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Experimental evaluation of ultrasonic motors lubricated with oil
油潤滑した超音波モータの実験的検討

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1. Introduction

Ultrasonic motors are driven by frictional force. Torsional vibration is usually used for rotating the rotor, and longitudinal vibration is used for changing the pressing force between contact surfaces. If the phase difference between torsional and longitudinal vibrations is 90 degrees, high frictional force can be obtained because of high contact force and low frictional force will be obtained during another half period of the torsional vibration because of low contact force. If the contact surfaces detouch during low friction period, it is an ideal case. However, it is very difficult to realize it because the contact force is usually very high to obtain sufficient frictional force. Therefore, opposite frictional force causes frictional loss, then the maximum efficiency of the conventional ultrasonic motors is around 40-50 %.

In this report, we tried to change the friction coefficient in addition to the contact force change. If the friction coefficient during acceleration period is high and that during deceleration period is low, we can expect low frictional loss and high driving efficiency.

2. Control of frictional force

Lubricant has an interesting feature that frictional coefficient between lubricated surfaces varies by changing sliding speed and contact force as shown in **Fig. 1**. When the biased pre-load between contact surfaces is properly set, we can obtain remarkable change of the friction coefficient as drawn in **Fig. 1**.

3. Oil between sliding surfaces

Although a lot of researches have been reported in the hybrid transducer type ultrasonic motors[1)], such as principle, design, characteristics and so on, few researches have been reported for the motors using lubricant between contact surfaces.

First of all, existence of oil film between contact surfaces was confirmed by measuring the electric resistance between them. Nissan CVT oil NS-1 was used for the experiment. 400V_{p-p} was applied to the PZT for longitudinal vibration and 500V_{p-p} was applied to the PZT for the torsional vibration. 2-dimensional laser Doppler vibrometer was used to measure the displacement between contact surfaces and electric resistance was measured to estimate the oil existence. Bias contact pressure p can be changed by the coil spring. The results were shown in **Fig. 2**[2)].

The bigger the electric resistance, the bigger

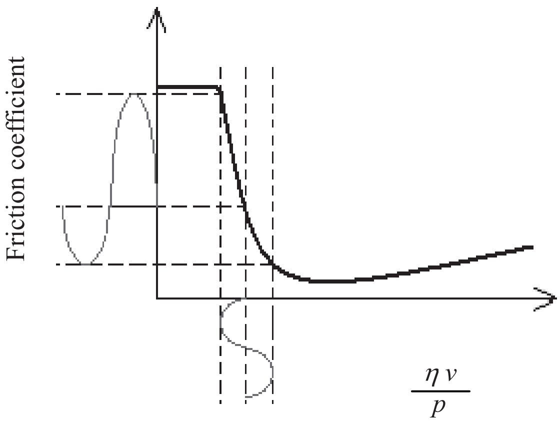

Fig.1 Stribeck curve.

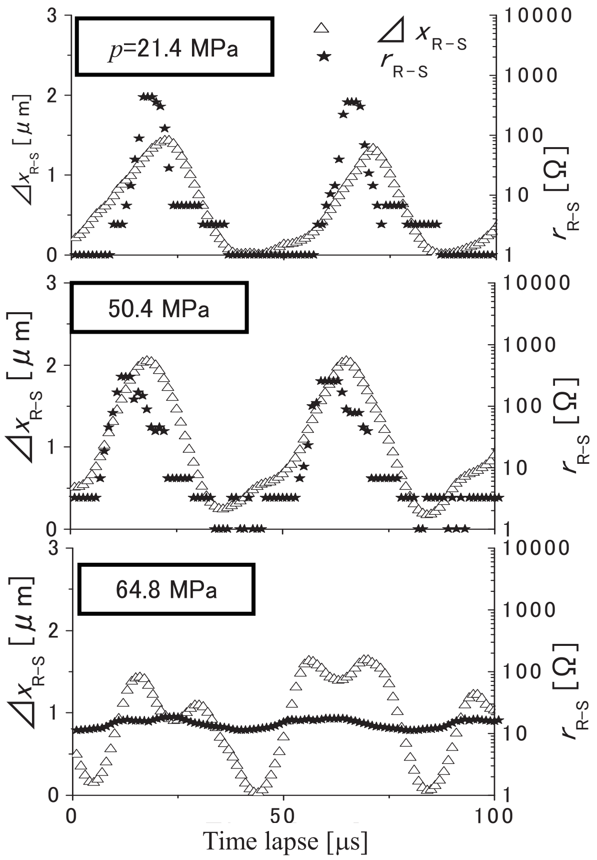

Fig.2 Relative displacement and electric resistance between sliding surfaces.

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the displacement, hence the oil film exists between contact surfaces. In the figures for p=21.4 MPa and 50.4 MPa, large change in resistance shows the existence of the oil film. In the figure for p=64.8 MPa, almost no change in resistance shows the almost no oil film is expected. In the figure for p=50.4 MPa, high resistance period is a little bit longer than that for p=21.4 MPa.

4. Efficiency of the motor

Motor characteristics were measured under the same conditions as shown in **Fig. 2**. Rotor revolution, torque and input electric power were measured, and efficiency was calculated by the following expression.

$$Efficiency = \frac{Mechanical\ output\ power}{Electric\ input\ power} = \frac{mgv}{Input\ power\ to\ torsional\ PZT},$$

where m mass of the weight, g gravitational acceleration and v speed of the weight.

Basically, electric input power to the ultrasonic motor has to be the total of longitudinal and torsional power. Longitudinal electric power is about several milli-Watts, while torsional one is about several Watts for this ultrasonic motor. Hence the longitudinal power is negligible. Torque vs. efficiency characteristics are shown in **Fig. 3**[2].

The maximum torque increases with increasing the preload p. The maximum efficiency was obtained at the optimum preload of 50.4 MPa and its value was 72 %. This value is rather high compared with that for the ultrasonic motor using conventional frictional material. One example of the maximum efficiency using asbestos joint sheet for frictional material is about 43 %.

The maximum efficiency decreased under the condition of the preload of 64.8 MPa. This can be explained under almost no-lubricant condition between contact surfaces as shown in **Fig. 2**.

Next, three kinds of lubricant were used for the ultrasonic motor. These are oils for AT, CVT and High-traction. The results are shown in **Figs. 3** and **4**. Since there are some condition differences in the ultrasonic motors used for between figure 3 and figure 4 experiments, maximum efficiencies are not the similar values. In the figure 4 experiments, 130$V_{p\text{-}p}$ was applied to the PZT for longitudinal vibration and 130$V_{p\text{-}p}$ was applied to the PZT for the torsional vibration.

As shown in the **Fig. 4**, the efficiency reveals higher value by using oil for high traction than using oil for CVT. This result suggests that we can expect improved maximum motor efficiency by using oil for high traction.

5. Conclusions

In order to improve the maximum efficiency of the ultrasonic motor, we propose the use of lubricant on the sliding surfaces taking advantage of the characteristics of the friction coefficient change.

The electric resistance between sliding surfaces was measured to estimate oil existence, and periodic change in resistance was observed.

The maximum driving efficiency was obtained by using NS-1 (CVT fluid) and that value was 72 %.

Three kinds of fluid were used for the experiments and we can expect higher efficiency by using oil for high traction rather than oil for CVT.

Acknowledgment

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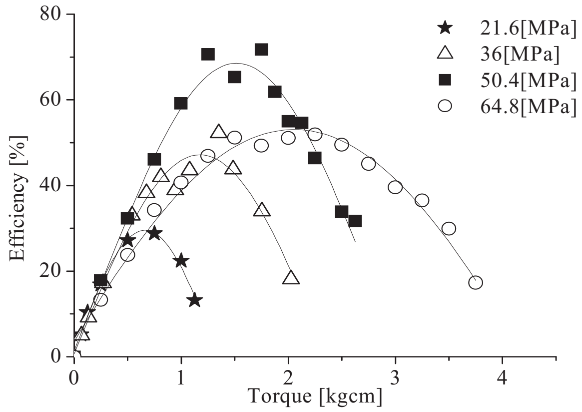

Fig.3 Torque vs. efficiency

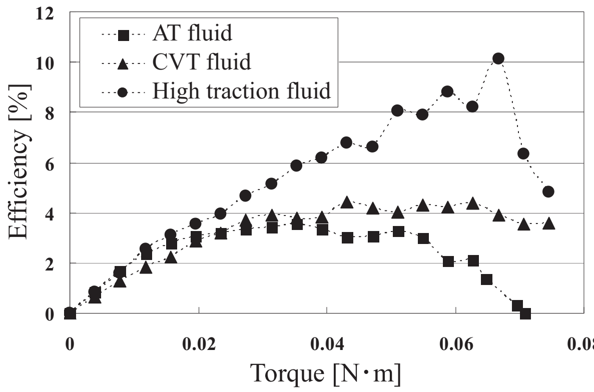

Fig.4 Torque vs. efficiency