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Visualization of mode shapes in unelectroded quartz crystal resonators using a microphone

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1. Introduction

A number of methods for plotting the vibrational patterns of a quartz crystal resonator have been reported [1–7]. Laser interferometric methods are applicable to measure the vibrational patterns of spurious vibrations of high-frequency resonators [3, 4]. Although the interferometric methods are reliable, they have some disadvantages in that the quality of the results depends on the condition of the resonator surface, and severe mechanical-isolation from the external vibrations is required. To overcome these disadvantages, the authors developed a system using an electrostatic microphone [7]. In the system, a resonator is driven by strongly modulated RF signal and the microphone with an attached needle detects the modulation components. Although this system solved the disadvantages of the interferometric methods, it could not apply to the unelectroded crystal resonators.

A system that uses a microphone for measuring the mode shapes of unelectroded quartz plates is described in this report. The microphone with an attached needle is embedded in the ground electrode and detects the modulation components according to vibrational distribution. An upper electrode is placed above the quartz plate with narrow air gap. This method succeeds to the advantages of the previous microphone method such as independent of the device surface conditions.

The experiments were performed using a 1 MHz rectangular AT-cut quartz plate. The mode shapes of fundamental thickness-shear and some spurious modes were measured. We also calculated the mode shapes using a finite element analysis (FEA) method [8] to verify the reliability of the proposed system.

2. Measurement system

The construction of the probe head is shown in Fig. 1. An electrostatic microphone with a needle is embedded in the ground electrode. The tip of the needle comes in contact with the bottom of the quartz plate through a small hole. The high-frequency voltage supplied to the upper electrode is modulated by low-frequency rectangular waves so that the quartz plate is periodically excited. The principle of the measurement is described in Ref. [7].

Figure 2 shows a block diagram of the measurement system. A computer controlled X-Y table moves a quartz plate. To avoid damage to the resonator surface, an electromagnet is used for pulling down the probe module while the quartz plate is moving. The low-frequency components that synchronize with the modulation signal are detected by a lock-in amplifier.

3. Experimental results

We measured a rectangular AT-cut quartz plate that was not electroded. The mode shapes of a fundamental thickness-shear mode and some nearby spurious modes were measured to test the usefulness of the propose system. We also calculated the mode shapes of u_2 that is perpendicular to the plate surface using FEA program [8] to verify the measured results. The dimension of the plate used was $x_1(x) = 13.964$ mm, $x_2(y') = 1.737$ mm and $x_3(z') = 13.000$ mm. The FEA program results were completely reliable for the rectangular plate with the dimension. Figure 3 shows the results for the quartz plate. The curve in the figure shows the frequency characteristics of a normalized input capacitance. In each image in the figure, the magnitude of the vibration is expressed in terms of absolute value; that is, the white regions indicate high-amplitude vibration and black, nodes or nodal lines. It is evident in Fig. 3 that highly distinct patterns are obtained in the images on left. Moreover, these patterns correspond well to the calculated images on the left. However, a vibrational pattern of the fundamental thickness-shear mode is distorted. We estimate that the reason for the results is an acoustical coupling between the quartz plate and the ground electrode.

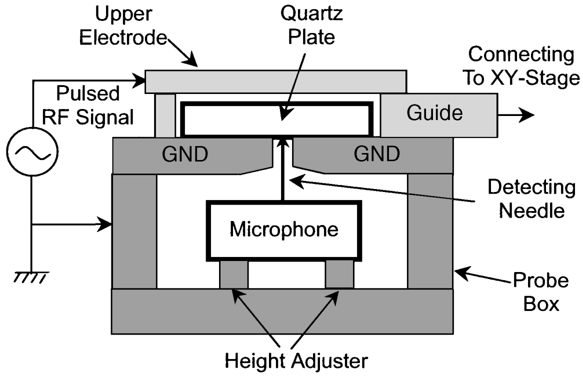

Fig. 1 Probe head.

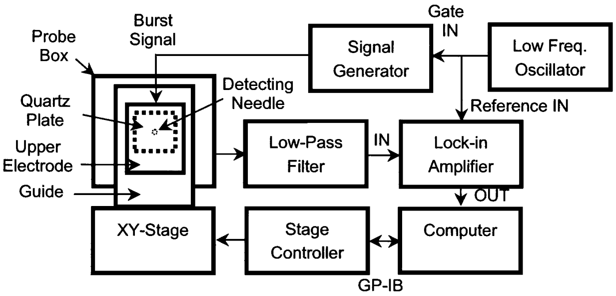

Fig. 2 Block diagram of measurement system.

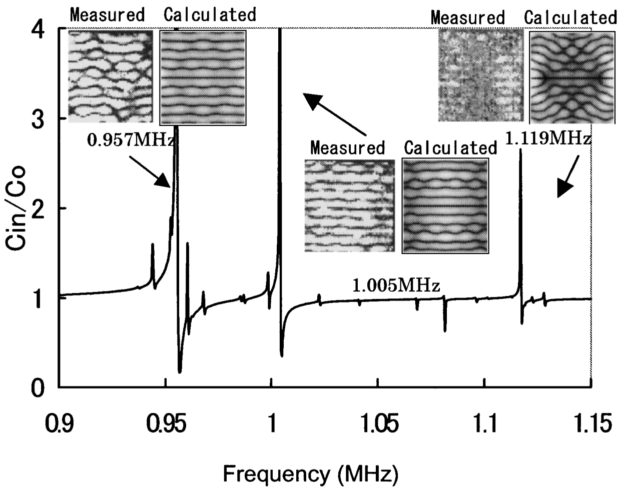

Fig. 3 Experimental results.

4. Conclusions

The system described here is capable of plotting the u_2 component of the vibrational distribution for unelectroded quartz plate spurious modes. It uses a microphone with a needle embedded in the ground electrode to pick up the modulation signal in the mechanical vibration. The experimental results for a rectangular AT-cut quartz plate and the calculated vibrational-patterns concur well. However the experiment of the fundamental thickness mode is distorted. The reason of the result is a problem to be solved.

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