United States Patent

[11] 3,584,245

[72] Inventor **Ralph K. Helfen**
Chicago, Ill.

[21] Appl. No **801,118**
[22] Filed **Feb. 20, 1969**
[45] Patented **June 8, 1971**

[73] Assignee **P. R. Mallory & Co., Inc.**
Indianapolis, Ind.

[54] **PIEZO-ELECTRIC RESONATOR UTILIZING ELECTRODES LARGER THAN THE POLARIZED REGION FOR CONTROLLING THE COUPLING COEFFICIENT THEREOF**
4 Claims, 8 Drawing Figs.

[52] **U.S. Cl.** **310/9.5,** 310/8.9, 310/9.4
[51] **Int. Cl.** **H01v 7/00**
[50] **Field of Search** 310/9.7, 9.5, 9.4, 9.3, 9.1, 8.9, 8.2, 8.0

[56] **References Cited**

UNITED STATES PATENTS

2,640,165	5/1953	Howatt	310/9.7X
2,974,296	3/1961	Rosen	310/8.2X
3,017,525	1/1962	Wolfskill	310/9.7X
3,104,377	9/1963	Alexander et al.	310/9.7X
3,374,367	3/1968	Cowan	310/9.7X
3,384,768	5/1968	Shockley	310/9.5
3,401,283	9/1968	Curran et al.	310/9.7X
3,423,700	1/1969	Curran et al.	310/9.7X
3,433,982	3/1969	Kaname et al.	310/9.7X

Primary Examiner—Milton O. Hirshfield
Assistant Examiner—Mark O. Budd
Attorneys—Richard H. Childress, Robert F. Meyer, Henry W. Cummings and Carter Ells

ABSTRACT: Only part of the center of a ceramic body, such as a circular disc, is subjected to a polarizing voltage. In the case of a radial mode resonator this poled area may be a circular area in the center of the major faces of the resonator. This poling is accomplished by using temporary electrodes, which may or may not become part of the final electrode structure. After the element has been thus poled, a new or added electrode is applied to the resonator. This electrode is greater in area than the area of the poling electrode, and can be placed immediately over the poling electrodes, while still making electrical contact to the adjacent area of the ceramic body, or to the poling electrode, which in turn is in contact to the ceramic. By controlling the percentage area of the final electrode that is poled it is possible to decrease the separation of the resonant and antiresonant frequencies of the piezoelectric resonator, thereby decreasing the coupling factor of the element.

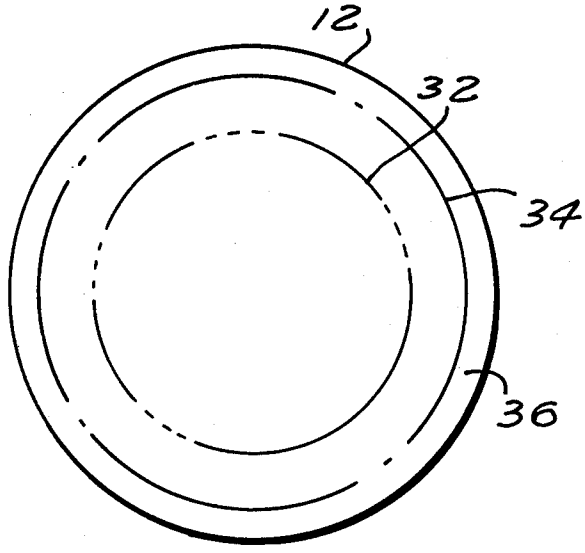


FIG. 1

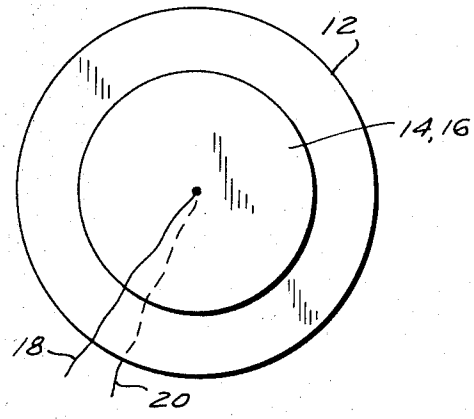


FIG. 2

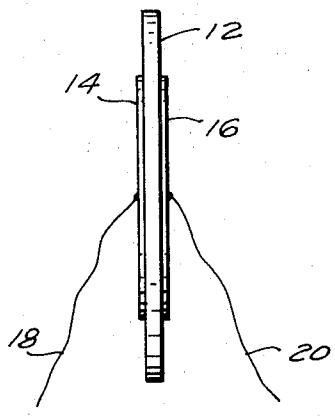
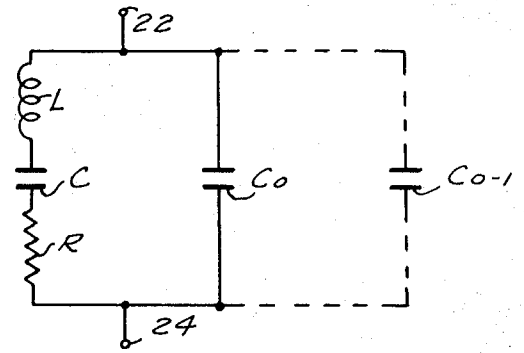


FIG. 3



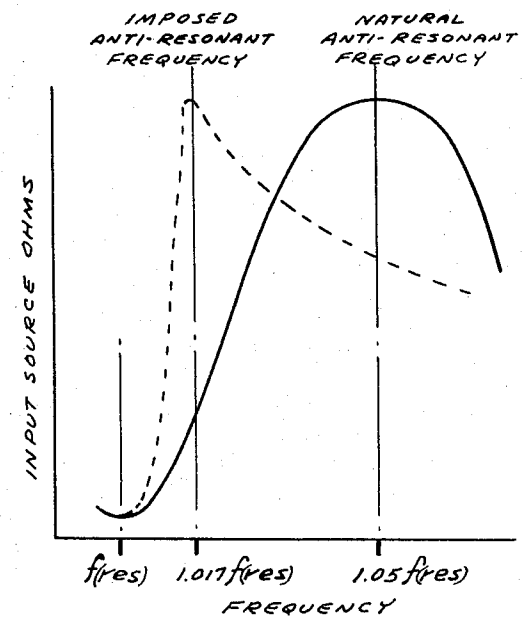


FIG. 4

INVENTOR
RALPH K. HELFEN
BY
ATTORNEY

FIG. 6

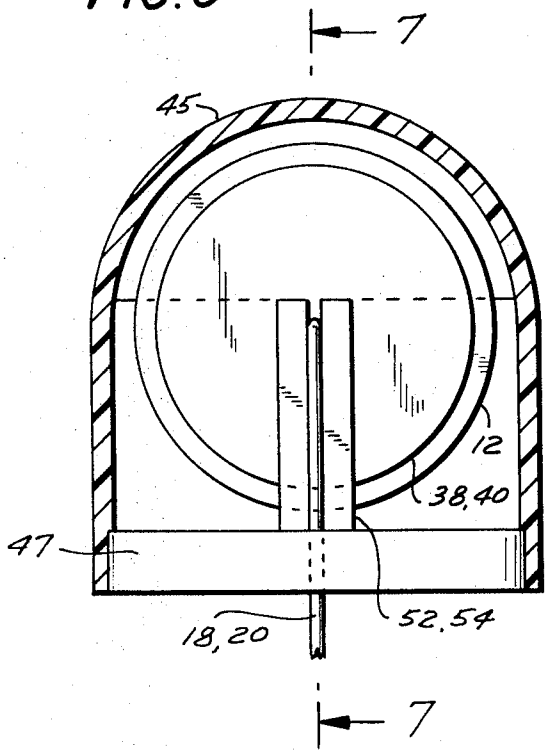


FIG. 7

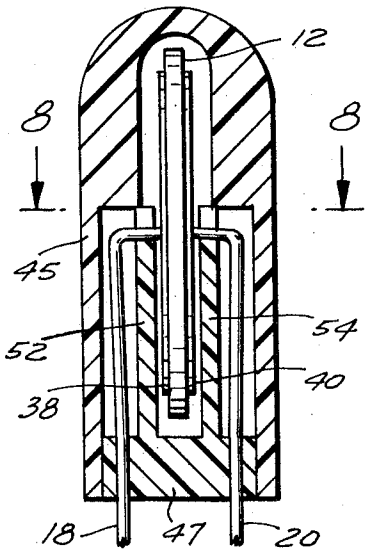


FIG. 8

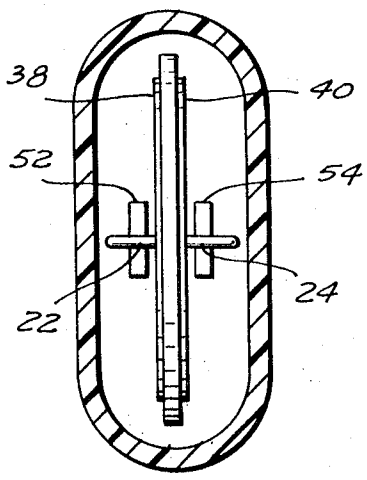
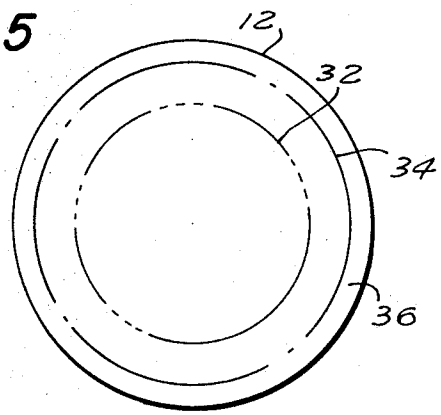


FIG. 5



INVENTOR
RALPH K. HELFEN
BY
ATTORNEY

PIEZO-ELECTRIC RESONATOR UTILIZING ELECTRODES LARGER THAN THE POLARIZED REGION FOR CONTROLLING THE COUPLING COEFFICIENT THEREOF

DESCRIPTION

This invention relates to peizoelectric resonators. It specifically relates to a method of preparing a piezoelectric resonator and its construction, to provide for controlling the coupling coefficient of the resonator when finally completed. Such coupling characterizes the frequency range of operation of the resonator. Thus, the relationship between the physical characteristics and the parameters of a piezoelectric resonator element, such as a plate of disc, determines the electrical characteristics or parameters, such as the mass, the compliance, and the loading or energy dissipation, which collectively govern and control the natural frequency output of the piezoelectric element. That output frequency is the ultimate parameter, or output, desired from the resonator for appropriate control of an associated electrical circuit.

In the prior art, the coupling or frequency characteristic of a piezoelectric resonator has been varied by altering the composition of the material employed to constitute the resonator element, or by altering the processes associated with the manufacturing of those materials in producing the resonator element. Such prior art practice and techniques required different material compositions for applications which require different coupling factors.

The bandwidth of a piezoelectric resonator, when used individually as a bypass element or in combinations as in a filter array, is proportional to a coupling coefficient of the device. This coupling is determined by the separation of the resonant and antiresonant frequencies. For a given resonant frequency, the greater separation of the two characteristic frequencies indicates an increase in coupling.

Previous methods to alter the resonator coupling factor either decreased the mechanical Q of the vibrator, thereby (1) increasing losses, or (2) utilized a process which demanded a decrease in the polarization field, and was very difficult to control.

The process of adjusting the coupling factor of a resonator, under this invention, used full poling strength, which reduces the tendency to change the poling of the object once it is installed in a circuit and subjected to a voltage. Parts constructed in accordance with this invention, can be subjected to higher potentials without affecting the original coupling factor or bandwidth characteristics of the resonator or filter.

In accordance with the present invention, a piezoelectric element, illustrated in a preferred form as a circular disc in the present description, is polarized in the central coaxial region of the disc to establish two polar areas coaxially aligned and spaced by the thickness of the disc or plate, which is ordinarily quite uniform. After this polarized region is established, two electrodes are applied coaxially to the opposite faces of the disc, over an area that is larger in diameter than the treated area which was polarized. A small annular border area on each of the opposite major faces of the resonator is left exposed to permit a greater freedom to be available at the border and peripheral edge of the disc during vibrational operation at the operating frequency of the resonating plate or disc.

A primary object of the invention is to provide a method of preparing and conditioning a piezoelectric resonator disc or plate, in order to compensate for batch variations where the plates are manufactured from materials taken from different batches or mixtures, or to compensate for the use of materials from the same batch, and are to be applied in a variety of applications, where, normally, materials from different mixtures with different coupling characteristics would be required.

Another object of the invention is to provide a method of manufacturing and treating a resonator plate or disc, to modify the electrical parameters, and thereby to modify the coupling factor and the range of operating frequency of the resonator disc.

Another object of the invention is to provide a method of manufacture and treatment of the resonator disc that will artificially increase the effective capacitance parameter of the piezoelectric disc, in order thereby to modify and control and reduce the operating antiresonant frequency of the disc, and thereby shift such operating antiresonant frequency closer to the natural resonant frequency of the disc, with a resultant reduction in the coupling factor and in the range of frequency operation of the resonator disc. As a result, the tuning band will be narrower and sharper and permit finer control response and reaction between the resonator and the associated circuits with which it may be combined.

A particularly important feature of this invention is that it permits the detection of poor dielectric material, or of a poor sample of the dielectric material, during pretreatment, that is unsuitable as a resonator. By such early detection of a poor sample of material that will be unsuitable for an ultimate high quality resonator, the costly expense of putting final electrodes on these poor material waste elements is thereby eliminated.

Thus, another object of the invention is to provide as part of the conditioning process of the invention, a conditioning step, which, in the treatment of the disc, detects a poor material or inadequate sample at an early stage in the preparation of the sample for manufacture as a resonator.

Thus, for example, where a sample is to be polarized to operate at a certain predetermined frequency range, the polarizing step at high voltage would cause a breakdown in a poor sample and thus would eliminate that sample from further attention in making a resonator, and particularly would eliminate the expense of the costly step in the operation of applying finished electrodes to the plate, and then discovering inadequacy of the plate for service as an electrical resonator.

In treating a resonator plate for polarization, the region in the plate that is to be polarized is disposed between two polarizing electrodes for 4 minutes in mineral oil at a temperature of 100° C., at a voltage adjusted to the value that is at least 100 volts per mil of thickness of the plate.

With the procedure of the present invention, full polarizing voltage is applied, and any deficient condition in the dielectric material, that is being treated, is immediately detected by a breakdown in the material, with consequent short circuiting of the applied voltage, to indicate the deficient nature of the material being treated.

Thus, a further object of the invention is the provision of a piezoelectric resonator whose method of manufacture is such as to inherently assure that the ultimately finished resonator will be adequate and satisfactory in operation.

A further object of the invention is to provide a method of manufacture that is inherently economical by reason of assuring such early elimination of faulty samples, which would represent a substantial economic waste if their detection were necessarily deferred until after the completion of the manufacturing operation, which involves the expensive step of applying operating electrodes to the opposite faces of the disc.

These and other objects, features and advantages of the invention, and the manner in which these objects and advantages are obtained, will be apparent to those conversant with the art from the following description and subjoined claims taken in conjunction with the annexed drawings, in which:

FIG. 1 is a front view in elevation of a resonator disc with a poling electrode in place;

FIG 2 is a side elevational view of the disc of FIG. 1, showing both poling electrodes;

FIG. 3 is an equivalent circuit diagram of a resonator disc alone, shown in solid line, with an added condenser shown in the broken line circuit to represent the equivalent added capacitance which is added to the resonator disc by the manufacturing procedure and treatment of the present invention;

FIG. 4 is a graph illustrating the frequency-spectrum relationship between the natural inherent series resonance frequency of the resonator disc and the natural inherent antiresonance frequency of the untreated resonator disc, and shows how the antiresonance frequency is shifted to the broken line position in the resonator when the disc is treated and constructed according to this invention;

FIG. 5 is a plan view of a circular disc of piezoelectric material, and shows the central inner poled area of the region that is polarized according to this invention, and the enlarged electroded area which includes an additional annular space beyond the polarized region, but not extending to the periphery of the ring, at which periphery an uncovered annular border portion is left uncovered to permit unimpeded edge vibration of the disc during operation;

FIG. 6 is a front elevational view of a resonator disc of this invention, as ultimately electroded, and mounted within its sealed enclosing housing, with the front wall removed to show the construction of the base and its support for the disc;

FIG. 7 is a vertical sectional view, taken along the line 7–7 of FIG. 6, as a view from the side of the assembled structure of FIG. 6, cut open to show the disposition and structure of the inside of the housing and the disposition of the disc;

and FIG. 8 is a downward view in section taken along the line 8–8 of FIG. 7.

Generally speaking, the present invention describes a piezoelectric resonator, as modified to increase its normal capacitance parameter by polarizing a portion of the resonator within the area usually covered by a working electrode. As a consequence, the effective capacitance of the resonator plate is increased beyond the normal value of that parameter for an untreated plate, and the antiresonance frequency of the resonator plate due to its inherent parameters is decreased, the coupling factor is thus diminished and the bank width of the resonator during operation is diminished.

The manner in which the resonator of this invention is treated and constructed to achieve the improvement may be more readily understood upon referring to the drawings.

Referring to FIGS. 1 and 2, a piezoelectric resonator disc 12 is disposed between two circular poling electrodes 14 and 16 coaxially applied to the opposite faces of the disc 12. The two electrodes 14 and 16 are connected to two leads 18 and 20 for connection to an external electric circuit, through which a high voltage is applied to the electrodes to polarize the volume of the disc 12 between the electrodes, and to establish two fixed poles of opposite polarity on opposite faces of the disc. Those two fixed poles represent bound charges which add an artificial increase to the capacitance parameter of the disc.

In FIG. 3 the elements shown in solid line represent the equivalent circuit diagram of the parameters of the conventional piezoelectric disc shown in FIGS. 1 and 2, before polarizing treatment, and the two terminals 22 and 24 to represent their electrical equivalents.

In the series circuit between the two terminals 22 and 24 of the diagram in FIG. 3, the inductor L represents the vibrational mass of the resonator, C represents the compliance of the plate, and R represents the motional loss of the plate. The parallel capacitor C_0 represents the natural intrinsic dielectric capacitance of the resonator plate. The natural resonant frequency is controlled by the motional resonance, at the value where the reactance of the mass L is equal but opposite to the reactance of the series capacitor C, and represents a series resonant condition. When the frequency is greater than that resonant frequency, the inductive reactance increases so that the series branch is inductive and then at an appropriate resonance value will resonate with the parallel capacitance C_0, which then represents the parallel resonance condition.

Thus far, that is all prior art and represents the usual prior art operation of a resonator.

Referring now again to FIG. 3, if the dielectric capacitance of the resonator is increased by the addition of capacitance represented by C_{011}, as indicated by the broken line circuit, to establish additional capacitance in parallel to C_0, the natural dielectric capacitance of the plate, the parallel or antiresonance frequency will be diminished to a value less than the natural antiresonance frequency of the plate in which only the normal dielectric value of capacitance C_0 was available as an operating parameter.

In FIG. 4, the solid-line graph shows the natural impedance relationship relative to frequency over the short range between natural resonant frequency and natural antiresonant frequency. The broken line graph represents the modified shifted curve to shift the antiresonant frequency toward resonant frequency, and thus diminish the spacing between them that represents coupling.

FIG. 5 shows a disc 12 with the relative areas indicated for the poling area 32 which is to be polarized, and the electrode area 34 which is to be ultimately covered by an electrode on each opposite face of the disc 12 after the polarized condition has been established in the area within the circle 32 on each face of the disc. Thus, the area covered by the electrode 34 exceeds the area that is polarized within the circle 32. An outer annular region 36 is left unpolarized and uncovered by the electrode and provides an unimpeded region that is free to adjust itself in response to the vibrations at resonance frequency.

FIG. 6 shows the fully electroded disc 12 with the electrodes 38, one on each major surface of the disc 12.

The disc 12, when provided with the full electrodes 38 as in FIG. 6, is then mounted to be supported between two fingers 22 and 24 of the stanchions 18 and 20 with the two fingers 22 and 24 engaging the resonator disc coaxially by engagement with the two electrodes 38. A cap 45 is fitted over the base 47 to provide a complete enclosure as a housing for the resonator. Two posts 52 and 54 are shown as integrally formed on the base 47 and are separated to define a space to accommodate the resonator plate 12, and they serve also as support for the two upper fingers 22 and 24 which engage and press against the two sides of the electroded disc 12 to hold the disc in coaxially aligned position.

As shown in FIG. 8, the disc is supported by the two fingers 22 and 24 engaging the two electrodes 38 and 40 coaxially at the node points of the disc 12 for substantially single point support axially, with maximum freedom of vibration available to the disc without any impediment from any of the other supporting structures.

Thus, as disclosed herein, the invention includes the primary step of poling or polarizing a central region of the disc, over an area that is less than the full operating electrode area of the disc. A feature of this preliminary polarizing operation at relatively high voltage is the possibility of causing breakdown in poor dielectric material or in any improper mixture of the piezoelectric material, which permits detection of a faulty or defective piezoelectric disc before it has been fully processed through all steps of manufacture, and then found to be defective. Such preliminary detection of a defective disc is a substantial factor in the economy of the process of manufacture in accordance with the present invention.

Moreover, this procedure of polarizing and poling a central region of the disc after the material of the piezoelectric disc has been fired, provides a new took for treating a fired disc after such firing has ordinarily completed any control over the material while it is being prepared and formed as a piezoelectric disc.

A further feature of the invention is that this step of poling or polarizing a region of the material, by varying the ratio of the poled area to the electrode area, permits the discs from one batch of basic material to be variably treated to make a resonator available for various applications where different frequencies are desired, or where different coupling factors are desired.

Since the poling treatment can be applied independently of the nature of the material which enters into the piezoelectric disc, it will be obvious that various ratios between the poling area and the electrode area may be utilized to control the operational characteristics of the disc when finally formed. As indicated in the foregoing description, a reduction in the

coupling and therefore the frequency range of operation, is related to the ratio of the parallel resonant frequency to the series resonant frequency.

It will also be realized that when a portion of the disc is poled, and driven electrically, it must activate or vibrate the entire mechanical structure. Therefore, the dimensions of the complete resonator will determine the resonant frequency.

When the larger electrodes are applied for operation, an added capacitance is placed across the natural inherent capacitor C_0 in FIG. 3. With the increased capacitance, the parallel resonant frequency is lowered. Consequently, for a given physical structure, having a corresponding series resonant frequency, a decrease in the parallel resonant frequency will result in the decrease of the planar coupling factor. This added capacitance is determined by the passive section of the resonator, that is, that portion of the material contained between and covered by the final electrodes, which is unpoled.

The treatment and construction of the disc, and the ratio between poled and electroded areas, may be modified and varied without departing from the spirit and scope of the invention, as particularly defined in the claims.

What I claim is:

1. A piezoelectric resonator comprising a piezoelectric wafer having a substantially uniform thickness between two opposite faces, a central axial polarized thickness region and a peripheral unpolarized thickness region with each of said regions having a capacitance; and an electrode means on each face for electrical connection to an external circuit for energizing said resonator, said electrode means covering all of the surface area overlying the polarized capacitance region and at least a part of the unpolarized capacitance region and connecting said regions electrically in parallel to increase the capacitance and thereby reduce the coupling factor of the resonator.

2. A piezoelectric resonator according to claim 1, wherein said electrode means are oppositely opposed and of substantially the same surface area.

3. A piezoelectric resonator according to claim 1, wherein said electrode means are oppositely opposed and of substantially the same surface area.

4. A piezoelectric resonator according to claim 1 further including an electrical terminal including finger means for resiliently engaging each of said electrodes, a base means including post means for supporting said finger means, and a cap means enclosing said resonator, base means and finger means to provide a housing therefor.