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Structural design for R-SIDM with stacked piezoelectric actuator

Daichi Yatagai[1‡], Tatsuki Sasamura[1], Susumu Miyake[1] and Takeshi Morita[1,2] ([1]Grad. School of Frontier Sciences, The Univ. of Tokyo [2]School of Eng., The Univ. of Tokyo)

1. Introduction

SIDM (Smooth Impact Drive Mechanism) is one of the piezoelectric actuators, which is used in various precision devices because of its compact size and high precision drive capability[1)]. The previous SIDM used non-resonant vibration. Therefore, it was difficult to drive at high speeds due to the heat generation. On the other hand, resonant-type SIDM (R-SIDM) has been proposed to realize low-voltage SIDM drive[2)3)]. It utilized resonant vibrations with a resonant frequency ratio of 1:2 for exciting a pseudo sawtooth waveform for SIDM drive. Nevertheless, the proposed R-SIDM with a stacked piezoelectric actuator had difficulty to be supported the nodal points of the two resonant vibrations that did not coincide, resulting in a large support loss during the operation.

In this study, R-SIDM was designed to have same nodal positions for 1st and 3rd-order resonant frequencies. The resonant frequency ratio was also designed to be 1:2. These calculations had be conducted with the transfer matrix method for comprehensive understandings.

2. Driving principle of R-SIDM

Fig. 1 shows the driving principle of the SIDM. The SIDM consists of a stacked piezoelectric actuator, a friction part and a slider. The friction part is adhered to the piezoelectric element and is driven by the following the piezoelectric element expansion and contraction. The slider contacts the friction part by preload. In the periods ① to ②, the piezoelectric element slowly expands and the slider moves together with the friction part by the static friction. From ② to ③, the piezoelectric element is suddenly returned to the initial position, causing the slippage between the slider and the friction part due to inertial force. By repeating this process, the slider can be driven with a large stroke. Therefore, sawtooth wave driving with the piezoelectric actuator is indispensable for driving SIDM.

The R-SIDM used in this research utilizes the resonant vibrations to operate the SIDM with a low voltage, achieving a highly efficient drive and eliminating the temperature rise[3)]. As shown in **Fig. 2**, vibration modes with a resonant frequency ratio of 1:2 are superimposed to form a pseudo sawtooth waveform, and the SIDM can be driven with this waveform. This enables the same performance as a conventional SIDM with about 1/6 of the voltage and with reducing the temperature rise by 90℃ [3)]. However, this R-SIDM had a large support loss because of the mismatch of the nodal points of the two vibration modes.

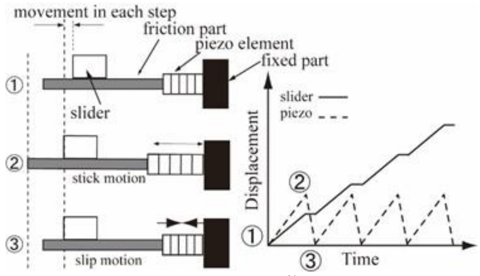

Fig.1 SIDM driving principle[3)]

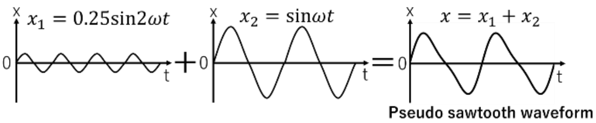

Fig.2 R-SIDM driving principle

3. Vibration analysis of R-SIDM stator

In this study, the shape of an R-SIDM stator transducer shown in **Fig. 3** is considered. In the previous study[3)], only the metal 1 was added between the piezoelectric element and the friction part. However, stepped structure can reduce the ratio between the 1st and 3rd-order resonant frequencies. Therefore, the metal2 was introduced as shown in Fig. 3.

The CFRP, which has high sound velocity, was chosen for the friction part since the friction part should reduce elastic deformation as much as possible. The effect of the shape of the metal 1 and 2 on the transducer was confirmed. The 1st and 3rd-order resonant frequencies and the positions of the nodal points of each mode were calculated by transfer matrix methods for different cross-sectional areas and lengths of metal 1 and 2, respectively.

The simulation verified the change in the ratio of the 1st and 3rd-order resonant frequencies when the cross-sectional area and length of metal 1 and 2 in Fig. 3 were changed. Each physical constant for the piezoelectric element was applied as the TAK050510 (TAISEI). The cross-section of metal 1 and 2 was square, the width of one side was varied from 2 to 4 mm, and the length 0 to 10 mm. **Fig. 4** shows the change in the ratio of the 1st and 3rd-order resonant frequencies when the cross-sectional area and length of metal 2 were changed with the size of metal 1 as $3 \times 3 \times 3$ mm^3. By optimizing the size of metal 1 and 2, it is possible to achieve the 1st and 3rd resonant frequency ratio of 1:2.

Fig. 5 shows the 1st and 3rd-order vibration mode shapes by fixing the size of metal 2 to $2.5 \times 2.5 \times 6.3$ mm^3, where the 1st and 3rd-order resonant frequency ratio is 1:2 in Fig. 4. Fig. 5 exhibits that the nodal points of the 1st and 3rd-order vibration modes are coincident. The conditions can be satisfied by appropriate design for the size of metal 1 and 2.

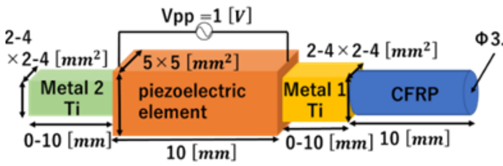

Fig.3 Structural model of R-SIDM

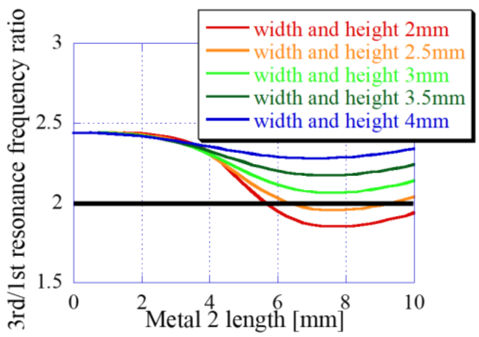

Fig.4 Calculation results of resonant frequency ratio change with metal size

4 Driving Experiments

Based on the simulation results, R-SIDM transducer was fabricated as shown in **Fig. 6**. Its admittance curve was measured by FRA (FRA5097). The ratio of the 1st and 3rd-order resonant frequencies was 1:1.81, which was slightly different from the result calculated by the transfer matrix method calculation. The reason for this discrepancy might come from the modeling difficulty of the stacked piezoelectric actuator. For precise modeling, the insulating layer of the stacked piezoelectric actuator should not ignore.

Next, driving experiments were conducted on this R-SIDM transducer. Two sinusoidal waves of 95 kHz and 190 kHz from a function generator (WF 1946A) were combined and amplified by an amplifier (HSA 4052). The applied voltage from the amplifier for each wave was 1 V_{pp}. **Fig. 7** shows the displacement of the tip of the friction part when operating under the above conditions, which was obtained with the LDV (LV-1800). In addition, a driving experiment was conducted by attaching a slider to the R-SIDM as shown in **Fig.8**. The slider could be driven by applying a voltage to the R-SIDM under the same conditions as in the previous experiment. It could also move the slider in the opposite direction by changing the 190 kHz input phase by 180 degrees. It was shown that pseudo sawtooth waves were generated at the friction part and that the SIDM drive was possible.

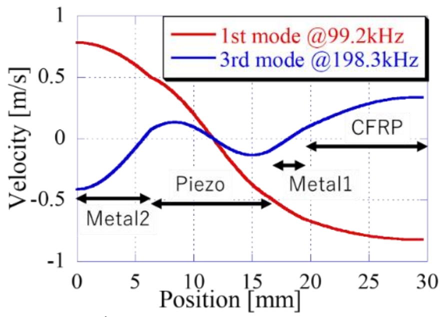

Fig.5 1st and 3rd-order vibration mode diagram

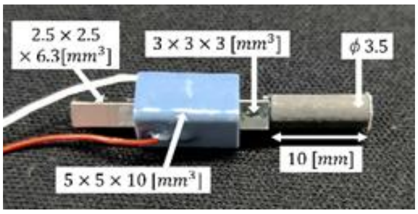

Fig.6 Photograph of the R-SIDM transducer

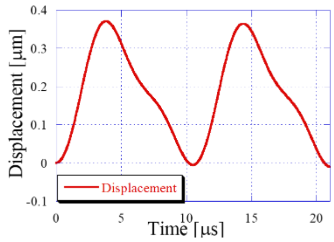

Fig.7 Displacement of the tip of the friction part

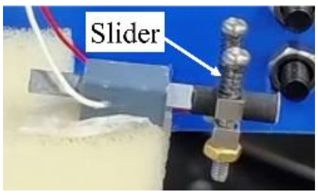

Fig.8 Slider driving experiment setup

5 Conclusion

R-SIDM with the coincided nodal points was designed by the transfer matrix method. An experimental transducer based on this design was shown to be capable of operating an R-SIDM. Future work includes the quantitative evaluation of the speed, generated force, and efficiency of the designed R-SIDM.

References

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