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Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 179-180
6-8 December, 2010

A study on the measurement system for the piezoelectric resonator with large amplitude vibration

大振幅振動の圧電共振子の計測システムに関する検討

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1.Introduction

Dynamic characteristics of piezoelectric vibrators are depended on its vibration amplitude.[1)] The loss of the vibrator increases with large vibration amplitude generally. The materials whose characteristics do not decrease in the large amplitude vibration are required for high-power application. Recently, in developing and applying lead-free materials, the high-power characteristics are concerned significantly.[2)] Authors have investigated a measurement method for the high-power characteristics called the continuous driving method which holds the motional current constant while sweeping the driving frequency around an evaluation resonant mode.[3)] The motional current is related with the vibrational velocity and can be estimated electrically by compensating the damped admittance. In this paper, we propose the measurement system implemented the compensation method using the software based internal model without external compensation circuits. Additionally, it is described that the difference of the measurement results using the proposed method and the other simple method to keep a constant input current.

2.Principle and measurement method

The piezoelectric resonator can be represented as an equivalent circuit shown in **Fig.1**, and it can be calculated from the dynamic admittance circle near the resonant as shown in **Fig.2**. The equivalent circuit constants indicate characteristics of the resonator and provide some properties, e.g., quality factor Q. The continuous drive method is based on the automatic system to measure the dynamic admittance using the motional current.[4)] The center of admittance circle is shifted by the effect of the damped admittance Y_d. If we remove Y_d-branch from the equivalent circuits, the mechanical branch L, C and R and the motional current I_m are observed directly; and the resonant frequency ω_0 can be easily obtained when the phase difference $\theta_m = \mathrm{Arg}(I_m) = 0$. Additionally, direct observation of I_m is useful to evaluate the high-power characteristics. Because elasticity modulus depend on the vibration amplitude and temperature; and we cannot use the measurement results to apply the linear equivalent circuit if the vibration amplitude were changing while measuring the admittance circle. In other words, linearized equivalent parameters must be measured in each vibration amplitude. As note about the temperature dependence, the data acquisition must be done after heat generation reached a steady state. In this measurement, the vibration velocity can be used instead of the amplitude because the frequency sweep range is narrow; therefore, the motional current which is equivalent to the vibration velocity is suitable for the control target signal. The conventional systems used the compensation circuits which cancel the effect of Y_d, especially C_d. However, elements of the circuits have frequency characteristics

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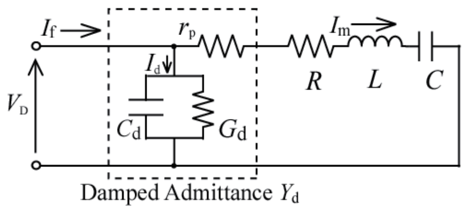

Fig.1 An example of expanded equivalent circuit for high power driven vibrator.

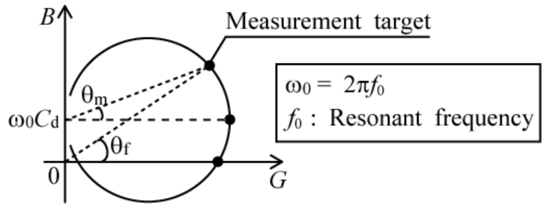

Fig.2 Motional admittance circle. ($Y_d = C_d$)

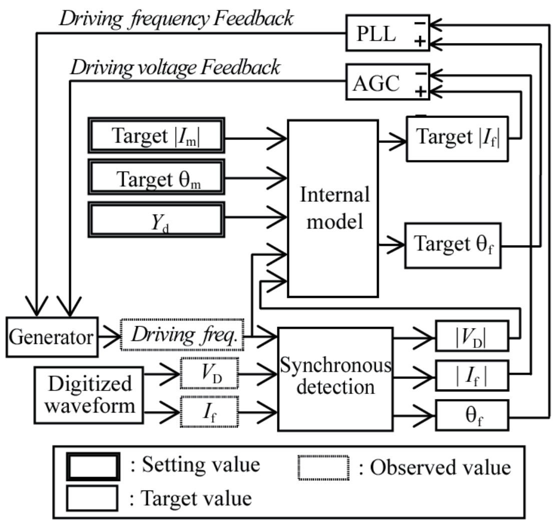

Fig.3 System diagram of the driving control.

and errors. Authors propose the system that operates based on an internal model to compensate Y_d described by software. First, as a simple model, let's think about the equivalent circuit model that is $Y_d = C_d$. We can obtain required input driving current I_f to apply expected motional current I_m from the following equation:

$$\boldsymbol{I_f} = \boldsymbol{I_m} + \boldsymbol{I_d} = \boldsymbol{I_m} + j\omega\, C_d \boldsymbol{V_D}\,. \qquad \text{Eq.(1)}$$

Where the driving frequency ω, voltage $\boldsymbol{V_D}$ and predefined damped capacitance C_d are used to calculation. Equation (1) is expanded to fit the equivalent circuit shown in Fig.1. This is named the internal model which outputs the values of amplitude and phase of the target driving current from the input values of the target motional current $|\boldsymbol{I_m}|$, θ_m and some other parameters. The internal model can be constructed with the complex Y_d ciruits without error of the elements.

Figure 3 shows the block diagram of the drive control part of this system. The difference values of $\boldsymbol{I_f}$ are used in the AGC and PLL feedback control to change the driving voltage and frequency. Thus, the motional current is maintained at target values, and changing the target phase θ_m applies the sweep operation for measuring the admittance circle. The system with the tracking driving and automatic measurement control is implemented using LabVIEW software.

3.Measurement system

Hardware construction of the system is shown in **Fig.4**. The signal generator, power amplifier and digitizer are main components used for drive control. The waveforms of driving voltage, current and vibration velocity of the measured resonator are digitized with a voltage probe, current sensing transformer and Laser Doppler Vibrometer, respectively. A cycle of the control loop as shown in Fig.3 which digitized signals, calculated control values and changed output voltage ran in about 10ms/cycle in LabVIEW system on Windows.

Simultaneously, controlling the environmental temperature and sensing the heat generation of the resonator are required. The resonator is placed in the thermostatic chamber of 41.5 x 35 x 38cm^3 of which inner temperature is remained in 29^{o}C. However, heat generation of the resonator raises the local temperature of near the resonator. Therefore, the internal air is circulated by an air flow fan. The temperatures of environment and surface of the resonator are measured using K-type thin thermo couples. The surface temperature as the heat generation is one of the high-power characteristics and is recorded by the system.

4.Measurement example results

Measured sample is a rectangular resonator of 12x3.0x1.0mm^3 made of C-213 of Fuji Ceramics using lateral effect to drive the longitudinal 1st resonant mode. Typical results with the I_m-constant drive are shown in **Fig.5**. The results show the general trend as the decrease of quality factor Q and resonant frequency, and the increase of the resonator temperature with the increase of the vibration velocity. Additionally, a simple drive method without the internal model, I_f -constant drive, was proved. The both results of frequency and heat generation were almost similar. These values are measured in the zero-phase tracking condition. The sample is hard type material and has high-Q, that is, the difference of locked frequencies is small. However, the equivalent circuit constants, especially C and L, which are derived by the sweep operation show different results obviously as shown in **Fig.6**. We expect the reason is the vibration velocity is held constant or not. The vibration velocities of the tip of resonator in the sweep measurement are shown in **Fig.7**. The velocities are almost constant in I_m-constant drive, and deviate from the constant values in I_f-constant drive. Therefore, it is thought that I_m-constant drive is necessary to evaluate the equivalent circuit constants.

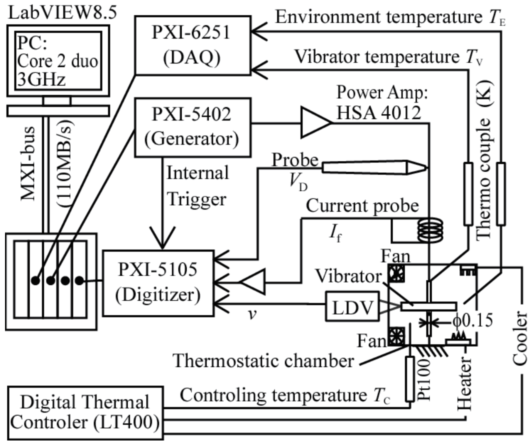

Fig.4 Hardware construction of the measurement system.

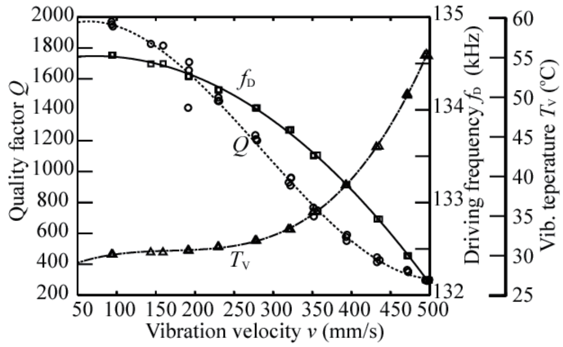

Fig.5 Mesurement results of Quality factor, resonant frequency and resonator temperature.

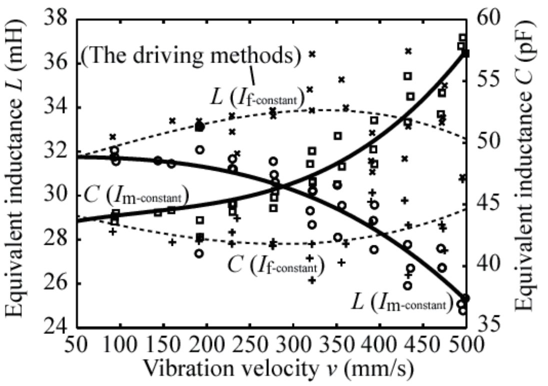

Fig.6 Mesurement results of L and C.

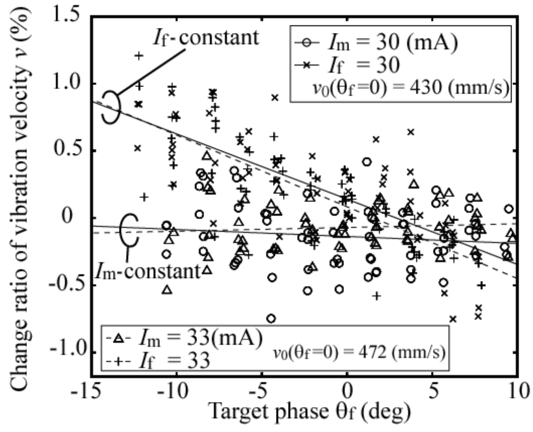

Fig.7 Deviation of vibration velocity depended on the driving methods.

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