Wear Mode Control of Drive Tip of Ultrasonic Motor for Precision Positioning

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A precision stage positioning system driven by ultrasonic motor(USM) with drive tip and driven rail as frictional elements has been developed. Fig.1 shows schematic diagram of the stage system. Ultrasonic oval oscillation (40kHz) is generated at the drive tip due to the piezoelectric actuator, hence friction force is produced in the contact interface between drive tip and driven rail, which is the driving force of the stage.

In this system, wear of drive tip and the deterioration of the accuracy of stage positioning due to it is unavoidable in principle. Therefore in order to inhibit the wear of drive tip is a significant problem to keep the reliability and durability of precise positioning.

In this study Al_2O_3 ceramics is introduced into the drive tip of USM and the driven rail of stage as a

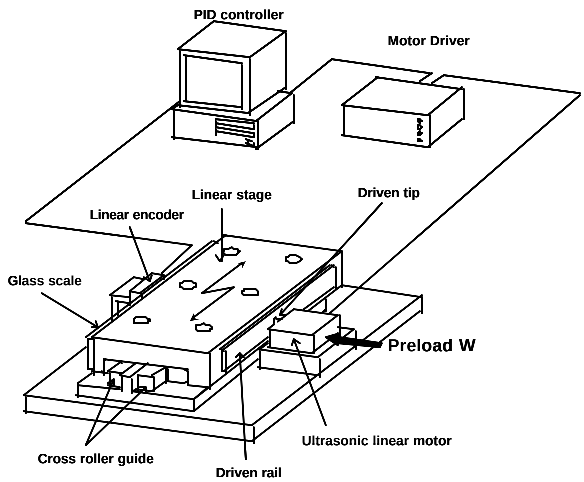
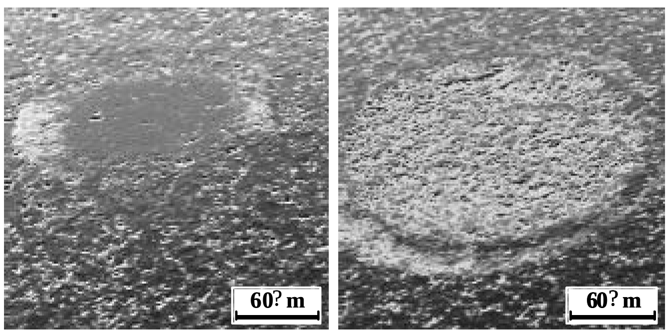


Fig.1 Schematic diagram of the stage system using ultrasonic motor



(a) (b)

Fig.2 SEM image of the mild wear(a) and severe wear(b) mode of worn surface of Al_2O_3 drive tip frictional material because ceramics has a higher wear resistance than that of metals. The wear mode of Al_2O_3 ceramics is classified into mild wear mode and severe wear mode [1]. There also exist two wear modes(mild and severe wear mode) in Al_2O_3 ceramics drive tip of USM due to stage driving condition, gains of PID controller, preload of USM, applied load on the stage et al, in which the required accuracy of stage positioning is obtained. Consequently, mild wear mode of drive tip should be kept in driving the stage for keeping precise positioning. Fig.2 shows SEM images of these two types (mild wear and severe wear) of worn surface of Al_2O_3 drive tip.

In this study the method for setting the optimum gains of PID controller on keeping mild wear mode of drive tip is proposed and verified to be of use experimentally.

Even though gains of PID controller are set as the required positioning accuracy is obtained, after

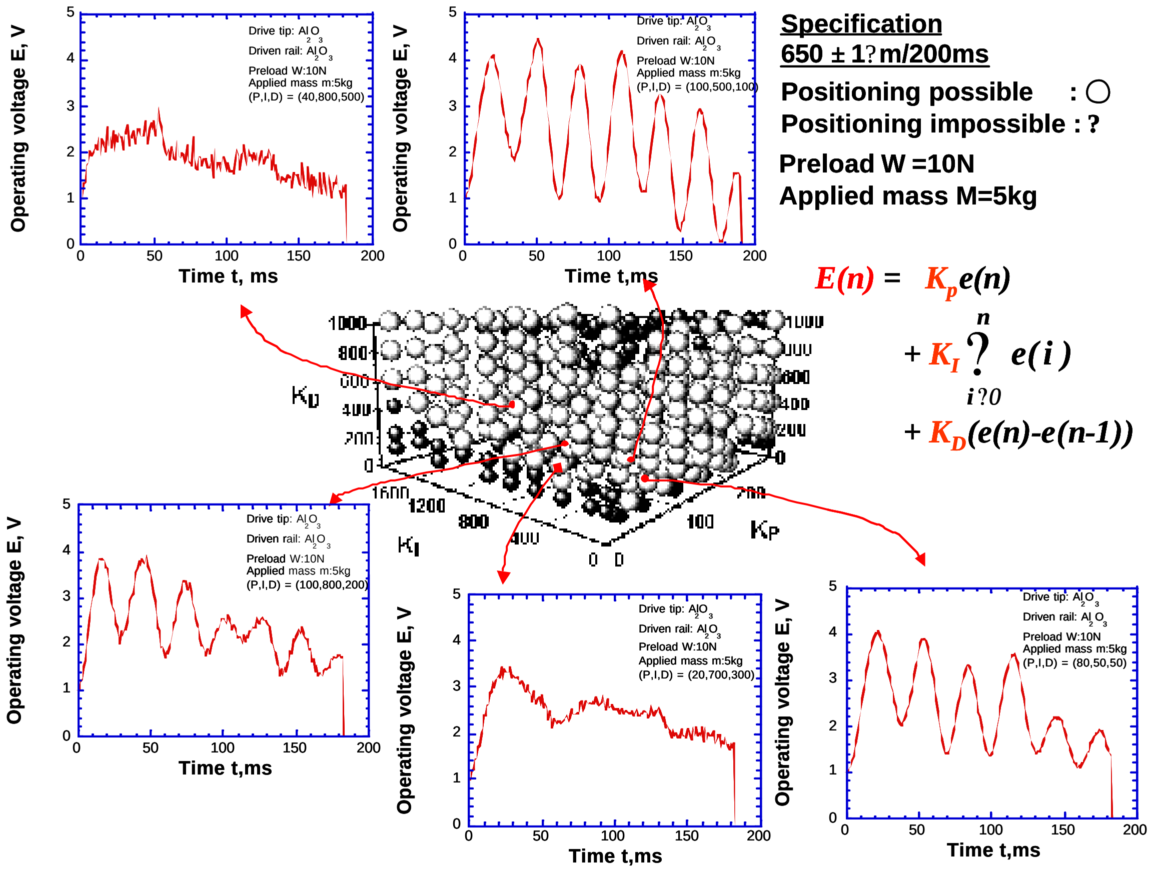


Fig.3 Various waveforms of operating voltage applied into USM in a step of a stage positioning

driving stage for a given distance, wear of drive tip is clarified to be mild wear mode or severe wear mode. Then the difference of P,I and D gains results in the difference of operating voltage applied into USM which is controlled by PID controller. Fig. 3 shows various waveforms of operating voltage applied into USM in a step of stage positioning, which is produced in various condition of P,I and D gains. In order to quantify the difference of these waveforms, we propose the parameter expressed bellow;

$$E_f = \frac{\sum_{n=0}^{N} (E_{n+1} - E_n)}{N} \qquad \text{(V)} \qquad (1)$$

where $\boldsymbol{n}$ is the number of sampling time, $\boldsymbol{N}$ is the number of the sampling time when the required positioning is completed, $\boldsymbol{E(n)}$ is the operating voltage applied to USM at $\boldsymbol{n}$th sampling . This parameter means the amount of fluctuation of operating voltage applied into USM, which physically means the fluctuation of tip velocity, hence it may indicate the extent of microscopic slip generated in the contact interface between drive tip and driven rail. Using this parameter makes it clear to classify the wear modes of Al_2O_3 drive tip into mild wear mode and severe wear mode, which is obtained in

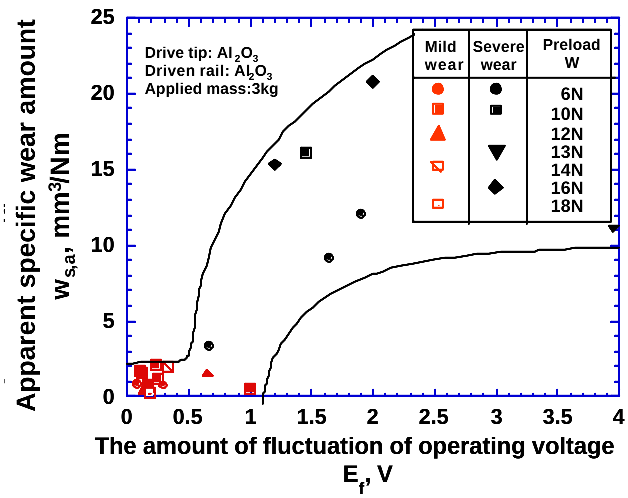


Fig.4 The distribution of apparent specific wear amount of drive tip as a function of the amount of fluctuation of operating voltage $\boldsymbol{E_f}$

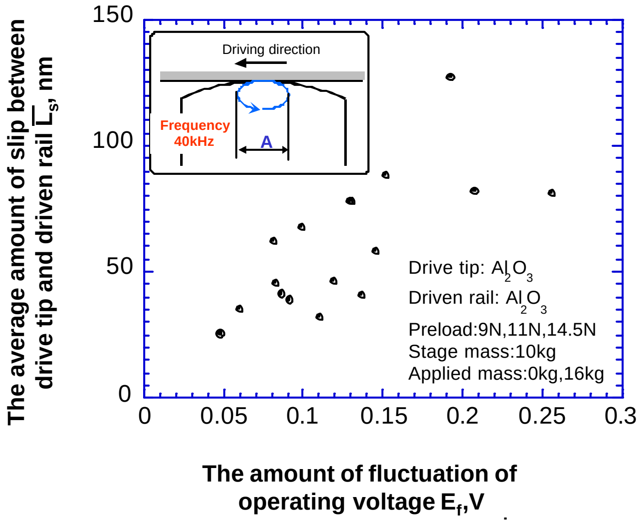


Fig.5 The distribution of the average amount of slip between drive tip and driven rail as a function of the amount of fluctuation of operating voltage $\boldsymbol{E_f}$

wear test of drive tip in several conditions of P,I and D gains(Fig.4). In this system used in this study , by setting gains of PID controller which satisfy the following condition of E_f,

$$E_f < 0.5 \quad \text{(V)} \qquad (2)$$

mild wear mode of drive tip is guaranteed, hence higher wear resistance of this stage system is also guaranteed.

Fig. 5 shows the distribution of the average amount of slip between drive tip and driven rail as a function of the amount of fluctuation of operating voltage E_f. It is clarified that the parameter E_f can be a monitoring parameter for microscopic slip between drive tip and driven rail.

References

[1] Adachi K. et al (1997), Wear map of ceramics, Wear, 203-204, pp 291-301.