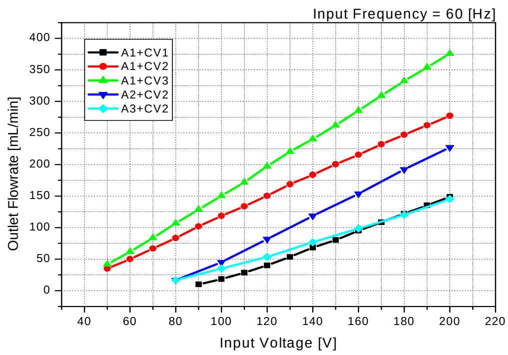

Fig. 13 Result of input voltage versus outlet flow rate test

The performance test was conducted and the flow rate was measured by applying the high voltage driving system with multi-phase shifter, as designed and manufactured so, to the piezoelectric pump. Fig. 12 shows the results of measuring each change in the outlet flow rate of the pump when the driving power for the piezoelectric pump was constantly maintained at 200V and the frequency of the input power was varied. Fig. 13 shows the results of measuring each change in the outlet flow rate of the piezoelectric pump when the frequency of the driving power was fixed at 60Hz and the input power was increased. Fig. 14 shows the change of the outlet flow rate of the piezoelectric pump by a change in the load pressure when the voltage and the frequency of the driving power were respectively 200V and 60Hz.

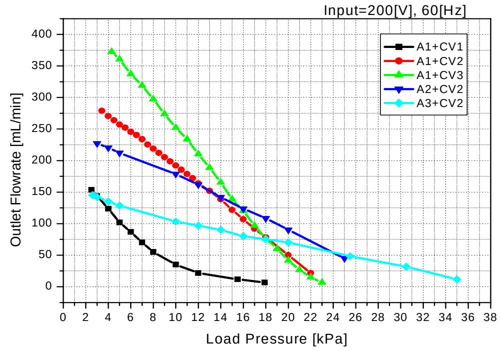

Fig. 14 Result of load pressure versus outlet flow rate test

V. CONCLUSION

The high voltage driving system with multi-phase shifter was designed and manufactured, and the operational characteristic test and the performance test were conducted on it by applying it to the piezoelectric pump. The developed driving system showed that the gain of the output power versus the input voltage was linearly 96.2%, the phase shift was available by 60°, 120° and 180° and the control resolution was 1°. The results that the operating voltage was stable, the voltage loss ratio was very low and the response velocity was fast could be obtained. Also, as a result of conducting the performance test on the piezoelectric actuator by using the high voltage driving system with multi-phase shifter, it showed such characteristics that the maximum displacement was 202.4 ㎛ (200V) and the hysteresis was within 5.2%. As a result of measuring each change in the outlet flow rate of the piezoelectric pump, it was shown that the frequency-flow rate characteristic, the voltage-flow characteristic, and load pressure-flow rate characteristic were improved. In order to applying the results of this study to the piezoelectric pump and applied apparatus practically, problems relating to performance, reliability and life-span of the system, suitability of the material and others should be solved.

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