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Effect of Preload on Rotary Ultrasonic Motor Driving Characteristics

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1. Introduction

Ultrasonic motors (USM) have been thouroughly studied in the past few decades due to their superior features including miniturization, fast response, high energy density, and high torque at low speed. In USM, the mechanical power is transmitted from the stator to the rotor through frictional forces. Preload force between the rotor and the stator is a key factor in determining driving characteristics. The preload force is carefully adjusted to offer the best performance (rotor speed and torque) for a given application.

In this research, we study the effect of preload on the driving characteristics of rotary type USM and the feasability of using dynamic preload to enhance motor performance. Dyanmic preload is confirmed to increase the driving efficiency, and enhance the motor dynamic response.

2. Experimental Setup

In this study, a FUKOKU USR60-B4 USM and a “Mechano-Transform MTKK12S400F140” Piezo linear actuator (PLA) were used. The motor was driven at different preloads while sweeping either the output torque, or the driving frequency while fixing the other. The motor characteristics were first evaluated statically under different preloads using a helical spring of stiffness 29.4 N/mm. Then, by controlling the voltage to the PLA, the preload was dynamically controlled. The PLA used has a maximum output force of around 110 N. **Fig.1** shows the setup for dynamic preload control. The measurements were collected through a power meter (HIOKI 3332), and a torque detector (ONNO SOKKI SS-050). The output torque was applied using a power brake (MITSUBISHI ZKB-1.2XN).

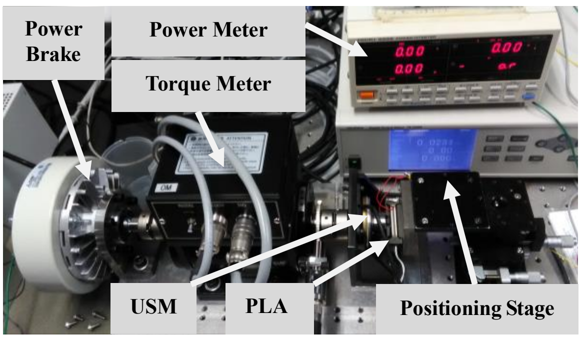

Fig. 1 Preload Controllable USM

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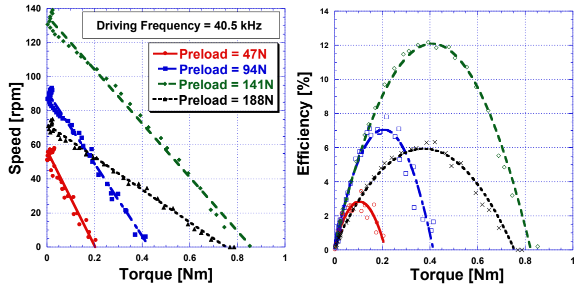
3. Effect of Preload on Driving Characteristic

3.1 Performance in relation to output torque

Changing the preload force can offer a wider operation range to suit various applications. In **Fig.2a**, the no-load speed increases initially with increasing the preload; however, it starts dropping under excessive preloads. The maximum output torque has the same tendency. For any preload, increasing the torque reduces the speed. In **Fig.2b**, there exists an output torque that maximizes the driving efficiency, and it is shifted to higher torques range as preload is increased. Accordingly, for efficient driving at a given torque, preload force needs to be dynamically adjusted.

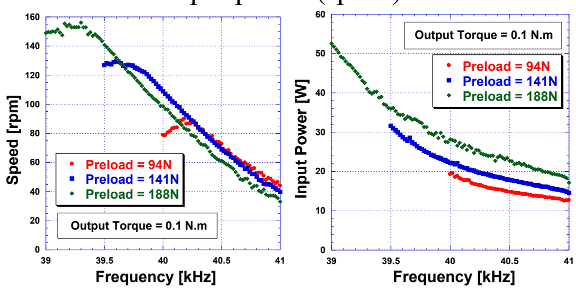


(a) Speed (b) Efficiency

Fig. 2 USM Performance in relation to Torque

3.2 Performance in relation to driving frequency

To maximize output power, the USM is desired to be driven around resonance frequency region. By increasing the preload, this region shifts to lower frequencies, and the maximum achievable speed increases. **Fig.3a** illustrates this behavior. It is also noted that preload effect on speed variation is minimum in off-resonance regions. On the other hand, power consumption is reduced under lower preloads as shown in **Fig3.b**. Consequently, controlling the preload can minimize input power for the same output power (speed).



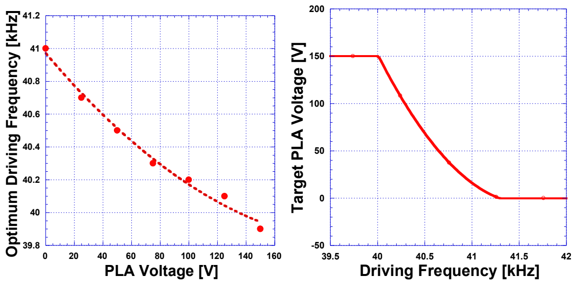
(a) Speed (b) Input Power

Fig. 3 USM Performance in relation to Frequency

4. Merits of Dynamic Preload Control

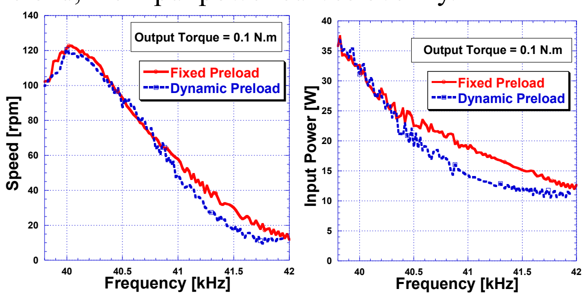
4.1 Efficient Driving

Through the setup explained in Fig.1, the driving characteristics under different PLA voltages were evaluated. The obtained measurements match the data obtained using spring loading in Fig.3. For an output torque of 0.1 Nm, **Fig.4a** shows the fitted curve between the applied PLA voltage, and the corresponding optimum driving frequency. This frequency is slightly higher than resonance frequency. Using this relation, the PLA voltage is applied according to **Fig.4b**. The saturation regions are due to the limits on PLA voltage (0-150 V).



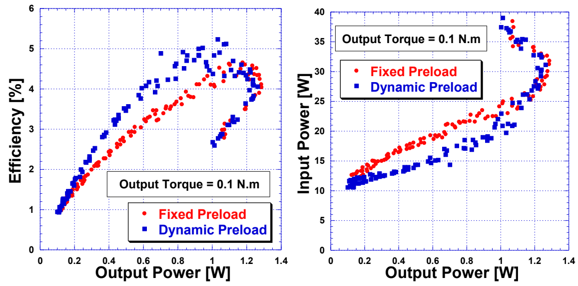
(a) Fitted Curve (b) Applied Control
Fig. 4 Target PLA voltage in relation to driving frequency

By controlling the driving frequency, and preload force simultaneously, efficient driving was realized. In **Fig.5**, USM performance under a fixed preload of 150 V applied to PLA is compared to the performance with the proposed dynamic preload under an output torque of 0.1 N.m. As shown in **Fig.5a**, both speeds (output powers) match except at low speed region where the applied preload wasn't sufficient to drive the motor under the given torque. **Fig.5b** shows the reduction in the power consumption where optimized preload is applied. Under the same preload, the input power curves overlay.



(a) Speed (b) Efficiency
Fig. 5 Dynamic preload control vs. Static preload with respect to driving frequency

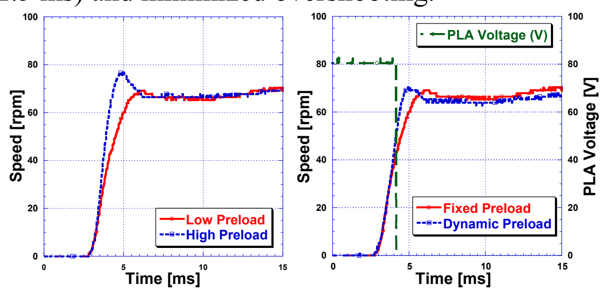
Due to the mismatch of speed in high frequency region, the results are plotted directly against the output power rather than driving frequency. **Fig.6a** confirms that efficiency with dynamic preload control is higher than static preload. Similarly, **Fig.6b** shows the reduction in input power for the same output power. Where the preload was optimized, the efficiency has increased around 1.2 times, and the input power was reduced around 5 Watts. Hence, this can reduce heat generation and surface wear, and prolong the motor's life.



(a) Efficiency (b) Input Power
Fig. 6 Dynamic preload control vs. Static preload with respect to output power

4.2 Enhanced Dynamic Response

Dynamic preload control can alter the motor dynamics at startup. As shown in **Fig.7a**, the rising time at low preload is longer than high preload. However, high preloads suffer from severe overshooting. In **Fig.7b**, the response of a low fixed preload (0 V applied to PLA) is compared to the dynamic on-off switching of PLA voltage. Midway to the target speed, the preload is switched from high preload (80 V) to low preload (0 V). Combining the merits of low and high preloads resulted in a faster response (rising time from 3.5 to 2.5 ms) and minimized overshooting.



(a) Static preload (b) Dynamic preload
Fig. 7 Dynamic Response at Startup

5. Conclusion

In this research, the effect of preload on the motor performance was studied. A dynamic preload control scheme was proposed to increase driving efficiency, and enhance response dynamics. Future work will target structure compactness, expanded operation region, and closed-loop control scheme.

References

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