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Development of remote-batteryless displacement sensor using polarization relaxation of bare resonator

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1. Introduction

In recent years, the aging of social infrastructure has become a serious issue. The primary causes of aging in structures made of metallic materials include creep and fatigue. In concrete materials, internal cracks and corrosion caused by moisture infiltration are significant concerns. These factors lead to changes in stress applied to structural components, resulting in changes in surface and internal strains. Therefore, it is important to monitor strains of the infrastructure.

However, traditional methods such as strain gauges have limitations, including the inability to perform a long-term monitoring due to wired measurements and the inability to adapt to measurements on moving parts, such as wind turbines. Additionally, because existing methods are available only to the surface-strain measurement, they cannot measure strain within the internal components.

In response to these challenges, this study aims to develop a strain or displacement sensor, which is capable of wireless and batteryless measurement. This sensor employs an AT-cut quartz resonator. AT-cut quartz resonators demonstrate extremely high temperature stability in the through-thickness shear resonance near room temperature.[1)] When an electromagnetic field with a frequency identical to the resonant frequency of the quartz resonator is radiated remotely, polarization occurs on the surface of the resonator due to the piezoelectric effect, causing the resonator to vibrate. This vibration, in turn, radiates an electromagnetic field back from the resonator, which can be detected by an antenna remotely. Therefore, it is possible to measure the resonant frequency of the resonator with a wireless-batteryless manner. [2,3)]

In this study, a displacement sensor is developed by relaxing the polarization on the bare quartz-resonator surface by approaching a metallic plate, thereby altering the resonance frequency, because the piezoelectric stiffening effect[4)] is deteriorated.

We have used thin resonators with resonance frequencies higher than 100 MHz, reaching the VHF (30-300 MHz) and UHF (300 MHz-3 GHz) bands.

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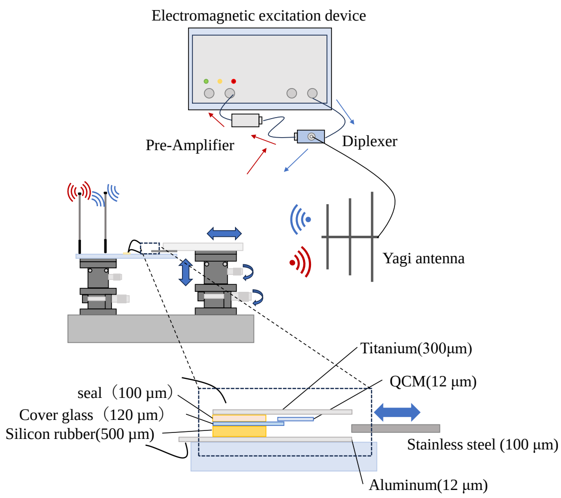

Fig. 1 Schematic of the remote-batteryless displacement sensor. The distance between the Yagi antenna and the quartz resonator is 10 m.

As a result, fully batteryless and remote measurements are made possible.

2. Experimental procedure

The schematic diagram of the experiment for the remote-batteryless displacement sensor is shown in **Fig. 1**. Two stages equipped with micrometers were attached to the base using screws, and an acrylic plate was fixed to each stage. The electromagnetic wave for excitation of the vibration was generated by a gated amplifier and sent to the sensor via a Yagi antenna. After the excitation, the same Yagi antenna detected the electromagnetic wave launched by the resonator. By sweeping the frequency of the electromagnetic wave and acquiring the amplitude of the same frequency component of the detected electromagnetic wave, the resonant spectrum of the resonator can be measured as shown in **Fig. 2**.

The sensor chip has a multilayer structure composed of a 12 μm aluminum foil as the lower flat antenna, a 500 μm thick silicone rubber, a 120 μm thick cover glass with an AT-cut quartz resonator (area:1.8×1.6 mm^2, resonant frequency:125 MHz) glued at its corner, a 100 μm thick plastic seal on the cover glass, and a 300 μm thick titanium plate as the upper flat antenna.

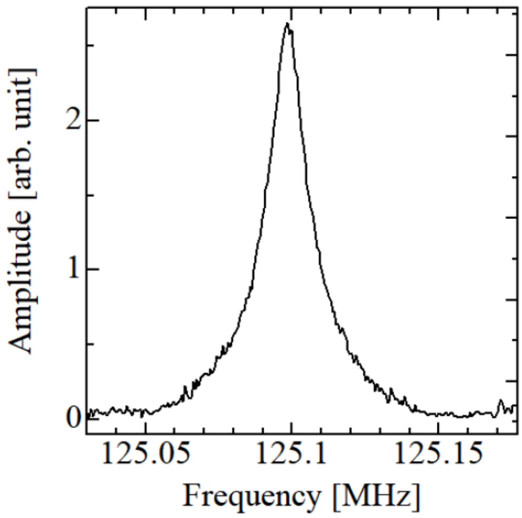

Fig. 2 Resonant spectrum measure remotely at a distance of 10 m.

A 100 µm thick stainless steel attached to an acrylic plate on the right stage was moved in and out along the horizontal axis by the micrometer attached to the stage. This movement relaxed the piezoelectric effect through the stainless steel, causing a frequency shift, which was monitored.

3. Result and discussion

Figure 3 shows the frequency change observed when the distance between the resonator and the stainless steel was varied. The distance between the Yagi antenna and the sensor was 10 m. As the stainless steel was withdrawn, thereby reducing the area covering the quartz resonator, the frequency increased. This indicates that the stainless steel is relaxing the polarization on the surface of the quartz resonator. As the covered area decreases, the amount of polarization relaxation also decreases, bringing the frequency closer to the original resonant frequency of the material, resulting in an increase in frequency.

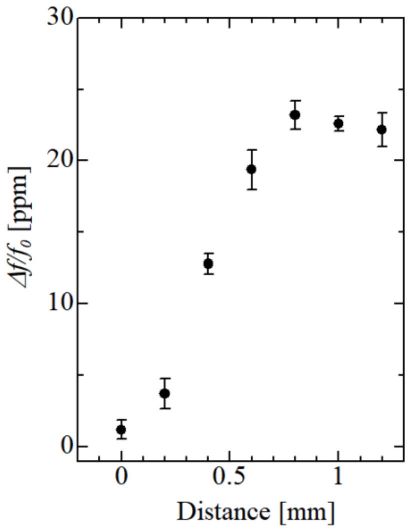

Fig. 3 Relationship between the frequency change and the resonator/metallic plate distance. Distance 0 is the state where the stainless-steel plate covers the entire surface of the crystal, and as the horizontal axis increases, the plate moves away from the resonator.

These findings suggest that this approach is a significant first step towards the development of a sensor capable of remotely and perpetually monitoring displacement.

4. Conclusion

In this study, an electrode-free AT-cut quartz resonator (resonant frequency 125 MHz) was used to measure the distance between the resonator and a metallic plate, which can be used as a displacement sensor. The mechanism is based on the relaxation of the surface polarization of the bare resonator induced by the piezoelectric effect. Because the resonance frequency of the resonator can be measured with a remote and baterryless manner, it is possible to monitor the displacement change even inside a material for a long time of period.

Acknowledgments

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References

1) I. Koga : Physics **3**, 70 (1932).
2) H. Ogi : Proc. Jpn. Acad. Ser. B **89**, 401 (2013).
3) H. Ogi : Jpn. J. Appl. Phys. **63** 040802 (2024).
4) B. A. Auld : Acoustic Fields and Waves in Solids, Vol. I (Wiley-Interscience, New York, 1973), p. 288.