THE JOURNAL OF THE ACOUSTICAL SOCIETY OF KOREA VOL.26, NO.1E 2007. 3 pp. 27~32

Active Vibration Control Method Using Frequency Controllable Piezoelectric Transducer

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(Received February 1 2007; Accepted March 5 2006)

Abstract

Hydraulic actuator and electro-magnetic liner actuator have been used as typical active vibration control methods. However these methods have many kinds of disadvantages such as causing space limit, difficult maintenance, complicate structures, etc. The purpose of this paper was to study on the possibility of active vibration control using piezoelectric transducer. Piezoelectric transducer generated a vibration and GIC (General Impedance Converter) amplifier was adopted to give adjustable vibration signal to transducer and high amplitude of vibration. Resonance frequency of piezoelectric transducer was controlled by GIC amplifier and higher amplitude of vibration was achieved. Finally active vibration control using piezoelectric transducer was performed.

Keywords: *Frequency controllable transducer, Active vibration control, General impedance converter, Vibration control, Multi-layered piezoelectric vibrator*

I. Introduction

The active vibration control method has been widely used in various industrial fields and diverse principles of the methods have been reported. [1-6] However, most of the methods used in large-scale structures or manufacturing plants are rarely available for a precision instrument. [7-8] In general, the external vibration penetrate into the precision instrument through the sustaining part. The passive vibration control method with vibration-absorbing materials might cause the problems of structural sustainability and durability.

In this paper, we suggest a new active vibration control method that the piezoelectric vibrator is inserted in the pillar of the instrument. The Langevin-type piezoelectric transducer is proper to the purpose mentioned above because it has enough durability to sustain the structure. However, the resonant frequency range of the transducer is too high to cancel the external vibration and its efficiency is not high enough to drive in low frequency range. The frequency controllable piezoelectric transducer is employed as the actuating part of the Langevin transducer to overcome these problems. [9-10] The resonant frequency of the transducer is controlled by an external electric inductance connected to the tuning part of the transducer. [11] An enormous inductance would be necessary to make the low resonant frequency enough to cancel the external vibration. However, it is impossible to make the inductance by using a coil. In this study, a GIC (General Impedance Converter) type inductor is therefore designed by employing OP-amplifiers and capacitances. [12] The frequency controllable transducer and the GIC type inductor are fabricated, and their theoretical and experimental characteristics are investigated. The result of excluding the external vibration were demonstrated with a vibration test system by using the active vibration control system suggested.

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II. Theory

2-1. Frequency Controllable Piezoelectric Transducer

The construction and the equivalent circuit of the frequency controllable piezoelectric transducer are shown in Fig. 1. In Fig. 1 (a), the two-layered PZT in center of the transducer vibrates as driving part. The other two pair of the PZT ceramics take a role of frequency tuning of the transducer. The polarization directions of each PZT layer in the driving part and the tuning parts are mutually opposite. To control the resonant frequency of the transducer, the mechanical impedance of the tuning parts should be changeable with variable inductance L_e. The equivalent circuit of the transducer is shown in Fig. 1 (b). In this figure, impedance Z_1~Z_4, capacitance C_0, and n are given by Mason's model. [13] The equivalent mechanical impedance Z_e, inner dot-line, can be calculated by Eq. (1).

$$Z_e = j\frac{n^2}{\omega C_0}\frac{1}{1-\omega^2 C_0 L_e} \quad (1)$$

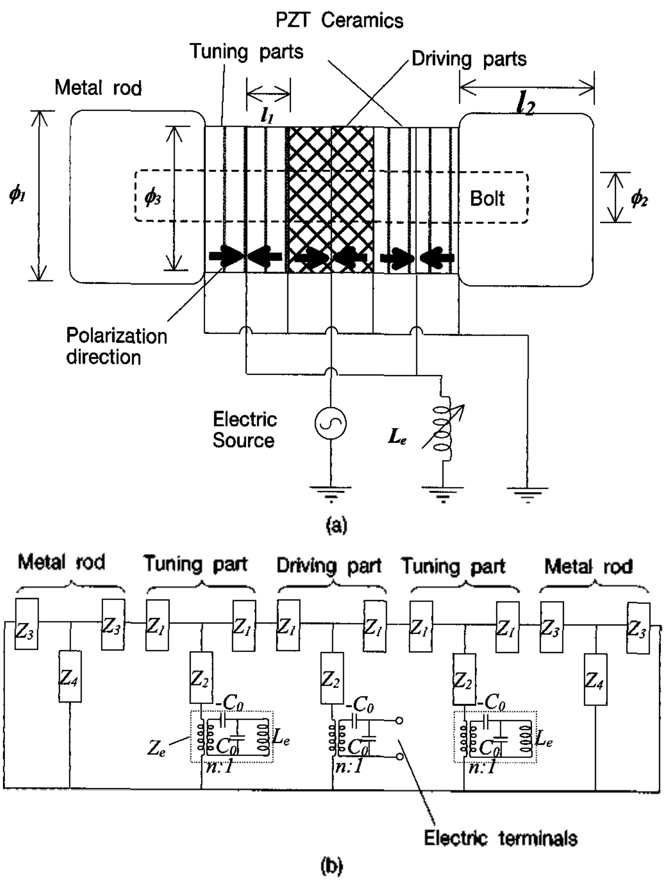


Fig. 1. Construction and equivalent circuit of frequency controllable transducer.

Here, angular frequency ω=$2\pi f$, and f is frequency. In this equation, we can see that if $\omega^2 C_0 L_e \approx 1$, the impedance Z_e becomes very large. It makes the transducer to have low resonant frequency. However, it is difficult to make large inductance enough to satisfy above condition with coil and ferrite core. Therefore, we designed the electronic inductance with GIC circuit as shown in next section. [12]

2-2. GIC-Type Electronic Inductance

The electronic inductance was designed with GIC circuit as shown in Fig. 2. This circuit consisted of two OP-amplifiers, one capacitor, and three resistors. And to change the inductance value, a variable resistance was also used in this circuit. In this figure, the impedance on port A is given by Eq. (2).

$$Z_a = \frac{R_2 R_4 R_5}{R_3\left(-\frac{1}{j\omega C_1}\right)} \quad (2)$$

From this relation, the inductance L_e is easily obtained as following equation.

$$L_e = \frac{R_2 R_4 C_1 R_5}{R_3} \quad (3)$$

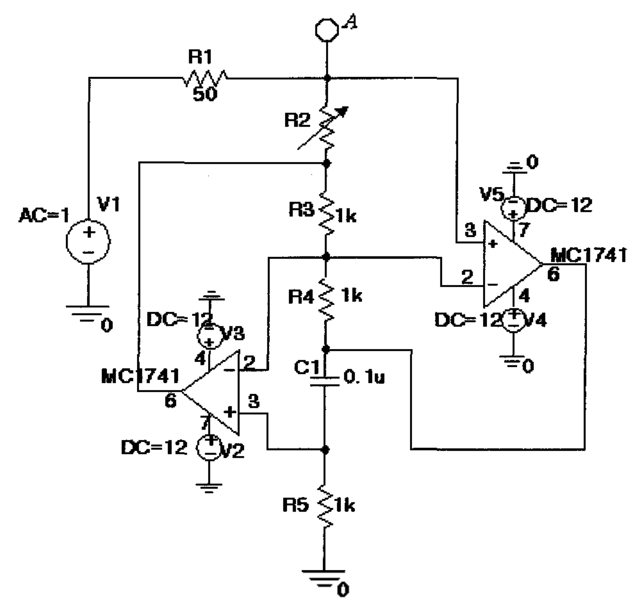
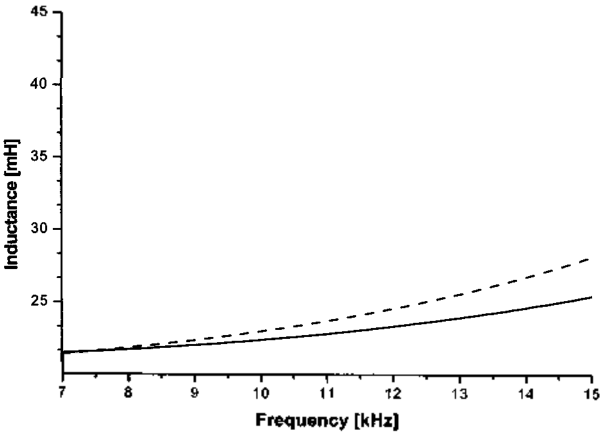


Fig. 2. PSpice equivalent model for electronic inductance.

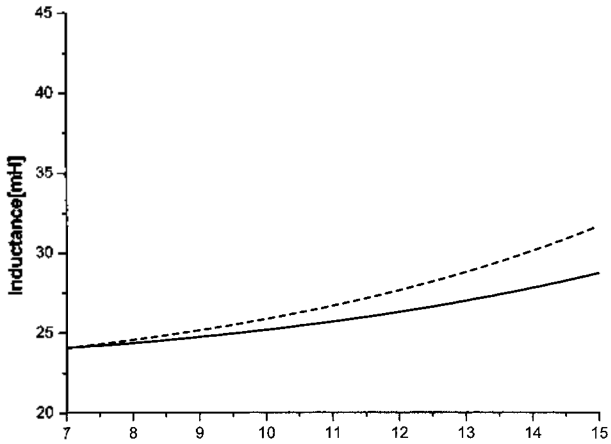
III. Results

3-1. Characteristics of Fabricated Inductance

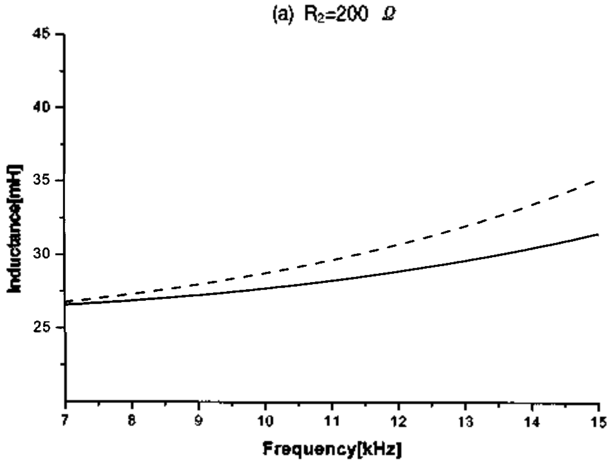
To simulate the GIC-type inductance, a circuit simulation program, "PSpice" was used. [14] For the required inductance value, the values of each electronic elements are chosen as shown in Fig. 2. The change of inductance value L_e was measured with various resistance of R_2. Here, the OP-amplifieris are MC1741 (Motorola). The experimental results (solid line) were shown in Fig. 3 with simulation results (dot line). In this result, the inductance was increased gradually by large resistance of R_2 in the given frequency range. For example, by changing the value of R_2 from 200 Ω to 300 Ω, the inductance



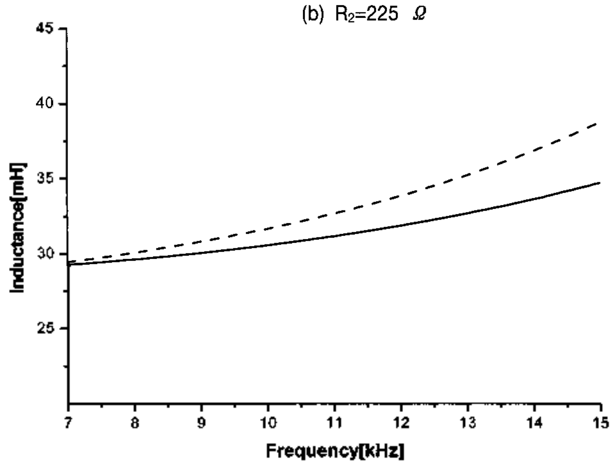
(a) R_2=200 Ω



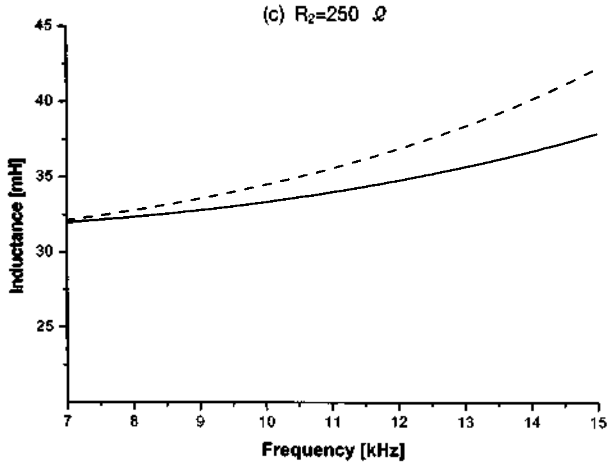
(b) R_2=225 Ω



(c) R_2=250 Ω



(d) R_2=275 Ω



(e) R_2=300 Ω

Fig. 3. Frequency characteristics of electronic inductance.

change from 22.5 mH to 32.5 mH was obtained at 10 kHz. The simulation results were well corresponded to the measured one. It shows that comparatively large inductance can be obtained simply by adjusting the variable resistance R_2 in the GIC−type inductance.

3-2. Characteristics of Frequency Controllable Piezoelectric Transducer

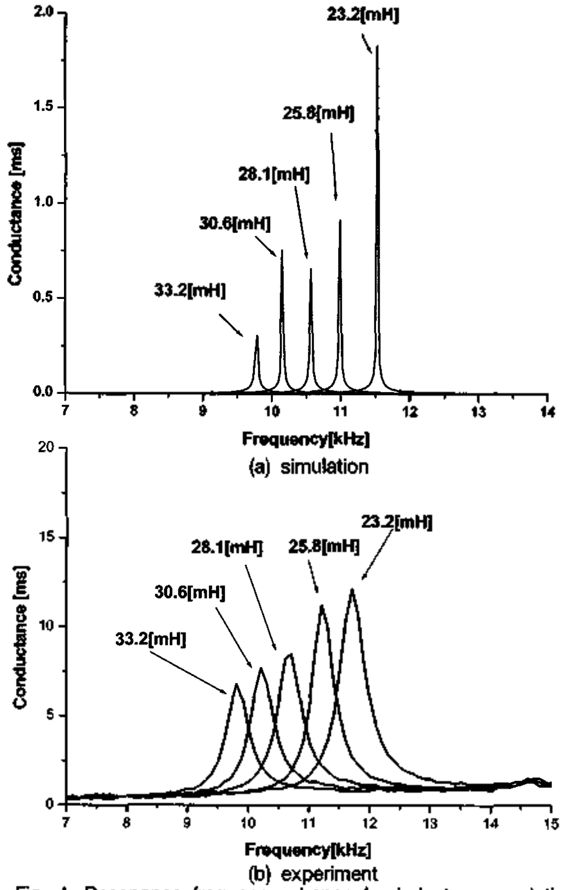


Fig. 4. Resonance frequency change by inductance variation.

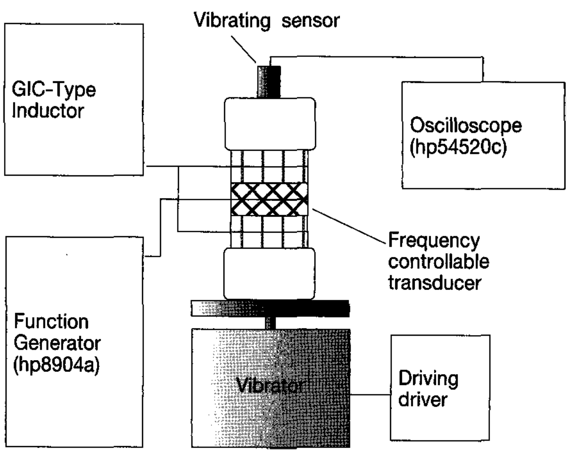


Fig. 5. Experimental setup for active vibration control.

The fabricated frequency controllable transducer was designed with following size in Fig. 1 (a).

ϕ_1=40 mm, ϕ_2=15 mm, ϕ_3=38 mm, l_1=5 mm, l_2=5 mm

The metal rods in each side of the transducer are aluminum, and steel bolt was used. The fundamental resonant frequency of the transducer was about 30 kHz without any external inductance L_e. This resonant frequency can move to below 10 kHz by connecting the electronic inductance as shown in Fig. 4. In this figure,

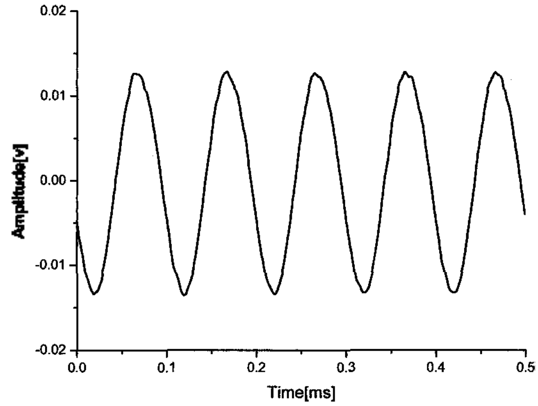


Fig. 6. Vibration wave from vibrator.

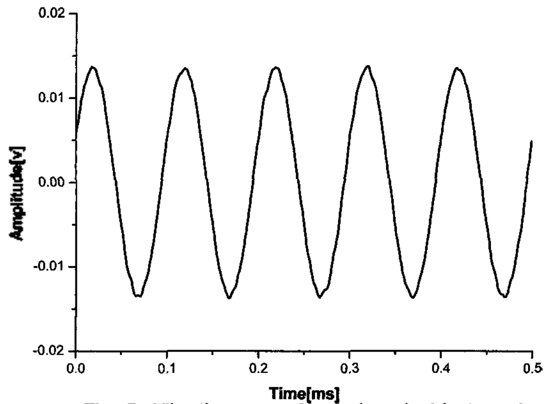


Fig. 7. Vibration wave from piezoelectric transducer.

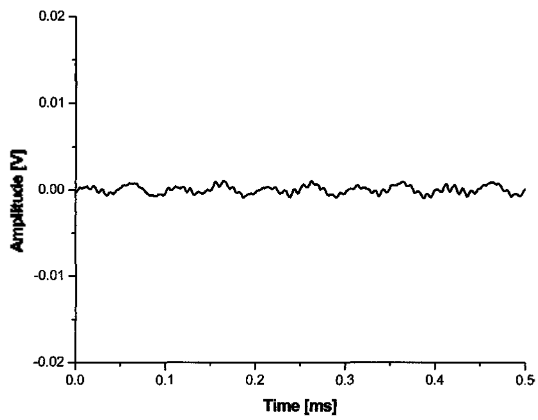


Fig. 8. Canceled waveform of vibration.

the peak of conductance of the transducer were changed by the inductance L_e, and the simulation results were good agreement to the experimental one.

3-3. Vibration Control Results

To confirm the performance of the vibrating control by the suggested method, the experiment system was set up as shown in Fig. 5. As the external vibrating source, the vibrator was vibrated by driving driver (LDS, V201) with 10 kHz. On the plate of the vibrator, the frequency controllable piezoelectric transducer was fixed and a vibrating sensor detected the vibrating acceleration at the top of the transducer surface. The received vibration of the transducer surface from the sensor was shown in Fig. 6. To cancel the vibration, the external inductor of 31.5 mH using the GIC was connected with tuning part of the transducer. By the inductor, the resonant frequency of the transducer becomes 10 kHz, and the transducer was driven with 10 kHz using a function generator. In this case the phase of the signal from the function generator should be out of phase to the vibrator's. To confirm the phase and amplitude of the transducer, the received wave from the sensor was shown in Fig. 7 when the vibrator was not driven. Now, both of the transducer and vibrator were driven with opposite phase each other, then the vibrations were cancelled each other, the amplitude of the wave detected sensor was decreased as shown in Fig. 8.

IV. Conclusion

A new active vibration control method was suggested using frequency controllable piezoelectric transducer and GIC-type electronic inductor. To obtain the large inductance for the frequency control of the transducer, an electronic inductance was designed using GIC. The designed inductance can be changed easily over the wide frequency range. By connecting the inductor with the tuning part of the transducer, the resonant frequency of the transducer can be controlled wide frequency range. Applying the transducer and inductor to vibrating test system, the vibration of 10 kHz from the vibrator can be cancelled below about 5% of original amplitude.

This vibration control transducer could be inserted to legs of an experiment table or a precision machinery because the transducer is solid enough to sustain the structure. Therefore it can be expected that this vibration control system could be applied to industrial field widely.

Acknowledgment

This work was supported by Pukyong National University Research Fund in 2006 (pk-2006-057).

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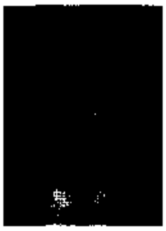

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