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Load Characteristics of a Diagonally Symmetric Form Ultrasonic Motor Using a $LiNbO_3$ Plate

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1. Introduction

The authors study on the high-speed rotational ultrasonic motor using $LiNbO_3$ [1,2] single crystal which is the Pb-free piezo-electric material and has better vibrational velocity dependence over the wide vibrational velocity range [3,4]. Especially in performing the miniaturization of the motor, the ultrasonic motor using the mode-coupled diagonally symmetric resonator has some advantages in the point of view of the structure being simple and the driving method being easy [5]. This paper describes the experimental results of the torque and the efficiency of this motor

2. Motor Construction and the Measuring Method

Figure 1 shows the structure of the proposed ultrasonic motor, where exist coupled two vibration modes and the excitation amplitude of the higher-frequency vibration mode is larger than another one[6]. For keeping higher quality factor Q, copper plates, fabricated as shown in **Fig.2**, are used for the electrical connections and supporting the vibrator. The copper plates are connected with the conductive adhesive material to the vibrator at its longitudinal centers both of the top and bottom surfaces. Then, the copper plates are set to the acrylic holder as shown by the right side illustration of Fig.2 and the vibrator with the supporting system is placed on the linear slide stage. In the previous study, the thickness of the plate was 0.1mm. Because this copper plates were thin, the supporting plates were twisted significantly at the connecting area, so that the top end of the stator vibrator shifted from the contact point between the rotor shaft and the stator, and therefore the pre-load force cannot be evaluated correctly. In this study, the thickness of supporting plate has been changed to 0.2mm. Moreover, to decrease the influence to the vibrator, width of the supporting plate has been changed from 1.0mm to 0.78mm at the connecting area between the supporting plate and the stator vibrator. As a result, the vibrator shift by the pre-load has been decreased and the quality factor Q of the driving vibration mode has been increased. **Table I** shows the equivalent constants of the vibrator after mounted to the supporting holder. The value of Q is higher than in the previous study (Q=4000 to 7000). **Figure 3** shows the measurement system.

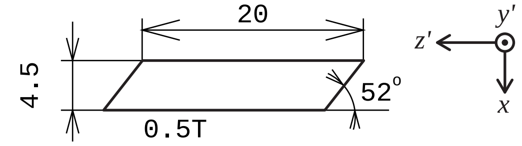

Fig. 1 Diagonally symmetrical vibrator using $LiNbO_3$ X-rotated 128° Y-cut plate.

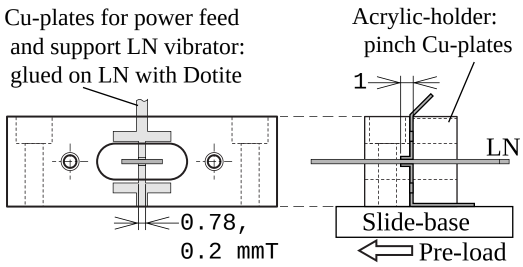

Fig. 2 Support structure of the vibrator.

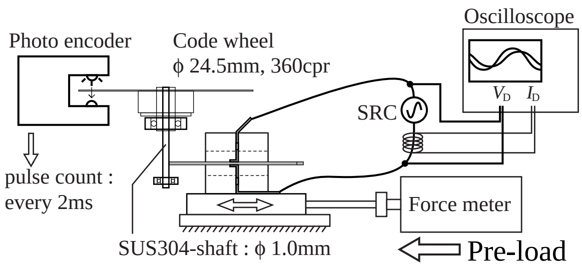

Fig. 3 Measurement system.

The step response of the motor was measured for obtaining of the motor torque of the small value and the efficiency [7]. Pre-load was given to the vibrator mounted on the linear stage with supporting holder, in monitoring by the Force meter. Revolution speed was measured by the photo encoder (AVAGO HEDS-9100-360) counting the number of the pulse obtained by the code wheel with 360 holes per revolution attached to the stainless steel shaft of 1mm diameter. Since the revolution speed of this motor is slow in the rising period, the pulse number was counted every 2ms. **Figure 4** shows the experimental result of the step response of this motor. Input electric power in the stable state of the motor was also obtained by measuring the driving voltage, current and the phase difference. Using these experimental values, the load characteristics was obtained as shown in **Fig.5**.

Table I Equivalent constants of the vibrator.

Q	9469.4
f_0 (kHz)	142.035
R (Ω)	9.8
L (mH)	104.1
C (pF)	12.1
C_d (pF)	78.2
k_{vn} (%)	36.6

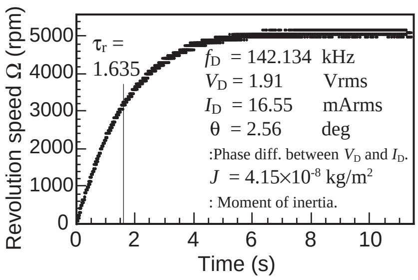

Fig. 4 Step response of the motor.

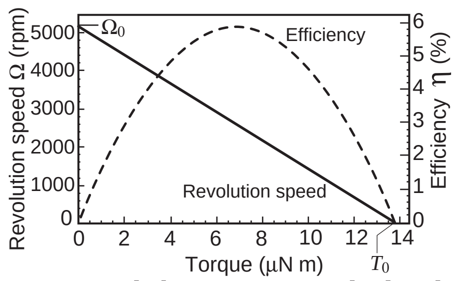

Fig. 5 Load characteristics calculated by the step response.

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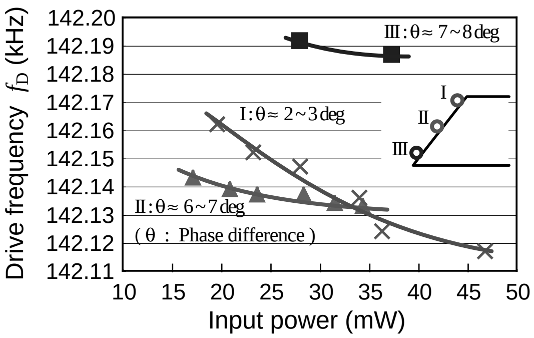

Fig. 6 Drive frequency vs. Input power.

3. Experimental Result

Motor characteristics are varied by changing the contact point between the rotor shaft and the vibrator. In the measurement, three contact point I, II and III as illustrated in **Fig.6**. **Figures 6-10** show the averaged result by fifth time measurements for each contact point I,II and III. The static pre-load force is about 0.07N with about ±0.04N tolerance. This is because of controlling to obtain higher revolution speed and time-dependence of the supporting state. Driving frequency f_D was controlled in changing the input voltage to obtain the higher revolution speed. Figure 6 shows the experimental driving frequency after controlling. In the figure, phase differences θ between the driving voltage and current are also shown. These values of θ are from 2 to 8 deg, being different in each contact state. In another case, which is not described in this paper, when the friction material zirconia thin tip is adhered to the vibrator at the contact area, the phase difference after controlling driving frequency is from 6 to 40 deg, being changed significantly by the driving conditions. In this case, the rotor shaft is made also with the material of zirconia, and the maximum efficiency is about 2%. In any case, in increasing the input power, the rotational speed become higher and therefore the optimum driving frequency become lower and approaches to the resonance frequency of the vibrator. This is because the mechanical load by the rotor shaft to the vibrator becomes lower when the rotational speed becomes higher. By comparing the results in Figs.7-10, it is found that the characteristics in the case of the rotor shaft contact point II is better than that in another contact case. For example, in the input voltage of about 2Vrms and input power of about 34mW, maximum revolution speed Ω_0 of 5200rpm, maximum torque T_0 of 13.8μNm and maximum efficiency η_{max} of 5.5% have been obtained. Since this motor is the high-speed one, the torque is low and the rising time is long. However, in this improved ultrasonic motor, the driving voltage is lower and the efficiency is 2 to 3 times higher than in the previously developed asymmetric vibration mode ultrasonic motor using piezo-ceramics. When the shaft contacts at the point III, maximum revolution speed has been obtained among all the contact points. However, in decreasing the input power, the revolution speed becomes lower drastically. In another case when the motor shaft contacts at the point I, the driving voltage becomes low and the vibration displacement is recognized to be large by the analysis and the previously reported experimental values. However, the practical revolution speed and the practical efficiency are small.

4. Remaind Subject

Subjects represented below must be studied as the next subjects: that is, the measurement in changing the pre-load, characteristics change when the friction material is used, and the evaluation of the limitation of the material under the high power operation.

Acknowledgment

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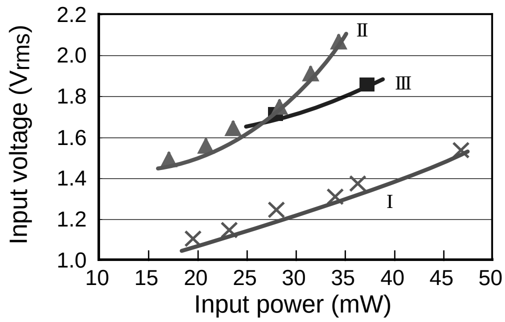

Fig. 7 Input voltage vs. Input power.

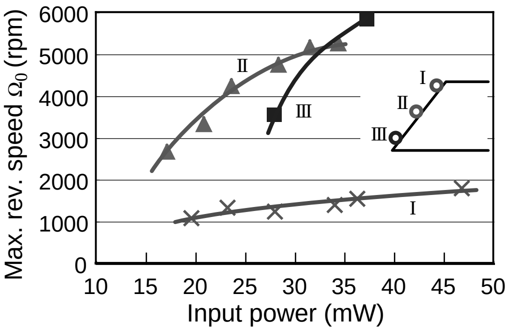

Fig. 8 Max. revolution speed vs. Input power.

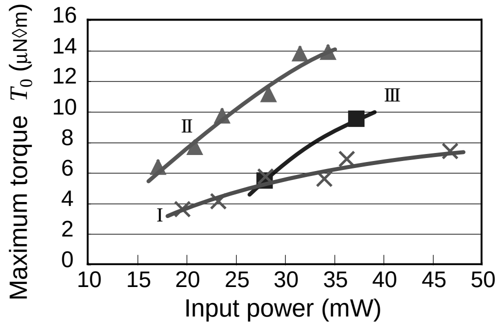

Fig. 9 Maximum torque vs. Input power.

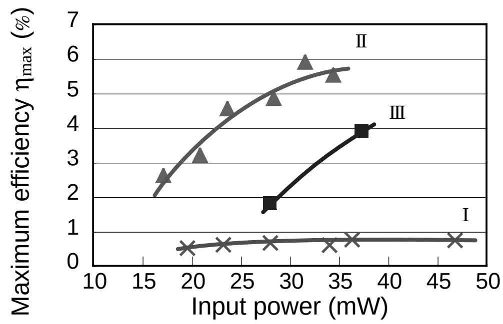

Fig. 10 Max. efficiency vs. Input power.

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