THE EFFECT OF PIEZOELECTRIC OSCILLATION ON THE INTENSITY OF X-RAY REFLECTIONS FROM QUARTZ

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Abstract

In an attempt to determine the amplitude of vibration of the ions in a quartz lattice brought about by piezoelectric oscillations, a series of Laue photographs have been made of both Curie and thirty-degree-cut plates, using the white radiation from a Coolidge universal tube. This tube had a tungsten anode and carried a current of four milliamperes at 95 kilovolts. Eastman duplitized x-ray film was used with no sensitizing screens. On examination, the patterns produced by each plate, oscillating and non-oscillating, appear identical except in one respect; the pattern of the oscillating plate is several times as intense as that of the non-oscillating. A four-hour exposure of a non-oscillating plate to radiation of the above mentioned type, produces but the rudiments of a pattern, whereas, the same plate oscillating produces a very beautiful intense pattern for the same time of exposure. The effect does not depend on the mode of vibration but does depend on the amplitude. Further work is in progress which it is hoped will establish the cause of this peculiar intensity difference.

Introduction

PIEZOELECTRIC quartz plates used as frequency controllers for vacuum tube oscillators have a visible vibration[1] when in mechanical resonance with the electrical circuit. Such mechanical oscillations must be accompanied by considerable internal movement of the ions of the crystal lattice. It was proposed to investigate this internal motion by shooting a beam of x-rays through a quartz plate both when oscillating and when not oscillating and by observing whether there was any difference in the appearance of the Laue diffraction patterns.

If there was considerable motion of the crystal planes, it might be expected that the spots on the Laue pattern would be altered. Upon first consideration, one might think that this alteration would occur either as a linear smearing of the spots or as a diminution in the intensity of the pattern. The first hypothesis seemed reasonable because of the experiments of Professor Joffé[2] in which a linear smearing of the spots was produced by a mechanical distortion of the crystal. The second hypothesis appeared reasonable from temperature consideration. The usual result of raising the temperature of a crystal is that the reflection slowly decreases almost linearly with increase in temperature. Backhurst[3] gives some data on graphite and ruby, finding a fifteen percent decrease in reflecting power for a rise in temperature of 500° Centigrade.

[1] H. Osterberg, Nat. Acad. Proc. **15,** 892 (1929).
[2] Joffé, The Physics of Crystals, p. 38.
[3] Backhurst, Proc. Roy. Soc. London **102,** 340 (1922).

Gibbs[4] called attention to the unusual increase in reflecting power of certain planes in crystal quartz which took place at the transition temperature (575°C) when the so-called α form changed over to the β form. Since this large increase was attributed to a relative movement of the ionic planes of only 0.025 Angstrom unit, it seemed possible that oscillations in quartz might produce a change in the relative intensity of the Laue spots.

Apparatus and Methods

Eastman duplitized x-ray films were used throughout. Sensitizing screens were tried at first but were soon discarded for fear they might influence results. The film was placed in a box made of 1/8″ lead sheet closed except for a small 1/2″ hole in the top. Directly above this hole was mounted in intimate contact, the lower contact plate for the crystal, made of brass and polished flat. In its center was a 1/4″ hole. The upper contact plate of the crystal was also made of polished brass. In its center was drilled a 1/8″ hole. Radiation from a Coolidge universal tube was delimited by a number 60 drill hole in each of two lead screens mounted approximately five inches apart. Attached to the lower screen and in line with the hole was a two-inch narrow tube of

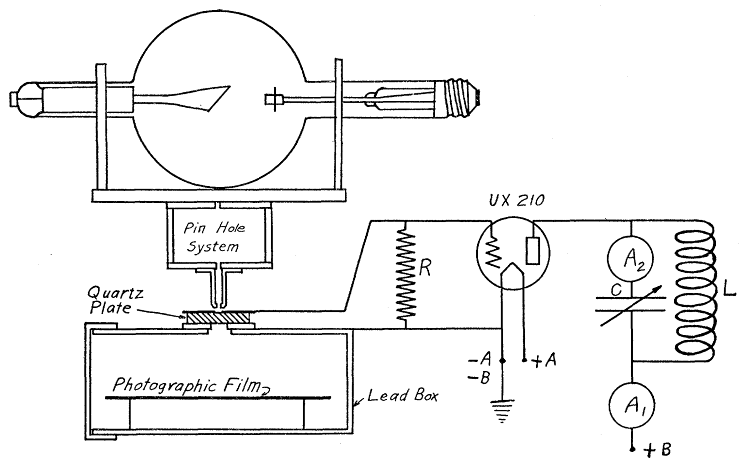


Fig. 1. Schematic diagram of x-ray tube and crystal circuit.

brass also having a number 50 drill hole in its end. This was merely to facilitate pointing the x-ray beam at the hole in the upper electrode.

The driving circuit is shown in Fig. 1, together with a schematic drawing of the whole layout. The vacuum tube was of the UX210 type employing a filament voltage of 7.5 volts. Plate voltages from 50 to a maximum of 350 volts were used at various times. Resonant conditions in the circuit were determined by observations of the D.C. plate milliameter A_1 or the radio frequency ammeter A_2. In this type of circuit using a resistance bias, oscillations are indicated by a large drop in the D.C. plate current and a corresponding increase in the reading of the high frequency ammeter.

[4] Gibbs, Proc. Roy. Soc. London **A107,** 561 (1925).

Results

A preliminary run with the non-oscillating crystal showed that at 95 kilovolts peak and 4 milliamperes x-ray tube current at least a four-hour exposure would be necessary to get even a visible pattern. With the same exposure, however, this same plate, oscillating, gave a very beautifully developed Laue pattern. This was curious, and since the exposure on the oscillating crystal had been made in two parts with a lapse of several hours between, and since the film had been developed at a different time and with a different solution than that of its non-oscillating mate, it was assumed that some difference in technique had produced the decided change in intensity. To test this point three different diffraction patterns were made of the same quartz plate; the first, with the plate not oscillating; the second with the plate oscillating; and

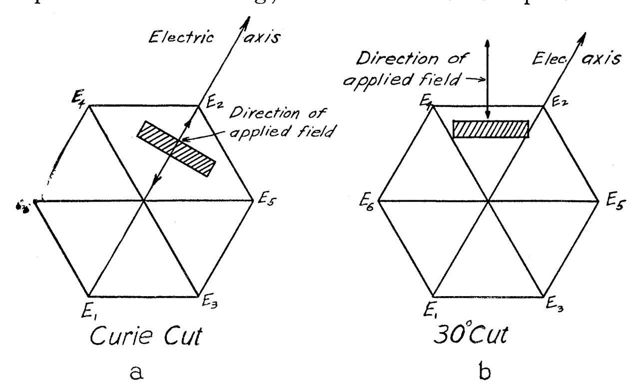


Fig. 2. (a) Curie-cut. In use the applied electric field is parallel to an electric axis of the crystal. The optic axis is normal to the plane of the figure. (b) 30-degree-cut. In use the applied electric field makes an angle of 30° with an electric axis of the crystal.

the third with it not oscillating again. In each instance, a four-hour continuous exposure was made at 95 kilovolts and 4 milliamperes. Over a four-hour period slight voltage-current fluctuations were bound to occur but an average current of four milliamperes over the necessary twelve-hour period is probably very close to the truth. All three exposures were then simultaneously developed in a single large tray and were fixed at the same time. Examination of all three films showed beyond doubt that the pattern made by the oscillating plate was decidedly more intense than either pattern made by the non-oscillating plate. This discovery made it necessary to go into the phenomenon in more detail.

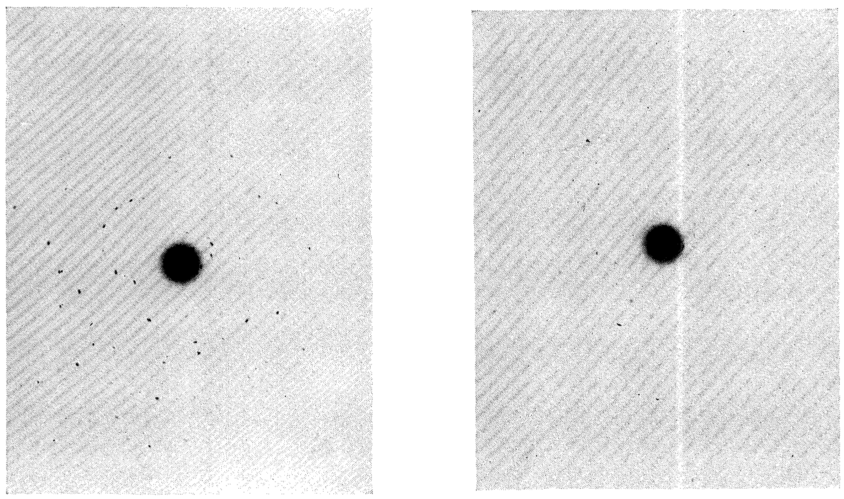
Table I

Curie-cut Frequencies (kilocycles)	30-degree-cut Frequencies (kilocycles)
3590	3850
1900	1875
320	325

Six plates were cut from a specimen of optical quality crystal quartz, three of each type of cut as shown in Fig. 2. These plates were then ground down to the following approximate frequencies, as shown in Table I.

The Curie-cut plates have an average wave-length of about 105 meters per millimeter thickness and the 30-degree-cut, about 145 meters per millimeter thickness.

Two four-hour exposures were then made for each plate. Simultaneous development and fixing were carried out. In each case, the same result was obtained, viz.; *an exposure which gave but the rudiments of a pattern with the plate not oscillating, gave an intense pattern when the plate was vibrating.* Visual examination shows the patterns to be identical with the same spots occurring but the intensity is decidedly different. Fig. 3 shows a reproduction of the patterns produced by a 30-degree-cut plate, oscillating and not oscillating. This plate had an approximate frequency of vibration of 1875 kilocycles. It



a b

Fig. 3. (a) oscillating; (b) not oscillating.

was not possible to note any smearing of the spots as was suggested might happen though the method is too crude to detect small changes.

To test the possibility that the effect was due to some sort of an electric strain set up by the applied electric field, a test was run on the same plate whose pattern is shown in Fig. 3. Again two runs were made, the first with no applied field and the second with the line voltage of 120 volts, 60 cycles, applied to the crystal. Both exposures were identical. The two exposures proved to be no different showing that the effect is definitely a resonance phenomenon.

To test this conclusion further, the same piezo-plate was used in a series of three four-hour exposures. The x-ray energy was kept constant and the amplitude of vibration was changed by increasing the plate voltage on the vacuum tube. The voltages used were 50, 150, and 300 volts, respectively. The three exposures show definitely that the intensity of the spots on the patterns depends on the amplitude of vibration of the quartz plate. The 150 volt exposure is decidedly stronger than the 50 volt one and the 300 volt exposure is much stronger than either.

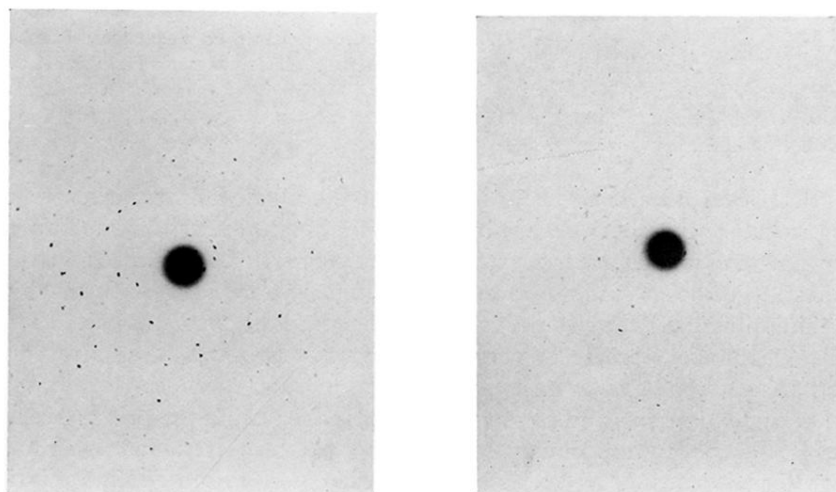


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Fig. 3. (a) oscillating; (b) not oscillating.