

May 4, 1948.

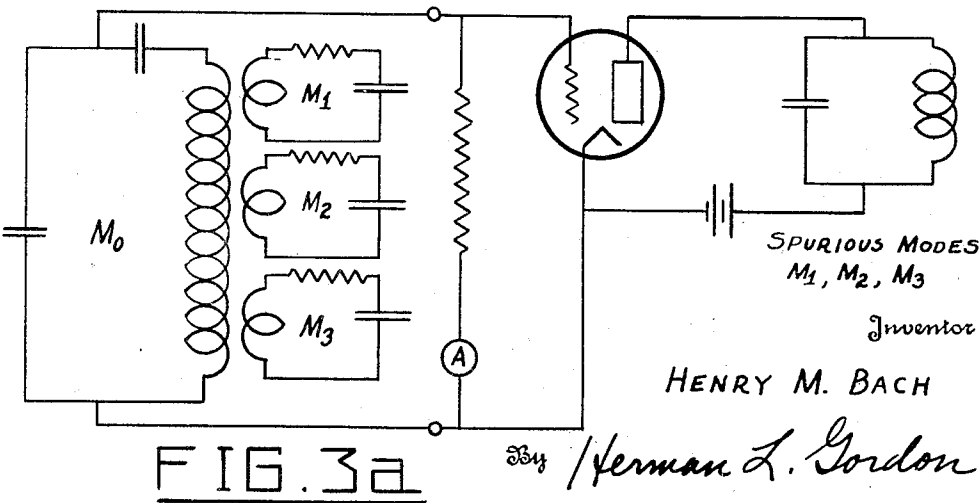
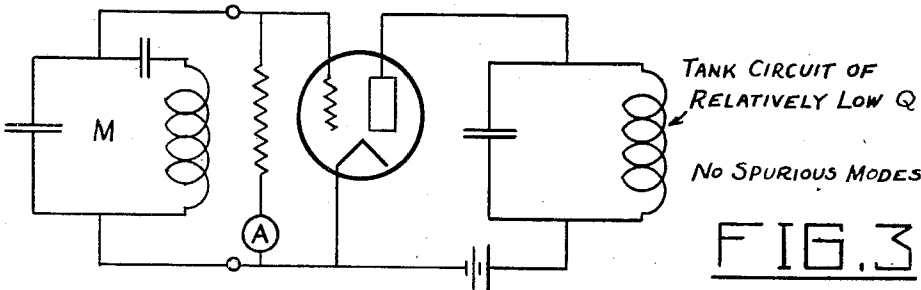
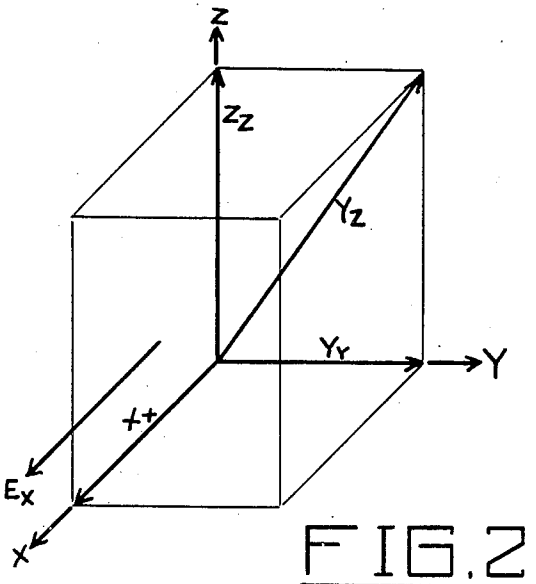
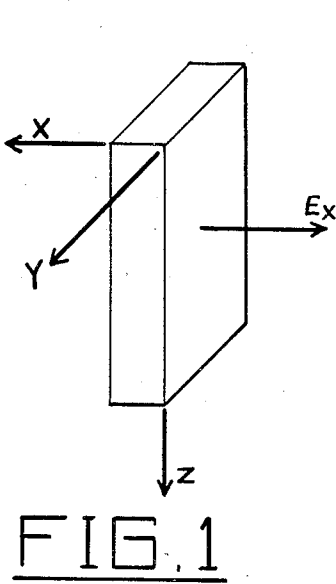
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2,440,886

METHOD AND MEANS FOR PROCESSING PIEZO-ELECTRIC CRYSTALS

Filed Aug. 29, 1944

3 Sheets-Sheet 1



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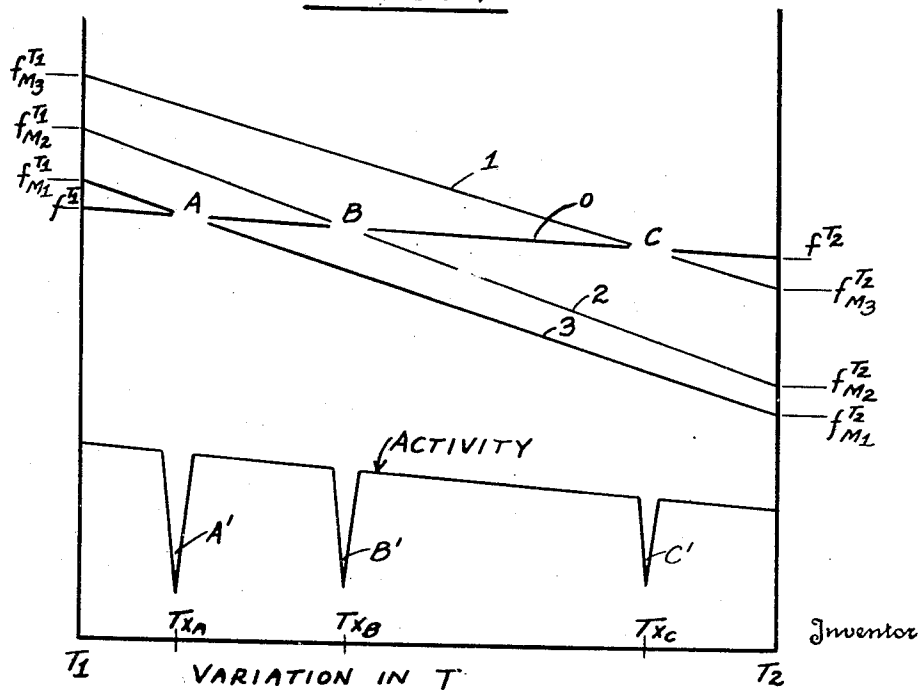
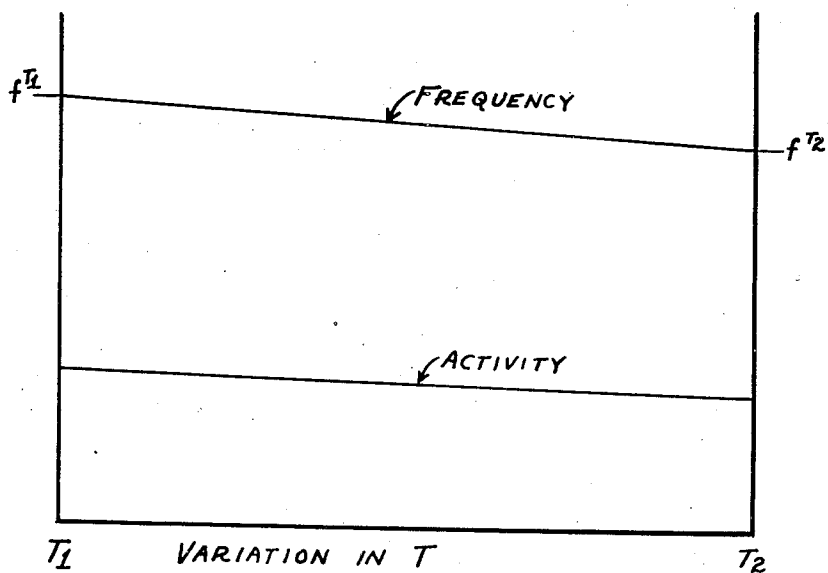
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METHOD AND MEANS FOR PROCESSING PIEZO-ELECTRIC CRYSTALS

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3 Sheets-Sheet 2



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METHOD AND MEANS FOR PROCESSING PIEZO-ELECTRIC CRYSTALS

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3 Sheets-Sheet 3

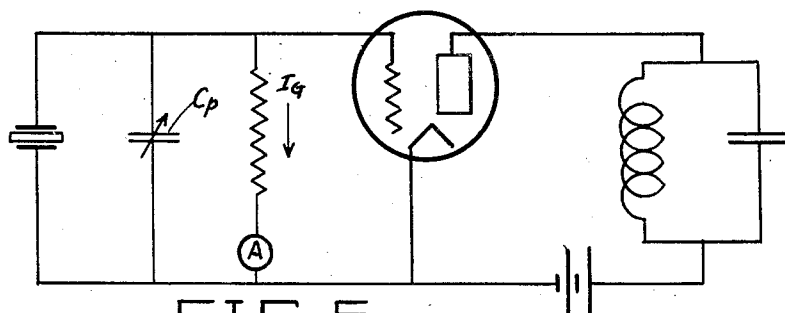


FIG. 5

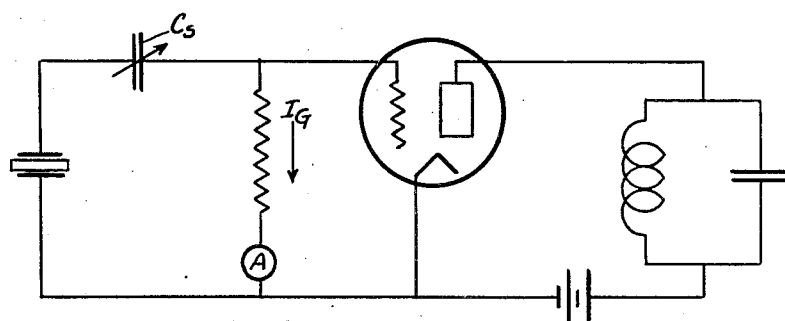


FIG. 6

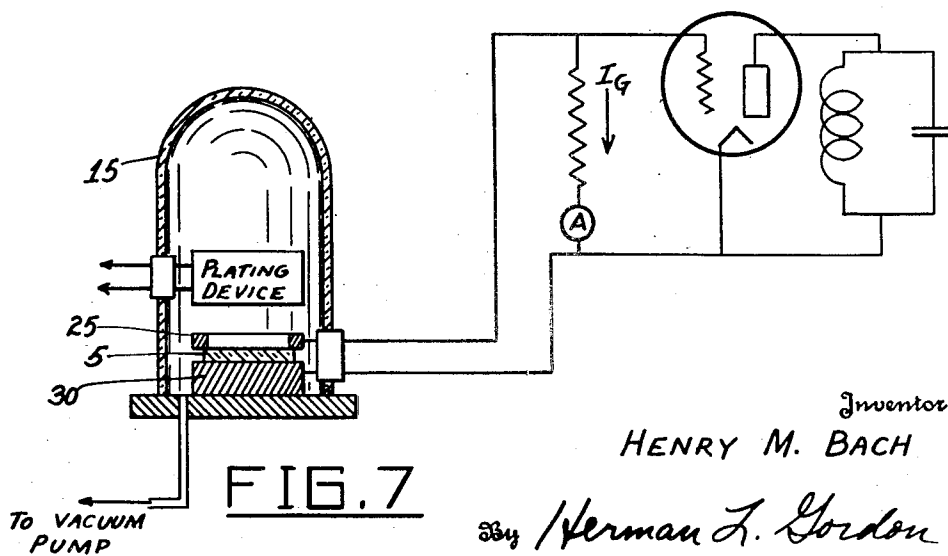


FIG. 7

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2,440,886

METHOD AND MEANS FOR PROCESSING
PIEZOELECTRIC CRYSTALSHenry M. Bach, Lawrence, N. Y., assignor to
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Application August 29, 1944, Serial No. 551,737

11 Claims. (Cl. 171—327)

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This invention relates to piezo-electric apparatus and more particularly to a method and means for predetermining the performance characteristics of piezo-electric plates.

An object of this invention is to produce piezo-electric plates in which couplings between oscillations of desired frequencies and of extraneous, or undesired, frequencies are eliminated.

A further object of this invention is to produce piezo-electric plates in which activity dips or activity discontinuities over the working range of temperatures are eliminated.

A still further object of this invention is to eliminate the necessity of making a large number of temperature runs in testing piezo-electric plates for satisfactory performance over the range of temperatures likely to be encountered in service.

A still further object of this invention is to predict the performance of piezo-electric plates under a wide range of temperature conditions without actually submitting the plates to the said range of temperature conditions.

A still further object of this invention is to select proper dimensions for a piezo-electric plate, the dimensions being so related that spurious frequencies over the range of operating temperatures for the plate will be avoided and activity discontinuities over this range will not be present.

A still further object of this invention is to simulate artificially conditions which reveal the presence of spurious frequencies in a piezo-electric plate without subjecting the plate to a temperature run.

Other objects will appear from the following description and claims when considered together with the accompanying drawings, wherein:

Figure 1 is a view in perspective of a typical piezo-electric plate showing the nomenclatures of the directions along which the lengths of the various dimensions are measured with respect to the direction of an applied electric field E_x normal to the plane of the plate.

Figure 2 is a view in perspective showing the relationship of the crystallographic directions in a typical piezo-electric plate with respect to an applied electric field E_x and the resolution of the electric field into component vectors associated with possible modes of motion along the crystallographic axes and also showing the resolution of a possible shear mode Y_z .

Figure 3 is a schematic view of a circuit equivalent to a piezo-electric plate having no spurious modes of vibration for a given range of tempera-

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tures T_1 to T_2 , said equivalent circuit being connected in a typical oscillator circuit in the same manner as the piezo-electric plate would be connected.

Figure 3a is a schematic view of a circuit equivalent to a piezo-electric plate having spurious coupled modes of vibration capable of being excited within the given range of temperatures T_1 to T_2 , to affect the performance of the plate, said equivalent circuit being connected in a typical oscillator circuit in the same manner as the piezo-electric plate would be connected.

Figure 4 is a set of curves illustrating the behavior of performance characteristics of the plate whose equivalent circuit is represented in Figure 3 over the range of temperatures T_1 to T_2 .

Figure 4a is a set of curves illustrating the behavior of performance characteristics of the plate whose equivalent circuit is represented in Figure 3a over the range of temperatures T_1 to T_2 , showing the effect of spurious modes.

Figure 5 is a schematic circuit showing one arrangement for artificially simulating a temperature cycle to detect the presence of spurious modes in a piezo-electric plate.

Figure 6 is a schematic circuit similar to Figure 5 but somewhat modified.

Figure 7 is a schematic view diagrammatically illustrating another arrangement for artificially simulating a temperature cycle to detect the presence of spurious modes in a piezo-electric plate.

In the design and manufacture of piezo-electric plates, such as quartz oscillator plates, the proper performance of the vibrating plates over substantial variations in ambient temperature is an ever present problem.

The problem of the variation in frequency of the vibration as a function of temperature is rather academic. It is well known that the rate of change of vibration frequency F with temperature T and the "temperature coefficient," the summation of dF/dT over any specified temperature interval T_1 to T_2 , in the absence of coupled vibrations, is a function of the orientation of the quartz plate. By X-ray diffraction technique the orientation may be accurately measured and the temperature coefficient held within preassigned limits.

However the variation in vibrating activity or amplitude (as measured conveniently by the direct current component of grid current in an oscillator, or by the output amplitude of the oscillator, etc.) is no such prosaic problem. It is appreciated that the cause of changes in activity as a function of temperature (solely within the

quartz plate as differentiated from air-gap resonance, electrode effects, etc.) is that spurious vibrations are coupling to the desired vibrations at certain temperatures or over certain temperature intervals, and, as is well known in coupled circuit phenomena, causing variations in the desired vibration.

The usual types of vibration utilized in quartz plates include shears (both "thickness" and "face" types), longitudinal, torsional and flexural modes of vibration. These vibrations are excited by suitable electrical alternating current fields having an X or Y axis component. From the mathematical theory of elasticity and crystal structure the types of vibration that may be excited electrically by any certain electrical field are known. Known also are the types of vibration (and the approximate frequency relationship these vibrations will have to the desired vibration) that will be excited mechanically due to the desired vibration. Thus, as shown in Figures 1 and 2, if we have an Ex field, that is, a field directed normally to the Y-Z crystallographic plane, of proper frequency we may excite Xx, Yy, Zz or Yz vibrations electrically in a plate where the Xx vibrations are extensional vibrations in the X direction, Yy vibrations are extensional vibrations in the Y direction, Zz vibrations are extensional vibrations in the Z direction, and the Yz vibrations are face shear vibrations in the Y-Z plane. Mechanically, a Yy vibration may couple (mechanically) to an Xx, a Zz or a Yz (shear). The Yz shear may couple to flexural vibrations.

In the design of a particular vibrating quartz plate of frequency f , the engineer skilled in the art chooses a type of vibration most suited to comply with the performance requirements consistent with manufacturing difficulty, material costs, etc. He then assigns the required orientation angles for the particular cut and calculates the linear dimensions.

In the final analysis the calculation of the linear dimensions is substantially an empirical computation. Consider, for example, the design of a high frequency thickness shear plate of the AT type. It may be shown that the frequency of a shear may be represented by the following equation:

$$\text{Frequency} = K_s \sqrt{\frac{m^2 + n^2}{A^2 + B^2}}$$

where K_s is a constant depending on the shear elastic constant for a particular orientation and the density. m and n are integers, 1, 2, 3, etc., and A and B are the linear dimensions determining the shear. Let us consider an AT plate where $m=1$, $n=1$, and wherein A , the dimension in the X direction, is very much greater than B , the dimension in the rotated Y (or Y') direction. It is known that the AT₁₁ (XY' thickness shear) wherein the X, or length, dimension is greater than, say, twenty times the thickness, or Y', dimension of the plate, the frequency value is substantially approximated by:

$$\text{Freq. AT}_{11} = \frac{1645}{Y'} \quad (1)$$

where Y' is expressed in millimeters and frequency in kilocycles per second.

The frequency as a second order effect is a function of the X dimension, increasing slightly as the X dimension is reduced:

$$\text{Freq. AT}_{11} = \frac{1}{2} \sqrt{\frac{C'_{66}}{p}} \sqrt{\frac{1}{X^2} + \frac{1}{Y'^2}}$$

where C'_{66} and p are constants for a given cut of quartz crystal. The above expression for a quartz plate of AT cut reduces to:

$$\text{Freq. AT}_{11} = \frac{1645}{Y'} \sqrt{1 + \left(\frac{Y'}{X}\right)^2} \quad (2)$$

The AT₁₁ frequency however does not vary inversely linearly with a variation in Y' as indicated by (1) or (2). It is found that if the length and width dimensions are invariant but the thickness dimension Y' is reduced in small intervals, the frequency increases continuously except for a substantial number of discontinuous regions.

These are due to couplings between the AT₁₁ shear and other modes of vibration mechanically excited by the AT₁₁ vibration at certain ratios of length, width and thickness.

The main interfering modes are flexures, defined by X and Y', and shears, determined by X and Z'. These may be calculated and linear dimensions may be assigned to X and Z' for a given AT₁₁ frequency wherein these main interfering modes are suitably far removed so as not to be excited mechanically. However, activity dips (amplitude discontinuities) over a temperature range are still experienced due to additional secondary resonances which are extremely complex in form and whose calculation is extremely complicated.

In Fig. 3 the plate is represented by its equivalent electrical network for a given range of temperatures T_1 to T_2 and is connected in a conventional oscillator circuit containing an ammeter A for indicating the rectified grid current of the oscillator tube as a measure of the "activity" of the oscillator plate. M represents a network which is electrically equal to a plate which, as defined above, is dimensioned to have no modes capable of being excited over the working temperature range of the plate other than the desired mode of oscillation. The circuit is characterized by the relatively high "Q" of network M with respect to that of the tank circuit. This enables oscillations to continue as long as they can be sustained in network M, assuming that the tank circuit is initially tuned substantially to the oscillation frequency of network M. The oscillation frequency of a circuit such as shown in Figure 3 is generally subject to variation due to the variation in the frequency-determining parameters thereof, in this case the equivalent electrical parameters of network M. This variation may be caused by any external means, including changes in temperature.

Fig. 4 illustrates how a continuous change in the parameters of network M, caused by changes in temperature over a range of temperatures T_1 to T_2 can affect the frequency and the "activity" of the circuit.

Figs. 3a and 4a show two ways of illustrating the presence of undesired couplings in an oscillator plate. In Fig. 3a the plate is represented by its equivalent electrical network and is connected in a conventional oscillator circuit containing an ammeter A for indicating the rectified grid current of the oscillator tube as a measure of the "activity" of the oscillator plate. M₀ represents the network for the desired mode of oscillation. M₁, M₂ and M₃ represent networks coupled to the desired mode network M₀ in such a manner as to effectively reduce the rectified grid current indication at ammeter A at certain frequencies between the limits over which M₀ will oscillate. The coupling characteristics are of course determined by the properties of the plate expressed in

terms of electrical parameters for the networks M_1 , M_2 and M_3 , etc., in relation to the parameters of M_0 .

Due to a continuous change in circuit conditions, as described in connection with Figs. 3 and 4, the frequency associated with M_0 will normally vary from frequency f^{T_1} to f^{T_2} over a range of temperatures T_1 to T_2 , as shown by broken line 0 in Fig. 4a. Corresponding frequency drift characteristics exist for the spurious frequencies associated with M_1 , M_2 and M_3 , and are shown at 1, 2 and 3, respectively, in Fig. 4a. At points A, B and C interference occurs between the desired mode and the spurious modes, resulting in activity dips, as shown at A', B' and C' in Fig. 4a.

In the conventional design and manufacture of quartz oscillator plates for example, AT plates, either the length and width dimensions are altered by a trial and error method so that at room temperature the AT₁₁ shear operates with maximum amplitude, or, in a second conventional method of procedure, predetermined values of X and Z' are used. In both cases proper operation over the temperature range will only occur if no coupled modes exist over the temperature range. Now, the predetermined values of the above mentioned second method are also obtained by trial and error so that in obtaining the values it is required that each set of trial dimensions for each desired frequency be tested continuously over the temperature range until a set of values is obtained that is free from couplings with reasonable manufacturing tolerance on length and width.

In the above-mentioned first conventional method of design the only known measure of the "goodness" of the plate, that is, the correctness of the geometry, over the temperature range is a temperature test; if the plate has dips it must be "re-edged" in a cut-and-try manner and re-subjected to the temperature run. In the second conventional method of design small deviations in orientation or dimensions are actually measured by the temperature run; if all the crystal units had no deviation in elastic constants and no deviation in dimensions all would be good, and would require no temperature run. As heretofore pointed out, however, in either method of manufacture a relatively great number of temperature runs are necessary as the plate is varied in its geometry until a satisfactory plate is finally obtained.

Thus, it is appreciated that according to the prior art procedures the time-consuming temperature run is a necessary test, and an instantaneous "good or no-good" measure at room temperature is not available.

By the teachings of this invention methods of instantaneous test are available to eliminate the need for the temperature run since the methods of this invention show up most quartz plates that would exhibit "dips" in the temperature test. It is readily apparent that such methods would be of great assistance to the "trial-and-error" finisher whose percentage of rejects in the heat run on high activity crystals may run 50% or more, and furthermore would be of great assistance in the trial of predimensioned crystals and in the inspection and test of crystal blanks which may have been erroneously dimensioned.

It will be further apparent that by the teachings of this invention a rapid method is provided for arriving at a satisfactory set of dimensions for a quartz plate, said dimensions being of such value as to allow their successful use in predimensioning technique.

Referring again to Fig. 4a, the desired frequency of vibration of the quartz plate at any point between the limits T_1 and T_2 would be given from curve 0. The other frequencies mechanically excited would be given by curves 1, 2, 3, etc. Now when the temperature is varied over a specified range, say from T_1 to T_2 , the respective frequencies will vary according to Fig. 4a. If at any temperature within the range T_1 to T_2 the frequency of the main mode is equal to the frequency of a mechanically excited interfering secondary mode, as at A, B, C, etc., of Fig. 4a, the amplitude of the desired frequency will undergo a change which will be a function of the magnitude of the coefficient of coupling between the desired frequency and the interfering mode. Likewise over a range adjacent the temperatures at which the interfering modes are equal to the main mode in frequency the amplitude of the main mode will be changed, the magnitude of the change being a function of the coefficient of coupling and the proximity to the temperature at which the interfering mode becomes equal in frequency to the main mode.

In the general case of a vibrating quartz plate which experiences a change in temperature from a first value T_0 to a second value T_a , the frequency of the plate, F^{T_a} , at the second temperature T_a and the rate of change of frequency with temperature at T_a in the absence of discontinuities for any type of vibration F may be expressed as follows:

$$F^{T_a} = F^{T_0} + K_1(T_0 - T_a) + K_2(T_0 - T_a)^2 + K_3(T_0 - T_a)^3 + \dots + K_N(T_0 - T_a)^N \quad (3)$$

$$\frac{dF^{T_a}}{dT_a} = K_1 + 2K_2(T_0 - T_a) + 3K_3(T_0 - T_a)^2 + \dots + NK_N(T_0 - T_a)^{N-1} \quad (4)$$

wherein the values for the "K" constants depend on the temperature coefficient of the linear dimensions, the temperature coefficient of the elastic modulus for the particular vibration, and the density of quartz. The elastic modulus of course varies as a function of orientation. For a particular type of vibration at a particular orientation, then, the values of the "K" constants are fixed.

For all practical purposes, powers higher than the third in Equation 3 may be neglected, that is, values of $K_4 \dots K_N$ are negligible with respect to K_1 , K_2 and K_3 . As a matter of fact, in most cases where the main mode is a longitudinal extensional vibration, K_2 and K_3 approach zero. These include X_x , Y_y and Z_z , wherein K_1 is of much greater magnitude than either K_2 or K_3 . For the low-drift shear modes (AT, BT, CT, DT, ET, FT, Q, etc.) K_1 and K_3 approach zero and K_2 is of importance, that is, the form of (3) is a parabola in the latter and a straight line in the former. The rate of change of frequency with temperature (4) in the latter is linear, varying from a positive to a negative value and passing through zero, and in the former is a constant (independent of temperature) of negative value. For the coupled longitudinal bars K_2 is of importance and K_1 and K_3 approach zero, and for the GT cut K_1 and K_2 approach zero and K_3 is of importance.

In almost all cases of mechanically coupled modes coupled to low coefficient modes the frequency-temperature characteristic of the mechanically coupled mode will have K_1 of such greater magnitude than K_2 or K_3 that K_2 and K_3 may be ignored and the frequency-temperature

characteristic of said mechanically coupled mode considered linear.

Discontinuities in the amplitude of a desired vibration f over the temperature range, then, are caused by the displacement of a single mechanically coupled mode or a number of mechanically coupled modes relative to f . The frequency of any mechanically coupled mode f_m will be a function of the elastic modulus associated with the particular vibration, the density of quartz, and the linear dimensions determining the vibration. These parameters vary with temperature; when the parameters have a certain value (at a certain temperature T_x) that places them in proximity to f , the vibration of f will mechanically excite the frequency f_m and as f_m passes through f the vibration of f will be affected as a function of the magnitude of the coefficient of coupling. f changes slowly in comparison to most of the mechanically coupled modes as a function of temperature.

A further discussion of coupling between modes of motion in quartz crystals will be found in "Quartz Crystals for Electrical Circuits" by Raymond A. Heising, D. Van Nostrand Co., Inc., New York, 1946, pages 221 to 240.

It is obviously impossible to vary the aforementioned intrinsic frequency determining parameters associated with the mechanically coupled modes in a given plate of fixed geometry without affecting the main mode frequency determining parameters substantially, except by varying the temperature. This invention deals with the variation of f by an external means other than temperature over a substantial range to see if, due to this artificially induced variation in f , the amplitude of f varies discontinuously. If the amplitude of f does vary discontinuously then we may be sure that f is mechanically exciting coupled modes and the plate when temperature-tested will exhibit a discontinuity over the temperature range due to the presence of the coupled modes. The invention further discloses methods for quickly ascertaining optimum dimensions for a particular frequency plate as required in predimensioning technique without resorting to countless time-consuming temperature runs. It further discloses a new method of finishing crystals by the "trial and error" method.

It is usually found that the "temperature coefficient" of a coupled mode f_m is negative, that is, the value of K_1 is positive in (3) and (4). However, room, or test, temperature T_r is usually toward the center of the temperature range over which the plate must operate. Hence, even if the suspected f_m is above or below f at room temperature T_r it can cause trouble at either a plus or minus temperature with respect to T_r . If the suspected f_m has a negative "temperature coefficient" and f_m is greater than f at T_r then f_m will cause trouble at a temperature above T_r , as can readily be seen from Fig. 4a if T_r is assumed to be to the left of T_{x1} and T_2 represents an increase in temperature over T_1 . If f_m is less than f at T_r , it will cause trouble at a temperature below T_r , as can be seen from Fig. 4a if T_r is assumed to be to the right of T_{x1} .

Accordingly, in one embodiment of the invention, the quartz plate to be tested is placed in an oscillating circuit wherein the frequency of the crystal may be varied over a substantial range rapidly in a smooth and continuous manner, as for example by changing the input reactance into which the crystal looks. Two examples of such a circuit are shown in Figs. 5 and 6 respectively.

In Fig. 5 the variable capacitor C_p is shunted across the crystal for this purpose, whereas in Fig. 6 the variable capacitor C_s is in series with the crystal for the same purpose. Obviously other means of varying the crystal input reactance may be employed within the spirit of this invention. The oscillator is designed to develop a substantial voltage across the quartz plate. As the parallel reactance C_p of Fig. 5 or the series reactance C_s of Fig. 6 is varied, the frequency f will vary. If f mechanically excites an f_m it will be observed by a discontinuous variation in the oscillator D. C. grid meter A as f is varied continuously. Whenever T_r is substantially in the center of the required performance temperature range, a discontinuity in the amplitude of f as f is varied indicates a plate which will exhibit at least a single break in its activity over the temperature range. If the T_r is the lower, or upper, extremity of the required performance temperature range, it may be that f_m will move in a direction away from f over the required performance temperature range and will not cause a discontinuity. This is easily demonstrated by the following example:

Suppose the plate is being tested at the lower extremity of the required performance temperature range and f is being varied by a condenser such as C_p in Fig. 5 in parallel with the quartz plate. The discontinuity in the amplitude of f is found at a substantially higher capacity setting of said condenser than the crystal looks into in the ultimately specified oscillator circuit. The crystal is heated a convenient amount (say 1° to 5° C.) by allowing it to oscillate for a minute or so, or by any other means. If it is found that the discontinuity has moved to a lower f frequency, that is, condenser C_p capacity has to be increased to "tune in" the discontinuity, then it is known that the dF_m/dT is negative. (If the increment of f_m and the increment of T are known the "temperature coefficient" of f_m is known and the value of K_1 thereof may be evaluated.) It may then be assumed that since we are testing at the low extremity of the temperature range and since f_m will at least have the same increment as f over the range, there is no chance for this particular f_m to couple with f over the specified temperature range.

Other variations are obvious, such as f_m with positive coefficient and higher than f at the low extremity of the temperature range, f_m with negative coefficient and above f at the high end of the temperature range, etc.

Whenever a more accurate instantaneous scanning is desired, the room temperature check may be expanded to checks at one or more points at convenient spots over the temperature range. It is most convenient for the finisher to have two roughly controlled ovens operating midway between T_r and the lower and upper extremities of the temperature range respectively. If his finished plate is satisfactory after the room temperature "vari- f " test it is tested at one of the other temperatures, usually the one below T_r . If still satisfactory it is checked at the third temperature. If satisfactory it is passed into the temperature run. Crystals so tested will show an extremely high passing percentage in the temperature run.

The value of the "vari- f " test to the engineer in the task of pre-dimensioning plates is readily apparent. The test provides a means of following the mechanically coupled modes until they

are outside the working range; when a potentially interfering f_m is present in a plate, an edge dimension may be altered slightly until the "vari- f " test shows the plate to be satisfactory.

A variable air gap holder may be used for varying f separately or in combination with the variable reactance method above described. A variation in f of as much as 0.1% by the combination is entirely practical.

Another embodiment of the "vari- f " test is extremely useful in the design of predimensioned thickness shear crystals. A crystal of known linear dimensions X , Y and Z is given a very light coat of plating. The crystal is then oscillated in a vacuum (which increases the crystal frequency). Plating is gradually deposited on the quartz plate while it is oscillating, said plating being effected by an evaporation process. This is continued until the amplitude of the thickness shear vibration becomes so weak due to loading of the plating layer on the oscillating plate that oscillation can not be sustained. The frequency of the thickness shear will have been decreased from an original value f^a to a final value f^b . At certain frequencies, or over certain frequency ranges, say, at $f_1, f_2, f_3 \dots f_N$ between f^a and f^b the amplitude of oscillation (as conveniently indicated by a D. C. grid current meter in the oscillator) will have changed discontinuously due to the presence of coupling between the thickness shear vibration and the mechanically excited parasitic modes. The proper, or optimum, value for the shear vibration for the given X and Z dimensions may be assigned by choosing the cleanest region, that is, a value of f substantially midway in the largest region free from coupling. For the given X and Z dimensions this then will provide a satisfactory f value. To translate to any other frequency desired the following transformation is employed:

$$\frac{f_0}{f_a} X_0 = X_a; \frac{f_0}{f_a} Z'_0 = Z'_a; \text{ and } Y'_a = \frac{1645}{f_a} \quad (5)$$

wherein the "o" subscripts represent the values obtained for "optimum" in the preceding paragraphs and the "d" subscripts represent values for the desired frequency f_a .

A diagrammatic sketch of the apparatus employed is shown in Fig. 7. The apparatus herein disclosed is extremely simplified. The specimen plate 5 which is to be investigated and which has been previously given a light coat of plating is placed under a bell jar 15. A "window frame" type of electrode 25, similar to that disclosed in applicant's Patent No. 2,327,487 is placed over the quartz plate, the outer length and width dimensions of the frame being larger than the quartz plate in order to prevent plating from being deposited on the edges of the plate. Connections from frame electrode 25 and base electrode 30 are made to an external oscillator of conventional design; the D. C. grid current of the oscillator may be recorded by a strip chart recorder and the frequency difference between the oscillations and a convenient reference frequency standard may be measured by a conventional audio frequency meter whose output is impressed on a second strip chart recorder. Both recorder strip charts move at the same rate of speed. The specimen plate 5 is of convenient linear dimensions X_0 and Z'_0 accurately known, and of frequency (determined by Y'_0) in the same range as that for which the desired dimensioning information is required. The specimen is

placed in the aforementioned equipment, oscillated, and the air under the bell jar 15 is removed. Plating is applied to the specimen in a smooth and continuous manner and the effect on frequency and activity of the plate as a function of plating is recorded permanently on the strip chart recorder. If the frequency of the specimen before the plating run was f^a and the ultimate frequency at the conclusion of the run was f^b , a group of frequencies $f_1, f_2, f_3 \dots f_N$ will be observed on the frequency chart at which the activity chart shows dips. In fact, ranges $f_N \pm \Delta f_N$ will be found wherein substantial activity depressions are present. These activity dips will be accompanied by discontinuities in the frequency curve. The frequency curve from f^a to f^b in fact would contain discontinuities in the same manner as aforementioned, if the thickness of the plate were to be reduced by grinding, holding X and Z' dimensions constant.

Certain regions on the charts wherein for a substantial change in frequency no discontinuities are present will be observed. Choosing, say, the largest clean region, that is, wherein the band between discontinuities, f_N to f_{N-1} , is a maximum, and calculating f_0 from

$$f_0 = \frac{f_N + f_{N-1}}{2}$$

an optimum frequency for the thickness shear for the particular X and Z' dimensions used is provided. By the transformation Equations 5 the dimensions for the desired frequency f_a are computed. Plates then are made up with the proper X_a and Z'_a dimensions but of varying Y'_a dimensions so that the frequencies of the plates vary about f_a in small increments. By the use of the "vari- f " test and then by careful temperature runs it will be found that all plates within a frequency f_a plus or minus Δf_a are free from dips. From the equations

$$\frac{f_a}{f_a \pm \Delta f_a} X_a = \pm \Delta X_a \text{ and } \frac{f_a}{f_a \pm \Delta f_a} Z'_a = \pm \Delta Z'_a$$

the maximum tolerances on X and Z' dimensions may be assigned.

Another method of varying the frequency of the plate in a gradual and continuous manner to locate interfering modes of vibration could be by continuous exposure to high intensity X-ray radiation or to bombardment by radio-active emission. It is possible to change the physical constants, and hence the vibration frequency, of a piezo-electric quartz plate by distorting the lattice structure of the quartz. This is taught by an article by Edward F. Holden appearing in "The American Mineralogist," Journal of the Mineralogical Society of America, vol. 10, No. 9, Sept. 1925, entitled "The cause of color in smoky quartz and amethyst" wherein the coloration of quartz is traced to exposure to such radiation or bombardment, and a paper in the "Proceedings of the Physical Society," London, vol. XLV, part 4, read April 7, 1933, entitled "Quartz as a standard for accurate lattice spacing measurements," by A. J. Bradley and A. H. Jay, wherein the discolored quartz is shown to have a distorted lattice structure (and hence changed frequency-determining physical constants).

This invention is not limited to the above specifically described methods but contemplates any method of varying the desired vibration frequency with respect to the secondary spectrum over a substantial range to locate the frequencies

at which the desired vibrations are coincident with secondary mechanically coupled vibrations determined by the geometry of the plate. It further contemplates any method of varying the frequency and simultaneously observing the effect of the secondary vibrations on the desired frequency.

Numerous modifications are possible, and I do not therefore wish to be limited to the precise embodiments shown and described herein, but desire to include and have protected by Letters Patent all forms and modifications of my invention which come within the scope of the appended claims.

What is claimed is:

1. A method of testing a piezoelectric plate without changing its geometry at substantially constant temperature to locate secondary modes in the vicinity of the main mode which might interfere with the main mode over the working temperature range of the plate, comprising the steps of varying the frequency of the main mode continuously over a range of frequencies by varying the input impedance of the plate and observing the effect of such variation on the amplitude of the main mode.

2. The method of claim 1, and wherein the frequency of the main mode is varied by varying the shunt capacitance across the plate.

3. The method of claim 1, and wherein the frequency of the main mode is varied by placing capacitance in series with the plate and varying said capacitance.

4. A method of testing a piezoelectric plate without changing its geometry to detect secondary modes in the vicinity of the main mode which might interfere with the main mode over the working temperature range of the plate, comprising the steps of varying the frequency of the main mode continuously over a range of frequencies with the plate held substantially at a constant temperature, observing the effect of such variation on the amplitude of the main mode, changing the temperature of the plate by an amount which is small compared to the working range of temperatures, again varying the frequency of the main mode, and again observing the effect of the variation in frequency of the main mode on the amplitude of said main mode.

5. The method of claim 4, and wherein the frequency of the main mode is varied by varying the input reactance of the plate.

6. The method of claim 4, and wherein the frequency of the main mode is varied by varying the shunt capacitance across the plate.

7. The method of claim 4, and wherein said constant temperature is approximately the lower extremity of the working temperature range of the plate.

8. The method of claim 4, and wherein said constant temperature is approximately the higher extremity of the working temperature range of the plate.

9. A method of testing a piezoelectric plate without changing its geometry to locate secondary modes in the vicinity of the main mode which might interfere with the main mode over the working temperature range of the plate, comprising the steps of holding the temperature of the plate substantially constant at a first temperature value in its working temperature range, varying the frequency of the main mode continuously over a range of frequencies, observing the effect of such variation on the amplitude of the main mode, changing the temperature of the plate to a second substantially constant temperature value in its working temperature range, again varying the frequency of the main mode, and again observing the effect of the frequency variation on the amplitude of said main mode.

10. The method of claim 9, and wherein said second temperature value is approximately midway between said first temperature value and the lower extremity of the working temperature range.

11. The method of claim 9, and wherein said second temperature value is approximately midway between said first temperature value and the upper extremity of the working temperature range.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,886,315	Hund	Nov. 8, 1932
1,985,620	Heising	May 15, 1934
1,994,228	Osno	Mar. 12, 1935
2,111,382	Bokovoy	Mar. 15, 1938