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Analysis of Lubricating Effect of Hybrid Transducer-type Ultrasonic Motor

Wei Qiu[1‡], Yosuke Mizuno[1], Daisuke Koyama[1], and Kentaro Nakamura[1] ([1]P&I Lab., Tokyo Tech)

1. Introduction

Ultrasonic motor (USM) is a relatively new solid state motor driven by the ultrasonic vibration generated from piezoelectric components in most cases. This type motor presents several advantages, such as large torque at low speed, precise positioning, and no electromagnetic interference, and has been utilized in certain fields which need the merits of this motor[1)]. However, because the operating mechanism of ultrasonic motor is friction drive between rotor and stator, low efficiency and short life are inevitable and also the obstacle for wider applications.

In order to solve the preceding problems, the concept of lubrication in the contacting interface of ultrasonic motor has been introduced and some positive results have been obtained[1,2)]. In this report, we experimentally analyzed the lubricating effect in hybrid transducer-type ultrasonic motors (HTUSM), as well as the comparison of motor efficiency when different lubricants were used.

2. Concept of Lubrication in USM

The driving principle of ultrasonic motor is to form the elliptical motion of the particles in contacting surfaces, generally by two orthogonal vibration modes. Thus, friction loss occurs when the elliptical trajectories of the particles are opposite to the moving direction of rotor. On the other hand, this kind of energy loss might be reduced by applying lubricant, since lubrication has the function to vary the friction coefficient during contacting, due to the change of viscosity of lubricant, relative velocity of contacting surfaces or the load on the interface, which has been described by Stribeck curve[3)] (See **Fig. 1**). Based on this unique feature of lubricant, the friction loss during the reverse cycle of the elliptical motion can be suppressed.

3. Experimental Setup and Method

The ultrasonic motor used in this experiment was hybrid transducer-type ultrasonic motor, which contains torsional and longitudinal vibrators for

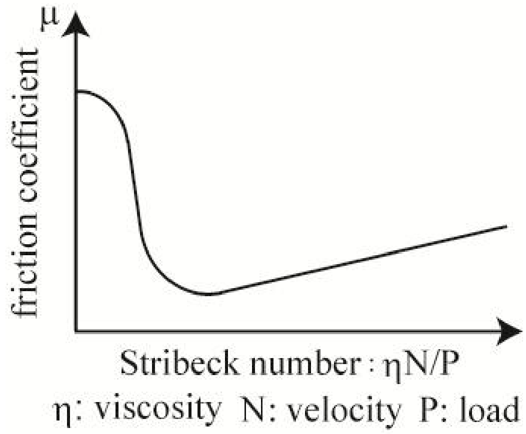

Fig. 1 Stribeck curve.

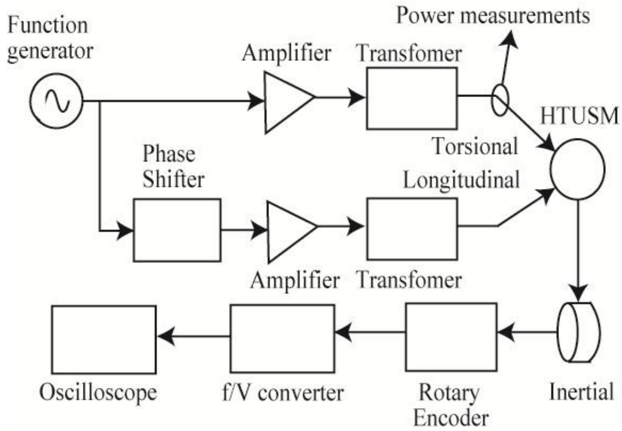

Fig. 2 Schematic diagram of measuring system.

generating elliptical motion. Alumina and silicone nitride were chosen as the friction materials for stator and rotor, respectively. Three kinds of oil, automatic transmission fluid (ATF), continuously variable transmission fluid (CVTF) and high traction fluid (HTRF), with two different viscosities for each were applied as the lubricants for the contacting surfaces between rotor and stator. **Table I** lists the characteristics of lubricants. The mechanical performance and motor efficiency were obtained being based on transient-response measurements[4)]. The measurement system of motor's transient responses is depicted in **Fig. 2**. Motor efficiency was calculated by the ratio of output power to input power of torsional PZTs, which is the transduction efficiency of motor.

qiu@sonic.pi.titech.ac.jp

Table I Characteristics of lubricants.

	ATF 32	ATF 100	CVTF 32	CVTF 100	HTRF 32	HTRF 100
Viscosity (40°) (cSt)	32.6	129.3	34.3	116.9	33.77	100
Viscosity Index	206	122	190	120	113	125
Density (15°)	0.806	0.879	0.848	0.879	0.960	0.956

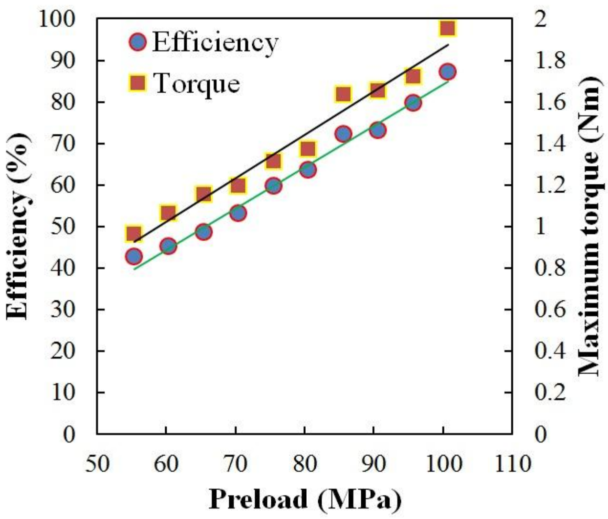

Fig. 3 Motor efficiency and maximum torque as a function of static preload.

4. Experimental Results

Fig. 3 illustrates the variation of efficiency and maximum torque under different preloads. High traction fluid of 32 cSt viscosity was applied as the lubricant. The input voltages of torsional and longitudinal PZTs were 500 Vp-p and 450 Vp-p, respectively. Torsional and longitudinal resonance frequencies were matched at 22.1 kHz. The motor efficiency and maximum torque were improved by increasing static preload. The maximum efficiency as high as 85% was achieved at 100 MPa static preload. If we do not ignore the input power of longitudinal PZTs (11.5 W), the actual motor efficiency was 45%. The contacting surfaces were well protected by lubricant so that the motor operation was still stable even under high preloads.

Table II shows the comparison results of the motor efficiency using different lubricants at the same static preload. The contacting surfaces were cleaned by ultrasonic cleaner between each test of different lubricants. The results behave the same improving tendency of the motor efficiency when the static preload was increased, which we have discussed in last paragraph. The effect of different lubricants under the same static preload was similar. Slight discrepancy existed which might be caused by in completely same operating condition.

Table II Efficiency comparison using different lubricants at same static preload.

Preload (MPa)	Efficiency (%)					
	ATF 32	ATF 100	CVTF 32	CVTF 100	HTRF 32	HTRF 100
55	43	41	46	45	43	40
60	49	50	53	48	45	49
65	55	51	56	55	49	53
70	61	55	58	61	53	55
75	63	62	63	64	60	59
80	66	67	67	65	64	65

The motor was also tried to be operated in dry condition in order to compare the efficiency and mechanical performance with that using lubricant. However, the HTUSM could not be driven at high preloads without lubricant. This phenomenon indicated the effect of lubrication in the situation friction materials with high friction coefficient were used, and also showed the significance of lubricant for stable operation at high preloads and motor efficiency improvement.

5. Conclusions

In this paper, we investigated the lubricating effect of hybrid transducer-type ultrasonic motor. The motor efficiency was significantly improved by appropriate lubricant and friction materials at high preloads and high maximum efficiency of over 80% was realized stably. The contacting surfaces were well protected due to the effectiveness of lubrication. The influence of different lubricants to motor efficiency was not evident in this experiment. The undriveable phenomenon in dry condition at high preloads indicated the function of lubricant in contacting interface for ultrasonic motors.

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