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Laser Measurement and Identification of Vibration Modes of AT-cut Quartz Crystal Resonators

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1. Abstract

It is important to guarantee AT-cut quartz crystal plate vibrating in a pure thickness shear mode, since mode coupling always causes performance degradation. Many plate vibration analyses and simulations have been done in past 60 years; however, there were only few works to measure crystal mode shapes, especially for high frequency ones. In this paper we use laser radiation instrument to detect the vibration shapes. It can clearly tell the displacements in each axle which help to distinguish the vibration modes easier. Moreover the measured frequency can be more than 100MHz. By this instrument thickness shear mode and inharmonic mode have been measured. The result matches theory quite well. The displacements of mode coupling samples and pure thickness shear mode samples, are compared which can tell what happen on plate when two modes couple. These results can help engineers to resolve the coupling problem.

2. Introduction

For modern communication systems, the performance of quartz crystal resonator/oscillator are expected to be higher and higher. One of the most difficult problems for crystal engineers is frequency and resistance activity dip due to temperature change. For miniature resonators, it is hard to avoid all unwanted modes only by electrical response in the whole working temperature range (usually from -40℃ to 85℃ or higher). Many years ago, people tried to use probes to detect the electric charge of excited quartz crystal plates to get the vibration shape of plate. In 1960s, Harata and Spencer[1] used X-ray topography to describe the mode shapes. But those methods could usually measure vibrations at relatively low frequencies and could only tell a composite displacement of 3 axes. In this paper we use laser radiation instrument, MEMSMap510 (made by Optonor Corp., Norway) to detect the vibration shapes to get more information of displacement field and couple modes for high end AT crystal resonator design.

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3. AT-cut Quartz Plate Vibration Theory

Many of different modes, like thickness shear, thickness twist, flexure, and face shear mode, etc. are well known by former studies. The vibration theories help engineers figure out good design to avoid mode coupling. Mindlin's[2] plate theory is the most famous one. However, whether the calculation results match the actual vibration shape is still a big question. It also influences to improve the accuracy and effectiveness of plate theory. Based on Mindlin's 2D model, we develop a finite element analysis (FEA) program[3,4] to simulate the vibration modes of crystal plate and verify the results with the measurement data by MEMSMap510.

4. Simulation and Measurement Results

We prepare two samples for test. One is 3225 size (3.2mm by 2.5mm) 40MHz, and the other one is 8045 size (8.0mm by 4.5mm) 8MHz. In the 40MHz sample, we see pure thickness-shear mode (TS mode, uniform in-plane displacement along X_1 direction), as **Fig. 1**, and inharmonic mode (periodic opposite in-plane displacement along X_1 direction), as **Fig. 2**. The measurement data of both modes match theory quit well.

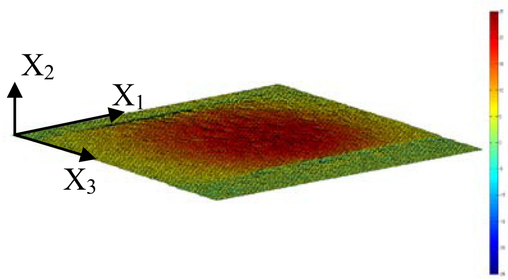

Fig. 1 Displacement of x_1 axle of the pure TS mode whose frequency is 40.13MHz.

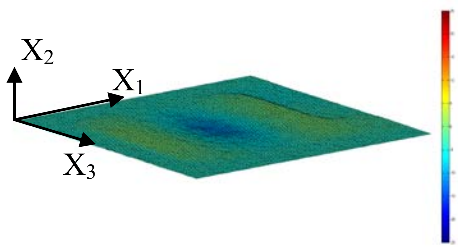

Fig. 2 Displacement of x_1 axle of an inharmonic

mode whose frequency is 40.72MHz.

In the 8MHz sample, we see a strong couple (out-of-plane displacement) with TS mode due to improper design, as **Fig. 3** and **Fig. 4**. The couple mode is not a typical flexure mode we know before. The out-of-plane displacements are “plaid,” and the directions of two nearby areas are opposite. It matches the simulation results by Mindlin’s 2D mode, as **Fig 5**. According to these information, the size and contour of quartz chip are changed, and a new resonator is redesigned with better vibration performance. The couple mode is depressed as shown in **Fig. 6** and **Fig. 7**.

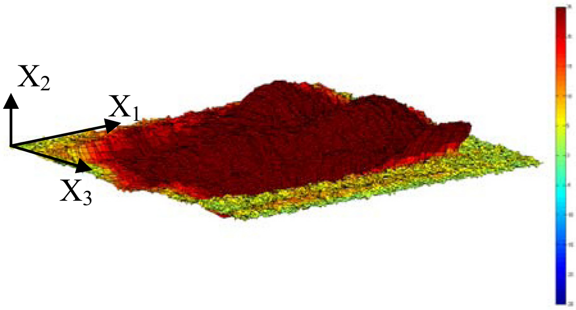

Fig. 3 Total displacement of the 8MHz sample with strong out-of-plane couple mode.

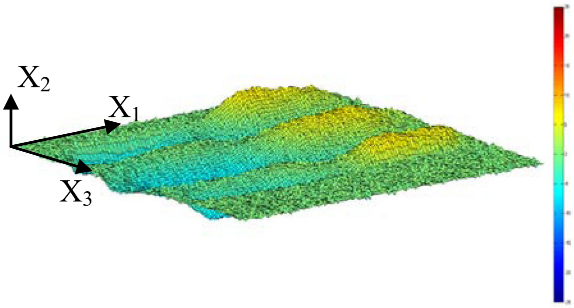

Fig. 4 Displacement of X_2 axle of the 8MHz sample with “plaid” out-of-plane displacement. The directions of two nearby areas are opposite.

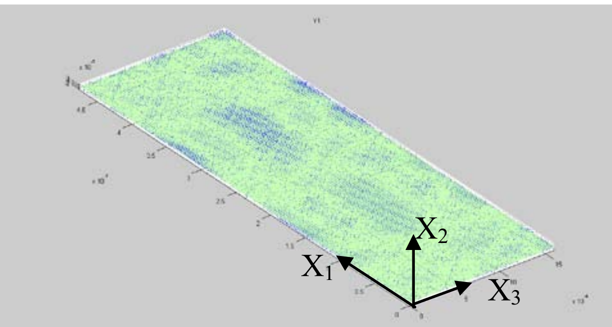

Fig. 5 The simulation displacement of X_2 axle of the 8MHz sample. It matches the measurement data shown in Fig. 4.

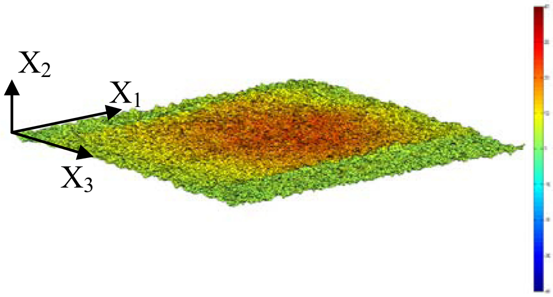

Fig. 6 Total displacement of the new design 8MHz sample. It shows that the out-of-plane mode are depressed.

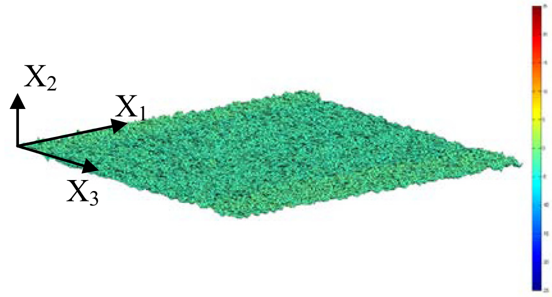

Fig. 7 Displacement of X_2 axle of the new design 8MHz. The out-of-plane displacements are almost undetectable.

4. Conclusion

By the laser radiation instrument, MEMSMap510, the vibration displacement field of high frequency AT-cut quartz plate can be detected directly. It can clearly tell the displacements in each axle which help to distinguish the vibration modes easier. In this paper, first, a 40MHz sample is test. Some typical modes, like pure TS and inharmonic modes, are identified. Second, an 8MHz sample is test also. In this case, an abnormal out-of-plane unwanted mode is observed. The unusual flexure modes matches the simulation results. According to the mode shape information, a new design for 8MHz is applied, and we get another 8MHz resonator with better performance.

References

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