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PIEZOELECTRIC CRYSTAL APPARATUS

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FIG. 1

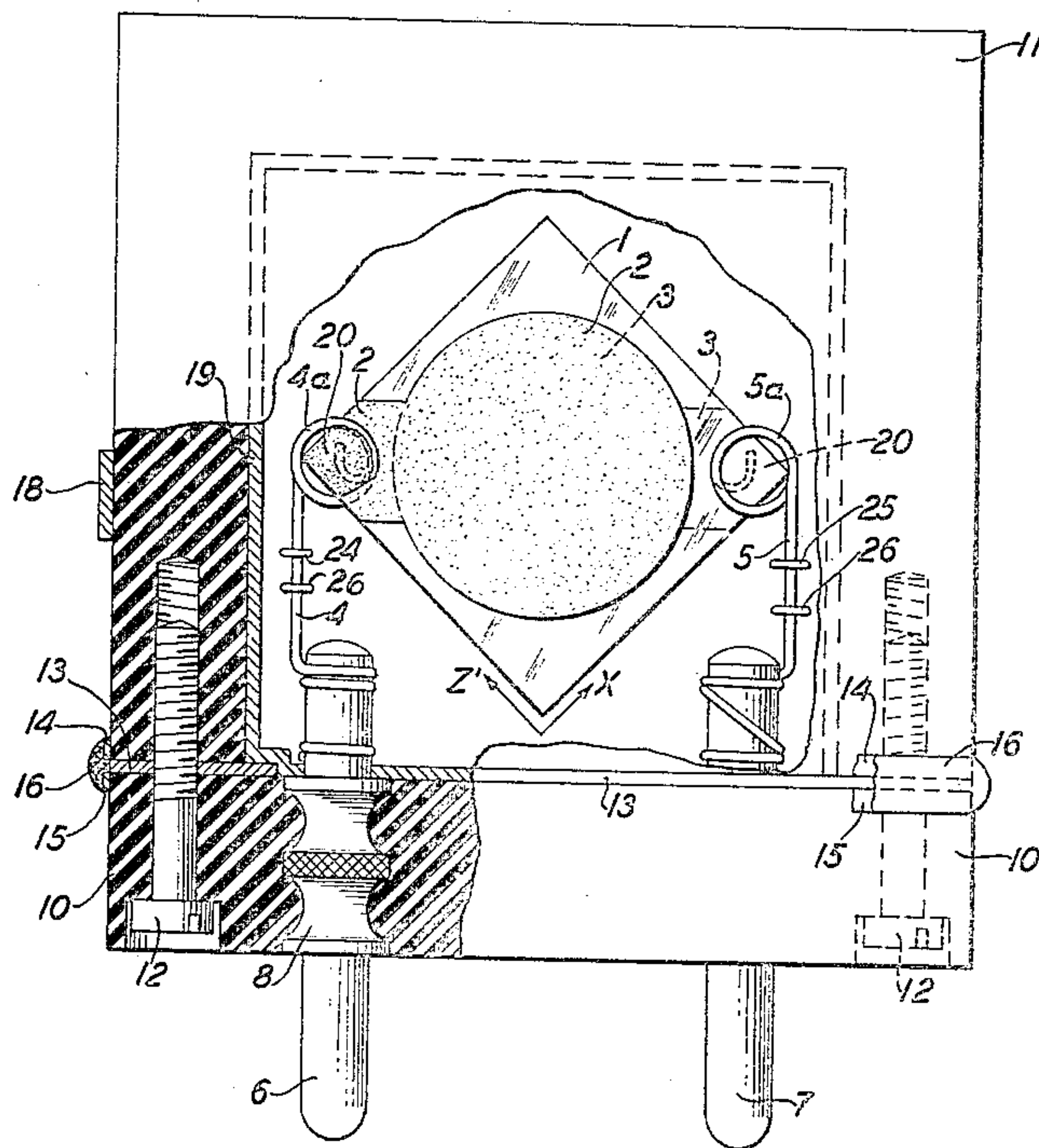


FIG. 2

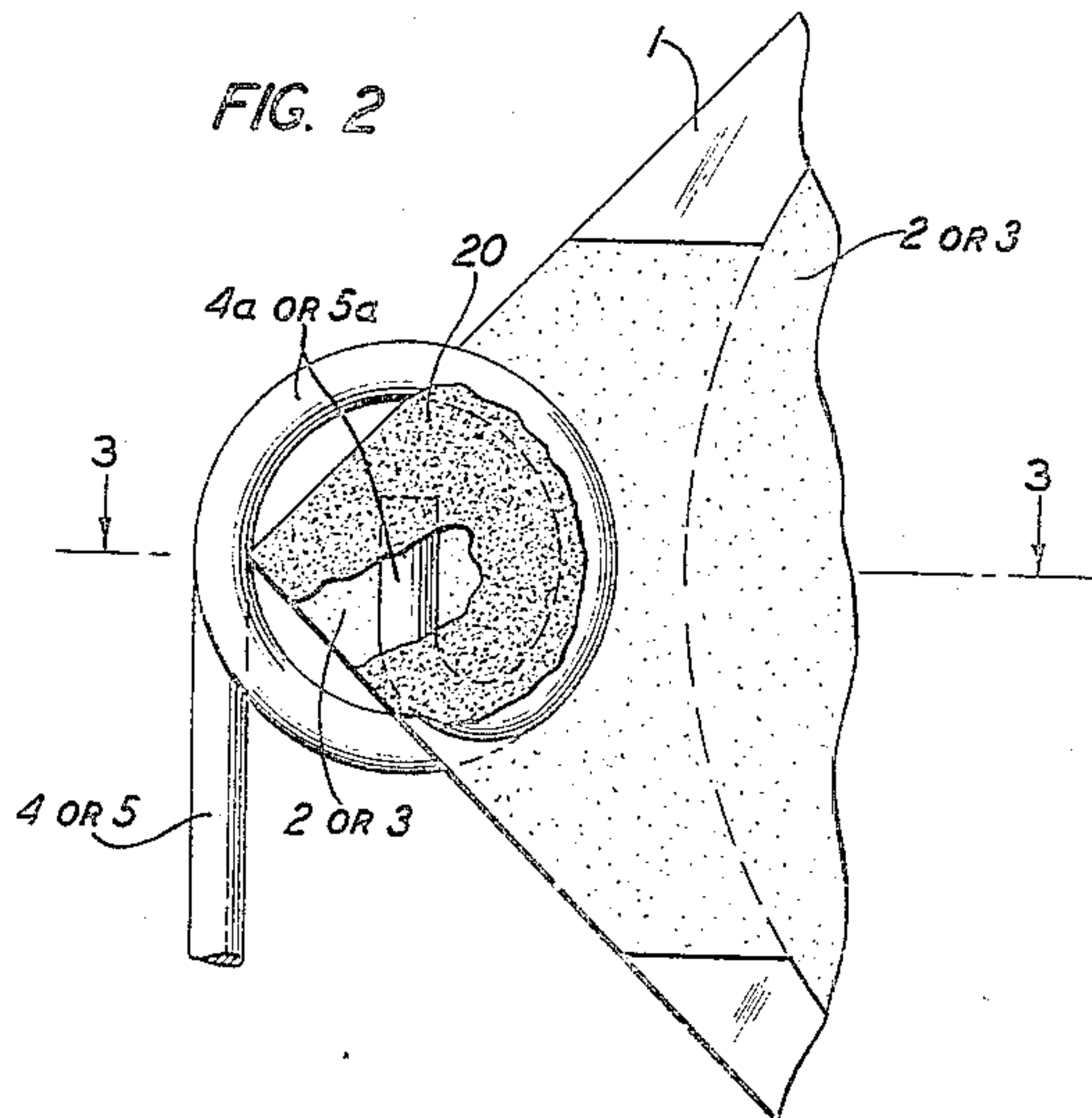
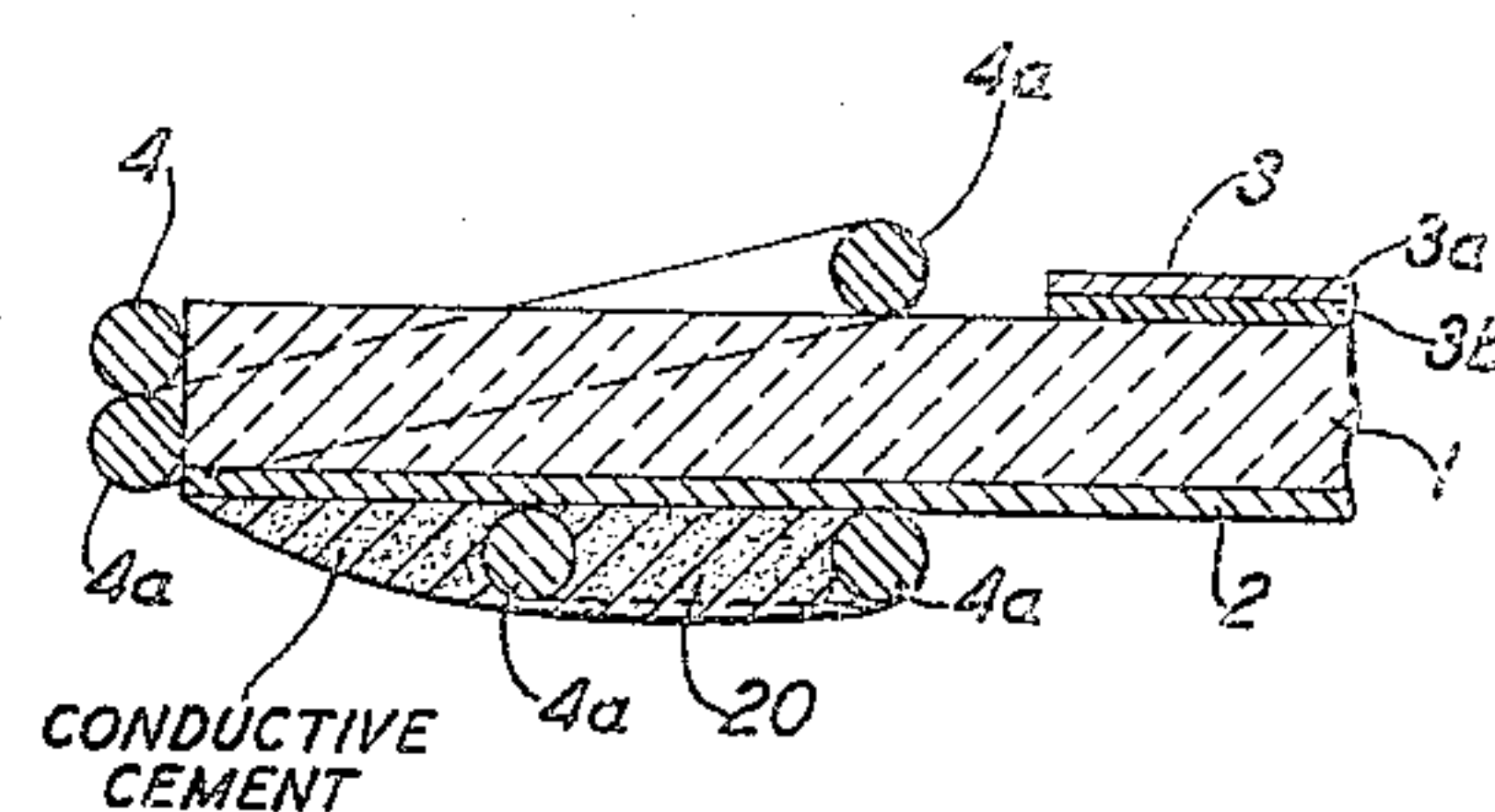


FIG. 3



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## UNITED STATES PATENT OFFICE

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## PIEZOELECTRIC CRYSTAL APPARATUS

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17 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystal apparatus and particularly to mounting arrangements for piezoelectric crystal elements, such as wire supported thickness mode quartz crystal elements, useful as circuit elements in oscillation generator systems and in other systems utilizing electromechanical vibratory elements.

One of the objects of this invention is to provide improved mounting arrangements for piezoelectric crystal elements such as wire supported quartz crystal plates having integral or adherent electrode coatings and operating in thickness mode vibrations of the shear type.

Another object of this invention is to improve the operating stability and frequency stability of piezoelectric crystal units.

In piezoelectric crystal elements of the high frequency type employing thickness modes of vibration and operating at relatively large amplitudes of motion, it has been difficult heretofore to utilize electrode coatings thereon of the adherent or integral type without gradually wearing away the integral coatings and eventually opening the circuit connections at the points of support. Moreover, in the case of wire supported crystal elements it has been difficult to keep the supporting wires attached to the integral coatings of a thickness mode crystal element for any considerable period of time.

In accordance with this invention, a spring wire supporting system may be provided for a thickness mode type of crystal element which does not wear away the relatively thin integral coatings of the crystal element at the points of support and which will remain attached thereto indefinitely in operation. For this purpose the coated crystal element may be mechanically supported and electrically connected at any two of its corners, such as two diagonally opposite corners thereof, by means of a pair of separate spring wire coils, each of which may have its adjacent turns sprung over and straddling one of the corners of the crystal element and adhesively secured as by solder, conductive plastic cement, or electroplating for example, to that part of the integral electrode coating that is adjacent the corner of the crystal element. The spring wire coil may be made from a relatively fine spring wire coiled in helical, spiral or other suitable form to provide adjacent coil turns which may be sprung over the corner edge of the crystal element and there exert a compression force on the corner of the crystal element in the direction of the thickness or thin dimension of the crystal element. The compression force exerted by the spring wire coil may selectively control the amount of mechanical damping of unwanted modes of motion in the corner portion of the crystal element. The spring wire coils may serve as an electrical connection agent and also as a supporting agent for the crys-

tal element. The spring wire support terminated in the spring wire coil having its adjacent turns sprung over the corner edge of the crystal element provides a flexible form of crystal mounting that does not tend to come off in use or to wear away the crystal coating during long periods of operation of the unit. Moreover, the coil turns being tightly sprung over the crystal corner are more or less self-retaining in position and accordingly may be easily held in place by means of a relatively light adhesive means such as conductive plastic cement composed, for example, of finely divided silver or other metallic powder admixed with Bakelite or other suitable cement. Such conductive plastic cement may have little adverse effect on the reactance-resistance ratio  $Q$  of the crystal element when subjected to temperature variation, and moreover may be utilized in connection with certain crystal elements composed of crystalline material which will not stand the relatively high temperatures generally required when using a solder, such as silicon or other solder, as an adhesive agent for securing the wire to the crystal coating. The conductive plastic cement or other adhesive agent may serve both as an electrical connection agent and as a mechanical mounting agent for the crystal element, and also may function as a means for reducing unwanted modes of motion in the corner of the crystal element, particularly when the adhesive cement is in plastic form.

The crystal electrode coatings may be partial or reduced area electrode coatings which may extend to two opposite corners of the crystal element and which may consist of a layer of gold, for example, applied in the form of gold bright, evaporated gold or in the form of baked metallic paste to the bare quartz or other crystalline material. The inner or initial coating of gold bright, when gold bright is used as the basic coating, may then be electroplated with a coating of nickel, for example, to the correct frequency for the coated crystal element, or alternatively an additional coating of gold, silicon film or other material may be added to adjust the coated crystal element to the desired final frequency.

For a clearer understanding of the nature of this invention and the additional advantages, features and objects thereof, reference is made to the following description taken in connection with the accompanying drawing, in which like reference characters represent like or similar parts, and in which:

Fig. 1 is an enlarged view partly in section of a crystal unit embodying the invention;

Fig. 2 is a greatly enlarged view showing the corner mounting arrangement of the crystal element illustrated in Fig. 1; and

Fig. 3 is a sectional view taken on the line 3—3 of Fig. 2.



Referring to the drawing, Fig. 1 is an enlarged view, partly in section, of a piezoelectric crystal unit comprising a thin quartz or other piezoelectric crystal plate or element 1 provided with a pair of metallic or other conductive electrode coatings 2 and 3 adhering to and formed integral with selected parts of the opposite rectangular or square major surfaces thereof, and mounted at two of its diagonally opposite corners by means of a pair of conductive equal length spring wires 4 and 5, each of which at one of the ends 4a and 5a thereof may be coiled in the form of a helical spring which has its adjacent turns tightly sprung over the edges of the diagonally opposite corners of the crystal element 1 in individual electrical contact with the corner extension tabs of the corresponding crystal electrode coatings 2 and 3.

The crystal element 1 may be a thickness mode quartz or other crystal plate having square or rectangular shaped major faces of selected dimensions and having a thickness or thin dimension made of a value corresponding to the value of the desired thickness mode frequency. The electrodes 2 and 3 disposed on the major faces of the crystal element 1 provide an electric field for operating the crystal element 1 at its desired frequency which may be determined mainly by the thickness of the crystal element 1 at the region thereof within the influence of the electric field provided by the electrodes 2 and 3.

In a particular case, the crystal element 1 may be a thickness shear mode quartz crystal plate of the AT or BT cut type as disclosed, for example, in Lack, Willard and Fair Patent 2,218,200, dated October 15, 1940, and in G. W. Willard Patent 2,218,225, dated October 15, 1940. Such AT and BT cut quartz plates operate in the shear mode of motion at a frequency which is determined mainly by the value of the thickness or thin dimension thereof. The width and length major face dimensions thereof may be made of relatively large values or at least of not too small values with respect to the value of the thickness dimension thereof in order to secure good activity for the crystal plate. This is for the reason that the activity of such thickness shear mode quartz crystal AT or BT cut quartz plates, is a function of the size of the major face area of the crystal plate, a factor which limits the minimum size for the major face area of the crystal plate that may be used effectively. For small thickness shear mode crystal plates which have a major face area that is already relatively close to the minimum major face area permissible, the activity thereof may be increased roughly in proportion to the size of the effective field area provided by the electrodes 2 and 3 since the activity of the crystal plate 1 is also a function of the size of the partial field producing electrodes 2 and 3.

Also, the width and the length dimensions of the major faces of such AT and BT cut quartz plates may be relatively so proportioned with respect to the value of the frequency determining thickness dimension as to avoid interference with nearby spurious modes of motion therein such as undesired overtone flexures, shears and other more complex undesired modes of motion that may be present therein, as disclosed in R. A. Sykes Patent 2,306,909, dated December 29, 1942. Such major face dimensioning of the crystal element relative to the thickness dimension thereof removes the more serious effects of spurious modes of motion therein and results in obtaining a more constant activity for the crystal ele-

ment over a wide temperature range. The most serious interfering modes are those resulting from flexure modes in the X—Y' plane propagated along the X axis, shear modes in the X—Z' plane of high order along the X axis and shear modes in the X—Z' plane of high order along the Z' dimension. The X and Z' major face dimensions of the crystal plate should then be chosen such that high orders of the above-mentioned interfering modes are not near the desired principal high frequency X<sub>y'</sub> shear mode. In the case of the BT cut crystals, for example, the above-mentioned interfering modes near the high frequency X<sub>y'</sub> shear mode are given by:

$$f_{xf} = \frac{1818}{X} n_{xf} \text{ kilocycles per second}$$

$$f_{xs} = \frac{1635.14}{X} n_{xs} \text{ kilocycles per second}$$

$$f_{zs} = \frac{1664.5}{Z'} n_{zs} \text{ kilocycles per second}$$

where X and Z' are given in millimeters and the subscripts to f and n correspond to the three modes respectively as given above. n in the case of flexure takes on even integral values and in the case of shear takes odd integral values. In the case of AT cut crystals the above formulae become:

$$f_{xf} = \frac{1338.4}{X} n_{xf} \text{ kilocycles per second}$$

$$f_{xs} = \frac{2542}{X} n_{xs} \text{ kilocycles per second}$$

$$f_{zs} = \frac{2540}{Z'} n_{zs} \text{ kilocycles per second}$$

While it is possible to choose different or unequal values for the X and Z' dimensions of the crystal plate, it has been found that over an extended range of frequencies as from 3 to 10 megacycles per second the same or equal values therefor are possible, resulting in square crystal plates. This is a decided advantage in manufacture. It is to be noted that the above-mentioned equations give rules for dimensioning that include only the three principal interfering modes of simple orders. A more complete description of the above relation is given in a paper by R. A. Sykes entitled "Modes of motion in quartz crystals, The effects of coupling and methods of design," Bell System Technical Journal, January 1944.

The thickness mode AT or BT cut quartz crystal plate 1 may also be thickness shaped by making it very slightly thicker in the center region than at the peripheral edges thereof in order to improve the activity of the desired thickness shear mode of vibration. By vacuum baking the bare crystal element 1 just before laying down the metal coatings 2 and 3, gas molecules on the surface of the crystal plate 1 may be removed with a resulting improved quality for the electrode coatings 2 and 3.

Accordingly, a number of variables associated with the crystal plate 1 may determine or govern its activity performance. These factors include the major face area of the crystal plate 1, the area and quality of the plated electrodes 2 and 3, the thickness shaping of the crystal plate 1, and spurious modes of motion that may be present therein, as mentioned hereinbefore; and also the damping that may be introduced therein by the mounting, and the relation of the crystal



characteristics such as the crystal static capacitance to the circuit capacitance in which it may be connected.

The relation of the piezoelectric activity  $PI$  of the crystal element 1 with respect to the static capacitance  $C_0$  thereof and the circuit capacitance  $C$  which may be connected across or in shunt with the crystal element 1 is given by:

$$PI = \frac{Q}{r} \times \frac{C_0}{\omega(C_0 + C)^2}$$

where

$r$  is the ratio of capacities of the equivalent circuit  
 $Q$  is the reactance ratio of the crystal element 1  
 $\omega$  is  $2\pi$  times the frequency.

As indicated by the last-mentioned equation, the piezoelectric activity is a maximum when the static capacitance  $C_0$  of the crystal element 1 equals the circuit capacity  $C$  that may be connected across the crystal element 1; and since  $C_0$  is proportional to the effective area of the electrodes 2 and 3, this establishes the optimum area for the electrodes 2 and 3 for a particular value of the shunt circuit capacity  $C$  which may be used with the electroded crystal element 1.

While the crystal element 1 has been particularly described as a thickness shear mode quartz crystal element of the AT or BT cut type, it will be understood that it may be a thickness shear mode quartz element of another orientation or cut than the AT or BT cut mentioned, or that it may be a thickness mode quartz element of the longitudinal mode type, or a quartz or other element of any type that may be supported at one, two or more of its corners or edges by means of a spring wire coil 4a having its adjacent turns thereof sprung over a corner or over an edge of the crystal element 1. Also, while a quartz element 1 has been particularly described, it will be understood that the crystal element 1 may be any suitable piezoelectric element such as, for example, a crystal element cut from Rochelle salt, or from ammonium dihydrogen phosphate, potassium dihydrogen phosphate, or the corresponding arsenates.

As illustrated in Fig. 1, the electrode coatings 2 and 3 may be reduced area electrodes partially covering the opposite major faces of the crystal element 1 and leaving uncovered the marginal portions thereof, except for the narrow connection coatings which may extend to the diagonally opposite corners of the crystal element 1 for making individual electrical connections with the spring wire supports 4a and 5a. As illustrated in Fig. 1, the overlapping oppositely disposed portions of the electrode coatings 2 and 3 may be substantially circular or they may be alternatively square or rectangular in shape for applying an electric field of selected shape and area to the central portion only of the crystal element 1. Effective field producing electrodes of substantially circular shape are disclosed, for example, in S. C. Hight Patent 2,343,059 granted February 29, 1944, on application Serial No. 357,251 filed September 18, 1940.

Such partial or reduced area field producing electrodes 2 and 3 may be made of a selected area relative to the major face area of the crystal element 1 in order to obtain a selected value of impedance for the electroded crystal element 1. In cases where it is desired to fix the impedance between the electrodes 2 and 3 at a certain value such as, for example, to match the capacitance of the electroded crystal element 1 with the ca-

pacitance of the circuit that may be connected therewith, the oppositely disposed or overlapping portions of the electrodes 2 and 3 may be made of an area calculated to provide such value of capacitance or impedance.

The reduced area centrally located electric field produced by the partial electrodes 2 and 3 may be made of a selected value relative to the major face area of the crystal element 1 in order to increase the activity of the crystal element 1 and reduce the number of spurious frequencies therein. This effect results from removing the exciting field from the outer marginal or peripheral portion of the crystal element 1 and confining the excitation to a more limited central area only, thereby reducing the number and magnitude of undesired spurious frequencies generated in the crystal element 1. The reduced area electrode coatings 2 and 3 also are useful to reduce wear at the marginal or corner points of supports 4a and 5a of the crystal element 1. In this arrangement the edges and corners of the crystal element 1 being isolated from the active central vibratory portion within the influence of the field produced by the oppositely disposed central portions of the electrodes 2 and 3 are relatively motionless and accordingly may be there mounted and electrically connected without wearing away the conductive coatings 2 and 3 at the corner points of mounting adjacent the coiled spring wires 4a and 5a.

While in Fig. 1 the electrode coatings 2 and 3 are illustrated as extending to two of the diagonally opposite corners of the crystal element 1, they may extend to two adjacent corners thereof, or to any parts of the edges thereof, to suit the location of the coiled springs 4a and 5a with which they may be electrically connected.

The integral conductive coatings 2 and 3 may consist of one or more films or layers of metallic or conductive material such as gold, platinum, silver, nickel, aluminum, chromium or other conductive material applied to the quartz or other crystal element 1 by any suitable method or process such as spraying, evaporation in vacuum, electroplating or otherwise. The metallic coatings 2 and 3 may be applied using a mask or shield over the portions of the crystal element 1 where no metallic deposit is desired. If no mask has been employed during the metallic coating process, the undesired portions of the coatings near the edges of the crystal element 1 may be etched off afterwards, or otherwise removed or segregated electrically and mechanically, to form the effective reduced area electrode coatings 2 and 3. The frequency of the metal coated crystal element 1 may be adjusted by control of the thickness of the metallic platings 2 and 3 on its surfaces, the frequency being lowered by adding metal or raised by removing metal from one or both major surfaces of the crystal element 1. Where the metallic coatings 2 and 3 are applied by evaporation in vacuum or by spraying, for example, the crystal element 1 may be connected in a suitable circuit and oscillated at its natural frequency while applying the metal coating, the coating process being cut off or stopped when the frequency of the metallized crystal plate 1 reaches the desired value.

In any process described herein, the unplated crystal blank 1 may be ground to a frequency above that desired by an amount given by:

$$\Delta f = kf_0^2$$

where  $f_0$  is the final desired frequency and  $\Delta f$



is the increase in frequency for which the unplated crystal blank 1 must be ground. This insures that a uniform thickness of film for the electrodes 2 and 3 will result on all crystals when adjusted to the final frequency. For example, when using crystal blanks 1 from 10 to 10.6 millimeters square and electrodes 2 and 3 of 6 millimeters diameter the above given equation reduces to:

$$\Delta f = 1.39 f_0^2 \times 10^{-9} \text{ cycles per second}$$

At a frequency of 5000 kilocycles per second this results in a crystal blank 1 ground 35 kilocycles per second higher in frequency. The first or basic coatings for the electrodes 2 and 3, illustrated by the basic coating 3b in Fig. 3, are deposited for example by gold bright spray or evaporated gold in a vacuum to a thickness of between three-quarters to the full amount required to bring the crystal to the final frequency. The crystal blank 1 with its basic electrodes may then be mounted in the spring holders 4 and 5 and conductive plastic cement 20 applied to the tabs and springs 4a and 5a as shown in Figs. 1, 2 and 3. This forms a completed crystal unit except for the final adjustment to frequency. The frequency difference between this partially completed crystal and that of a completed crystal may be determined by the use of a duplicator. The duplicator may consist of two suitable oscillator circuits with a standard crystal and test crystal controlling these two oscillators. The output of the two oscillators referred to may be connected to a modulator, the output of which gives the frequency difference referred to. With a suitable circuit, the frequency difference may be read on a calibrated milliammeter.

The additional amount of film to be deposited to constitute the electrodes 2 and 3, as illustrated for example at 3a in Fig. 3, may be determined by the use of the duplicator referred to by observing the frequency difference from that of a standard crystal of the desired final frequency. When the final frequency adjustment is made by electroplating the additional metal the current and time may be so controlled as to electroplate at a fixed rate and as for example 500 cycles per second. By observation of the frequency difference, the time of plating may be accurately determined. By using a series of successive platings, the accuracy of the final frequency adjustment may be made as precise as desired. When the final frequency adjustment is made by evaporation of a metal, the crystal may be connected to an oscillator while it is in the vacuum chamber. Using a mask placed close to, but not touching, the crystal the evaporated metal film may be restricted to the central part of the crystal. When the pressure in the evaporation chamber is reduced to a sufficiently low value the electrically heated filament used for evaporating the metal is turned on, and evaporation takes place thereby depositing the evaporated metal on the central portion of the crystal and gradually lowering the frequency of the coated crystal element 1, as may be observed on the calibrated meter of the duplicator. When the frequency difference becomes zero or any assigned value, the current in the evaporator filament may be turned off, the coated crystal element 1 being thereby adjusted to final frequency. Using two small evaporators and a high speed vacuum pump with a single duplicator, an operator may adjust to final frequency as many as 100 crystals per hour.

Where the electroplating method is used to

metallize and adjust the final frequency of the coated crystal element 1, the initial coating applied to the bare crystal element 1 may be, for example, gold bright applied by spraying or gold applied by evaporation in vacuum, or other metal that will readily take an additional coating of electroplate thereon, such as gold, nickel or otherwise. The coatings 3a and 3b of Fig. 3 may serve to illustrate the outer and inner coatings respectively of the electrode coating 3 for example. As an example, the basic gold electrode forming part of the electrode films 2 and 3 may be formed on the bare crystal element 1 by spraying and baking thereon liquid gold bright of any suitable composition. Liquid bright gold is a material which has long been used for the decoration of china and glassware and is primarily a solution of gold resinate in a suitable organic solvent. Noble metals other than gold, such as platinum, rhodium, palladium, are often incorporated into the solution and can be deposited from the resinous film resulting after drying out the solvent by heating to temperatures above 400° C. When fired at such elevated temperatures, the adhesion of films is very good and in the case of crystalline quartz the baking temperature may be safely up to 540° C. The liquid bright gold solution may be applied on the bare crystal element 1 by means of a controlled air-brush spray, and the liquid gold bright solution may be supplied to the air-brush from a closed bottle. The amount of gold in the electrode coatings 2 and 3 is of some importance since it may be used as the first step in the adjustment of the crystal frequency, as well as acting as the electrodes for the crystal element 1. The gold may be applied in two or more separate spraying operations to more completely fire out carbonaceous matter from the gold layer and to cover up any pinhole areas in the coating of gold resulting from the first spraying operation. The crystal element 1 with its basic gold or other integral metallic films forming part of the electrode coatings 2 and 3 may then be mounted at its diagonally opposite corners between adjacent turns of the small coil springs 4a and 5a and the ends of the spring wires 4a and 5a may be secured to the coatings 2 and 3 respectively, by means of a spot 20 of solder, or conductive plastic cement, or by electroplating.

As illustrated in Fig. 1 and also in Figs. 2 and 3, each of the spring wire supporting coils 4a and 5a may be in the form of a helix, adjacent turns of which may be sprung over an edge of the crystal element 1 at one of the four corners thereof. One turn of the coil 4a may be in contact with the bare crystal element 1 and the other or adjacent turn of the coil 4a forming the end portion of the wire 4 may be in contact with the crystal electrode coating 2, the axis of the coil 4a being generally in a direction perpendicular to the major faces of the crystal element 1. The construction and mounting arrangement for the supporting coil 5a may be the same as that of the coil 4a except for being placed at the diagonally opposite corner of the crystal element 1 with the end of the wire 5a in contact with the crystal electrode coating 3, as illustrated in Fig. 1. The turns of the coils 4a and 5a are arranged in contact with one but not both of the electrode coatings 2 and 3 to avoid short circuiting thereof and to provide individual electrical connections therefor. The wire coils 4a and 5a function as a mechanical supporting agent and as an electrical connection agent for the crystal element 1 and also by reason of



the spring clamping action exerted on the corners of the crystal element 1, they may serve to reduce undesired spurious resonances in the crystal element 1.

The ends of the spring wires 4a and 5a may be secured directly to the crystal electrode coatings 2 and 3 respectively, by means of a spot or mass 20 of conductive plastic cement placed within the coil turn and over the ends of each of the wires 4a and 5a as illustrated in Figs. 2 and 3. The spot of cement 20 may be applied in paste form at the junction of the wires 4a and 5a with the crystal electrode coatings 2 and 3 respectively, by means of a pointed applicator or similar instrument to avoid getting the cement 20 outside the wire loops 4a and 5a. The amount of cement 20 used need be only enough to obtain coverage of the crystal corners and wire surfaces as illustrated at 20 in Figs. 2 and 3. The cement 20 in paste form may be dried and baked in an oven or by an infra-red lamp, for example, at a temperature sufficient to cause it to thermoset thereby providing a good mechanical bond with good electrical conductivity for securing the wires 4a and 5a to the crystal coatings 2 and 3 respectively. As an example, the conductive plastic cement 20 may consist of finely divided silver powder or other suitable conductive powder admixed with a suitable plastic binder such as Bakelite cement. The amount of powdered silver admixed with the Bakelite adhesive may be substantial or sufficient to render the spot of adhesive 20 electrically conductive. The mass 20 of conductive plastic cement functions as a mechanical supporting agent and as an electrical connective agent for the crystal element 1 and also, by reason of its plasticity, may serve to damp out undesired spurious frequencies that may be present in the corners of the crystal element 1.

As mentioned hereinbefore, the assembled wire-mounted electroded crystal element 1 may be electroplated to final frequency in one or more electroplating steps by the electrodeposition of an additional coating of nickel or other suitable metal of proper mass on top of the gold bright or other basic coatings previously formed on the bare crystal element 1. By suitable control of the electroplating current and the time required for deposit of a predetermined amount of metal forming the electrode coatings 2 and 3, the frequency of the electroplated crystal element 1 may be adjusted to a desired value. Any suitable timing and plating circuit may be used for the timing and current control of the electroplating. The plating current may be adjusted to produce a timed frequency change per second of plating time. In the case of nickel plating, electrolytic nickel or other high purity nickel anodes may be used. As an example, the solution for nickel plating may consist of a bath including nickel sulphate with sufficient nickel chloride present to insure good anode corrosion, and sufficient boric acid present to buff the cathode film and prevent it from becoming alkaline and sufficient nickel hydroxide present to insure high cathode efficiency. The solution may be treated with activated charcoal to remove impurities. In the case of nickel plating on a gold bright film base, there is an initial reduction of the gold bright base which may be compensated for by allowing extra plating time.

Alternatively, the additional coating of metal may be put on to form the crystal electrodes 2 and 3 by evaporating additional metal thereon in vacuum. The evaporated metal may be applied thereto while the crystal element 1 is being os-

cillated at its resonance frequency connected in circuit with a suitable oscillator circuit. The layer of additional metal thus put on to form the electrode coatings 2 and 3 adds to the loading of the crystal element 1 and gradually lowers its frequency. The deposition of the evaporated metal may be stopped when the observed desired frequency has been reached.

The frequency of the electroded crystal element 1 may also be adjusted to final value by applying thereto a coating of non-conductive loading material such as silicon chloride. The coating of silicon chloride not only loads the crystal element 1 and thereby lowers its frequency but also forms an enclosing protective coating therefor. As an example, the silicon compound may be applied as a solution of silica sol. The silica sol solution is a suspension of hydrated silica in acetone containing a plasticizer of polyvinyl acetate, and may be prepared by adding to ethyl alcohol normal hydrochloric acid solution and adding slowly to this solution tetraethyl silicate while the alcohol acid solution is being agitated. The solution will become noticeably warm as a result of the hydrolysis of the silicate and a clear suspension of extremely finely divided hydrated silica is thus obtained. When the suspension is cooled, acetone in which the polyvinyl acetate has been dissolved may be added and the solution is ready for use. The solution when sprayed onto the surfaces of the crystal element 1 sets quickly to a rigid solid and by spraying the crystal element 1 while it is oscillating at its natural frequency, it is possible to decrease the frequency continuously while at the same time observing the decreasing frequency. Any type of spray gun or chamber that applies a fine moist spray to one or to both major faces simultaneously of the crystal element 1 may be used.

As illustrated in Fig. 1, the supporting spring wires 4 and 5 may be straight upright wires of equal length carried by terminal pins 6 and 7 for supporting and establishing individual electrical connections with the crystal element 1. The spring wires 4 and 5 may consist of steel, phosphor bronze or other conductive spring wire material of relatively small but sufficient diameter to support the crystal element 1 from the terminal pins 6 and 7. The lower ends of the supporting spring wires 4 and 5 may be individually sprung around the terminal pins 6 and 7 and secured thereto, as by solder. The upper ends of the spring wires 4 and 5 terminating in the spring wire coils 4a and 5a respectively may be constructed either from the same wire material or from different wire materials that may be soldered or otherwise connected together electrically and mechanically. The upright wires 4 and 5 may have circular or other shaped resilient bends therein for resiliently supporting the crystal element 1, as illustrated, for example, in A. W. Ziegler Patent 2,275,122, dated March 3, 1942. The spring wire uprights 4 and 5 may be so adjusted as to have the crystal element 1 free from pressure or tension thereon from the springs 4 and 5.

The pin-type terminal prongs 6 and 7 may be provided with corrugations 8 therein which may be firmly embedded in a base 10 forming one wall of an enclosing container which may consist of the base 10 and a sealed enclosing cover 11 for the crystal element 1. The container base 10 and its cover 11 may be composed of molded material such as Bakelite, glass, ceramic or other suitable material. The cover 11 may be secured to



the base 10 by a pair of screws 12 disposed at opposite ends or sides of the base 10. A gasket 13 may extend around the entire bottom edge of the enclosing cover 11 between the cover 11 and the base 10 in order to provide an hermetic seal for the enclosing container 10 and 11. Alternatively, the cover 11 may be secured to the base 10 by fusion. In the case of a base 10 and a cover 11 composed of glass or ceramic material, the base 10 and cover 11 may be joined together around the entire outer edge periphery by applying narrow strips 14 and 15 of baked silver paste, for example, to the adjacent edges of the base 10 and cover 11 and soldering the baked silver paste strips 14 and 15 together by means of a narrow rib 16 of solder.

The sealed crystal container 10 and 11 may contain dry air or other inert gas, which may be heavier or lighter than air, and of suitable density and pressure which may be greater or less than atmospheric pressure, to control the damping or the frequency of either the desired or undesired resonance in the crystal element 1.

The enclosing container 10 and 11 when composed of glass or other dielectric material may be made to serve as the dielectric of an adjustable electrical condenser by providing oppositely disposed metal coatings 18 and 19 of baked silver paste, for example, on a portion or portions of the inner and outer walls thereof. The inside wall of the dielectric container 10 may be partially or entirely metallized by the integral conductive coating 18, and the outside thereof may be partially metallized by the conductive coating 19. By adding or subtracting from the area of the outside coating 18, the final adjustment of the capacitance of the condenser comprising the electrodes 18 and 19 and the dielectric 11 therebetween may be made. The condenser electrodes 18 and 19 may be associated with the crystal element 1 in any suitable manner such as by connecting in series or parallel circuit relation therewith in a known manner for the purpose of providing a close adjustment of the resonant or antiresonant frequency.

Where the container base 10 and cover 11 are composed of Bakelite, for example, or a gasket 13 of "neoprene" artificial rubber, for example, is used, such materials may gradually give off volatile materials which may be absorbed by the metal of the crystal electrodes 2 and 3 with a resulting slight decrease in frequency of the electroded crystal element 1 over a period of time. To filter out, absorb and prevent such volatile material or moisture from reaching the crystal element 1 and its electrodes 2 and 3, paper shields or liners, for example, which may be impregnated with charcoal or other suitable absorbing agent, for example, may be inserted as at 19 in Fig. 1 along the entire inner wall of the container 10 and 11.

As illustrated in Fig. 1, a massed weight 24 or 25 may be secured to and suspended by either or both of the supporting spring wires 4 and 5 at a node of motion therein in order to reflect motion transmitted to the wire 4 or 5 from the vibratory crystal element 1 to thereby prevent such wire motion from adversely affecting the desired crystal frequency as disclosed in United States Patent 2,371,613, granted March 20, 1945, to I. E. Fair on an application, Serial No. 470,759, filed December 31, 1942. The massed weight 24 or 25 may be in the form of a single ball, disc or globule of solder or a thin metal disc soldered to each of the wires 4 and 5 at a node of motion

therein, as disclosed in the above-mentioned patent to I. E. Fair. Alternatively, to obtain freedom from the vibrational effect of the wire support system upon the motion of the crystal element 1, a structure which is equivalent to a mechanical filter may be made by loading either or both of the wires 4 and 5 with additional massed weights 26 secured to the wires 4 and 5 at definite intervals thereon. As illustrated in Fig. 1, the combination of the wire 5, for example, loaded with massed weights 25 and 26 at definite intervals thereon is equivalent to a filter structure where  $M_1$  is the mass of the section of the wire 5 between the crystal element 1 and up to the first weight 25 having a mass  $M_2$ , and  $C_1$  is the compliance of that section of the wire 5. This filter is equivalent to a low-pass filter of the infinite type with its low pass cut off occurring when  $M_2/2$  resonates the compliance  $C_1$ . The impedance is one which goes through zero at the resonance  $M_1, C_1$  at which point the loading effect of the wire on the crystal element 1 will be small. A second weight 26 similarly spaced on the wire 5 additionally decreases the effect of the end termination on the resonance of the crystal element 1.

Although this invention has been described and illustrated in relation to specific arrangements, it is to be understood that it is capable of application in other organizations and is, therefore, not to be limited to the particular embodiments disclosed but only by the scope of the appended claims and the state of the prior art.

What is claimed is:

1. A conductive wire support for a piezoelectric crystal element comprising a spring wire coil of substantially helical form having adjacent turns thereof sprung over and straddling a corner edge only of said crystal element and exerting a clamping pressure on said corner in a direction substantially normal to the major faces of said crystal element.
2. A conductive wire support for a piezoelectric crystal element comprising a spring wire coil of substantially helical form having adjacent turns thereof sprung over and straddling a corner edge only of said crystal element and exerting a clamping pressure on said corner in a direction substantially normal to the major faces of said crystal element, and means including a conductive spring wire comprising an extension of the wire forming said spring wire coil for supporting said spring wire coil and said crystal element.
3. A conductive wire supporting system for a piezoelectric crystal element having an electrode coating formed integral with a major face thereof comprising a conductive spring wire coil of substantially helical form having two adjacent turns thereof sprung over and straddling an edge of said crystal element, one of said adjacent turns of said coil being in contact with said electrode coating on said major face adjacent said edge of said crystal element, and the axis of said spring wire coil being substantially perpendicular to said major face of said crystal element.
4. A conductive wire supporting system for a piezoelectric crystal element having an electrode coating formed integral with a major face thereof comprising a conductive spring wire coil of substantially helical form having two adjacent turns thereof sprung over and straddling an edge of said crystal element, one of said adjacent turns of said coil being in contact with said electrode coating on said major face adjacent said edge of said crystal element, the axis of said



spring wire coil being substantially perpendicular to said major face of said crystal element, conductive adhesive means for securing the wire of said one of said turns to said electrode coating, and means including a conductive spring wire comprising an extension of the wire forming said spring wire coil for supporting said spring wire coil and said crystal element.

5. Piezoelectric crystal apparatus comprising a piezoelectric crystal element, electrodes on the opposite major faces of said crystal element comprising conductive coatings formed integral with said major faces and extending independently to different corners of said crystal element, and conductive supports contacting said coatings adjacent said corners only and establishing individual electrical connections with said electrode coatings, each of said supports comprising a spring wire terminated in a spring wire coil having adjacent turns thereof sprung over and holding one only of said corners in contact with one of said electrode coatings, the axis of each of said spring wire coils being substantially perpendicular to said major faces of said crystal element.

6. Piezoelectric crystal apparatus comprising a piezoelectric crystal element having substantially rectangular major faces, conductive coatings formed integral with the opposite major faces and extending independently to diagonally opposite corners of said crystal element, means including conductive supporting spring wires terminated in spring wire coils each having adjacent turns sprung over one only of said corners for mounting said crystal element at said corners and for establishing individual electrical connections with said coatings at said corners, and conductive adhesive means securing said wire coils to said corners and establishing individual electrical connections with said conductive coatings at said corners.

7. A thickness-mode piezoelectric crystal element having substantially rectangular opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of said thickness-mode frequency thereof, a pair of conductive coatings formed integral with said opposite major faces, said conductive coatings being disposed opposite each other at the central portions only of said major faces and forming electric field-producing electrodes spaced entirely inwardly of all of the peripheral edges of said major faces, one of said coatings on one of said major faces extending to one corner of said crystal element and the other of said coatings on the other of said major faces extending to another corner of said crystal element, conductive supporting spring wires comprising a pair of spring wire coils each having adjacent turns sprung over one of said corners for mounting said crystal element at said corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means securing said supporting wires to said corners and establishing individual electrical connections with said conductive coatings at said corners.

8. A thickness-mode piezoelectric quartz crystal element having substantially rectangular opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of said thickness-mode frequency thereof, a pair of conductive coatings formed integral with said opposite major faces, said conductive coatings

being disposed opposite each other at the central portions only of said major faces and forming electric field-producing electrodes spaced entirely inwardly of all of the peripheral edges of said major faces, one of said coatings on one of said major faces extending to one corner of said crystal element and the other of said coatings on the other of said major faces extending to another corner of said crystal element, conductive supporting spring wires comprising a pair of spring wire coils each having adjacent turns sprung over one of said corners for mounting said crystal element at said corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means comprising conductive plastic cement securing said supporting wires to said corners and establishing individual electrical connections with said conductive coatings at said corners.

9. A thickness-mode piezoelectric quartz crystal element having substantially rectangular opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of said thickness-mode frequency thereof, a pair of conductive coatings formed integral with said opposite major faces, said conductive coatings being disposed opposite each other at the central portions only of said major faces and forming electric field-producing electrodes spaced entirely inwardly of all of the peripheral edges of said major faces, one of said coatings on one of said major faces extending to one corner of said crystal element and the other of said coatings on the other of said major faces extending to the diagonally opposite corner of said crystal element, conductive supporting spring wires comprising a pair of spring wire coils each having adjacent turns sprung over one of said corners for mounting said crystal element at said corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means securing said supporting wires to said corners and establishing individual electrical connections with said conductive coatings at said corners.

10. A thickness-mode piezoelectric quartz crystal element having substantially rectangular opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of said thickness-mode frequency thereof, a pair of conductive coatings formed integral with said opposite major faces, said conductive coatings being disposed opposite each other at the central portions only of said major faces and forming substantially circular shaped electric field-producing electrodes spaced entirely inwardly of all of the peripheral edges of said major faces, one of said coatings on one of said major faces extending to one corner of said crystal element and the other of said coatings on the other of said major faces extending to the diagonally opposite corner of said crystal element, conductive supporting spring wires comprising a pair of spring wire coils each having adjacent turns sprung over one of said diagonally opposite corners for mounting said crystal element at said corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means securing said supporting wires to said corners and establishing individual electrical connections with said conductive coatings at said corners, the thickness of said crystal coatings being



made of a value corresponding to the value of the thickness-mode frequency desired for said coated crystal element, and said coatings comprising gold applied to said crystal element.

11. A thickness-mode piezoelectric quartz crystal element having substantially rectangular opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of said thickness-mode frequency thereof, a pair of conductive coatings formed integral with said opposite major faces, said conductive coatings being disposed opposite each other at the central portions only of said major faces and forming electric field-producing electrodes spaced entirely inwardly of all of the peripheral edges of said major faces, one of said coatings on one of said major faces extending to one corner of said crystal element and the other of said coatings on the other of said major faces extending to the diagonally opposite corner of said crystal element, conductive supporting spring wires comprising a pair of spring wire coils each having adjacent turns sprung over one of said diagonally opposite corners for mounting said crystal element at said corners and establishing individual electrical connections with said coating at said corners, and conductive adhesive means securing said supporting wires to said corners and establishing individual electrical connections with said crystal coatings at said corners, the thickness of said crystal coatings being made of a value corresponding to the value of the thickness-mode frequency desired for said coated crystal element, and said coatings comprising an electroplated metal.

12. A thickness-mode piezoelectric crystal element having substantially rectangular shaped opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of the thickness-mode frequency of said crystal element, a pair of substantially equal size and oppositely disposed field-producing conductive coatings formed integral with the central portions of said opposite major faces and spaced entirely inwardly of all of the peripheral edges of said major faces, and a pair of relatively narrow connective conductive coatings formed integral with said opposite major faces and extending from said field-producing conductive coatings to two different corners of said crystal element, conductive supporting spring wires comprising a pair of spring wire coils each having adjacent turns sprung over one of said corners for mounting said crystal element at said corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means securing said supporting wires to said corners and establishing individual electrical connections with said conductive coatings at said corners.

13. A thickness-mode piezoelectric quartz crystal element having substantially rectangular shaped opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of the thickness-mode frequency of said crystal element, a pair of substantially equal size and oppositely disposed field-producing conductive coatings formed integral with the central portions of said opposite major faces and spaced

entirely inwardly of all of the peripheral edges of said major faces, and a pair of relatively narrow connective conductive coatings formed integral with said opposite major faces and extending independently from said field-producing conductive coatings to two diagonally opposite corners of said crystal element, conductive supporting spring wires comprising a pair of spring wire coils each having adjacent turns sprung over one of said diagonally opposite corners for mounting said crystal element at said corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means securing said supporting wires to said diagonally opposite corners and establishing individual electrical connections with said conductive coatings at said corners.

14. A thickness-mode piezoelectric quartz crystal element having substantially rectangular shaped opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of the thickness-mode frequency of said crystal element, a pair of oppositely disposed field-producing conductive coatings formed integral with the central portions of said opposite major faces and spaced entirely inwardly of all of the peripheral edges of said major faces, and a pair of relatively narrow connective conductive coatings formed integral with said opposite major faces and extending independently from said field-producing conductive coatings to two diagonally opposite corners of said crystal element, conductive supporting spring wires comprising a pair of spring wire coils each having adjacent turns sprung over one of said corners for mounting said crystal element at said diagonally opposite corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means comprising conductive plastic cement securing said supporting wires to said corners and establishing individual electrical connections with said conductive coatings at said corners.

15. Piezoelectric crystal apparatus comprising a piezoelectric crystal element having conductive electrode coatings formed integral with the opposite major faces thereof, and supporting conductive spring wire coils each having adjacent turns thereof sprung over and straddling an edge of said crystal element in contact with one of said electrode coatings on one of said major faces, said coatings comprising basic coatings on said major faces, and an additional or outer coatings added upon at least a portion of one of said basic coatings, the mass of said added coating being made of a value corresponding to the value of the final frequency desired for said coated crystal element for fixing said final frequency thereof.

16. Piezoelectric crystal apparatus in accordance with claim 15 wherein said basic coatings comprise gold adhering to said crystal element, and said added coating comprises evaporated metal adhering to said basic gold coating.

17. Piezoelectric crystal apparatus in accordance with claim 15 wherein said basic coatings comprise gold adhering to said crystal element, and said added coating comprises electroplated nickel adhering to said basic gold coating.

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