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Measurements of sliding friction forces under ultrasonic oscillations: out-of-plane oscillations

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1. Introduction

There are many ways to measure friction forces. In the present paper, a new method for measuring sliding friction forces under ultrasonic oscillations is introduced. Besides, reduction of friction forces by ultrasonic oscillations is observed. Discussing about the reduction of friction forces, people usually deal with in-plane oscillations, [1, 2]. However, in this research, out-of-plane oscillations are considered since they are expected to be sufficiently effective to reduce friction forces according to cold-welding theory.

2. Experimental Setup

In this research, one of the most important parts is equipment. To measure the sliding friction forces and give ultrasonic oscillations on the specimen simultaneously, torque-system shown in **Fig. 1** was used. There are two main features in this system. First, the specimen doesn't move. Since the transducer has further equipment such as electric wires, it is hard to move the transducer. However, in this system, it is fixed and the plate under the transducer moves. So, it is possible to make ultrasonic oscillations to the specimen. Second, this system measures the sliding friction forces by calculating torques from the forces.

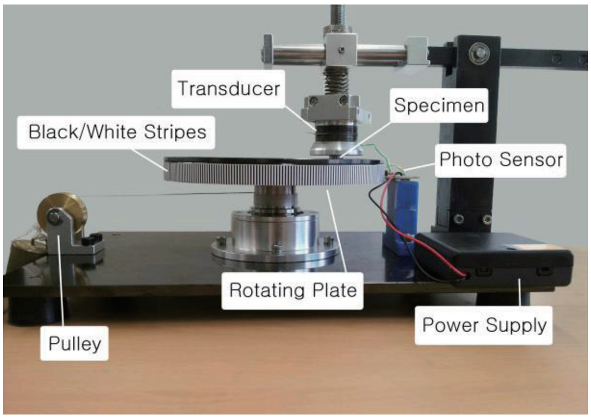

Fig. 1 Measurement instrument

Signals from the photo sensor are observed through oscilloscope as shown in **Fig. 2**. Since the photo sensor emits red light and, then, detects the reflected light, albedo decides its amplitude. So, the signals are sinusoidal (local maximum for white stripe and local minimum for black stripe).

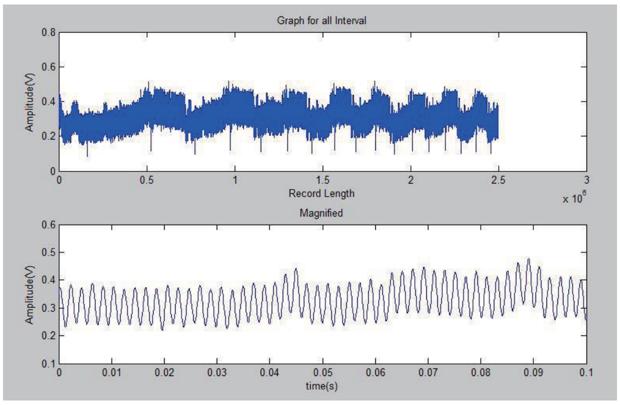

Fig. 2 Signals obtained from photo sensor

Using MATLAB, the acceleration of the rotating plate is calculated by checking the positions of the peaks as shown in **Fig. 3**.

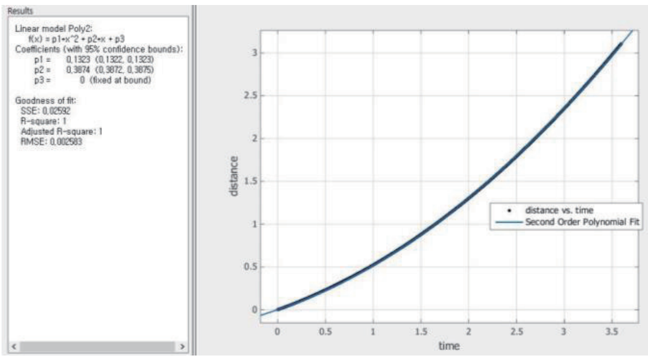

Fig. 3 Fitting curve to find the acceleration

From the acceleration, the friction forces can be calculated theoretically. Assignments of letters are shown in **Fig. 4**. The following equations are used to find friction forces.

$$I_1\alpha_1 = r_1T_1 - \tau_{f1} - xf$$

$$I_2\alpha_2 = r_2(T_2 - T_1\cos\theta) - \tau_{f2}$$

$$Ma = Mg - T_2$$

$$\alpha_1 = \alpha, \qquad \alpha_2 = \frac{r_1}{r_2}\alpha, \qquad a = r_1\alpha$$

Then these equations can be put together in one equation.

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$$\left(I_1 + I_2\frac{r_1^{\ 2}}{r_2^{\ 2}}sec\theta\right)\alpha = Mr_1 sec\theta(g - r_1\alpha) - \tau_{f1} - \frac{r_1}{r_2}sec\theta\,\tau_{f2} - xf$$

More simply,

$$C_1\alpha = Mr_1 sec\theta(g - r_1\alpha) - C_2 - xf$$

Constants can be determined by few experiments. Then, friction forces can be calculated with this equation.

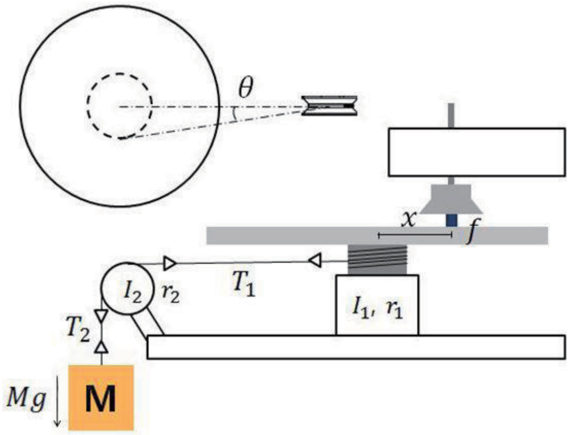

Fig. 4 Theoretical model for the instrument

3. Results and Discussions

Calculated constants are 0.0192 and -0.00093 for C_1 and C_2, respectively. Actually, it is impossible for C_2 to have a negative value because C_2 consists of the torques from inside frictions. The negative value means the inside frictions accelerate the rotation. However, since the magnitude is so small, it may come from the errors and not really affects calculations of friction forces.

From the constants and the equation above, sliding friction forces with different amplitudes of oscillations are calculated and shown in **Fig. 5**.

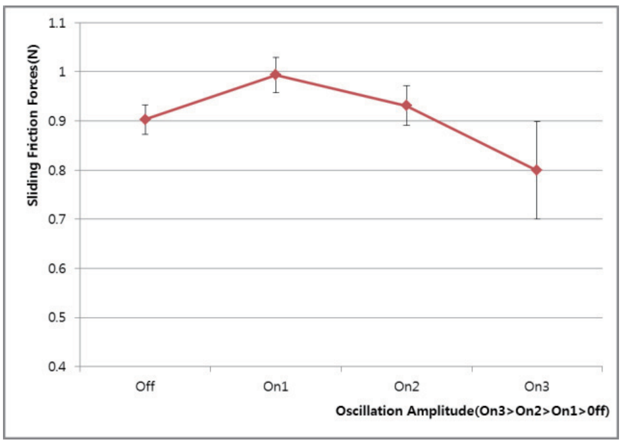

Fig. 5 Sliding friction forces with different amplitudes of ultrasonic oscillations

It is observed that the friction force increases when the ultrasonic oscillation is applied. This contradicts the hypothesis. However, there was an accident during the experiment. A three-ply thread was used for this experiment and two of them were cut during the experiment. Moreover, the tips of them went in the baring part. The data with no oscillations were measured before the accident and those with oscillations were measured after the accident. So, it is hard to compare them directly. This accident may be the reason why the data for on3 has a large error. However, it is possible to compare the data with oscillations with each other. The friction forces deceases as the amplitude of ultrasonic oscillations increases. This totally meets our hypothesis and the decreasing rate is pretty large. As a qualitative description, the ultrasonic oscillation disturbs the electrical bodings between the rotating plate and the specimen which make the friction force. Therefore, the friction forces are reduced.

4. Conclusion

The friction forces with and without various amplitudes of ultrasonic oscillations are measured with new method using torque-system. It is observed that not only in-plane oscillations, but out-of-plane oscillations also reduce the sliding friction forces. Because of the accident during the experiment, the results are not totally reliable. So, after repairing the instruments, additional experiments are needed. Finally, a new theoretical model of sliding friction force is required to explain this reduction effect of out-of-plane ultrasonic oscillations.

Acknowledgment

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References

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2. H. Storck, W. Littmann, J. Wallaschek and M. Mracek: Ultrasonics **40** (2002) 379-383.