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Aging and Retrace in Oven Controlled Crystal Oscillators

Quartz crystal oscillators are widely used as frequency and time standards in a variety of electronic systems. While quartz crystal oscillators are well suited to the task, best performance in demanding applications, as is true for any precision device, requires in-depth understanding of device idiosyncrasies.

Aging is the long term frequency drift of an oscillator. Though carefull design and manufacturing minimize aging at the time of shipment, aging continues for the life of the oscillator and is affected by the circumstances and duration of power-off storage. This paper highlights the physical processes responsible for aging and explains why, after being in poweroff storage, a re-stabilization period is highly recommended prior to oscillator frequency adjustment.

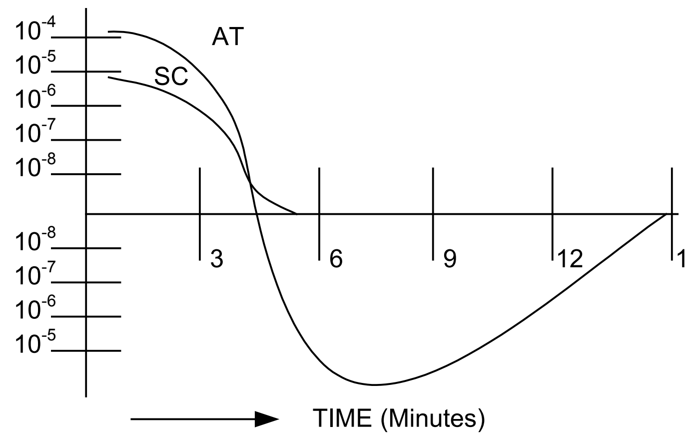
Aging has two basic causes. First, the frequency of a quartz crystal resonator is strongly affected by electrode mass. Contamination of the electrode or the surface of the quartz blank increases resonator mass and thereby lowers the resonant frequency. Water vapor is a prime culprit of this type of contamination, though oxygen and hydrocarbons cause problems as well. Outgassing of the conductive adhesive used to mount the resonator in its enclosure is also a factor. Crystalline quartz and metallic electrodes are both porous at sub-microscopic scales with a huge number of small cavities that harbor contaminants. Contamination is always present at some level, but production processes such as ozone cleaning, high temperature vacuum bake, and the use of hard vacuum can minimize contamination effects to almost negligible levels.

Contamination would be much less of a problem if the contaminants would remain in place. Unfortunately, contamination on a new crystal, especially one installed in an ovenized oscillator operating at an elevated temperature, moves under the influence of evaporation, adsorption, condensation, and mechanical acceleration. As a result, a new oscillator ages quickly until contaminate movement stabilizes.

Mechanical stress is the second cause of oscillator aging. A crystal is an orderly lattice of atoms whose shape, along with the atomic spacing, determines the physical properties of the crystal such as dielectric constant and elasticity. Many of these properties affect resonant frequency. Mechanical stress deforms the atomic lattice, slightly changing the atomic spacing which in turn slightly alters the physical properties of the crystal. If the crystal lattice being stressed happens to be a quartz crystal resonator, the result is a slight change in the resonant frequency. For this reason, AT-cut resonators exposed to mechanical stress shift frequency. Doublyrotated crystals such as IT- or SC-cuts are partially stress compensated and are affected less by stress. Therefore, re-stabilization times are less for doubly rotated cuts, but these resonators are much more difficult to manufacture and are more expensive than common AT-cut resonators.

Stress in quartz crystal resonators has many sources; mounting stress from the spring action of the mounting clips, contraction of conductive adhesive as it sets, residual stress from the cutting and grinding operation during manufacturing and differential thermal expansion and contraction. The last factor is particularly interesting in ovenized oscillators because the crystal is heated from room temperature to about 80°C every time power is applied, and because the coefficient of thermal expansion in crystalline quartz is different in each axis.

Because quartz conducts heat poorly, thermal gradients are steep and dissipate slowly. Ovenized AT-cut resonators undergo a strong, stress-induced frequency transient during warm-up, when the edge of the resonator, in contact with the mounting clip, is significantly warmer than the center. This transient is visible in the figure as the sharp frequency undershoot occurring at four to five minutes after turn-on. Residual stresses are at a maximum in a new oscillator just after turn-on, slowly relaxing during the first few days of operation until an equilibrium condition is reached.



Frequency shifts coming from contaminant redistribution and stress relaxation amount to as much as a few parts per billion per day for a new oscillator. Standard practice at Vectron is to burn in, or age, new oscillators while continuously monitoring frequency until daily aging rates stabilize. The amount of time needed depends upon the oscillator frequency and crystal cut along with the specified aging rate. Typical aging durations vary from less than a week to several weeks.

What happens when a new "well-aged" oscillator is turned off? Ovenized oscillators reacquire mechanical stress as they cool down, the amount of stress being a function of the difference between the oven temperature and the ambient temperature. This stress eventually dissipates, although the rate of stress relaxation is much reduced at lower temperatures.

When the oscillator is turned off, contaminants begin to move again towards a new equilibrium condition. As before, the rate of re-distribution is much less at lower temperatures. If the power off time is brief, and the storage temperature is modest, the oscillator will return to an aging rate close to that measured at the time of shipment after a brief warm up period. The actual frequency is close – but not identical – due to hysteresis and because aging continues during power-off periods, although not necessarily at the same rate.

An extended power-off interval, or (according to some references on the subject) exposure to temperature extremes during the power-off interval allows a greater degree of stress relaxation and contaminant re-distribution. Some of the aging stabilization acquired during the original production burn-in is lost in this case. Therefore, when power is reapplied, a much longer re-stabilization period is needed to reach the previous aging rate. The restabilization period varies. Re-stabilization for a third overtone AT-cut ovenized oscillator after 24 hours represents very good performance for a non-stress compensated crystal. The presence of even a small amount of crystal contamination would significantly extend the re-stabilization period.

What does all this mean in practice? First, an ovenized oscillator should be continuously powered if at all possible. If power interruptions are unavoidable, be aware that the oscillator will take some time beyond normal warm-up to return to the prior aging rate and, because of aging and hysteresis, is unlikely to return to exactly the same frequency. Hysteresis for AT-cut resonators is unlikely to be much better than a few parts in 10-8. Frequency adjustment during the re-stabilization period is not a good idea. With its extensive experience designing precision ovenized oscillators, Vectron is able to assist in determining an appropriate re-stabilization period, especially if the power-offperiod exceeds a few days and a longer re-stabilization period is necessary.

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