June 4, 1940. M. E. A. BRUZAU ET AL 2,203,322

MECHANICAL RESONATOR, SUCH AS PIEZOELECTRIC CRYSTAL DEVICES

Filed Jan. 22, 1937 2 Sheets-Sheet 1

Fig. 5.

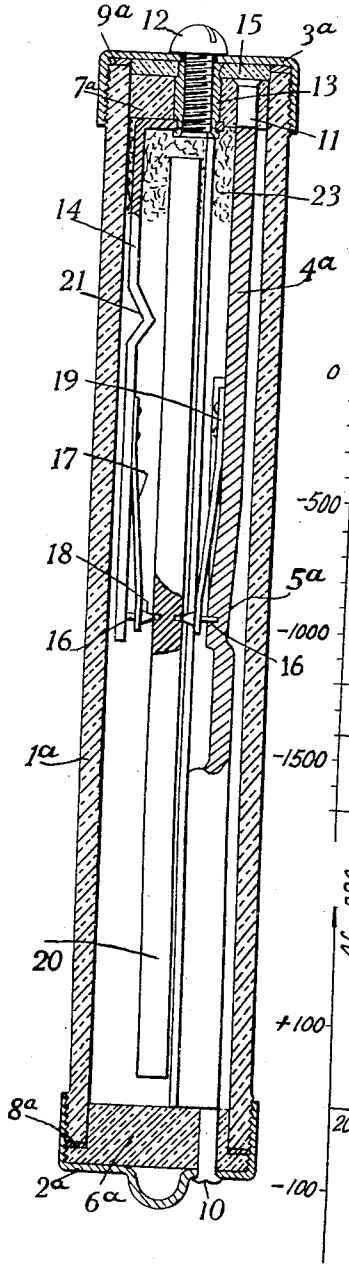


Fig. 6.

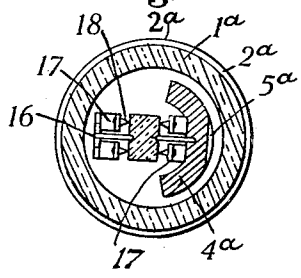


Fig. 1.

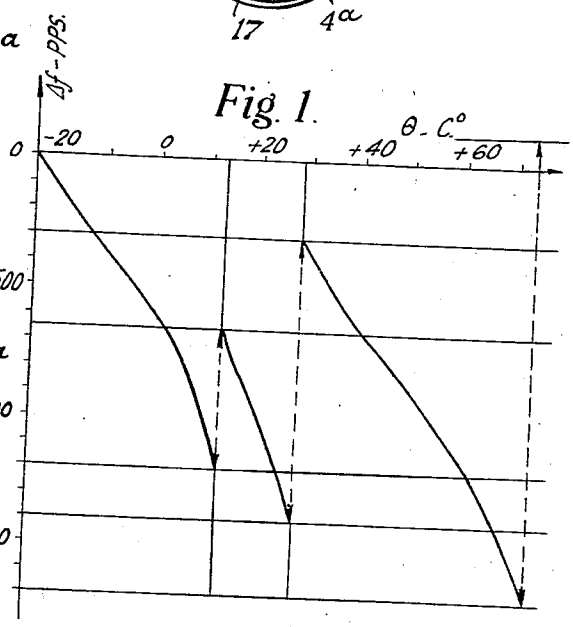
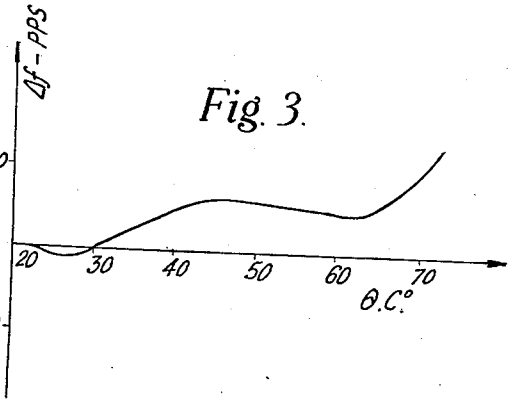


Fig. 3.



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Fig. 7.

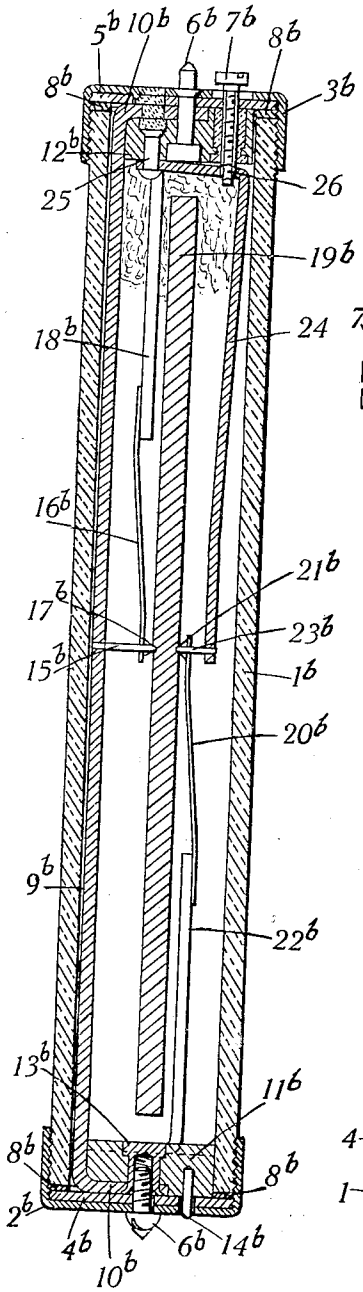


Fig. 8.

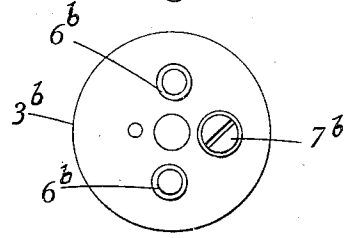


Fig. 9.

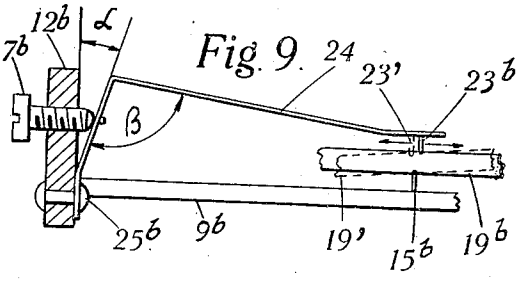


Fig. 2.

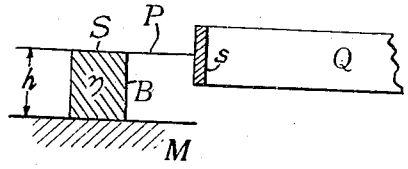
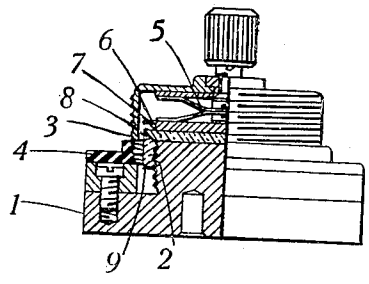


Fig. 4.



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UNITED STATES PATENT OFFICE

2,203,322

MECHANICAL RESONATOR, SUCH AS PIEZOELECTRIC CRYSTAL DEVICES

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In France January 30, 1936

5 Claims. (Cl. 171—327)

The present invention relates to improvements in means for supporting vibrating mechanical elements such as piezoelectric devices.

One object of the invention is to provide means for reducing the influence of harmful modes of vibration in vibrating mechanical elements.

Another object of the invention is to provide means for reducing the influence of temperature variations on the said vibrating elements.

Another object of the invention is to provide improved supporting means for piezoelectric and like mechanically vibrating elements which may be employed as frequency standards.

The invention will be described as exemplified in a device utilizing piezoelectric substances such as the well known quartz crystals.

The features of the invention will be understood from a reading of the following explanation and description of preferred embodiments based on the attached drawings in which:

Fig. 1 represents a curve of variation of frequency with temperature of a normal piezoelectric quartz plate in which vibratory movements are permitted to be set up along the electrical axis of the crystal;

Fig. 2 shows schematically a theoretical device in which the effect of a harmful mode is reduced;

Fig. 3 represents a curve of frequency variation with temperature of the piezoelectric quartz plate employed in the case shown in Fig. 1, but provided with a device employing features of the invention.

Fig. 4 shows an arrangement for maintaining in a suitable position a bevelled quartz plate in accordance with certain features of the invention;

Fig. 5 is a sectional longitudinal view of a piezoelectric resonator employing features of the invention;

Fig. 6 represents a transverse section of said resonator;

Fig. 7 is a longitudinal sectional view of another embodiment of the piezoelectric resonator employing features of the invention;

Fig. 8 represents an end view of the resonator shown in Fig. 7, and, finally,

Fig. 9 is a side elevation of a mechanical adjusting device provided in the resonator of Fig. 7.

The curve in Fig. 1 represents a quartz plate whose principal sectional plane contains the electric axis, but is inclined with respect to the optical axis at a certain angle suitably chosen to reduce the influence of temperature variations on the frequency. The plates of a crystal cut in the above fashion are in effect the seat of shear vibrations propagated through the thickness of the plate and reflected by the two principal faces. An elastic standing wave is thus produced whose length is equal to twice the thickness of the plate. This vibration is characterised by a zero temperature coefficient and would, if it were the only vibration, produce vibrations of a frequency independent of the temperature.

However, the shear deformation gives rise to a compressional deformation along the electrical axis contained in the plane of the quartz plate. This gives rise to a secondary vibration which, owing to reflection, produces a second system of standing waves. Along the thickness there is an elastic half shear wave and along the electrical axis there are several elastic half compression waves. There is a coupling between the fundamental of the vibration along the thickness and a harmonic or partial harmonic of the vibration along the electrical axis. This vibration along the electrical axis is characterised by a negative temperature coefficient and will influence the frequency of the vibration because of the coupling of the shear and compressional vibrations. It will give rise to discontinuities of frequency such as shown by the curve of Fig. 1 for a particular plate subjected to the test. This curve graphically represents the Δf from the normal frequency plotted as ordinates against the temperature θ plotter as abscissae.

Said discontinuities would not be produced if the plate were aperiodic with respect to the vibrations along the electrical axis of the quartz, that is to say, if the diameter of the plate were infinite. Any compressional deformation which in effect comes from the centre would in such case never reach the edges.

The problem thus consists in replacing a standing wave by a travelling wave. In terminated two conductor alternating current transmission lines a similar problem has been solved by terminating the line in a resistance equal to the characteristic impedance of the line.

A similar condition may be realised for a mechanical vibrating system. For an infinite bar of any elastic substance such as quartz or steel, etc., . . . having a modulus of elasticity E and a density ρ, there exist between the displacement ϵ of any section on either side of its position of equilibrium and the internal pressure P caused by its distortion, the relations:

$$\frac{\partial \epsilon}{\partial X}=-\frac{1}{E}P \qquad \rho\frac{\partial^2 \epsilon}{\partial t^2}=-\frac{\partial P}{\partial X}$$

where X is the distance from the origin to the point under consideration, and t is the time from some arbitrary instant of reference. Differentiating the first of the above equations with respect to X and combining them, there is obtained the following equation:

$$\frac{\partial^2 \epsilon}{\partial t^2}=\frac{E}{\rho}\frac{\partial^2 \epsilon}{\partial X^2}$$

This latter equation represents a wave motion whose speed of propagation V is

$$\sqrt{\frac{E}{\rho}}$$

Moreover, the internal pressure P and the derivative with respect to time of the displacement ϵ which is hereinafter referred to as the vibratory speed, v, are joined by the relations:

$$\frac{\partial v}{\partial X}=-\frac{1}{E}\frac{\partial p}{\partial t} \quad \text{and} \quad \rho\frac{\partial v}{\partial t}=-\frac{\partial p}{\partial X}$$

which may be differentiated with respect to X and t respectively, and then combined to give the following equation:

$$\frac{\partial^2 v}{\partial t^2}=\frac{E}{\rho}\frac{\partial^2 v}{\partial X^2}$$

Consequently, if a simple harmonic disturbance occurs at a point of the bar and is propagated in both directions, without being reflected since the bar is infinite, then at a distance X from the origin, v and p are given by the relations:

$$v=v_0 \sin\left(\omega t-\frac{\omega X}{V}\right) \text{ and } p=v_0\sqrt{E\rho}\sin\left(\omega t-\frac{\omega X}{V}\right)$$

where v_0 represents the maximum value of v, and ω represents the angular frequency of the assumed disturbance. These equations show that the vibratory speed v and the pressure p are in phase and that there is between them the true proportional relation

$$v=\frac{p}{\sqrt{E\rho}}$$

in which the quantity

$$\sqrt{\rho E}$$

plays the part of a mechanical characteristic impedance having the dimensions of a coefficient of viscosity divided by a length.

Now it is well known that a viscous system also offers a resisting force which is in phase with the velocity of the impressed motion and proportional thereto. Therefore, if a viscous system is coupled to the end of a given finite elastic bar, it will (if its coefficient of viscosity and dimensions have the correct values) present to the bar exactly the same forces as would be presented by a further similar bar of infinite length coupled to form an extension of the given bar. Consequently, if we terminate a finite bar of quartz or any elastic substance by a suitable viscous system, the same aperiodicity as if the bar were infinite will be realised. Fig. 2 shows schematically such an arrangement. B represents a block having a section S and a height h of a viscous substance having a viscosity coefficient η, fixed at its base to an immovable mass M and at its top to a lamina P connected to the end of the bar Q whose transverse section is s. Thus the base of the viscous block B will have no movement while its top will vibrate on either side of its position of equilibrium at the same frequency as the extremity of the bar Q. The speed of vibration v of the top of the block B will thus be the same as that of the bar Q. There will be a gradient of vibratory speed depending on the height h of the viscous block, which gradient will be assumed to be constant. The relation:

$$\frac{\partial v}{\partial h}=\frac{v}{h}$$

will then hold and the tangential force f to be applied to the top of the block B to produce its movement may be expressed in the following two different ways:

$$f=\eta S\frac{v}{h} \qquad f=p.s$$

which will give between p and v the relation:

$$v=\frac{p}{\frac{S}{s}\frac{\eta}{h}}$$

in which the quantity

$$\frac{S}{s}\frac{\eta}{h}$$

has the dimension of a coefficient of elasticity divided by a length. It has, therefore, the same dimensions as the characteristic impedance of the bar.

Consequently, if we realise the condition of equality between these two relations, that is

$$\sqrt{E\rho}=\frac{S}{s}\frac{\eta}{h}$$

the missing part of the bar, which would lie beyond the sectioned element if the bar were infinite, may be considered to be replaced by an equivalent "viscous" system in which will be dissipated the power which passes through the sectional element per second, i. e. the power which, in the case of an infinite bar, would go on to infinity. The bar will thus be the seat of a travelling and no longer of a standing wave.

If the condition of equality between these two expressions is practically realised by the removal of a portion of the bar Q, a finite bar will be obtained which will be equivalent to the infinite periodic bar. The finite bar will be the seat of a travelling wave.

Since only approximate equalization is possible, the reflected wave will not be completely eliminated, but its intensity will be less than that of the incident wave, and the vibratory condition of the bar may be considered as the superposition of a travelling wave on a weak standing wave. The quartz discs can thus be considered as quasi aperiodic.

In order to attain one object, we may employ one of a number of well-known mechanical dissipating systems such as mechanical transmission lines the characteristic impedance of which is adjusted or matched to that of the piezoelectric element. Obviously, the transmission lines must be adapted to cooperate with the vibrating element.

Experience has shown that the above calcula-

tions render it possible suitably to dimension the damping substance, but in many cases one may rest content with a certain approximation sufficient to obtain curves showing the variation of frequency with temperature which are without discontinuity and without great variations. Fig. 3 shows a frequency-variation, temperature curve obtained for the same sample, which, by comparison with the curve of Fig. 1 shows the degree of aperiodicity obtained by the means described. Not only have the three discontinuities of the curve 1 disappeared, but the whole of the curve is raised and remains positive on its greater portion. This curve, shown in Fig. 3, illustrates the effect of a thickness of $\frac{5}{100}$ mm. of stopper placed between the jar acting as a support and the disc of piezoelectric quartz. In many cases where an approximation of this kind is sufficient, one can rest content with resting the quartz plate on relatively soft metals such as lead or tin or a mixture of the two or the like which play the part of the viscous block mentioned in the above description.

The provision of these layers of soft metals may be effected either by sufficiently thick tinning of the jar serving as resting place for the quartz plate or by any other suitable means depending on the desired method of support of the quartz. One arrangement is shown in Fig. 4 in which 1 represents the base support which comprises a threaded cylinder 2, and 3 the cover of suitable shape screwing in to an insulating ring 4 mounted on base 1. This cover 3 tightens, by means of a spring with four double blades 5 and a disc 6, the quartz plate 7 whose circumference is bevelled as indicated at 8. The lowest surface of plate 7 contacts with the upper plane surface of the threaded cylinder 2 and the bevelled flange 8 with a correspondingly bevelled edge of a threaded ring 9. The ring is screwed onto the cylinder 2 and can thus be approximately adjusted. The bevelled flange of the ring 9 is covered in accordance with one of the features of the invention with a thickness of lead or tin with which the bevelled edge of the quartz plate 6 contacts and which takes the place of viscous block B of Fig. 2 to attenuate to a sufficient extent the harmful compressional vibration.

Figs. 5 and 6 show a piezoelectric resonator comprising a quartz support employing features of the invention. In this resonator, 1*a* represents a cylindrical glass sheath closed at its two ends by the two metal lids 2*a* and 3*a*. A brass guide member 4*a* of trough shaped in cross-section has a flat surface 5*a* near its middle. The guide 4*a* is fastened to insulating blocks 6*a* and 7*a* pressed on the ends of the glass tube 1*a* by lids 2*a* and 3*a* with the interposition of tightening washers 8*a* and 9*a*. The guide member 4*a* is fastened to these blocks by two rivets 10 and 11. The purpose of lid 3*a* is to hold a tightening screw 12 which through the agency of a cylinder 13 firmly holds together block 7*a* and a supporting plate 14. Atmospheric moisture is kept out of the tube by means of washer 15 provided between the lid 3*a* and the insulating block 7*a*.

The supporting plate 14 consists of a plane plate adjustable by a suitable folded portion 21 and having at its end a supporting point 16. This point 16, as more clearly shown in Fig. 6, passes between two leaf springs 17 soldered at one end to the plate 14 and carrying at their free ends short contact points 18. These contact points 18 engage the metallized surfaces of the quartz plate 20. Another pivot point like 16 is carried by the guide member 4*a*. To guide 4*a* are soldered two leaf springs like 17 provided with contact points like 18.

The plate of piezoelectric quartz 20 is engaged at its middle point by the two opposite pivots constituting a well defined elastic support corresponding to B, S and P of Fig. 2 and 5, 8, 9 of Fig. 4.

If the quartz plate is so long that the middle support is insufficient to hold it in equilibrium during transport, tampings 23 of frayed natural silk or other substances may be provided inside the tube at its ends.

By means of the supporting points 16 and the contact points 18 the damping of the crystal 20 may be controlled in a predetermined manner. If minimum damping is desired then the contact points 18 are placed on the neutral axis of vibration of the crystal, which, in the case of a crystal vibrating longitudinally is inclined at an angle of 90° to the largest dimension of the crystal.

Fig. 7 shows another embodiment of a piezoelectric resonator. In this resonator, 1*b* represents a glass sheath and 2*b* and 3*b* represent the metal lids separated from the ends of the sheath 1*b* by insulating washers 4*b* and 5*b* provided with suitable openings to permit the passage of the connecting posts 6*b* and 6′. 7*b* is an adjusting screw which also passes through a larger opening of the lid 3*b*. The insulating washers 4*b* and 5*b* press elastic washers 8*b* against the edges of glass tube 1*b* to make the apparatus moisture-proof. The terminals 6*b* and 6′ serve also to fix guide member 9*b* in position along the side of the sheath 1*b*. The bent up ends 10*b* of the member 9*b* are pressed by the terminals 6*b* between the insulating washers 4*b* and 5*b* and insulating blocks 11*b* and 12*b*. The lower terminals 6*b* are threaded and an assembly member 13*b* is held in the insulating block 11*b* into which the terminals screw. A pin 14*b* projecting from lid 2*b* facilitates the setting in place of the latter.

At its middle point the guide member 9*b* carries a pivot point 15 engaging the quartz plate 19*b*. The quartz plate passes between two flexible leaf springs 16*b* each provided at its end with a contact point 17*b* and connected to the terminals 6*b* by means of rigid rods 18*b*, only one of which is shown. In the same way on the other side of the quartz plate 19*b*, two flexible blades 20*b* are provided with points 21*b* at their ends and connected to the terminal screws 6*b* by means of rods 22*b*. A single pivot point 23*b* carried by a leaf spring 24 passes between the springs 20*b*. The spring 24 is bent and fixed to the insulating block 12*b* by a rivet 25 and is provided with an opening 26 through which passes the end of the adjusting screw 7*b*, a shoulder of which engages the edge of the opening.

The adjusting device of the resonator is more clearly shown in Fig. 9, in which the references correspond to those of Fig. 7. If the quartz plate, when first set in position, occupies the position 19′ shown in dotted lines, which is inclined to the axis of the resonator, and if the pivot point carried by the leaf spring 24 is at 23′ shown in dotted lines, then the angular deflection of the plate 19*b* may be compensated by adjusting the screw 7*b*. The rear end of spring 24 is bent back to form with the free end an angle β which is determined by an initial adjustment to insure the pressing of the quartz plate 19*b* against the points 15*b* and 23*b*. The angle α between the

rear end of spring 24 and the insulating block 12b to which it is fixed may be varied by means of the adjusting screw 7b. By shifting point 23 with respect to the fixed point 15b the plate 19b will be rotated at the desired angle until it is parallel to axis of the system. In the case illustrated in the drawings, the adjusting screw 7b must be screwed in to move the point 23b from its position 23' to the right.

As in the piezoelectric device shown in Figs. 5 and 6, the ends of the piezoelectric plate 19 may be embedded in frayed natural silk or any other suitable substance to permit transportation of the resonators without disturbing the equilibrium of the quartz plate. In certain cases this does not cause harmful damping and may be permanently retained in the device.

The invention is not restricted to the examples specifically described and is capable of other applications which will appear to those skilled in the art.

What is claimed is:

1. In combination a piezoelectric crystal element an edge support for the crystal element and a layer of lead, tin or other soft metal on said edge support and forming a bearing for said crystal element.

2. In combination a circular plate of piezoelectric material a bevelled peripheral edge thereon and a soft metal seating for said bevelled edge.

3. In combination a disc of piezoelectric crystal, electrically conducting supports engaging the faces of said disc, means for resiliently urging the supports together and means attached to one of said supports for damping lateral movement at the periphery of the disc.

4. In combination a circular plate of piezoelectric material, a bevelled edge thereon, electrodes engaging the faces of said plate, means for resiliently urging said electrodes together, a bevelled ring upon one of said electrodes surrounding said plate and a layer of soft metal between and in contact with said bevelled edge and said bevelled ring.

5. In the arrangement according to claim 4 means for axially adjusting said bevelled ring.

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