Drive Characteristics Using Resonant Frequency of a Ring Type Ultrasonic Motor

Shin-Yong Yoon*, Soo-Hyun Baek* and Cherl-Jin Kim**

Abstract - The rotational force of ultrasonic motors is able to get from the frictional force of elliptical vibration by contact between rotor and stator. Generally, ultrasonic motors are suitable for driving at resonant frequencies of about 20~80 [kHz]. The driving characteristics of ring type ultrasonic motors are the object of this study. A two-phase driving signal is delivered to the tested ultrasonic motor, which has a 90^0 phase difference respectively with both sine and cosine voltage waveforms. The driving frequency is almost equal to the mechanical resonant frequency for the proper operation, and the driving signal is supplied by the two-phase parallel resonant inverter. The validity of the proposed driving method is verified by experimental results with stable operation.

Keywords: Ring type ultrasonic motor, Resonant frequency, Two phase parallel type inverter.

1. Introduction

According to industrial information, actuator application is crucial in cameras, robots, information machines, etc. Currently, the industrial type actuator consists of an electrical motor using a magnetic field, oil pressure and an air pressure actuator, but this has resulted in the defect of small power ratio to mass. The study to solve this fault is underway using an ultrasonic motor, which utilizes a powerful vibration energy produced at the piezoelectric vibrator [1-4].

The ultrasonic motor can obtain both linear force and rotation force, by contact friction of ellipse vibration to the ultrasonic motor between the stator and rotor. The ultrasonic motor can be generally divided into rotation type, linear type and ring type [5-8].

This paper studies the resonant characteristics for driving the ring type ultrasonic motor with manufactured ones. Resonance was produced when the mechanical resonant frequency was similar with the driving frequency. It is feasible to drive in a resonant frequency of about 20 ~ 80[kHz]. In this paper, to obtain the suitable drive characteristics of a manufactured ultrasonic motor, the driver was organized with a two-phase parallel resonance type inverter.

The validity of this method will be established through the experimental results.

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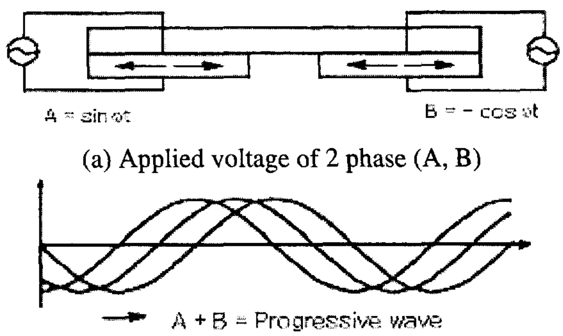
2. Drive and Control of Ultrasonic Motor

2.1 Drive Principle and Equivalent Circuit of Ultrasonic Motor

Fig. 1(a) is a state that the high frequency voltage of 2 phase (A, B) is applied with the phase difference. Fig. 1(b) illustrates the mixed bend advance wave produced by Fig 1(a) [3-5].



(a) Applied voltage of 2 phase (A, B)

(b) Mixed bend advance wave

Fig. 1 Drive principles of ultrasonic motor

When a high electric field is applied to the piezoelectric ceramic of the ultrasonic motor, mechanical vibration is caused. This time its frequency is almost identical to the mechanical resonant frequency determined by the dimension of piezoelectric ceramics and elastic body, resulting in vibration generated by the piezoelectric resonant.

Fig. 2 is the color density for stator vibration displacement at 7 order vibration mode. Here, the vibration displacement color of the outer diameter is higher than the vibration displacement color of the inner diameter. The analysis resulted in a resonant frequency 51.3[kHz]. Here, impedance analysis result is inserted at reference [8].

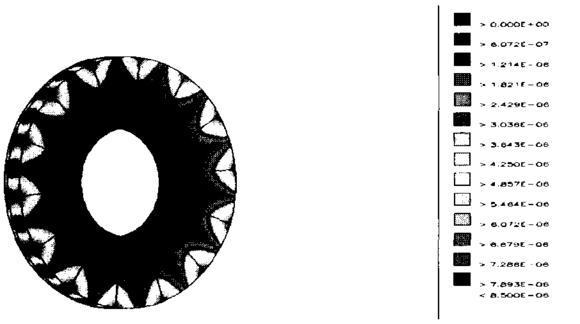


Fig. 2 Stator vibration displacement at 7 order resonant mode

Fig. 3 shows an experiment result for the impedance characteristics of a ring type ultrasonic motor. Here experiment results indicate a resonant frequency of 48.7[kHz]. We also obtained parameters L_m, C_m, C_d and r_0 from impedance analysis measurement (HP4192A).

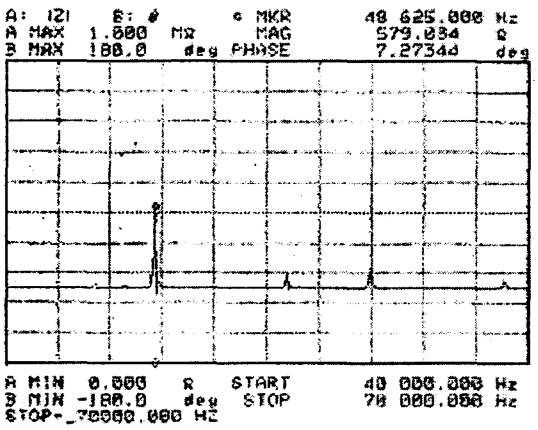


Fig. 3 Admittance measurement waveform for resonant frequency

This driving of the ultrasonic motor is made possible by an electrical-mechanical change. For electricity input, the relation equations of vibration and strain for the ultrasonic motor are as follows.

$$F = -AE + z_1 v$$
$$I = Y_d E + Av \tag{1}$$

Here, Y_d: damping admittance,

z_1:mechanical impedance, A: force factor,

F: drive force, v: vibration velocity,

I: current, E: voltage.

The equivalent circuit of the ultrasonic motor is shown in Fig. 4.

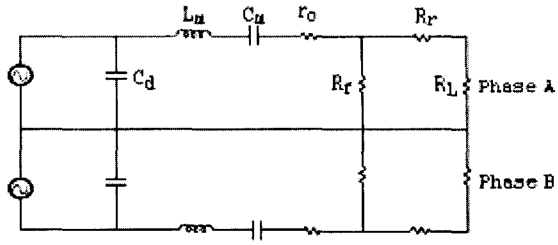


Fig. 4 Equivalent circuit of ultrasonic motor

Here, C_d : blocking capacitor, L_m : equivalent, C_m : equivalent, r_o : equivalent resistor, R_f :sliding losses resistor, R_r : mechanical losses resistor from the movement of the rotor , R_L : equivalent load.

From Fig. 4, the mechanical impedance is represented as Eq (2) using three equivalent variables.

$$z_1 = r_1 + j\left(\omega m_1 - \frac{s_1}{\omega}\right) \tag{2}$$

Here, m_1: mechanical resistance,

r_1: mechanical mass, s_1: mechanical stiffness

Admittance of the ultrasonic motor is represented as follows from Eq. (2) to the condition of $F = 0$.

$$Y = \frac{I}{E} = Y_d + \frac{A^2}{z_1}$$
$$= j\omega C_d + \frac{1}{\frac{r_1}{A^2} + j\omega\frac{m_1}{A^2} + \frac{s_1}{j\omega A^2}} \tag{3}$$

Here, $r_0 = \frac{r_1}{A^2}$, $L_m = \frac{m_1}{A^2}$, $C_m = \frac{s_1}{j\omega A^2}$

Using piezoelectric ceramics, it is possible to achieve a small strain by resonant voltage, but to produce a large strain by relatively low voltage, the resonant phenomenon method is the most effective. So in the ultrasonic motor, to obtain a high efficiency as shown in Fig. 5, resonant frequency must be moving between L_m and C_m, and the relation equation for this mean as a resonant phenomenon is represented by factor Q.

$$Q = \frac{\omega_0 m}{r_0} \tag{4}$$

Then resonant frequency ω_0 is similar to Eq. (5)

$$\omega_0 = \sqrt{1/(L_m C_m)} = \sqrt{k/m} \tag{5}$$

Here, k : spring coefficient of piezoelectric ceramic and elastic body

•: coupling mass

2.2 Drive Circuit of an Ultrasonic Motor

Fig. 5 is system block diagram for the driving of an ultrasonic motor. A main section of each was composed having a power supply unit, feedback detection, pulse production and driving circuit component. The power supply unit amplified power by the push-pull method of the 4 phase switching circuit, and was constructed to achieve the impedance union with a motor using the boost transformer.

The feedback circuit component is transmitted to control the circuit portion after performing a search of the sensor output terminal signal. This was also organized to detect the vibration voltage of the sine wave with 2 phase difference [7].

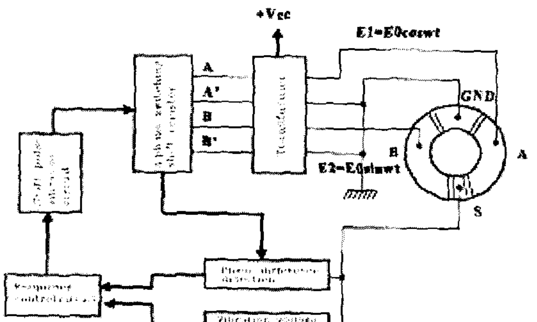
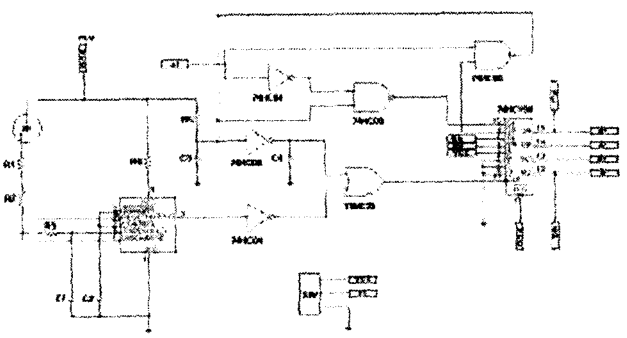


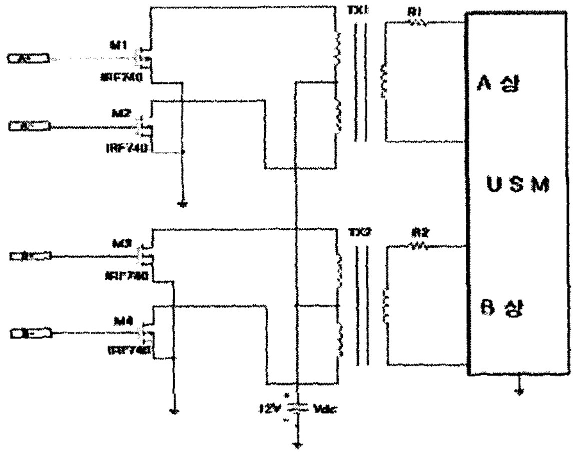
Fig. 5 Block diagram for driving of an ultrasonic motor

Fig. 6 is the driving circuit of an ultrasonic motor. Here Fig 6(a) shows the circuit portion of two-phase pulse producing that uses the 4 phase shift register. An oscillator circuit is composed to control the resonant frequency, with variable resistance value using timer LM555. Then, the 74HC194 of the 4 phase shift register is used to construct the gate pulse signal of 2 phase (A, A') and (B, B').

Fig. 6(b) is an inverter drive circuit of 2 phase parallel resonant type constructed by using the MOSFET(IRF740) 4 numbers and boost transformer 2 numbers. This time the boost transformer is used for obtaining the sine wave voltage by inductance characteristics.



(a) Signal producing portion of drive gate



(b) 2 phase parallel inverter

Fig. 6 Drive circuit of an ultrasonic motor

3. Simulation and Experiment Results

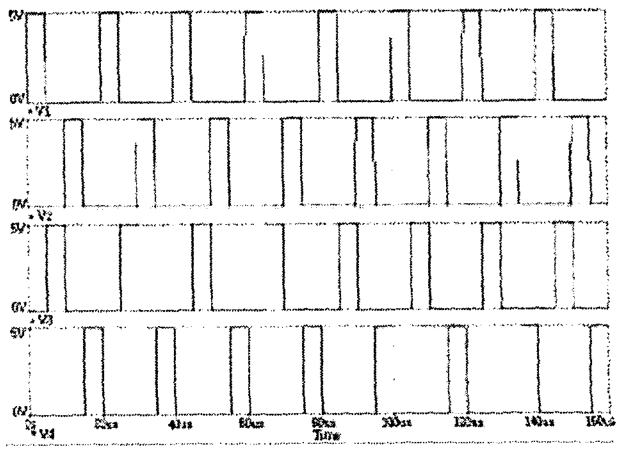
Table 1 shows the specifications of USM

Table 1 Specifications of the Ultrasonic motor

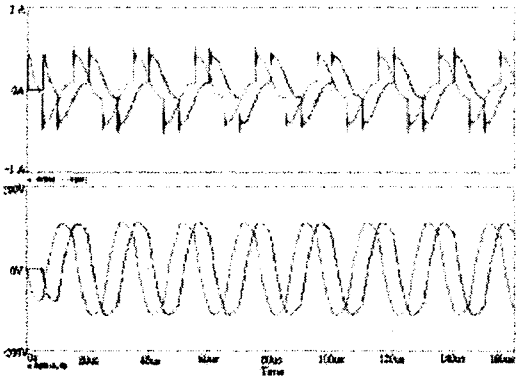
Item	Value [Unit]
Maximum Velocity	300 [rpm]
Drive Voltage	120 [V]
Drive Current	0.35 [A]
Drive Frequency	49.5 [KHz]
Torque	0.095 [Nm]

Fig. 7(a) shows the input voltage pulse signals for each MOSFET gate terminal composed from Fig. 6(a) and Fig. 7(b) indicates the simulation result of the output current and voltage waveform for the 2 phase inverter of Fig. 6(b).

Fig. 8 represents an output voltage waveform of the drive circuit along a variable velocity at no load. When the rotation speed of the ultrasonic motor is changed from

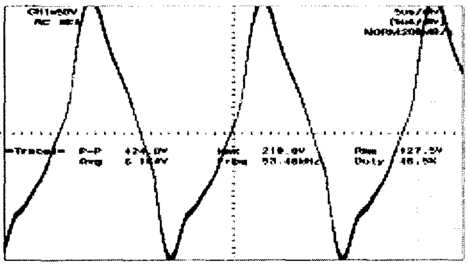


(a) Drive pulse signal of MOSFET

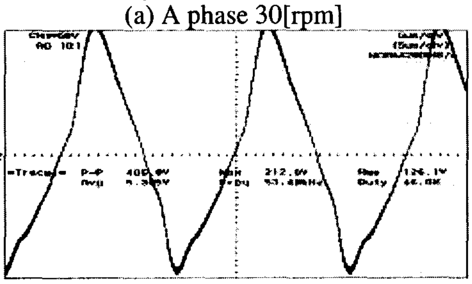


(b) Current and voltage waveform of inverter

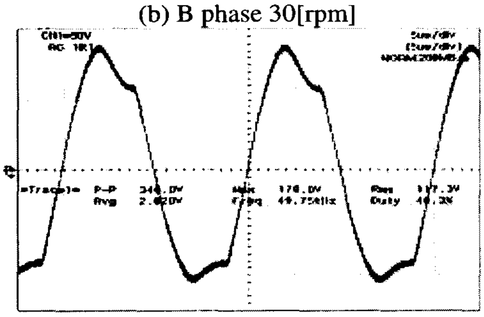
Fig. 7 Simulation waveform of drive circuit



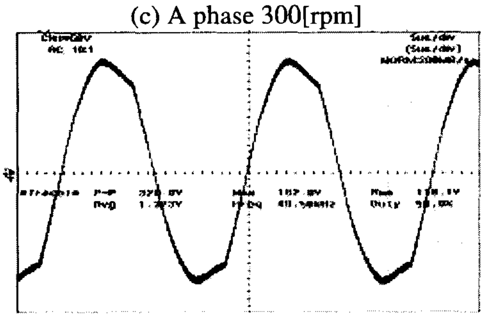
(a) A phase 30[rpm]



(b) B phase 30[rpm]



(c) A phase 300[rpm]



(d) B phase 300[rpm]

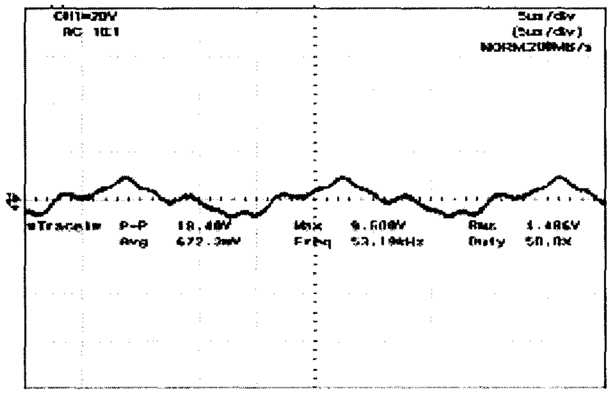
Fig. 8 Output voltage waveform of drive circuit to variable velocity

30[rpm] to 300[rpm], this was the measured result for the output voltage of inverter. Here we knew a fact that there were produced the 2 phase distortion voltage of phase difference at 30[rpm]. Otherwise that there could have gated the stable driving voltage of 2 phase at 300[rpm].

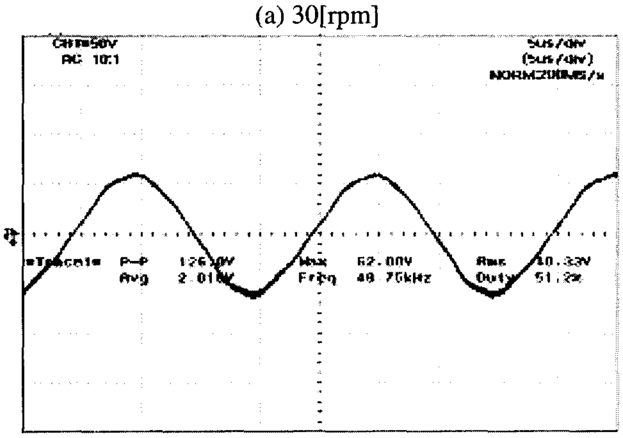
Through the 49.5[kHz] resonant frequency drive that compared results for the waves shown in Fig. 8(c) and Fig.8(d), the authors of this paper were aware of how to produce the stable voltage waveform of an average voltage decreased from 126[V] to 118[V], with velocity increased from 30[rpm] to 300[rpm].

The next step was the smooth progression on to the sinusoidal waveform so that the resonant frequency of the ultrasonic motor nearly approaches the driving frequency of the inverter. Namely, this means that the large force produced by an increase of the displacement of the piezoelectric vibrator reduces input impedance and moves the large current.

Fig. 9 is the detected voltage waveform at the feedback circuit section. Here we were aware that the quicker the rate of velocity, the greater the increase in voltage. A more stable voltage waveform at resonant frequency was also produced.



(a) 30[rpm]



(b) 300[rpm]

Fig. 9 Feedback voltage waveform by F/V converter

In the case of rotation speed 300[rpm] for an input voltage, Fig. 10 shows the compared result for measurement voltage of 2 phase (A, B). This time, the ultrasonic motor manufactured obtained the experimental result that the diving voltage of the two-phase difference was nearly produced to a 90^0 phase of both sine and cosine waveforms.

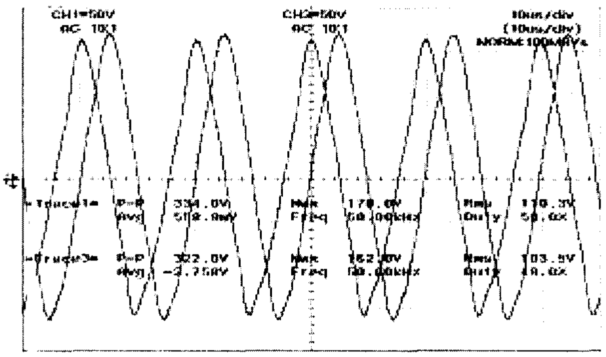


Fig. 10 Measurement voltage of 2 phase (A, B)

Fig. 11 shows an external appearance structure of an ultrasonic motor manufactured for measurement purposes. Here, the piezoelectric ceramic material manufactured for use is PZT5J.

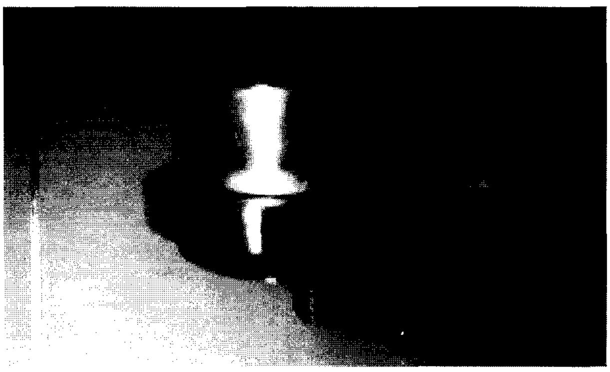


Fig. 11 Manufactured USM

4. Conclusion

This paper achieved the validity of stable control through driving characteristics of the ring type ultrasonic motor. For this, the two-phase parallel resonant type inverter was composed. Then, construction of the driving frequency of the ultrasonic motor for stable driving to no loss was completed with the equal switching frequency circuit compared with the mechanical resonant frequency of the ultrasonic motor.

The result of the experiment indicated that the stable speed control at maximum 300[rpm] is possible when the driving circuit was driving with almost equal frequency to the mechanical resonant frequency. Therefore, the output voltage of the ultrasonic motor manufactured employed the fact that the sine and cosine waveform voltages of stable two-phase are produced to a 90^0 phase difference.

These will be expected to be applied in the robot joint and hand, lens control type of automation camera, each small actuator and so on.

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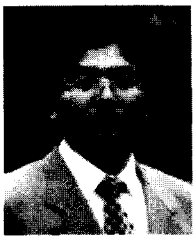

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