A Study of Temperature Compensated Crystal Oscillator Based on Stress Processing

Wei Zhou, Lin Li, Baoying Feng, Wenqing Zhang, Shanshan Qin
Dept. of Measurement and Instrument
Xidian University
Xi'an P. R. China

Wenbo Wang
Shijizhuang Electronic Ltd
Xi'an P. R. China

***Abstract*—The most temperature compensated crystal oscillators must use compensation circuits and always based on fundamental crystals. We combine the different characteristics of quartz crystal including frequency – temperature characteristics and frequency – stress characteristics, with the influence of stress on the frequency of crystal blank to compensate the temperature influence on the frequency of crystal. A lot of experiments have been done to prove that with stress processing the frequency – temperature performance of overtone crystals can be improved obviously. With this way, the new crystal oscillators can show a good frequency – temperature performance, lower power consumption, lower cost, lower phase noise and better short term stability. Now the frequency – temperature stability of the oscillator samples can be better than ±3 ppm from –30 to +85 deg. C temperature range. Based on the samples and with a simple circuit compensation it is easy to obtain ±0.5 ppm stability. To generate the suitable stress, we use the double plating electrode. It is a double metal temperature sensor, and when temperature changes there is a possibility for the shape of sensor to be changed also. Therefore, the electrode can apply the stress to the blank of the crystal. We choose overtone crystal and it can show better stability and aging than those of fundamental crystal, and higher frequency – stress sensitivity. Generally, the stress on the crystal will influence the aging of crystal and oscillator. Choosing suitable double-metal electrode materials and with the overtone crystal, the aging of the crystal oscillators can still show the same specification as conventional ones.**

I. Introduction

The most temperature compensated crystal oscillators must use compensation circuits and always based on fundamental crystals. According to the crystal temperature characteristic analog or digital way can always be used to generate compensating voltage to adjust the oscillator frequency. At the same time their power consumption, size, cost, phase noise, and the short-time frequency stability will be influenced in different degrees [1]. Therefore, we have been looking for ways besides or combined compensation circuits. It may show the same compensation effect by using the physical characteristics of the crystal without compensation circuit. With this way it is possible to lower the cost of TCXO and improve its size, reliability, phase noise and other performances. [2]

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II. Stress – Frequency Effect of Crystals and the Possibility to Improve Their Frequency – Temperature Performance

Crystals can show the functions both to stabilize frequency and to make up of different sensor. The former is based on its high frequency stability, and the latter is based on its sensitivity to outside. The frequency of crystals is influenced by the force applied to it. The frequency-temperature characteristic of a crystal can be compensated if the frequency variation caused by the force changes reversely to that caused by temperature.

When a force is applied on a crystal its frequency variation is shown as [3]:

$$\Delta f = K_f \frac{f_0^{\,2}}{D} F \tag{1}$$

Where D is the diameter of crystal, f_0 is the frequency of the crystal resonator, K_f is the force sensitive coefficient, F is the force value. And,

$$k_f = \frac{\Delta f}{F} \frac{nD}{\eta f_0^{\,2}} \tag{2}$$

where Δf is offset frequency of the resonator, n is the order of overtone, f_0 is the fundamental frequency of resonator, η is the modify coefficient (related with oscillator), F is the value of force. From equation 2 we can see that the sensitivity coefficient of overtone crystal is bigger than that of fundamental crystal.

The frequency of AT cut crystal is the function of azimuth angle. So the relation of force-frequency characteristic with angles is shown as follow [4]:

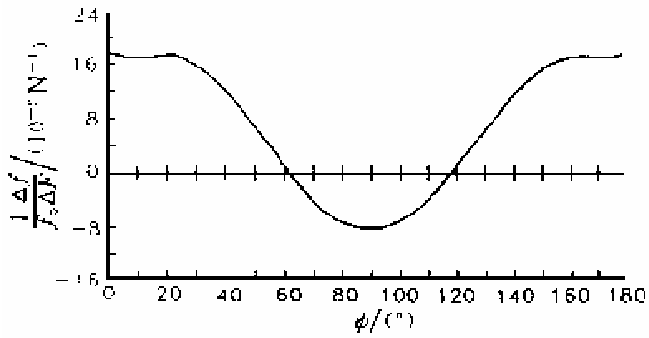

Figure 1. The relation of force-frequency characteristic with angles

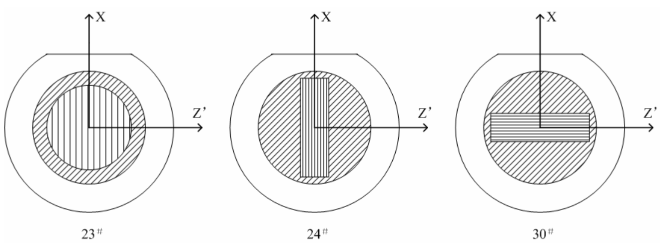

Figure 2. The shapes of the second plated film

The new TCXO is based on these characteristics.

III. THE CRYSTAL OSCILLATOR BASED ON STRESS PROCESSING

Crystal frequency is affected by temperature, while the frequency of the crystal is also affected by a force on it. If the frequency-temperature characteristic of the crystal is compensated. It can be gotten by generating different stress linearly according to different temperatures.

To generate the suitable stress, we use the double plating electrode. It is a double metal temperature sensor, which is a strip metal plated on another metal, and when temperature changes there is a possibility for the shape of sensor to be changed too. So the electrode can apply the stress to the blank of the crystal, which changes with temperature to adjust the frequency linearly. We choose overtone crystal and it can show better stability, aging than those of fundamental crystal, and higher frequency-stress sensitivity, which is easy to control compensation. Even if some of the performance is affected in a certain extent after being processed with stress, such as aging, it is better than traditional fundamental TCXO overall. After being processed by stress, the overtone crystal is easy for circuit to compensate further. Higher stability of frequency-temperature can be obtained.

IV. EXPERIMENTS AND THE RESULTS

A lot of experiments have been done to prove that with stress processing the frequency – temperature performance of overtone crystals can be improved obviously. These are only primary results.

The effect of shape of second plated film to frequency-temperature characteristic is proved through experiment 1.

The frequency-temperature characteristics of three second plated crystals and one reference crystal without second plated are tested. They are all 49U, AT cut, third overtone crystal with 38.88 MHz frequency. To the three second plated crystals silver films are plated on their golden electrode, and No.39 crystal only has golden electrode, but its frequency-temperature characteristic is similar to that of the first three crystals originally have not been plated for the second time.

The second plated shape of No.23, No. 24 and No.30 shown in fig 2.

The frequency-temperature characteristic curves of the 4 crystal oscillators are shown in fig 3.

From the two figures above we can see that the frequency-temperature characteristic curves of the three crystals compensated with stress are obviously improved compared with No. 39 crystal.

The compensation effect of No.23 reaches to 10ppm at lower temperature, but it increased 3ppm at higher temperature.

The compensation effect of No. 24 reaches to 5 ppm at lower temperature, 10 ppm at higher temperature.

The compensation effect of No. 30 reaches to 5 ppm at lower temperature, 5 ppm at higher temperature.

The relation between force direction and compensation effect shown in experiment is consistent with theory analysis. From Fig 1, when direction angle $\psi = 0^\circ$, the force sensitivity coefficient K_f reach to its maximum, so the compensate effect of No. 24 is best; the value of K_f when $\psi = 0^\circ$ is about twice than that when $\psi = 90^\circ$, so the compensation effect of No. 24 is twice that of No. 30.

Experiment 2: the effect of the frequency regulation quantity of square crystal to frequency-temperature characteristics.

49U AT cut, third overtone crystals with 16.62MHz frequency are chose and shown in Fig 4. The first layer metal electrode is silver, over which is gold layer, their frequency regulation quantities are between 500Hz and 3000Hz. The frequency-temperature characteristics of crystals with the different frequency regulation quantities are shown in Fig 5.

No.36 has not been plated for the second time, its testing data can be as a reference, and the frequency regulation quantities of No.1, No.2, No.3 and No.5 are 3 kHz, 1.0 kHz, 0.4 kHz, 2.4 kHz. As we all know that the frequency regulation quantities are directly proportional to the thickness of the electrode. From Fig 5 we can see that the performances of No.1 and No.2 are improved while that of No.3and No.5 get worse.

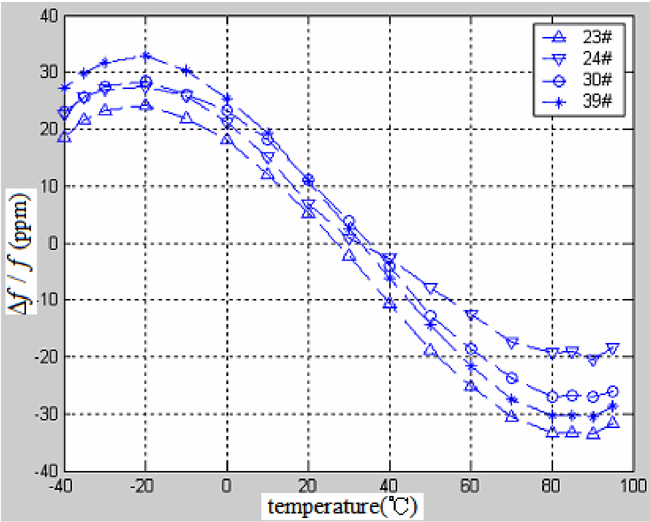

Figure 3. The frequency-temperature curves of crystal oscillators

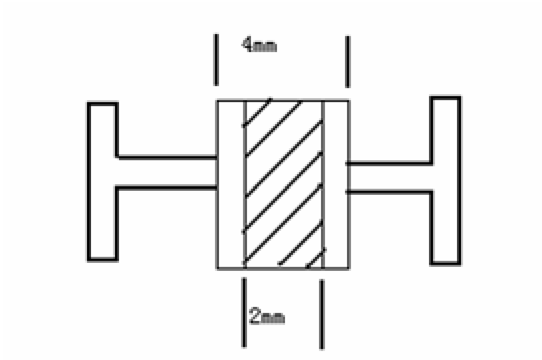

Figure 4. Square plated crystal

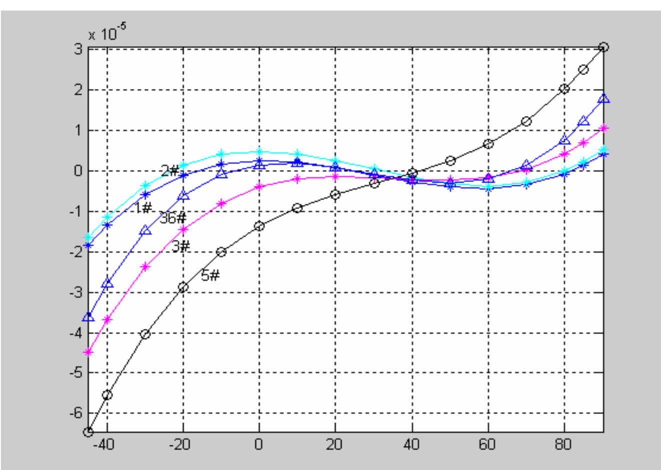

Figure 5. Frequency-temperature characteristic curves of crystals with the different frequency regulation quantities

After optimizing the frequency regulation quantities, the frequency-temperature characteristic of crystals can reach to ±3 ppm in the temperature range between -30℃ and 80℃. As the second plated crystal has improved the overtone crystal to a scale for the circuit to adjust, and it keeps its thrice temperature characteristic, so ±0.5 ppm can be obtained after simple analog compensation.

Experiment 3: aging experiment.

The aging performance of crystals after being processed by this method has been tested in a long period. The aging per day data are between 1.5×10^{-8} per day and 0.5×10^{-8} per day.

These are the only sample study works, these effects have not appeared in volume-production. Especially we found that the storage period and environment before the second plating, plating temperature, aging temperature of crystals will affect compensating effect, and the material make up of the electrode-temperature sensor should be further optimized.

V. CONCLUSION

Based on the different physical characteristics of crystals without compensation circuit the good compensation result can also be obtained. With this way, it is possible to enhance performance of oscillator, lower it cost, minimize its volume, and improve its reliability, phase noise, aging. We combined the stabilizing frequency function of crystal together with its sensing function to improve its frequency – temperature performance. A lot of experiments have proved the new principle can be used in improvement of TCXO. However, to manufacture the crystals and oscillators with this way we still need many things to do.

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