AN ANOMALOUS THERMAL EFFECT IN QUARTZ OSCILLATOR-PLATES

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ABSTRACT

The oscillation frequency of a quartz oscillator-plate shifts abruptly when the plate is suddenly exposed to infrared radiation. The shift is downward for *BT* cut plates and upward for *AT* plates. That the effect is distinct from normal temperature drift is shown by the fact that it can be made opposite to the normal drift by proper orientation and dimensioning of the plate. The magnitude of the effect is about one part in one hundred thousand, for radiation intensities employed. Since the shift occurs only when the surface of the plate is differentially exposed, it is tentatively concluded that the cause is related to thermal strain.

The discovery by Frondel[1] that the oscillation frequency of a quartz oscillator-plate could be substantially altered by prolonged exposure of the plate to *x*-radiation prompted the investigation of the effects of other wave lengths of radiation. It is the purpose of this note to describe a new thermal effect produced by radiant energy in the infrared region. Although the effect is of little or no practical use, its anomalous character is of sufficient scientific interest to warrant its discussion.

If a conventional quartz oscillator-plate, such as is used in the *CR* 5 unit, mounted in a holder which has been provided with a hole approximately one-quarter of an inch in diameter through both the plastic case and metal electrode, is suddenly exposed to infrared radiation while oscillating in a Pierce type circuit, an abrupt change in the fundamental oscillation frequency is observed. The source of radiation may conveniently be a soldering iron operated below red heat, circa 500° C. For a plate having a fundamental frequency of about eight megacycles and with the source of radiant energy about three inches from the crystal, the change observed is of the order of eighty cycles per second, or approximately one part in one hundred thousand. The jump in frequency is unrelated to the normal frequency drift encountered as the temperature of the unit increases and, indeed, may be made opposite to it in direction by proper orientation of the oscillator plate. When the radiation is cutoff, the frequency again shifts abruptly, this time in the opposite direction.

That the effect is distinct from normal heating effects is amply demonstrated by the fact that the direction of shift is downward for *BT* cut plates, regardless of the direction of temperature drift. Thus, a plate so

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[1] Frondel, C., *Am. Mineral.*, **30**, 432 (1945).

cut that its turning point is above room temperature and whose frequency, therefore, increases slowly as the unit is warmed, shows a drop in frequency on sudden exposure to infrared radiation. *AT* cut plates, on the other hand, show an upward jump, again regardless of the normal direction of drift, which may be negative in properly oriented and dimensioned plates. (The different direction of shift in the two cuts eliminates capacitance changes as a cause.)

Since there appeared to be little chance of practical application of the phenomenon, no thorough investigation of it was made. Certain preliminary experiments were conducted, however, and the results of these will be described briefly.

Rapidity of the Effect: If the oscillating crystal is brought to zero-beat with a standard oscillator and the Lissajous ring viewed on an oscilloscope screen, the frequency shift can be seen as the stationary ring begins immediately to precess. For shifts of the order of one hundred cycles per second, the change appears to occur instantaneously. For smaller shifts, in which the precession of the ring is slower, some evidence of a finite length of time for the effect to build up can be observed. The length of time required must, however, be about the same as that for the eye to adjust itself to the new pattern. If the shift is followed audibly by the change in the beat note, the same results are obtained. With a rapid alternation of the infrared source off and on, a fluctuating beat note can be heard. Exposure of a *BT* cut plate having a positive temperature coefficient results in an immediate change in the beat note followed by a gradual return to zero beat and beyond. The first change is the anomalous effect and the return is the normal frequency drift as the crystal warms.

Magnitude of the Effect: As indicated previously, the infrared frequency shift is about one part in one hundred thousand of the fundamental frequency for the radiation intensities employed. This applies particularly to *BT* cut plates. For *AT* plates, the shift is somewhat less. The magnitude is a function—probably exponential—of the fundamental frequency. This is shown by the following observations, Table 1, on an

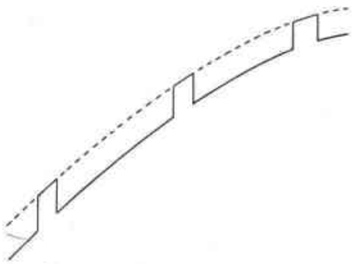
TABLE 1. ANOMALOUS SHIFT AS A FUNCTION OF FUNDAMENTAL FREQUENCY OF AN *AT* PLATE

Fundamental Frequency	Thickness of Plate	Anomalous Shift
2028.85 kc./sec.	.033 in.	+10 c./sec.
3073.00	.022	+30
4031.90	.016	+65

AT cut plate which was progressively reduced in thickness. The data in Table 1 were obtained using an infrared source, about 300° C., at about one and one-half inches from the oscillator-plate. They are not sufficiently accurate for purposes other than illustration. No effort was made, for instance, to take into account the possible influence of lateral dimensions of the plate on the magnitude of the shift. Actually, the plates were not "dimensioned." Such a study might be informative.

As would be expected, the magnitude of the effect varies inversely as the square of the distance from the source of radiation to the crystal. Exposure of both sides of the crystal simultaneously appears to double the amount of shift.

Persistence of the Effect: Experiments conducted over periods of time up to two hours indicate that the effect is a continuing one. In one typical experiment, a plate was exposed continuously for two hours. At fifteen minute intervals, the radiation was momentarily cut off and the frequency shift noted. Although the fundamental frequency of the plate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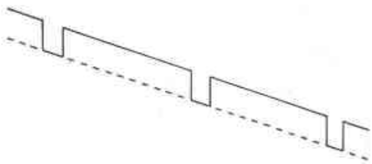
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Fig. 1. The frequency of a *BT* plate as a function of time during exposure to infrared radiation, with periodic cut-off of radiation. Dotted line is the normal frequency; solid line the actual frequency. Cut-off results in abrupt shift back to the normal frequency (schematic).

Fig. 2. The frequency of an *AT* plate as a function of time during exposure to infrared radiation, with periodic cut-off of radiation. Dotted line is the normal frequency; solid line the actual frequency. Cut-off results in abrupt shift back to the normal frequency (schematic).

changed a great deal during the test, the magnitude of the anomalous shift did not change appreciably. Actually, it appeared to increase slightly, but this observation has not been confirmed. Under the conditions described above of continuous exposure, the crystal is oscillating at a frequency different from its normal frequency and cut off of the radiation causes a reversion to the normal. In the case of *BT* cut plates, oscillation during exposure is below the normal and cut off causes an upward shift. For *AT* cut plates, the opposite is true. This is shown schematically in

Figs. 1 and 2, where the solid lines are the actual oscillation frequency and the dotted lines the normal frequency.

Influence of the Nature of the Surface: An oscillator-plate was etched sufficiently to be transparent and one side was roughened with aluminum oxide. Measurements were made of the anomalous shift with the rough surface and with the smooth surface exposed. The results were inconclusive, but exposure of the smooth surface appeared to give a higher shift.

Plated Crystals: A silver plated *BT* cut crystal was removed from its holder and exposed to infrared radiation while oscillating. When the entire surface was exposed, no anomalous shift was noted. A small area at the center of the plate was cleaned of silver by nitric acid etching. A small anomalous effect was observed. Bertsch,[2] while verifying the existence of the effect, observed an anomalous frequency shift using gold plated *BT* cut plates mounted in a plastic holder with a one-quarter inch entry port. The plating was not removed from the surface.

Effect of Cold Air: One of the more interesting aspects of the phenomenon is the effect of cold air. If the source of radiation is replaced by a cold air blast directed at the exposed surface of the plate, a frequency shift opposite to that produced by infrared is observed. The abrupt shift is upward for *BT* cut plates and downward for *AT*. The reversion to the normal frequency appears to be somewhat slower, however, than when infrared is used. There was some indication that the magnitude of the shift decreases on prolonged exposure.

Explanation of the Effect: A number of carefully controlled experiments will have to be conducted before other than a tentative explanation can be offered. It would appear, however, from the results of the experiments described above that thermal strain is the most probable cause. Further weight is given to this theory by the following observations using entry ports of various designs. If the metal electrode with a single, quarter inch port is replaced by one with a number of small ports distributed randomly over the entire surface, the magnitude of the anomaly is reduced. If it is replaced by a screen grid so that almost the entire surface of the crystal is uniformly exposed, what anomaly remains is so slight that it is difficult to detect.

The authors are indebted to Mr. Virgil E. Bottom for carrying out some of the preliminary experiments.

[2] Bertsch, C. V., Personal communication.