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Design for the resonant type SIDM (Smooth Impact Drive Mechanism) actuator

共振駆動型 SIDM の設計に関する研究

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1. Introduction

Among various piezoelectric actuators, a smooth impact drive mechanism (SIDM) actuator is a promising linear actuators[1,2]. The SIDM actuators have been practically applied in camera modules, cell phones and blue-lay devices because of their high accurate positioning ability with compact size. The SIDM driving principle is based on a stick-slip or a slip-slip motion achieved by the piezoelectric effect. For this principle, a saw-tooth like displacement is required. In the previous SIDMs, off-resonant drive was applied; therefore, it was not suitable for high-speed movement due to its heat generation. Other drawback was a small displacement with relatively large input voltage. The latest property of SIDM was 40mm/sec speed at no load by driving voltage of $10V_{p\text{-}p}$, and its temperature rose up to 130 degrees in 40 seconds.

On the other hand, our group has proposed a resonant type SIDM (R-SIDM) that enable the low input voltage operation[3,4]. In this study, we utilizes the transfer matrix method[5] for designing R-SIDM.

2. Resonant SIDM principle

The SIDM is composed of a fixed part, a piezoelectric element and a frictional part, as shown in Fig. 1. The slider is pre-loaded to the frictional part of the stator transducer. The SIDM is a stick-slip or slip-slip driving mechanism[1, 2]. With a saw-tooth piezoelectric displacement, the slider is driven with asymmetric driving force in time domain, resulting in the one directional movement. In the conventional SIDM, to realize the saw-shaped piezoelectric displacement, off-resonant movement was utilized; therefore, a large input voltage operation was indispensable.

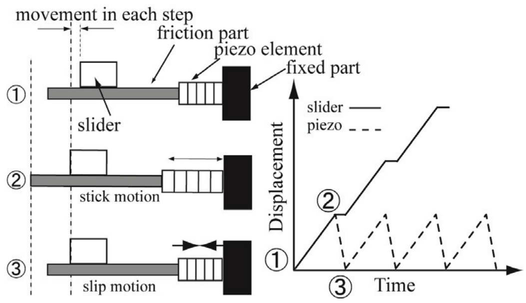

Fig. 1 Principle of conventional SIDM

We have already proposed the resonant type SIDM, which generates a quasi-saw shaped displacement by combining two longitudinal resonant vibration modes[3,4]. Due to its large amplitude resonant vibration with small voltage, high speed operation becomes possible with low input voltage. The resonant-type SIDM actuator in this study has a similar structure to the previous off-resonant type SIDM as shown in Fig. 2; however, the metal part is inserted between the multilayered piezoelectric part and a frictional bar so that the transducer has the first and second resonant frequencies to be 1:2. These resonant modes are combined to generate the quasi-saw shaped displacement.

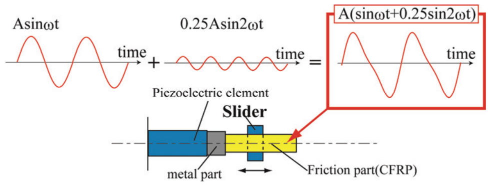

Fig. 2 Principle of resonant type SIDM

3. R-SIDM stator transducer design

A CFRP (carbon fiber reinforced plastic) rod was used as the frictional part, which have a high elastic property and low density. Its length was fixed to be 10 mm. The design concept for the stator transducer is to have low resonant frequency as possible for the small elastic deformation in frictional bar, and the first and second resonant frequencies ratio to be 1:2 for the quasi-saw shaped displacement.

Before designing, the resonant frequencies of a transducer without the metal part were measured. The measured resonant frequencies ratio was 1:1.74 that was far from 1:2 (f_1=121.6 kHz, f_2=211.2 kHz, f_2/f_1=1.74). Therefore, it was impossible to drive it as the resonant-type SIDM.

By installing the metal part in a stator transducer, we tried to adjust the resonant frequencies ratio to 1:2 by using the transfer matrix method [5]. In simulations, the thickness of metal part was fixed to be 3 mm and various Young modules, density and diameter for metal part were examined. Figure 3 shows the one example of the simulation results concerning the relationship between the diameter of the metal part and the vibration velocity. With larger diameter of metal part, the resonant frequencies ratio was increased. When we calculated the frequencies ratio as a function of metal's acoustic velocity, the resonant frequencies also decrease with smaller acoustic velocity.

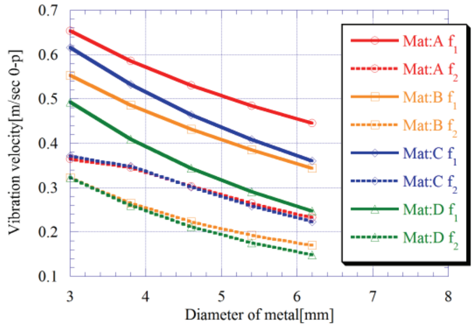

Fig. 3 The simulation results about vibration velocity as a function of the diameter of metal part.

4. Driving experiment

Figure 4 shows a photograph of a fabricated transducer based on the simulation results. We found that 3mm thick, 4.3mm diameter copper was optimum design as the metal part. From the admittance curve, the first and the second resonant frequency were measured to be 101 kHz and 200 kHz, respectively. And the elastic deformation was minimized. As shown in Fig. 5, a piezoelectric displacement at the tip of CFRP was measured with a LDV (Polytec NLV-2500-1). The quasi-saw shape vibration was excited as expected. At the same time, it was confirmed that the elastic deformation in CFRP rod was small.

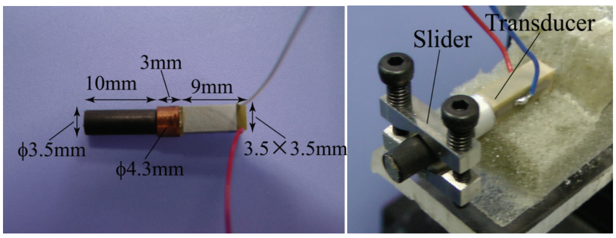

Fig. 4 Photograph of the R-SIDM

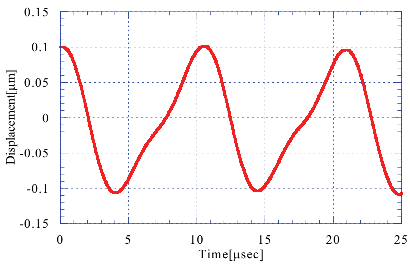

Fig. 5 Quasi-saw shaped displacement

For driving experiments, we prepared a 2 g slider that enabled the pre-load control. The contact surface sheets were made of alumina ceramics. To minimize the influence from the holding force, the transducer was fixed to sponge. As shown in Fig. 6, the maximum slider speed went up to 70 mm/sec at driving voltage of 2.2$V_{p\text{-}p}$. Slider speed was 40 mm/sec with input voltage of 1.6$V_{p\text{-}p}$. In the previous SIDM, it was 40mm/sec at driving voltage of 10$V_{p\text{-}p}$, so that, to compare with same slider velocity condition, it was possible to decrease driving voltage to one sixth. In the previous SIDM, temperature went up to 130 degrees C in 40 second with 10$V_{p\text{-}p}$. On the other hand, the resonant type SIDM only rose the temperature 60 degrees C with the input voltage of 2.2 $V_{p\text{-}p}$. As a conclusion, we can say that the resonant type SIDM enables to prevent the heat generation by realizing the low input voltage operation.

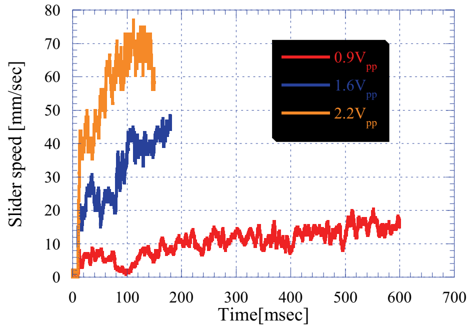

Fig. 6 Transient response of the R-SIDM (Preload 270mN)

5. Conclusion

The resonant-type SIDM (R-SIDM) actuator was driven with a combination of the first and second longitudinal resonant vibration modes. In this study, the stator transducer was designed with the transfer matrix method to satisfy the condition for driving the R-SIDM. Compared to the previous SIDM, the required voltage was one sixth and the heat generation was reduced.

Acknowledgements

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