NOTES ON QUARTZ PLATES, AIR GAP EFFECT, AND AUDIO-FREQUENCY GENERATION *

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Summary—*Experiments on the frequency of piezo-electric elements are described with special reference to the effect due to supersonic sound waves generated in the air gap of the holder and due to its capacity. It is shown that a mechanical load on the crystal increases its thickness frequency and that an air gap has a similar effect. The velocity of the supersonic sound waves is about the same as for ordinary sound waves. The value found is 338.68 meters per second at 24.5C deg. An appropriate air gap gives even more high-frequency output than a mechanically-loaded crystal and procures a steady frequency operation. Two sputtered piezo-electric elements can produce a beat frequency which is correct within a few parts in 100,000. A method is shown by means of which a low-frequency standard can be obtained by harmonic division of a high frequency due to piezo-electric element.*

ANYONE experimenting with piezo-electric plates will notice that the temperature, the load in the anode branch, and the holder of the piezo-electric element affect somewhat the frequency of the output current.

The effect is very pronounced when the beat frequency of two vibrating crystals is to be taken as a standard since the percentage error in the beat frequency is larger in the ratio

$$\frac{\text{average value of the two high frequencies}}{\text{beat frequency}}$$

than the percentage error in any one of the two high frequencies.

The temperature effect can be checked by a suitable thermostatic control and the circuit effect by using a fixed anode load.

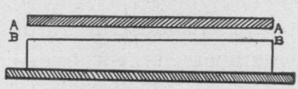

Fig. 1—Piezo-Electric Element and Its Electrodes.

The holder effect which is the subject of this discussion is twofold: One being due to the supersonic sound waves displaying

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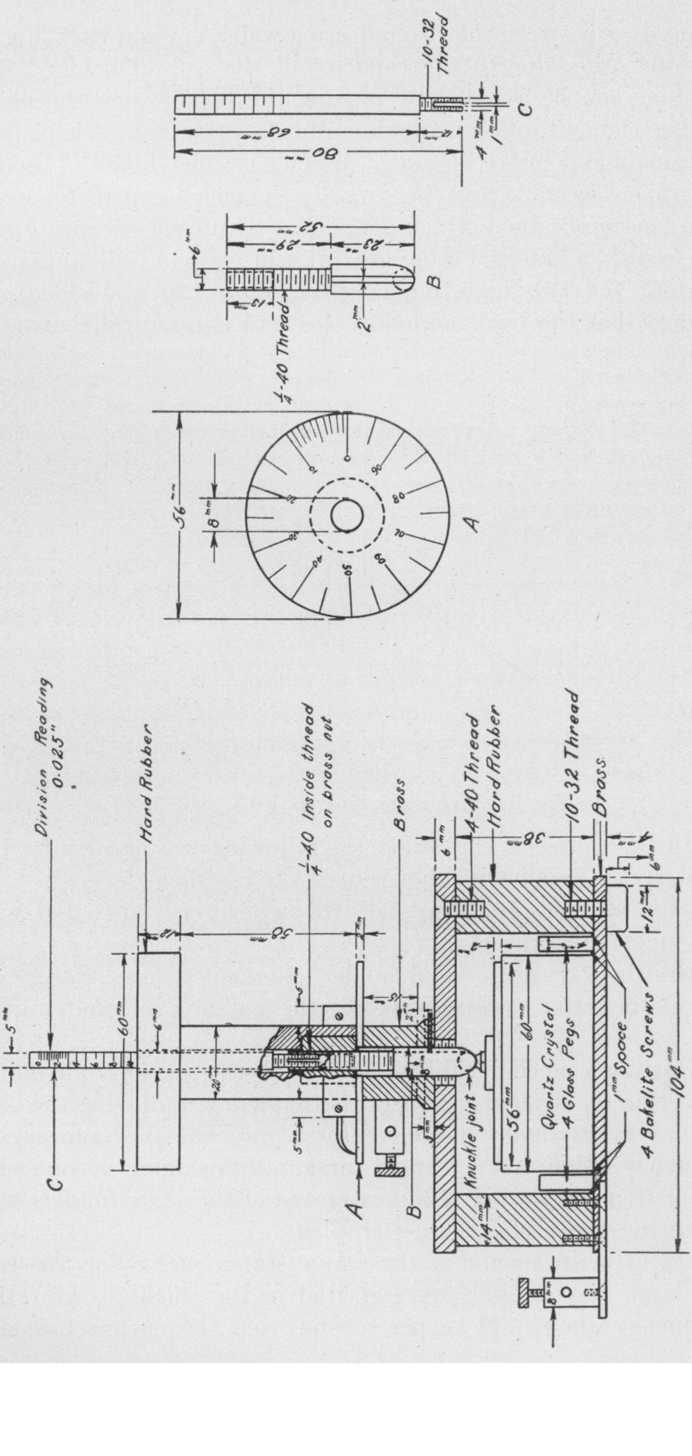

Fig. 2—Piezo-Electric Crystal Holder with Micrometer Adjustment.

themselves between the two reflecting walls A-A and B-B (Fig. 1) and the other due to the capacity of the crystal holder. The first one can be avoided by putting the holder with the piezoelectric element under a vacuum and the other can be kept fixed by using metal coated crystals. When a contact brush is used as the upper electrode and the crystal rests on a metal plate, operation can be obtained which gives beat frequencies accurate to a few parts in a hundred thousand. It will be found advantageous to work the two high-frequency currents into a shielded grid tube so that the back action of the load is practically avoided.

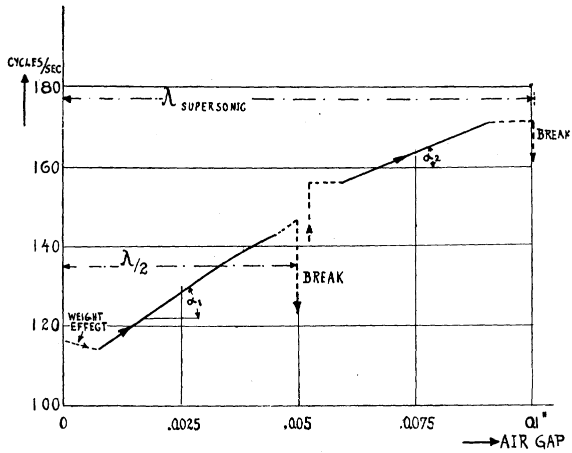

Fig. 3—Frequency Change with Air Gap.

In the course of this study the following was observed: The true crystal frequency is never used. It is either

(a) "the metallized crystal" frequency (crystal-coated with two metal layers), or

(b) the "crystal-crystal holder" frequency, or

(c) the latter partly affected by the load at a certain temperature.

Putting a mechanical load such as the metal electrode on the piezo-electric element increases its frequency, removing the electrode very gradually produces for a moment the true crystal frequency, while a very small air gap gives again a somewhat higher frequency. Fig. 2 indicates one of the plate holders with which the above effects were studied.

Fig. 3 verifies some of the above statements. For this case two large disk crystals were excited in the thickness vibration (frequency about 130 kc per second) and the output branches coupled to a common coil which had a rectifier in the circuit. The ordinates give the beat frequency and the abscissas the air-gap distance in inches.

It is seen that with the upper electrode just resting on the piezo-electric element the frequency is about 118 cycles per second. It drops then to a value of about 116 cycles per second and ascends again as indicated. The oscillation suddenly stops since the condition for one-half wavelength of the supersonic sound wave exists, and from the $\lambda/2$ as well as from the λ con-

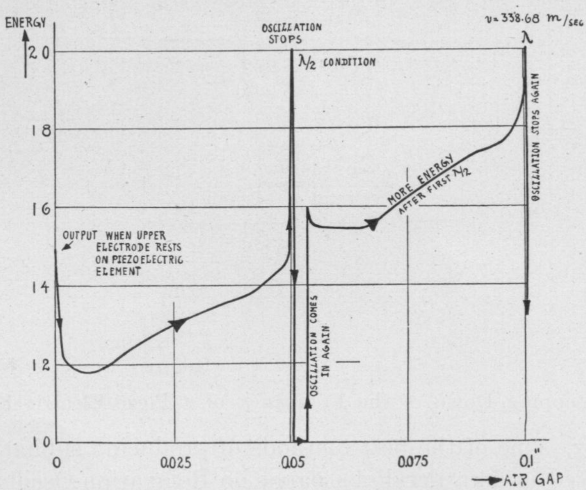

Fig. 4—Energy Curve with Respect to the Air Gap.

dition, the sound velocity in the gap is found as $v=0.258064 \times 131240=338.68$ meters per second at 24.5 deg. C. This shows that the velocity of supersonic sound waves is about the same as found for audible sounds as was also found by G. W. Pierce.[1]

After the $\lambda/2$ condition the oscillation starts in again and proceeds along a slope α_2 somewhat different than before. Many other crystals show about the same behavior.

Fig. 3 indicates that it is not wise to work with such a small air gap that the upper electrode nearly touches the piezo-electric element or with a gap distance very close to $\lambda/2$, λ, $3/2\lambda$, etc., of the supersonic sound wave. This is also shown by the curves of Fig. 4 where the ordinates stand for the energy output and the abscissas for the air gap. A very good position seems to be that which provides an air gap of 3/4 of the super-

[1] *Proc.* American Acad. of Science, **10**, 271; 1925.

sonic sound waves. Fig. 4 is a typical example of many tests of this kind.

The settings with an air gap are no doubt of value for high-frequency work while the metal sputtered piezo-electric elements seem at the present time most promising for low-frequency work.

When, therefore, a metal-coated piezo-electric element is used the accuracy of the high frequency must be very great, and a subharmonic in the audio-frequency range should give an audio-frequency standard which is just as accurate as the high

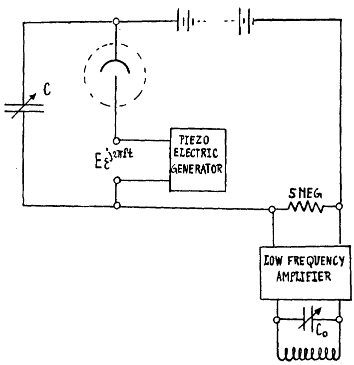

Fig. 5—Stepping Down of the Frequency of a Piezo-Electric Element.

frequency. One of the best methods of producing subharmonics is indicated in Van der Pol's paper on Relaxation Oscillations.[2] Applying such oscillations to our case suggests the new method for piezo-electric frequency standardization as indicated in Fig. 5. The voltage $E\epsilon^{j2\pi ft}$ is taken from a piezo-electric oscillator utilizing sputtered metal electrodes. The condenser C is varied and the output will produce audio-frequency currents which are sub-multiples of the high-frequency voltage $E\epsilon^{j\omega t}$ applied to the gas discharge system. Only frequencies which are submultiples will be given off at the output end. As the condenser C is varied the tones observed in the output branch will vary in steps producing the frequencies $f, f/2, f/3, f/4$, etc. The system will work just as well when the terminals for $E\epsilon^{j\omega t}$ are short-circuited and the emf due to the piezo-electric element is applied across the condenser C. A multivibrator and other arrangements using relaxation oscillations whose period is roughly given by $T=\pi/2\cdot CR$ can also be used for frequency division.

[2] Z. f. Hochfrequenztechnik, Dec. 1926, 178–187; April, 1927, 114–118.