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Dynamic resonant frequency controllable system for ultrasonic transducer

共振周波数の動的制御可能な超音波振動子

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1. Introduction

In general, the resonant frequency of ultrasonic transducer is considered to be uncontrollable because it is a function of the structural design and material parameters. For example, ultrasonic motors, which are driven with combined vibration modes of longitudinal and bending modes [1], the shift of resonant frequency results in the performance degradation. In case of R-SIDM actuators [2], the resonant frequency ratio between 1st and higher mode is important parameter. Therefore, precise mechanical design and fabrication are essential for realizing excellent performance.

Although, even with the sufficient design, the slight machining error and the resonant frequency shift are inevitable. It is owing to the boundary condition shift and non-linear effect during the high power driving. [3]

In this study, to overcome this problem, a continuous and dynamic control system of the longitudinal resonant frequency is proposed. For this purpose, the piezoelectric elements were introduced in addition to the driving piezoelectric elements. The stiffness of this additional piezoelectric elements were controlled by the MOSFET switching.

2. Principle

In the previous study, the static control system of the resonant frequency was reported [4]. We followed this study, and with the additional piezoelectric element connected to the electric elements, the Langevin transducer shown in **Fig. 1** changed its resonant frequency from 25.9 kHz to 28.4 kHz. Changing the electric boundary condition for the additional piezoelectric elements enabled the static resonant frequency control of the transducer.

This transducer has an equivalent circuit as shown in **Fig. 2** which has two electric terminals, where L_m is an equivalent mass, C_m is an equivalent compliance, R_m is a mechanical resistance, C_1 and C_2 are damped capacitors and Φ_1 and Φ_2 are force factors, respectively. The resonant frequency measured from the terminal 1 can be controlled by changing the condition of the terminal 2; for example, shorten, open or connecting inductors.

For realizing the dynamic control of the resonant frequency, the impedance condition connected to terminal 2 should be modified in real-time. In this study, a MOSFET switching between open and shorten as shown in **Fig. 3**, the average impedance was controlled by its duty ratio. The switching frequency was same as the driving frequency of the transducer. Changing the duty ratio of the switching signal, it can control the resonant frequency continuously and dynamically.

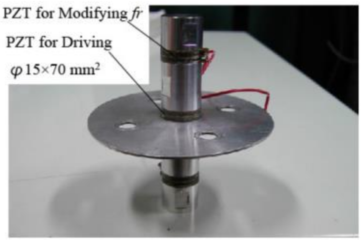

Fig. 1 Transducer which has two piezoelectric elements

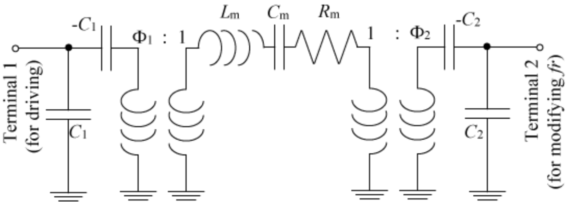

Fig. 2 Equivalent circuit of the transducer

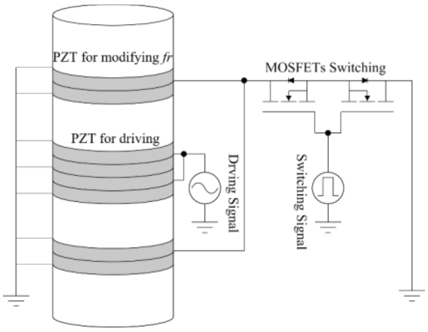

Fig. 3 Transducer connected to the MOSFET switching circuit

3. Simulation result using the equivalent circuit

From the admittance curve measurement measured from terminal 1 and 2 (**Fig. 4**), the equivalent circuit parameters were obtained as shown in **Table I**. When the admittance was measured from one terminal, the other terminal was shorten. The resonant frequency from each terminals are shifted between the electrical conditions for the terminal 2, shorten and open.

Using these parameters, the admittance curves of the equivalent circuit with MOSFET (Fig. 3) was simulated with a circuit simulator (MicroCap). **Figure 5** shows the simulation result of the admittance curves with every 5 % duty ratio of the MOSFET switching. This result suggests the possibility of the continuous resonant frequency of longitudinal 1st mode control between 26.31 kHz and 26.43 kHz.

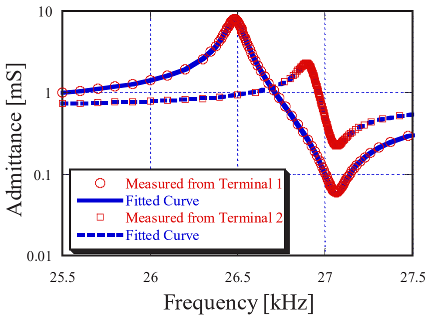

Fig. 4 Measured and fitted admittance curves

Table I Calculated parameter obtained by fitting curve

L_m [mH]	C_m [pF]	R_m [Ω]	C_1 [nF]	C_2 [nF]	Φ_1/Φ_2
791	43.8	483	3.96	4.18	1.94

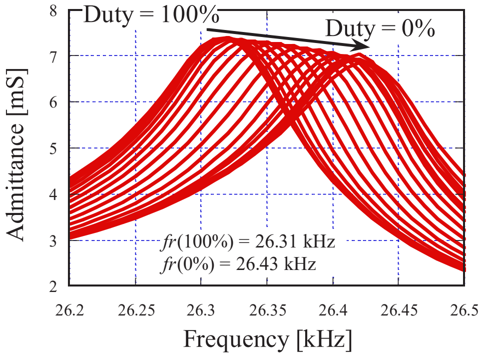

Fig. 5 Simulated admittance curve with various switching duty ratio

4. Experimental result

Experiments were carried out for controlling the resonant frequency with the MOSFET switching. As a result, the continuous change of the resonant frequency from 30.51 kHz to 30.37 kHz could be demonstrated as shown in **Fig. 6**. The resonant frequency of each admittance curves and the peak values are shown in **Fig. 7**

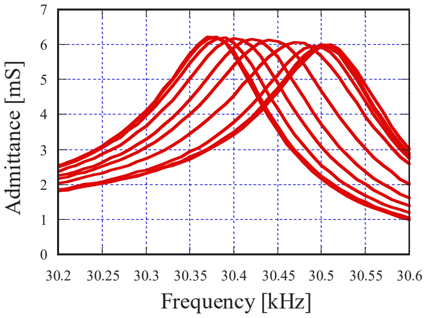

Fig. 6 Experimental results of admittance curve by changing the duty ratio

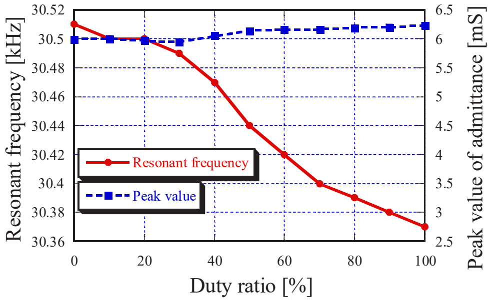

Fig. 7 Resonant frequency changing (solid line) and peak value of admittance (dot line)

5. Summary

In this study, we proposed the dynamic and continuous control of the resonant frequency using the additional piezoelectric elements connected to the MOSFET switching. The simulation result suggested the control range is 120 Hz, which agree with the experimental result of 140 Hz control could be carried out in the experimental result. As further works, the dynamic control system utilizing these continuous control should be designed.

Acknowledgment

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