Effect of atmospheric environment on frequency variation of QCM

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Abstract. In the natural/electric field environment, quartz crystal contact medium is generally considered as rigid thin film. However, with the increase of time, when the ash coverage reaches the level of microgram, the crystal frequency changes show characteristics similar to those in Newtonian fluid, that is, large damping causes the crystal frequency to change greatly, leading to large stray and chaotic peaks in both amplitude frequency and phase frequency. The spectrum curve amplitude is significantly reduced, the signal jitter is large, and the Q value is significantly reduced. The signal jitter in a small range results in a lot of burrs in the spectrum curve and causes the measurement error.

Keywords: frequency variation; atmospheric environment; QCM; environmental factors; frequency variation.

1. Introduction

Prophase study adopted ordinary oscillation circuit method, its circuit design is simple, real-time performance is good, but can only get the QCM design frequency information, and the crystal frequency slightly off series resonance frequency, or stop vibration occurs when it load big, lead to early test circuit three months in crystal product appeared unable to read data [1-3]. Based on the investigation of mature quartz crystal microbalance products on the market, it is found that the dissipative QCM in Italy adopts spectrum analysis method [4]. Compared with the method of oscillation circuit, the spectrum analysis can not stop the vibration in the large damping medium, the measurement frequency range is large, the image is intuitive, easy to calculate and interpret [5]. By scanning the frequency spectrum of QCM in a frequency range near its resonant frequency (amplitude frequency and phase frequency characteristics of QCM's equivalent impedance), multiple parameters such as QCM resonant frequency and Q value are analyzed to realize the transformation of characterizing pollution deposition amount in the natural/electric field environment for a long time [6, 7].

In the gas phase, the linear relationship between the load mass adsorbed on the surface of the quartz crystal electrode and the frequency variation of the quartz crystal was deduced. As traveling waves in the quartz crystal reflect between its surfaces to generate standing waves, the fundamental frequency of resonance frequency is [8]:
\[ f = \frac{v}{2h} \]  
\[ N = \frac{v}{2} \]  
\[ v = \sqrt{\frac{\mu}{\rho}} \]  
\[ h = \frac{M}{\rho A} = \frac{m}{\rho_q} \]  

h is the thickness of the chip; N is the frequency constant of the chip; V is the propagation velocity of elastic shear wave in the direction of normal of relative crystal plane; Q is the elastic modulus of quartz crystal, 2.947×10¹¹ g/cm×s²; Q is the density of quartz crystal, 2.651 g/cm³; A is the area of the quartz crystal; M is the mass of quartz crystal; M is the area mass (surface density) of the quartz crystal [9,10].

The natural fouling test frame of the metering building was set out, and 7 crystals of 5MHz, 6MHz, 8MHz, 9MHz and 10MHz were placed respectively. Among them, 5MHz, 8MHz and 10MHz crystals provided battery power supply, and the ash covering state was photographed and tested [11-13].

2. Experimental Details
The natural fouling test frame of the metering building was set out, and 7 crystals of 5MHz, 6MHz, 8MHz, 9MHz and 10MHz were placed respectively. Among them, 5MHz, 8MHz and 10MHz crystals provided battery power supply, and the ash covering state was photographed and tested.

![Fig. 1 Crystal outdoor lofting.](image)

The oscillating circuit of quartz crystal can maintain the stable oscillation of crystal vibration. The at-cut quartz crystal is still affected by external factors such as temperature and humidity. The starting circuit of crystal can ensure the long-term effective use of crystal in natural environment. Fig.2 shows the schematic diagram of power. The contamination detection shell should be easy to remove and replace QCM quartz crystal. The casing of the vibration starting circuit and differential frequency circuit is made of aluminum alloy and sealed with glue to prevent the circuit from being damaged by water.

![Fig. 2 Schematic diagram of crystal starting circuit.](image)
3. Results and Discussion

3.1. Outdoor natural contamination test

In order to improve the environmental pollution deposition status, different types of crystals, including 5MHz, 8MHz and 10MHz crystals, were lofting in the natural environment at the natural pollution deposition test station on the roof of the metering building, and the crystal frequency changes were measured according to the environmental changes and the changes after ash coating.

Among them, 6MHz and 9MHz crystals cannot be placed for too long and are easy to be damaged due to material problems. They are not suitable for outdoor applications. The 3MHz electrode was just received on January 3, 2019, and the test has just started, but the data volume is still insufficient.

The longest placement time of 8M C-Si and 8M-Au (small electrode): 8 October 2018 solstice January 5, 2019, about 3 months; 5M-AU (large electrode), 8M-Au (large electrode), 10M-Au (small electrode) due to the problem of purchase and delivery.

(1) 8M. C-Si electrode

![Fig. 3 Outdoor ash covering test for 8M C-Si crystals, (2018.12-2019.1).](image)

(2) 8M. Au electrode

![Fig. 4 Outdoor ash covering test for 8M Au crystals, (2018.12-2019.1).](image)

(3) 8M. Au electrode
Fig. 5 Outdoor ash coating test for 8M-Au crystals (removal of rain 10.16; 12.6 the snow), (2018.12-2019.1).

The two different electrodes have clear feedback on the pollution in the natural environment, in which the surface quality of quartz crystal changes on 10.16 rain, 10.24-11.5 haze, 12.6 snow and 12.29 wind, and the frequency value changes accordingly. Therefore, the preliminary results of environmental pollution detection are collected and analyzed. However, with the increase of pollution, the frequency acquisition circuit has a range. When there is rain and snow, the frequency value of quartz crystal changes greatly, and the frequency acquisition circuit signal is 0, but the true frequency is not necessarily 0.

(4) 5M. Au electrode

Fig. 6 Complete data diagram of outdoor ash coating test for 5M-A crystals, (2018.12-2019.1).

(5) 8M. Au-C electrode
Fig. 7 Outdoor ash covering test for 8M A-C crystals (12.6 Snow; 12.29 the wind, 2018.12-2019.1).

(6) 10M. Au-C electrode

Fig. 8 10M Au electrode diagram of indoor micromass and frequency value, (2018.12-2019.1).

The surface coating of 5M large electrode crystal is different, and the large electrode surface is obviously more intuitive than the small electrode surface. Therefore, it is determined that the large electrode quartz crystal operating surface is the contamination detection surface.

Two different electrodes, 5M and 10M, have clear feedback on pollution in the natural environment. In 12.6 snow and 12.29 wind conditions, the surface quality of quartz crystal changes, and its frequency value changes accordingly. Therefore, the preliminary results of environmental pollution detection are collected and analyzed. This experiment clarified the difference between the large electrode and the small electrode. Large electrode quartz crystal is generally tested with large electrode surface, while small electrode can be tested with the same two sides. Through indoor contamination test and outdoor natural contamination test, the performance of different quartz crystals is clarified.

4. Conclusion
In the next step, five kinds of quartz crystals, namely 5MHz Au (large electrode), 8MHz, Au (large electrode), 8MHz, C-SI, 10MHz and Au (small electrode), are used as test and data collection objects.
Therefore, the scheme of quartz crystal contamination detection module is determined. The next step is to carry out integrated design, reasonably layout quartz crystal array and add temperature and humidity sensors to form a new four-unit array contamination detection module.

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