June 17, 1958 D. H. ROBEY 2,839,695

FREQUENCY CONTROLLABLE PIEZO-ELECTRIC RESONATOR

Original Filed Jan. 9, 1953 2 Sheets-Sheet 1

Fig. 1.

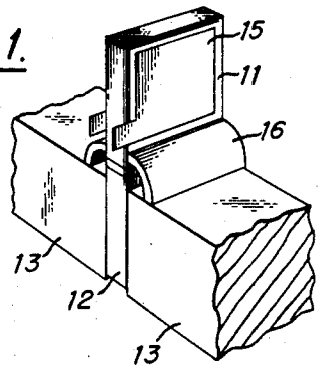


Fig. 2.

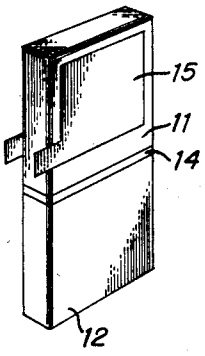


Fig. 3.

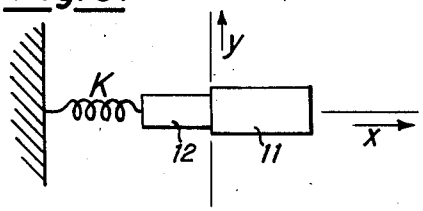


Fig. 4.

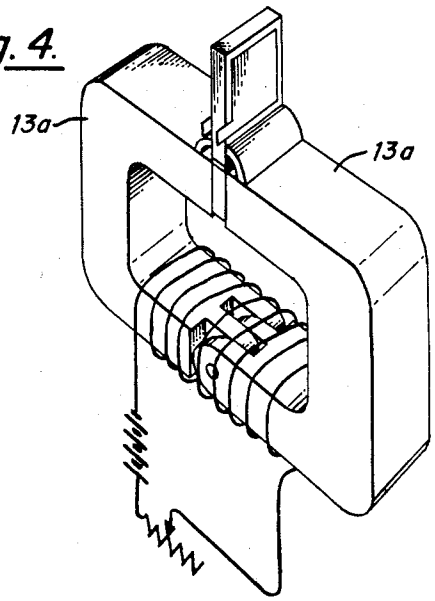
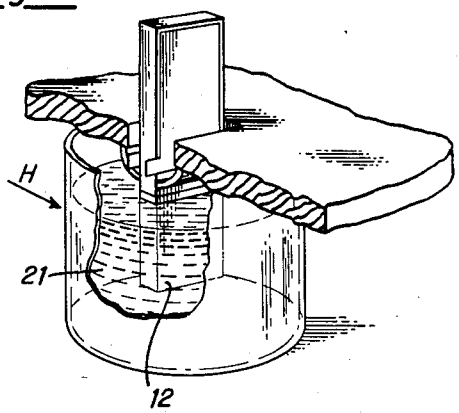


Fig. 5.



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Original Filed Jan. 9, 1953 2 Sheets-Sheet 2

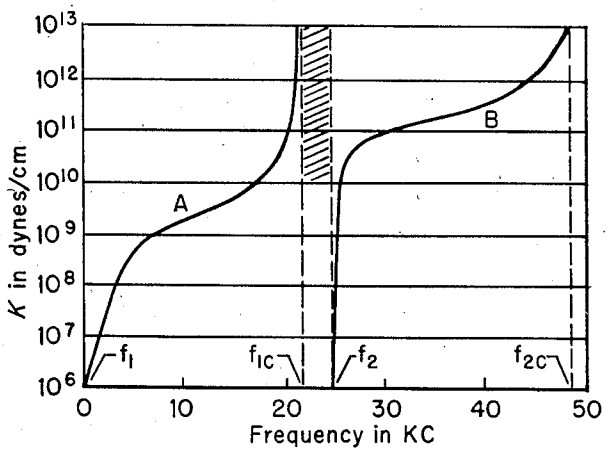


Fig. 6.

Fig. 7.

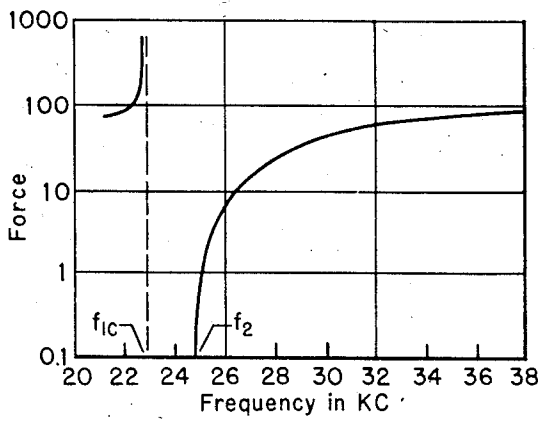
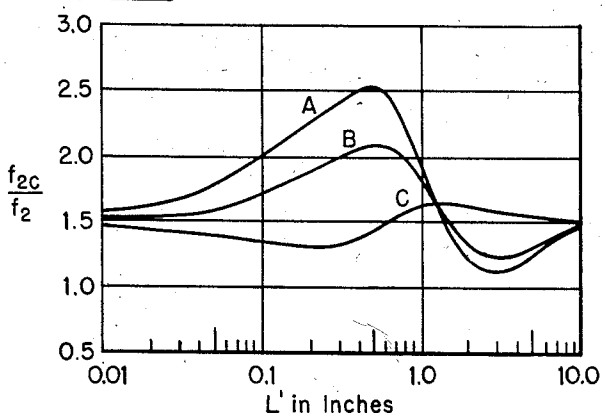


Fig. 8.



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FREQUENCY CONTROLLABLE PIEZO-ELECTRIC RESONATOR

Donald H. Robey, San Diego, Calif.

Continuation of application Serial No. 330,604, January 9, 1953. This application January 31, 1957, Serial No. 637,596

9 Claims. (Cl. 310—8.2)

(Granted under Title 35, U. S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This patent application is a continuation of the patent application of Donald H. Robey, for Frequency Controllable Piezo-Electric Resonator, Serial Number 330,604, filed January 9, 1953.

This invention relates to a new and improved frequency controllable piezo-electric resonator.

It is an object of the invention to provide a resonator, the frequency of which is controllably variable by selectively regarding or impeding the movement of the resonating element therein.

It is an object of the invention to provide a piezo-electric resonator, the resonant frequency of which may be controlled and varied at will.

It is a further object of the invention to provide a piezo-electric resonator, the resonant frequency of which is controllable by applying a controllable pressure against a portion thereof.

It is still a further object to provide a crystal resonator, the resonant frequency of which is controllably variable.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a view in perspective of an embodiment of the invention;

Fig. 2 is a further view in perspective of the embodiment shown in Fig. 1, showing the embodiment in more detail;

Fig. 3 is a schematic representation of the embodiment of the invention illustrated in Fig. 1;

Fig. 4 is a schematic representation of an embodiment wherein a movable jawed electromagnet is used as the retarding means;

Fig. 5 is a schematic representation of a further embodiment of the invention, wherein magnetic fluid is used;

Fig. 6 is a graph showing the theoretical variation of the first two characteristic frequencies of a composite crystal resonator made in accordance with the present invention;

Fig. 7 is a graph showing the actual frequency variation in a composite crystal resonator made in accordance with the present invention; and

Fig. 8 is a graph showing the theoretical frequency limit ratios of a one-inch crystal using backing plates of various material.

An elementary form of the invention is shown in Figs. 1 and 2. It comprises a longitudinally vibrating piezo-electric crystal **11**, having a backing plate **12** secured thereto in edge to edge relationship with a binder **14** such as cement. The crystal **11** has a pair of electrodes **15**, each on opposite lateral surface thereof as shown in Fig. 2. A means such as a vise having jaws **13** is provided for exerting selectively variable lateral pressure

on the plate **12**. The composite system is resiliently held in position as by a pair of pressure release supports **16**, made for instance of a non-conducting resilient material such as cork, which in turn may be secured and rest upon the surfaces of the jaws **13** of the clamping mechanism. A convenient pressure exerting means may be constructed in the form of an electromagnet having a pair of movable jaws **13***a* with an air gap therebetween as shown in Fig. 4.

The surface of the plate as well as the jaws of the vise or magnet, are ground and polished and the contact surfaces preferably are lubricated, as with grease or powdered graphite. The lubrication is provided to allow clamping action to take place gradually so as to prevent the frequency from changing in discrete steps.

An alternative to utilizing movable jaws is to use rigidly held pole pieces which need not touch the backing plate. Currents induced in the backing plate due to the plate vibrating in the magnetic field between the pole pieces react with the induction to produce complex opposing forces, the imaginary component of which is a stiffness reactance. The induced stiffness tends to clamp the plate thus increasing the resonant frequency.

As applied to a longitudinally vibrating resonator element, the expression clamped-free means that the resonator is free to move at one end and impeded at the other end. In the case of the composite crystal, i. e., the crystal and backing plate as hereindisclosed, the backing plate is impeded and the crystal is free to move. By the expression free-free is meant that the composite crystal is unimpeded, that is, both ends are free to move.

As the backing plate is gradually clamped, whatever mechanism is used to produce the clamping effect, the characteristic frequencies of the composite system increase until the clamped-free condition is obtained. The lowest resonance of the clamped-free composite bar is found to be the upper limit to the increase in the lowest resonance ($f_1=0$) of the free-free composite bar.

Dissipation between the surfaces of the backing plate and the vise may be neglected, since the losses may be kept low in practice. Also if the vise is massive compared to the composite resonator, mass coupling may be neglected except at very low frequencies. The clamping action of the vise can then be represented by a massless spring which couples the backing plate of the crystal to a rigid wall, as shown schematically in Fig. 3.

The resonant frequency for this system varies in accordance with the following equation:

$$K=-\frac{\sigma' Z'\omega\,[\cot k'l'+(\sigma' Z'/\sigma Z)\cot kl]}{1-(\sigma' Z'/\sigma Z)\cot kl\cot k'l'} \qquad (1)$$

wherein:

c=phase velocity

$k=\frac{2}{\lambda}=\frac{\omega}{c}$=wavelength constant

l=length of crystal

l'=length of backing plate

$Z=\epsilon c$=characteristic impedance

K=spring stiffness

ϵ=density

σ=cross sectional area

$\omega=2\pi f$=angular frequency

and wherein the primed characters refer to the backing plate.

By setting $K=0$, the equation for the resonant frequency of a free-free composite bar is obtained, i. e.,

$$\sigma Z\tan kl=-\sigma' Z'\tan k'l' \qquad (2)$$

Equation 2 is usually solved for the fundamental resonant frequency, designated as f_2, of a free-free com-

posite bar, by a series of approximations. The trivial resonance $f_1=0$ when K0 of a free-free composite bar has more significance when K is allowed to have values other than zero. This is shown in Fig. 6 wherein it is seen that as K increases, so does f_1 and f_2. The bar becomes clamped when K is infinite. The clamped-free resonances f_{1c} and f_{2c} may be calculated by setting the denominator in 1 equal to zero. This gives the equation

$$(\sigma Z/\sigma' Z') \tan kl \tan k'l'=1 \quad (3)$$

The frequency f_{2c} may be over an octave higher than f_2. If l' or l approaches zero, the ratio of f_{2c}/f_2 approaches 1.5, as may be seen in Fig. 8. Apparently this same number is approached when the ratio of l'/l is made large enough.

From Equations 2 and 3 an optimum length of backing plate can be calculated for any given crystal to obtain a maximum ratio of f_{2c}/f_2. A thin 45° Y-cut Rochelle salt crystal with a length of one inch was picked arbitrarily for the driving element. Backing plates of steel, aluminum and lucite were used to calculate the curves A, B, and C, respectively, in Fig. 8. It is seen that of these three materials a one-inch crystal with a one-half inch steel backing plate gives the maximum ratio; the frequency changing from 26.5 to 66.7 kc. The same crystal with a three-inch steel backing plate has a minimum ratio, the frequency only changing from 22.2 to 24.4 kc. Therefore it appears that the stability of the composite crystal, in this sense, depends upon the length and composition of the backing plate.

In general, the larger the ratio of f_{2c}/f_2, the easier it is to change the resonant frequency by lateral pressure.

In the use of normal magnets to apply pressure to the backing plate 12, the lateral pressure is limited to around 42 pounds/in.^{2} with practical flux densities. This is insufficient to change the resonant frequency very much unless the subtantially entire backing plate is inserted between the pole pieces. If this is done one finds that the Q suffers considerably as the lateral pressure is increased. A one-inch, Y-cut Rochelle salt crystal with a one-inch ferrite backing plate tried in this manner has been found to change in resonant frequency from 28.34 to 58.2 kc. However, the resonance in such case is hardly perceptible near 58.2 kc. due to the large damping. The results obtained with a one-inch steel backing plate using the same arrangement are shown in Fig. 8.

If only a fraction of the backing plate is clamped, for example 25%, the Q usually increases with increase in pressure. The final value may then be over 100 but the frequency change will be less, in general. If the area of the plate which is put under pressure becomes too small, there is no amount of pressure that will effectively raise the frequency, and the plate simply becomes embossed. Also the vise only effectively clamps the surfaces, and regions near the surfaces of the backing plates. This depends to a certain extent of the modulus of rigidity of the plate as well as its thickness.

As a further alternative to having movable jaws, a ferromagnetic backing plate and magnetic fluid 21 may be utilized with a suitable source of magnestism, not shown, for applying a magnetic field H to the backing plate 12. An energizable coil, not shown, having a gapped core of low reluctivity might be used, wherein the core might either be external to and adjacent to the fluid container with the container positioned in the gap, or the core might extend into the container with the backing plate in the gap. In this case the jaws forming the gap need not move, though such may be provided if additional clamping action is desired, since variation of the flux density in the electromagnet core acts through the medium of the magnetic fluid to variably clamp or impede the movement of the plate 12.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

Having described my invention, what is claimed is:

1. A resonator having a controllably variable resonant frequency comprising a longitudinally vibratable piezo-electric element having a backing member secured thereto in end to end relationship therewith, and means for variably clamping said backing member laterally thereof.

2. A variable frequency resonator comprising a driven element having a movable backing member secured thereto in end to end relationship therewith, and means for variably applying force to said member transversely of the direction of movement thereof for selectively retarding said movement of said backing member.

3. A controllably variable resonant mechanism comprising a composite piezo-electric crystal and a backing element secured thereto in end to end relationship therewith and vibratile in a substantially lineal direction, and means for variably applying lateral pressure to said element to produce an effective spring action for retarding the movement of said element in said lineal direction.

4. A controllably variable resonant mechanism comprising a piezo-electric element vibratile along a particular axis, a backing member secured to said element in end to end relationship therewith, and means for variably clamping said member laterally of said axis to impede the movement of said element and member along said axis.

5. A controllable resonator system comprising a piezo-electric crystal, a backing plate secured to said crystal, a cored electromagnet having an air gap in the core thereof, means for supporting said crystal and plate, a portion of said plate being positioned in the air gap of said electromagnet.

6. A controllable resonator system comprising a piezo-electric crystal, a backing plate secured to said crystal, a pair of jaws movable toward and away from each other, means for setting up a magnetic flux in said jaws whereby they are mutually attracted to each other, and means for supporting said crystal and plate, a portion of said plate being positioned between said jaws.

7. A controllable resonator system comprising a piezo-electric crystal, a backing plate secured to said crystal, a pair of jaws movable toward and away from each other, means for setting up a magnetic flux in said jaws whereby they are mutually attracted to each other, means for supporting said crystal and plate, a portion of said plate being positioned between said jaws and lubricant means between said jaws and said plate.

8. A controllable resonator system comprising a piezo-electric crystal having a ferromagnetic backing plate secured thereto, said backing plate being positioned in a magnetic fluid, and a source of magnetism positioned adjacent said fluid and backing plate.

9. A controllable resonator system comprising a longitudinally vibratable clamped-free piezo-electric crystal having a ferromagnetic backing plate secured thereto, and magnetic means for applying lateral force to said plate for impeding movement of said member longitudinally.

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