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The resonant frequency control of the ultrasonic transducers by connecting electric elements
電気素子を用いた超音波振動子の共振周波数動的制御

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1. Introduction

To operate the ultrasonic motors, it is often required to synchronize some resonant modes or to combine higher resonant mode [1]; for example, the hybrid transducer type ultrasonic motor[2] utilize the synchronized resonant vibrations such as longitudinal and bending modes, and the R-SIDM actuator[3] controls the longitudinal resonant frequency ratio to be 1:2. To obtain the sufficient performance, such synchronization should be controlled precisely.

For the precise control, authors have proposed the resonant frequency control system using FET[4,5] connected to the passive piezoelectric parts additional to the conventional Langevin transducer[6]. By switching FET open and short, stiffness of the passive piezoelectric elements could be controlled between c^E and $c^D = c^E/(1-k^2)$. This variation is a result of the electric charge's effect transferred from the force during the vibration on the passive piezoelectric parts. When the FET is switched off, it means the passive piezoelectric elements have the electric open boundary condition, electric charges are accumulated on the passive piezoelectric part. Therefore, a part of the vibration energy is consumued for electric charging and stiffness increases to c^D from the electric short boundary condition, c^E.

In the previous study[5,6], the FET was switched with the same frequency to the driving frequency. In this manner, the average stiffness in time could be controlled continiously by the duty ratio of switching-on time. This continuous variation could realize the resonant frequency modification precisely.

In this study, a practical use of this control method was applied by modifying the resonant frequency ratio for the R-SIDM actuator, which requires the resonant frequency ratio control.

2. Resonant frequency ratio control method

In this study, the longitudinal resonant frequency ratio between the first and the third mode was treated. We fabricated a Langevin transducer with step structure as shown in Fig. 1. With this step structure, the resonant frequency ratio was designed around 1:2 in advance, and it was precisely controlled by FET switching method.

To control the resonant frequency ratio effectively, the mode shape was considered by calculating the transfer matrix of the transducer. Namely, one of the first or the third resonant frequency was modified. As mentioned above, the resonant frequency control was realized by the stiffness variation of the passive piezoelectric parts. This stiffness variation's magnitude is determined by the amount of the accumlated charge of the passive piezoelectric parts under the open electric boundary condition. Therefore, the third mode shape was designed as the anti-nodal point was at the passive piezoelectric parts as shown in Fig. 2. With this design, little strain with the third mode appeared at the passive piezoelectric parts. As a result, with FET switching, only the first resonant frequency shifted, while the third resonant frequency did not change.

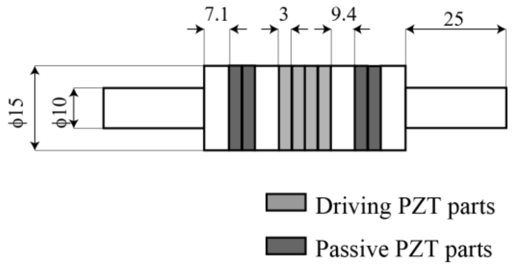


Fig. 1 Transducer for the resonant frequency control with the step structure

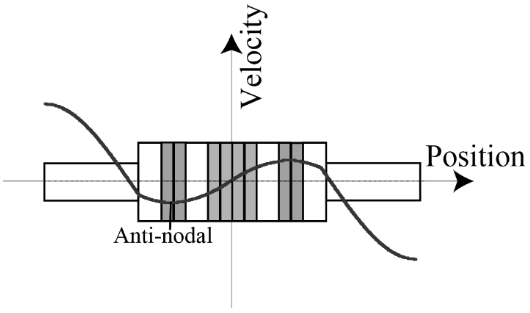


Fig. 2 Anti-nodal point was designed as it was on the passive piezoelectric parts

3. Experimental results

Resonant frequency ratio control was demonstrated by connecting the FET to the fabricated transducer as shown in Fig. 3. By switching the FET, the stiffness of the passive piezoelectric parts was varied between c^E and c^D. By changing the duty ratio, the frequency response of the velocity around the first and the third resonant frequency were shifted as shown in Fig. 4 (a) and (b), respectively. Each resonant frequency and peak admittance value as a function of the duty ratio was plotted in Fig. 5 (a) and (b). As expected, the third resonant frequency was not changed while the first mode was shifted from 25.12 kHz to 25.21 kHz. From these resonant frequencies, the resonant frequency ratio was modified from 1.997 to 2.005 as shown in Fig. 6.

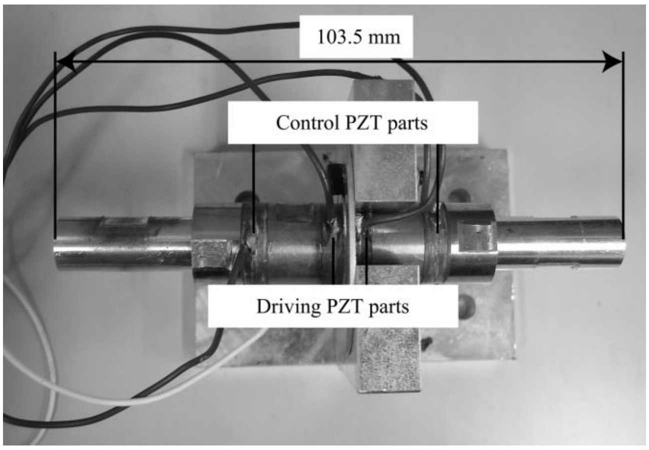
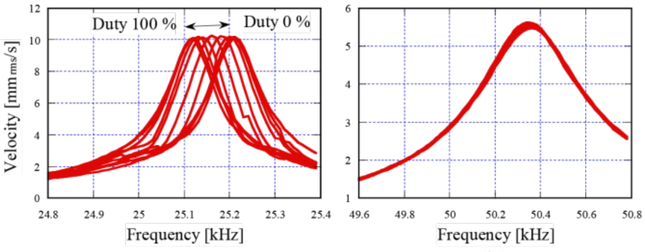
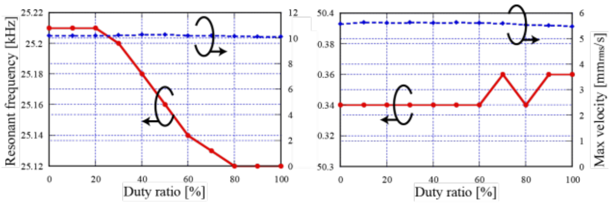


Fig. 3 Fabricated transducer for the resonant frequency control with the step structure



(a) (b)

Fig. 4 Frequency response of velocity shift by changing the duty ratio for the first mode: (a) the third mode: (b)



(a) (b)

Fig. 5 Relationship between the resonant frequency and duty ratio for the first mode: (a) the third mode: (b)

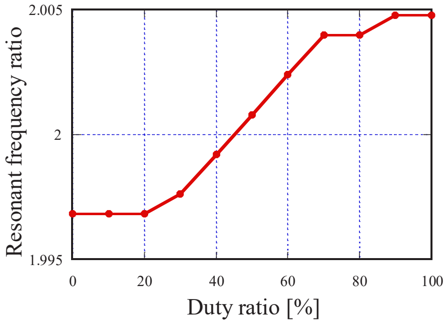


Fig. 6 Relationship between the resonant frequency ratio and the duty ratio

4. Summary

This study demonstrated the resonant frequency control using a Langevin transducer with the passive piezoelectric parts. By switching connected FET to the passive piezoelectric parts, the first resonant frequency was shifted from 25.12 kHz to 25.21 kHz, while the third resonant frequency did not change. As a result, the resonant frequency ratio was modified from 1.997 to 2.005.

Acknowledgment

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Reference

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