

March 20, 1945.

I. E. FAIR

2,371,613

PIEZOELECTRIC CRYSTAL APPARATUS

Filed Dec. 31, 1942

3 Sheets-Sheet 1

FIG. 1

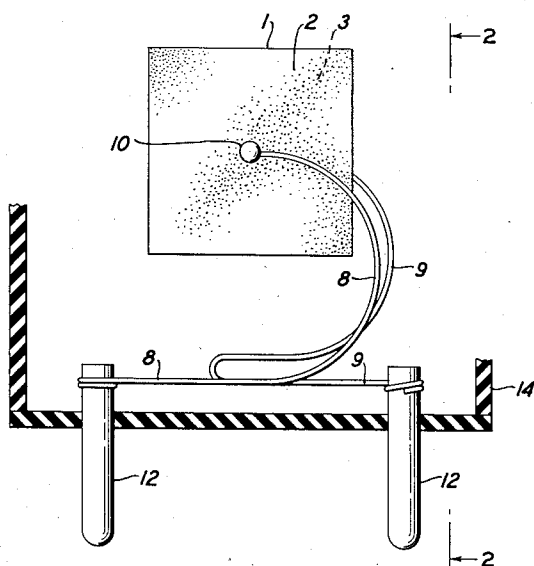


FIG. 2

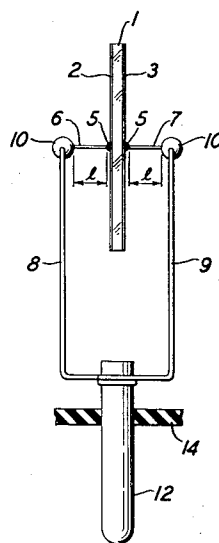


FIG. 3

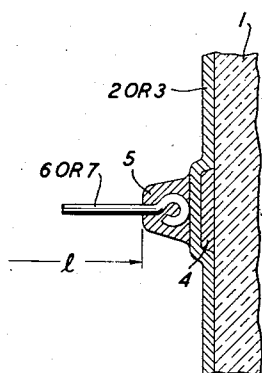
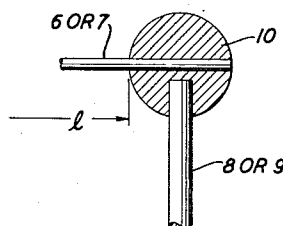


FIG. 4



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FIG. 5

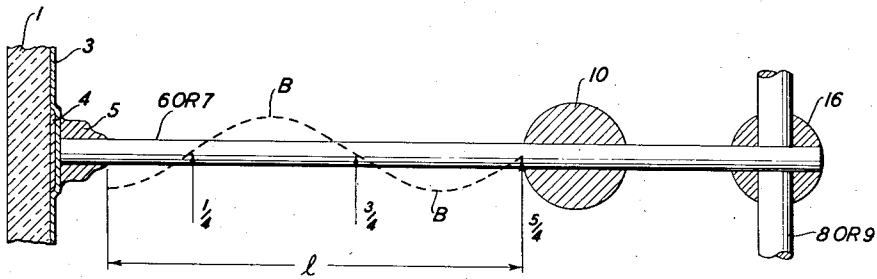


FIG. 6

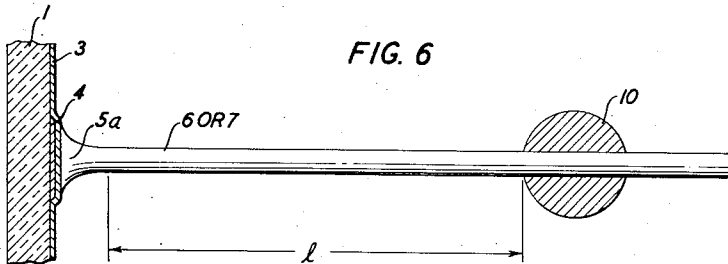


FIG. 7

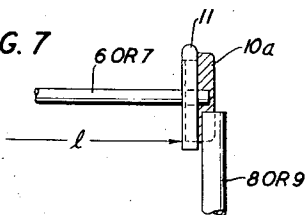


FIG. 8

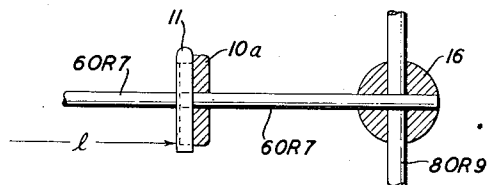
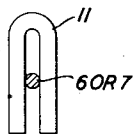


FIG. 9



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PIEZOELECTRIC CRYSTAL APPARATUS

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FIG. 10

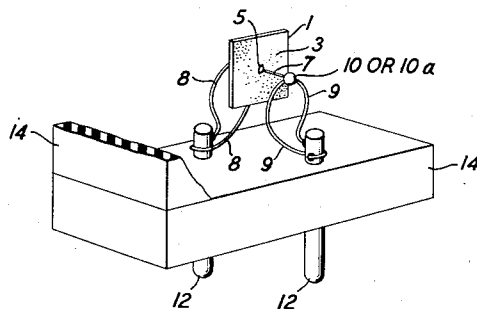


FIG. 11

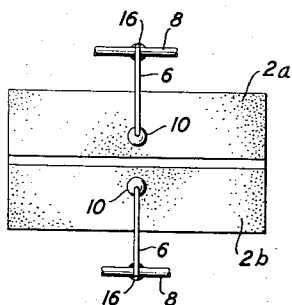


FIG. 12

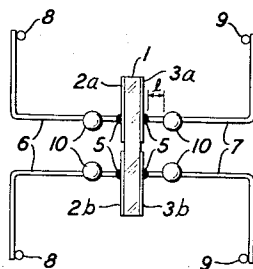


FIG. 13

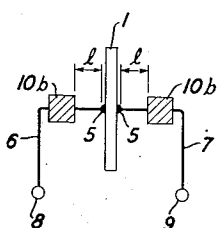


FIG. 14

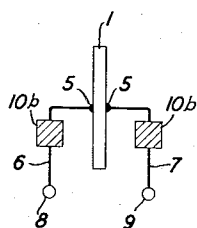


FIG. 15

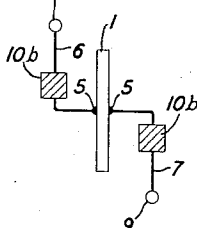


FIG. 16

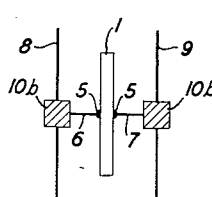
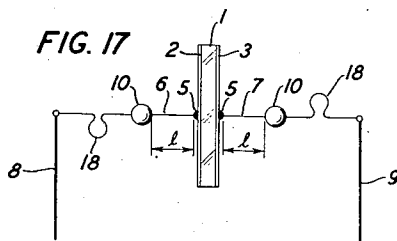


FIG. 17



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2,371,613

PIEZOELECTRIC CRYSTAL APPARATUS

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Application December 31, 1942, Serial No. 470,759

16 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystal apparatus, and particularly to wire support systems for piezoelectric crystal elements useful, for example, in oscillation generator systems, filter systems, and in electromechanical vibratory systems generally.

One of the objects of this invention is to prevent wire vibrations in wire-supported piezoelectric crystals from adversely affecting the desired crystal vibration.

Another object of this invention is to reduce the effects of vibrations in crystal supporting wires upon the crystal activity and frequency.

Another object of this invention is to improve the activity and the frequency stability of wire-supported crystal elements.

In order that a piezoelectric crystal may vibrate freely, it is desirable that the means used to support the crystal and to maintain contact with its plated electrode surfaces have a low mechanical impedance and at the same time have sufficient rigidity that the complete crystal unit assembly when subjected to mechanical shock or other externally applied vibration may not change its characteristics as an oscillator. If a crystal supporting spring wire be fastened or otherwise held against the crystal at any point, the crystal when in an oscillating condition will tend to generate motion in the support wire in contact therewith, and the closer the support wire is placed to the nodal point of the crystal, the less will be the motion generated by the crystal in the support wire. Accordingly, the crystal supporting wires may be placed as close as possible to a nodal point of the crystal and also so constructed as to have a very low mechanical impedance at or near the desired operating frequency or frequencies of the crystal. A type of support which meets this requirement is that of a thin spring wire or rod vibrating in flexure, one end thereof being in effect clamped at or near a wire node and the other end being free to vibrate in contact with the surface of the crystal, the length thereof being such that its frequency of antiresonance equals that of the crystal, or approximately so, so that very little energy from the crystal is required to drive the supporting wire, and any energy received by the supporting wire from the crystal is reflected from the clamped end of the supporting wire and thereby kept within the composite vibrating system.

In piezoelectric crystal devices of the spring wire supported type such as, for example, those disclosed in A. W. Ziegler Patent 2,275,122, dated March 3, 1942, the wire support system may be set

into vibration as a result of the vibration of the crystal element which is suspended by such supporting wires, and the wire vibration may adversely affect the desired crystal vibrational frequency or render it sluggish in vibration or prevent its operation altogether in some cases. These adverse effects may be the more pronounced where the crystal element is relatively very small in size or where the supporting wires are not attached to the crystal element at or very near to a node thereof.

In accordance with this invention, a wire-supported crystal may be provided with massed weights or clamps placed on and suspended by the crystal supporting conductive lead wires, the massed weights being not only of sufficient mass but also of suitable location with respect to the nodes of the supporting wires as to prevent vibrations in the supporting wire system from adversely affecting the activity or the desired frequency vibration of the crystal element.

In accordance with a feature of this invention, a small solder globule or ball or other suitable mass may be placed or cast firmly on the flexible spring supporting wire or wires at a selected location between the crystal and the far or outermost end of the supporting wire system. More particularly, the small solder ball may be placed at or near a node of each supporting wire and away or remote from the loop of motion thereof, the effective wire length between the crystal element and the solder ball being thereby made to have a natural frequency which is fundamentally or harmonically related to the desired crystal frequency, and the solder ball being made of a mass sufficient to prevent the crystal lead wire vibration from passing therethrough to the far or outermost portion of the spring wire support remote from the crystal. Such small weights or loads of metal as lead-in solder balls placed on and suspended by the crystal supporting wires substantially at a node of motion thereof and made of adequate mass will function to reduce damping and improve the Q and operation of such wire mounted crystals.

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 drawings, in which like reference characters represent like or similar parts and in which:

Figs. 1 and 2 are enlarged front and side views respectively of a piezoelectric crystal mounting

embodying this invention, Fig. 2 being a view taken on the line 2—2 of Fig. 1;

Fig. 3 is an enlarged detail view showing a support wire attached to the crystal by means of a solder cone soldered to a baked silver paste spot on the crystal element;

Fig. 4 is an enlarged detail view showing a spherical solder ball joining the ends of two wires forming a wire support for a piezoelectric crystal device;

Fig. 5 is a greatly enlarged detail view of a crystal supporting wire fastened at one end to the crystal by means of a bell-shaped solder cone, and extending straight through a solder ball to an outer support;

Fig. 6 is an enlarged detail view showing a modification of the crystal supporting wire of Fig. 5;

Figs. 7, 8 and 9 are enlarged views showing the use of a nodal soldered stirrup as a substitute for the nodal solder ball of Figs. 1, 2, 4, 5 and 6;

Fig. 10 is a perspective view of a modification of the crystal mounting shown in Figs. 1 and 2;

Figs. 11 and 12 are respectively face and end views of a four-wire support system as applied particularly to a longitudinal mode type of crystal element; and

Figs. 13 to 17 are views showing various modifications of the invention.

Referring to the drawings, Figs. 1 and 2 are enlarged front and side views of a piezoelectric crystal device comprising a face-mode quartz crystal element 1 having opposite, conductive electrode coatings 2 and 3 formed integral therewith and thickened at the central regions of support 4 where two horizontal or laterally extending supporting fine spring lead wires 6 and 7 are soldered thereto by means of two small solder dots or cones 5. The outer ends of the two horizontal lead wires 6 and 7 are welded or soldered by a cast solder ball or other metallic mass 10 to the top ends of two supporting upright semi-circular spring wires 8 and 9 which may be a part thereof. The lower ends of the wires 8 and 9 are wound around and soldered to two pin terminals 12 of an enclosing container 14, which may be hermetically sealed or evacuated and constructed of any suitable size, shape and material.

The flexible spring wires 6, 7, 8, 9 function to resiliently support the electroded crystal element 1 and to establish individual electrical connections with its opposite electrode coatings 2 and 3, and may be composed of phosphor bronze wire, spring-tempered and tinned, tinned steel piano wire or of other suitable springy conductive material. The lead wires 6 and 7 may consist of fine spring wires of about .005-inch diameter, for example, and the support wires 8 and 9 may be of the same or slightly larger diameter, as may be required to support the crystal element 1.

It will be understood that the crystal element 1 may be of any type that it may be desired to mount, such as, for example, a quartz crystal element of the face shear mode type having its node or point of minimum motion at or near the center of the crystal element. Examples of such face shear mode crystals are disclosed, for example, in G. W. Willard United States Patent 2,268,365, issued December 30, 1941.

To obtain stability in its resonant resistance, the bare quartz plate 1 may be uniformly etched in hydrofluoric acid, for example, to remove any particles of quartz dust left in the small crevices of the quartz plate 1 that are not tightly bonded

to it and which may by their presence hinder the motion of the crystal plate 1 when in operation. The etching referred to should not be overdone inasmuch as with too much etching, the silver coatings 2 and 3 may have a tendency to flake off near the edges and corners of the crystal with a resulting absorption of energy from the crystal plate 1 and a decreased Q thereof. When the etching bath is agitated, the time of etching may be decreased and some improvement in uniformity of resonant resistance may be obtained. Also, the thickness of the crystal plate 1 may be adjusted to a suitable value relative to its major face dimensions in order to avoid nearby or coupled undesired frequencies or modes of motion therein, that may interfere with the desired resonance. Among the undesired modes of motion prevalent in quartz crystals are the harmonic flexure modes vibrating along the thickness and propagated along the width and length of the crystal plate 1. Accordingly, the thickness of the crystal plate 1 may be adjusted relative to the major face dimensions in order to place undesired modes in regions that do not conflict with the desired main resonant frequency or with any desired secondary resonance thereof.

The crystal coatings 2 and 3 may consist of any suitable conductive coating such as, for example, a very thin coating of silver applied to the crystal surfaces by evaporation in vacuum or by other suitable process. At the points where the lead wires 6 and 7 are to be attached, a small spot 4 of baked silver paste may be applied to the quartz and baked firmly thereon in a known manner. Fig. 3 is a detail showing a circular-shaped baked silver paste spot 4 which has been baked onto the quartz crystal 1 at or near a node thereof, a thin electrode film 2 or 3 of evaporated silver being applied thereover and a lead wire 6 being soldered to the baked silver paste spot 4 by means of a small solder dot or cone 5. The lead wire 6 may have its end firmly embedded in the solder cone 5, as illustrated in Fig. 3.

For purposes of mechanical strength and electrical conductivity, a good joint is needed between the crystal 1 and the supporting lead wire 6 and also between the lead wire 6 and the mount wire 8. The silver spot 4 may be burnished or otherwise cleaned in order to obtain a clean surface for soldering the supporting wire 6 or 7 thereto. The proper shaping of the solder cone 5 results in a stronger joint between the lead wire 6 or 7 and the silver spot 4. If the solder cone 5 is made too high and too narrow, it may under stress at the base thereof pull off from silver spot 4, and if the solder cone 5 is made too low in height, a straight-ended lead wire 6 or 7 may under stress pull out from the solder cone 5. If desired, the end of the lead wire 6 or 7 may be bent at right angles, or bent in hook form as illustrated in Fig. 3, in order to prevent it from pulling out from the solder cone 5. If desired, the soldering may be done by indirect heating such as by hot air blast or radiated heat, for example, in order to prevent possible damage to the crystal by direct heating.

The lead wires 6 and 7 may be soldered to the silver spot 4 on the crystal by using a small disc or pellet of solder placed therebetween and then fused to have the approximate cone or bell shape as shown in Fig. 3. The disc of solder referred to may initially be of about .019-inch diameter by .015-inch thick or equivalent or other suitable volume, and may be composed of 40 per cent lead,

60 per cent tin with about 0.1 per cent silver added. The small quantity of silver is added to prevent the solder from absorbing the silver from the silver coatings 2, 3 and 4. A rosin alcohol flux in the proportion of 2 grams rosin to 8 ounces alcohol may be used for soldering. After soldering, a camel's hair brush may be used to wash the soldered joint with denatured alcohol.

Since the Q or ratio of mass reactance to resistance of ordinary soft solder itself such as, for example, solder composed of 50 per cent tin and 50 per cent lead is rather low and decreases further with an increase of temperature, and since the solder dot 5 occupies a moving area on the crystal surface and the same type of motion occurs in the solder 5 as that of the crystal in contact therewith, the effect of the solder dot 5 may be minimized by making it as small as possible and by placing it as near as possible to a crystal node thereby to minimize absorption of energy in the solder with resulting decrease of activity of the crystal 1. The effect of the solder dot 5 on the activity of the crystal 1 may also be minimized by using a tin-antimony solder or other hard solder instead of the ordinary soft lead-tin solder since the former may have a better Q at the upper operating temperature limits due to its higher melting point. Accordingly, by using a hard solder such as, for example, a solder composed of 95 per cent tin and 5 per cent antimony, the effect of decreasing crystal activity at high temperatures may be eliminated or reduced. This effect may also be reduced by limiting the amount of solder 5, whether hard solder or soft solder is used. A lead-tin eutectic solder composed of 63 per cent tin and 37 per cent lead will permit less solder to be used at the crystal joint 5 and thereby reduce the amount of coupling to the supporting wire system. The effects produced by using different size solder dots 5 and different placement of the lead wires 6 and 7 on the crystal can be determined by their effects on the constants of the crystal 1. Typical constants for face shear mode CT crystals are: ratio of capacities—350 and Q —15,000 to 30,000. The main effect of large solder dots 5 on the crystal is to reduce the Q since motion will be transmitted to it from the crystal 1. The amount as well as the shape of the solder 5 at the crystal will affect the Q of the crystal 1.

Fig. 4 is an enlarged detail showing the use of the spherical solder ball 10 for joining together the two ends of the lead wire 7 and the upright spring wire 9 embedded therein. While the supporting spring wires 8 and 9 of Figs. 2 and 4 are therein shown in a particular position, namely, in planes at right angles with respect to the substantially coaxial lead wires 6 and 7, it will be understood that they may extend from the solder balls 10 in any direction. As illustrated in Figs. 1 and 2, the upright spring wires 8 and 9 may have semicircular, circular or other bends therein to provide a resilient support for the crystal element 1. As particularly illustrated in Figs. 1 and 2, the semicircular springs 8 and 9 may be in planes that are substantially parallel with respect to each other; or they may be inclined inwardly towards the crystal, or outwardly and away therefrom. The bent portions thereof may be elliptical or semicircular and may be of substantially the same shape and size having their curved or bent portions extending from the same side of the horizontal coaxial lead wires 6 and 7, as shown in Fig. 1, in order to prevent twisting of

the horizontal lead wires 6 and 7 soldered thereto, whenever the crystal device is subjected to externally applied shock or jar, as may occur, for example, in mobile installations or during transportation.

Fig. 5 is a greatly enlarged detail view of the crystal lead wire 6 or 7 arranged to extend straight through the solder ball 10, and having a bell-shaped solder cone 5 for fastening the lead wire 6 or 7 to the crystal coating 2 or 3. This bell-shaped type of solder cone 5 allows the lead wire 6 or 7 to be twisted in handling without much danger to breaking away the top or apex of the cone 5 and thereby forming a crater. For the purpose of analysis, the solder cone 5 is assumed to become part of the crystal 1 and to move with it, and the length of the lead wires 6 and 7 vibrating in flexure is computed or determined from the top or apex of the solder cone 5 as described hereinafter. The amount of solder used in the cone 5 is kept at a minimum in order that the constants of the crystal equivalent circuit may not be modified too much by it. The effect of the solder in the cone 5 on the equivalent circuit is to raise the resistance in the equivalent circuit for the crystal and this resistance may increase with an increase in temperature. Accordingly, the amount of solder permissible in the cone 5 is determined by the maximum temperature at which the crystal unit is to be operated and the minimum Q allowable for the crystal unit.

As illustrated in Fig. 5, the lead wire 6 or 7 extends straight through the solder ball 10 which is suspended thereby and is attached to the support wire 8 or 9 by any suitable means such as a solder joint 16. Alternatively, instead of soldering, the lead wires 6 and 7 may be spot welded at 16, to the supporting spring wires 8 and 9 without softening the phosphor bronze lead wires 6 and 7 to any appreciable extent. A very tight bond at 16 is obtained by such spot welding. Also, a solder pellet may be placed on the joint 16 and spot welded at the same time in order to add weight at the joint 16, if it is found necessary to add additional weight at this joint in order to keep standing waves off the mounting spring wires 8 and 9.

Fig. 6 is a greatly enlarged view illustrating another type of crystal wire support utilizing a headed wire at 5a, in place of a solder cone 5 of Fig. 5, for attaching the lead wire 6 or 7 to the crystal 1. The headed wire end 5a may be similar to that of an ordinary nail head and may be connected to the crystal coating 4 by sweating the wire head 5a to the crystal coating 4. The wire head 5a may be a machined part and may be made of constant or uniform dimensions for many or all types of mountings. The amount of solder necessary to sweat the wire head 5a to the silver spot 4 of the crystal 1 is considerably less than that used in a solder cone 5, and hence the headed wire form of mounting 5a as illustrated in Fig. 6 will have less dissipation of energy at the higher temperatures. Moreover, the coupling between the vibrating system of the wires 6 and 7 and the vibrating system of the crystal 1 is reduced by the use of the headed wire 5a shown in Fig. 6. This results in reducing what may be termed a double system of standing waves on the wires 6 and 7, one resulting from reflections from the solder ball 10 or clamped end of the wire, and the other resulting from reflections between the two or more resonant wires 6 and 7 coupled through the crystal 1. These

effects may be reduced by a reduction of the coupling between the crystal 1 and the wire vibrating systems 6 and 7. It is difficult if not impractical to try to balance the solder cones 5 sufficiently to prevent the crystal motion from being transmitted to the lead wires 6, 7, 8, 9. In most cases, the considerable amount of crystal motion transmitted to the lead wires 6, 7, 8, 9 may be sufficient to set up standing waves therein.

Instead of using the integral form of headed wire 5a, the nail head form of Fig. 6 may consist of a metal washer having a small central opening of about the same size as the outer boundary of the wire 6 or 7, the washer opening being placed on the extreme end of the wire 6 or 7 and soldered both to the wire 6 or 7 and crystal coating 4 at the same time. By proportioning the thickness and the diameter of the washer, the joints between the wire and washer and between the washer and crystal plating may be made to have the same strength. If desired, the washer may be stamped cone-shape, the larger diameter of the cone being placed at the joint between the washer and the crystal plating 4.

As stated hereinbefore, the ends of the support wires 6 and 7 attached to the crystal 1 move with the crystal motion at the region of attachment, whether a shear, longitudinal, flexure or other type of face-mode or thickness-mode vibration is employed in the crystal 1.

The effect of the wire support system on the crystal frequency may be reduced by increasing the size of the crystal element 1, thus increasing the ratio of mass of the crystal 1 with respect to the mass of the wire supports. In the case of face-mode crystals the frequency of which is determined mainly by the major face dimensions, the thickness dimension may be conveniently increased in order to increase the crystal mass relative to the supporting wire system. Since in practice the lead wires 6 and 7 are not ordinarily attached to the crystal exactly at a nodal point thereof, some of the motion of the crystal 1 is imparted to the lead wires 6 and 7 which support the crystal 1, and the lead wires, therefore, become a part of the mechanically vibrating system. If the lead wires 6 or 7 should be terminated at or too near a loop or point of maximum motion thereof, such as multiple half wavelengths of the desired crystal frequency, a high mechanical impedance would be presented at the point of contact 5 between the crystal 1 and the lead wires 6 and 7, which would tend to prevent motion of the crystal 1 and absorb energy from it with resulting increased resistance at resonance, and where there are several supporting lead wires on the crystal 1, considerable energy may be absorbed from the crystal 1.

It is possible to damp or dissipate the motion in the wires 6, 7, 8, 9 by placing thereon along the entire lengths thereof some damping or dissipative medium such as, for example, rubber cement, cotton sleeving, gold or other soft metal plating or other viscous material. Such dissipative media on the supporting lead wires may be used to improve the activity of the crystal 1, but at the same time they tend to reduce the springiness of the lead wires 6, 7. Alternatively, instead of using such dissipative media, the crystal activity and stability may be improved by using a properly placed single massed weight 10 on each of the lead wires 6 and 7 in order to reflect, rather than to dissipate, the wave motion therein. By the use of such weights 10, harmful vibrations in the crystal supporting leads 6,

7, 8, 9 connecting the crystal 1 with the mounting posts 12 may be eliminated by compelling the lead wires 6 and 7 adjacent the crystal plating 4 to vibrate in effect as a clamped-free bar between the weights 10 on the lead wires and the crystal 1. The weights 10 may consist of any suitable massed weight fastened to the lead wires 6 and 7 at a proper point thereon. The proper point is at or near the wire nodal point or that at which the portion of the lead wires 6 and 7 between the solder dot 5 on the crystal 1 and the weight 10 acts as a clamped-free bar in resonance to the motion transmitted to the wires 6 and 7 by the crystal 1. The remaining portions of the lead wires between the weight 10 and its far ends 12 may be bent or mounted in any manner without affecting the activity or frequency of the crystal 1 to any appreciable extent.

Fig. 5 illustrates the type of motion in the lead wires 6 and 7 which are displaced roughly as indicated by the displacement of the dotted line from the solid lines 6 or 7. The arrows in Fig. 5 indicate nodal points on the lead wires 6 and 7. Less damping is introduced into the crystal 1 when the weight 10 is placed at or near one of the wire nodal points. The weights 10 may be placed off the wire nodal points up to about a quarter of the distance between the nodes providing the motion transmitted to the wire 6 or 7 is not so great as to effect too much damping of the crystal 1. The allowable variation in any case depends upon the amount of motion in the lead wires 6 and 7, and the size of the crystal 1 relative to its supporting wire system.

When the solder mass 10 is substantially nodally located on the support wires 6 and 7 and is of sufficient mass relative to the support wires, the support wires 6 and 7 between the mass 10 and the crystal element 1 become a composite vibrator at the crystal frequency and the support wires 8 and 9 between the solder mass 10 and the fixed base 12 do not affect the crystal vibration adversely. Loads 10 so placed on the mount wire system of the crystal 1 preserve high crystal activity or high "Q," and low activity of the crystal 1 resulting from coupling between the vibrating wire supports and the crystal 1 may be avoided. The procedure of placing the weights 10 at the nodal regions on the wire supports controls the mechanical coupling between the crystal and the crystal supporting wire system. The mass 10 is added at a specified distance along the lead wires 6 and 7 on both sides of the crystal 1 to cause reflection of the flexure vibrations produced on the lead wires 6 and 7 by the crystal 1 when it is operated. The distance is selected to cause maximum output in the crystal oscillator unit. The solder balls 10 are placed on the lead wires 6 and 7 at or near a node thereof corresponding to the frequency of the crystal. Since in most cases the solder ball 10 need not be exactly at a node of the lead wires, the wire length between the solder ball 10 and the crystal element 1 may be a fixed value representing a compromise suitable for use with crystals of different frequencies but which are not too widely different in frequencies.

The small balls of solder 10 are placed $\frac{1}{4}$, $\frac{3}{4}$, $\frac{5}{8}$, etc. of a wavelength of the waves produced on the lead wires 6 and 7 from the top or apex of the solder cone 5. Depending upon the particular design, the solder balls 10 may be about .060 inch in diameter or of other suitable value to give a mass sufficient to prevent motion on the outer support wires 8 and 9 from adversely affecting the crystal vibration. When such solder weights

10 are used on and suspended by the wires 6 and 7, the ends of the lead wires 6 and 7 beyond the weights 10 may be soldered to the supports at any point without affecting the crystal resonant frequency or activity. The size of the solder ball weight 10 is determined just sufficient to prevent vibration from the crystal 1 from being transmitted past the weight 10. This allows the support to be fastened at any point on the wire support on the side of the weight 10 away from the crystal 1. The weight for one particular case was about 1.5 milligrams of solder. Only a small amount of mass 10 is necessary and where the mass 10 is a damped material such as a lead-tin solder, there will be little or no motion of the wires outside the load points 10. Any suitable means may be employed to space and place the nodal solder ball 10 at a given distance from the crystal surface.

Accordingly, with the lead wires 6 and 7 soldered onto the crystal platings 4, each soldered junction 5 itself moves and generates a transverse wave in the lead wires 6 and 7, the motion being roughly indicated by the dotted line in Fig. 5. When the lead wire 6 or 7 is soldered by the solder ball 10 at a point corresponding to a nodal point on the lead wires 6 and 7, there is no adverse reaction on the crystal. But if the lead wire 6 or 7 should be soldered at a point B, which is a loop or point of maximum motion in the lead wire 6 or 7, the effect is to offer a high mechanical impedance at the point of contact 5 with the crystal 1 which would be reflected as a lowering of the activity of the crystal 1. The nodes and loops on the lead wires 6 and 7 may be determined by trial, as by using a fixed clamp support on the lead wires 6 and 7 at various distances from the crystal 1. When the clamp occurs at a loop of motion in the lead wire 6 or 7, the oscillator activity may decrease to zero. The effects of clamping the lead wires 6 and 7 over wide ranges around the wire nodes thereof is to give a change in crystal frequency, the amount of which will be determined by the coupling between the lead wires 6 and 7 and the crystal 1. A clamp or weight 10 placed at or near a node of motion on the lead wires 6 and 7 gives good activity for the crystal unit and stabilizes the frequency.

The motion in the lead wires 6 and 7 is roughly that of a round rod vibrating in clamp-free flexure. However, this is not strictly a case of pure clamp-free effect, since the point of contact 5 with the crystal 1, which is the assumed free end, is restricted to a small slope, and the other end at the solder ball 10 is more of a yielding type support than a fixed type of clamp.

The frequency f of a spring phosphor bronze clamp-free long rod or wire vibrating in flexure is given by the equation:

$$f = \frac{m^2 dv}{8\pi l^2} \quad (1)$$

where

v = transmission velocity of longitudinal waves in centimeters per second

d = diameter of rod in centimeters or the direction of particle motion

l = length of rod in centimeters or direction of propagation

$m = 1.875$ for the first flexure mode; and $=(n - \frac{1}{2})\pi$ for the second, third, etc. flexure mode where n is the numerical order of the mode of vibration as 2, 3, etc.

From Equation 1, the length of a given rod or wire at a given frequency may be computed.

As an example, assuming a 100-kilocycle per second crystal 1 using a spring phosphor bronze wire rod of 1 millimeter in diameter, the length l of such clamp-free wire rod for the first mode will be

$$l = 1.875 \sqrt{\frac{1 \times 3.6 \times 10^6}{8\pi \times 10^6}} = .225 \text{ centimeter}$$

and for the second mode will be $l = .567$ centimeter.

As another illustrative example for a phosphor bronze lead wire 6 or 7 of .0063 inch diameter acting as a clamp-free support, the length l thereof to have a frequency of 164 kilocycles per second is for the first mode $l = .0277$ inch.

These illustrative values from Equation 1 indicate approximate nodal points on the lead wires 6 and 7 where the wire 6 or 7 may be clamped so that the mechanical impedance of the wires 6 or 7 at the crystal 1 will be so low that its restriction to the motion of the crystal 1 will be negligible. The Q of the crystal 1 will decrease as the lead wire anti-nodes or loops are approached, which occur half-way between the values given by Equation 1, and the decrease in Q will be proportional to the degree of coupling between the two mechanical systems constituting the wire system and the crystal 1.

Also, as indicated by Equation 1, the proper length of the lead wire 6 or 7 varies inversely as the square root of the frequency, and, accordingly, where the same lead wires 6 and 7 are used to support a crystal 1 having more than one effective resonance frequency, the distance to the lead wire solder ball 10 must be a compromise in order to isolate the supporting system at both the lower and the higher resonances.

The simple flexure formulas (1) apply in the case of a long thin rod or wire. When the length l approaches or becomes equal to or less than the wire diameter, the resonating wire support member may be designed according to the particular mode of its vibration which may be, for example, a shear mode of motion especially in the case of the higher frequencies, such as 5 megacycles per second, for example. In the case of a wire support soldered to the crystal coating, the theory of resonating supports is similar to that heretofore discussed but takes into account also the actual solder cone connection 5 that fastens the wires 6 and 7 to the crystal 1, and the special coupling between the crystal 1 and the wire vibrating system.

It will be understood that the solder ball 10 acts as a clamp for the wires 6 and 7 and may be placed at any point along the wires 6 and 7 corresponding to a wire node. The size or diameter of the solder ball 10 need only be sufficient to act as a clamp, and, in general, the size will be in proportion to the wire diameter. The spacing between the solder ball 10 and the head or top of the cone 5 may be roughly computed from Equation 1, or may be determined by experiment. In practice, the optimum spacing as determined by test may be found to be slightly greater than that given by the Formula 1, due to the fact that the crystal or free end of the wires 6 and 7 is restricted to a small slope. The diameter of the solder ball 10 that acts as a clamp may also be determined experimentally by increasing its size or mass until there are no standing waves on the wires at the side of the solder ball 10 remote from the crystal 1.

Figs. 7, 8 and 9 are enlarged detailed views of wire supports illustrating the use of a nodal

massed weight 10a in the form of a soldered wire stirrup 11 instead of a solder ball 10 as illustrated in Figs. 1, 2, 4, 5 and 6. Except for the substitution of the soldered stirrups 10a, 11 in place of the solder ball 10, Fig. 7 is similar to Fig. 4 and Fig. 8 is similar to Fig. 5 or 6. Fig. 9 shows the hairpin type stirrup 11 placed at a node on the lead wire 6 or 7 prior to soldering it thereto by means of the solder mass 10a of Figs. 7 and 8. As illustrated in Fig. 9, the U-shaped copper wire stirrup 11 may be squeezed or clamped on or over the lead wires 6 and 7 at or near a node thereof and then, as illustrated in Fig. 7 or 8, soldered thereto on the side at 10a away from the crystal 1, in order to remove the effects of standing waves in the supporting wires 8 and 9. The crystal 1 may then be ground to the desired frequency and soldered into the spring mount wires 8 and 9 with little or no changes in the crystal activity or frequency. The U-shaped copper wire stirrup 11 may be used to properly locate and space the solder mass 10a at a given distance from the crystal surface so that the resulting soldered stirrup 10a, 11 is at or near a node on the lead wires 6 and 7. The U-shaped stirrup 11 itself may be composed of .016 inch diameter tinned phosphor bronze wire, soft tempered and having an over all length when bent into U shape of about $\frac{1}{8}$ inch, for example.

Alternatively, the massed weight 10a, 11 may consist of a small copper or other disc threaded on and soldered to the lead wires 6 and 7 at or near a node thereof.

Fig. 10 is a perspective view of a crystal mounting, similar to that of Figs. 1 and 2, having the laterally extending lead wires 6 and 7 terminated in the solder masses 10 or 10a which form the soldered joints between the lateral lead wires 6 and 7 and upright spring wires 8 and 9. The upright spring wires 8 and 9 in this instance, as shown in Fig. 10, comprise full elliptical or circular-shaped springs, the two semicircular springs 8 together forming a plane that is substantially parallel to the plane of the two semicircular springs 9. If desired, additional bent springs (not shown) may extend laterally between the housing 14 and either or both of the springs 8 or 9 for the purpose of laterally bracing or stabilizing and damping lateral oscillations in the springs 8 and 9. As an example, the lateral stabilizing springs for the spring crystal mounting may consist of extensions of the spring wires 6 and 7 of Figs. 1, 2 and 10, the spring wire extensions extending outwardly from the solder balls 10 and then being sprung in bent quarter-circular form against the opposite inner side walls of the enclosing cover or container 14. Such lateral stabilizing springs are useful as snubbers for protection against shock or jar and also for dampening the effects of acoustical resonance waves upon the crystal during operation.

Figs. 11 and 12 illustrate, respectively, face and end views of a four-wire support system as applied particularly to a longitudinal mode type of crystal 1 having longitudinally divided platings or coatings 2a, 2b, 3a, 3b. The four L-bent spring lead wires 6 and 7 provide the nodal supports for the crystal 1 and also the individual electrical connections for the crystal 1, and in addition are provided with the massed solder weights 10 or 10a as hereinbefore described, suitably spaced from the crystal 1 for the purposes as hereinbefore described. The balls 10 may be composed of soft solder or of other metal or material and each may ordinarily weigh from 12 to 20 milligrams or more, for example. The balls

10 are as hereinbefore described securely attached to the wires 6 and 7 and substantially centered thereon, the line of adhesion to the wires 6 and 7 being clear cut and definite, particularly on the side thereof that is facing toward the crystal 1.

Figs. 13 to 17 are schematic views illustrating various modifications of wire supported crystals. In Figs. 13 to 16, the massed nodal weights 10b secured upon the crystal support wires 6 and 7 are illustrated as being of cubical form although they may be in the form of the solder ball 10 as hereinbefore described. Also, the massed weights 10b of Figs. 13 to 16 are shown at various nodal positions on the L-bent support wires 6 and 7. In Figs. 14 and 15, for example, the nodal weights 10b are shown at points on those parts of the wires 6 and 7 that are remote from the crystal 1 and removed from the L-bends in the wires 6 and 7. It will be understood that the weights 10b are located on the support wires in such positions and for the same purposes as hereinbefore described in connection with the solder balls 10 and the soldered stirrups 10a. Fig. 17 illustrates a wire supported crystal mounting similar to those heretofore described except for the use of U-shaped bends 18 in the spring wires 6 and 7 for the purpose of providing additional protection to the crystal unit in absorbing externally applied shock or other vibrations.

While the invention has been described with reference to particular wire support mountings for particular crystals, it may be applied generally to wire supported crystal units, examples of which are given in United States Patent 2,275,122, issued March 3, 1942, to A. W. Ziegler. 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 piezoelectric crystal mounting comprising a flexible spring lead wire support attached to and suspending said crystal, a solder ball fastened on said wire support substantially at a node thereof and away from a loop of motion therein, the wire length between said ball and said crystal being substantially equal to an odd order multiple of a quarter wave-length of said crystal frequency whereby the natural frequency of said wire length is related to said frequency of said frequency of said crystal, and means including a spring wire for supporting said solder ball.

2. Piezoelectric crystal apparatus comprising a piezoelectric crystal, a supporting spring wire secured to said crystal and flexibly suspending said crystal, and a massed weight suspended on said wire substantially at a node thereof and intermediate the ends thereof, the wire length between said massed weight and said crystal having a natural frequency substantially equal to the frequency of said crystal and means including a bent flexible spring wire fastened to said first-mentioned wire on the side of said weight that is away from said crystal for supporting said weight.

3. A mounting for a piezoelectric crystal comprising crystal supporting flexible spring lead wires fastened to the crystal and carried by supports, and a clamp supported by and placed on each of said crystal supporting lead wires, said clamps each consisting of a massed weight fas-

tened onto each of said lead wires substantially at a nodal point thereof, the length dimension of that portion of each of said lead wires between said weights and the crystal being made of a value to render each of said portions of said lead wires substantially a vibrating clamped-free bar in resonance to the motion transmitted to said portions by the crystal, said weights being means for reflecting said motion and comprised of sufficient mass to substantially eliminate said motion from the crystal from being transmitted through said weights to said supports through the remaining portions of said supporting wires, whereby the activity and frequency of the crystal are not appreciably affected by said supporting wires.

4. A crystal mounting in accordance with claim 3 wherein said resonant lead wire portions are substantially coaxial with respect to each other, substantially perpendicular to the major surfaces of the crystal, and fastened to the crystal substantially at points of minimum motion thereof.

5. A crystal mounting in accordance with claim 3 wherein said crystal supporting wires have substantially coaxial portions and said weights are placed thereon intermediate the ends of said substantially coaxial portions.

6. A crystal mounting in accordance with claim 3 wherein said resonant wire portions are substantially coaxial with respect to each other, said remaining wire portions are angularly disposed with respect to said resonant wire portions, and said weights are placed at the junctions between said resonant wires and said angularly disposed wires.

7. A crystal mounting in accordance with claim 3 wherein said weights are carried by bent spring wires.

8. A crystal mounting in accordance with claim 3 wherein said weights comprise a mass of solder on said crystal supporting wires.

9. A crystal mounting in accordance with claim 3 wherein said weights each comprise a spherical solder ball surrounding a portion of said lead wires.

10. A crystal mounting comprising a face shear mode piezoelectric crystal element having a nodal point substantially at the center of the crystal element, metallic coatings formed integral with the major faces of said crystal element, crystal supporting conductive lead wires soldered to said crystal coatings substantially at the centers of said major faces of said crystal element, spring mounts including bent spring wires carrying said lead wires, and a solder mass placed on each of said lead wires substantially at a node thereof, said mass of solder being of adequate mass to substantially prevent energy from being transmitted therethrough to said spring mounts.

11. A crystal mounting comprising a face shear mode piezoelectric crystal element having a nodal point substantially at the center of the crystal element, metallic coatings formed integral with the major faces of said crystal element, crystal supporting conductive spring lead wires soldered to said crystal coatings substantially at the centers of said major faces of said crystal element, spring mounts including bent spring wires carrying said lead wires, and a solder mass placed on each of said lead wires substantially at a node thereof, said mass of solder being of adequate mass to substantially prevent energy from being transmitted there-

through to said spring mounts, said lead wires being soldered to said spring mounts substantially at said nodes of said lead wires.

12. A crystal mounting comprising a face shear mode piezoelectric crystal element having a nodal point substantially at the center of the crystal element, metallic coatings formed integral with the major faces of said crystal element, crystal supporting conductive lead wires soldered to said crystal coatings substantially at the centers of said major faces of said crystal element, spring mounts including bent spring wires carrying said lead wires, and a solder mass placed on each of said lead wires substantially at a node thereof and being of adequate mass to substantially prevent energy from being transmitted therethrough to said spring mounts, said solder mass comprising a ball of soft lead-tin solder.

13. A crystal mounting comprising a face shear mode piezoelectric crystal element having a nodal point substantially at the center of the crystal element, metallic coatings formed integral with the major faces of said crystal element, crystal supporting conductive spring lead wires soldered to said crystal coatings substantially at the centers of said major faces of said crystal element, spring mounts including bent spring wires carrying said lead wires, and a massed weight placed on each of said lead wires substantially at a node thereof and being of adequate mass to substantially prevent energy from being transmitted therethrough to said spring mounts, said massed weight comprising a U-shaped copper wire clamped over said lead wires at said node and soldered thereto on the side away from said crystal element.

14. A mounting for a piezoelectric crystal having metallic platings on its opposite major faces, mounting spring wires soldered to said crystal platings, a solder ball weight placed on each of said wires substantially at a nodal point of said wires, the wire distance between said weights and said crystal platings being a value to allow said wires to vibrate substantially as a clamped-free bar at the crystal frequency, the size of said solder ball weights being sufficient to prevent vibration from the crystal from being transmitted past said weights, and support wires fastened at points on said first-mentioned wires on the sides of said weights that are away from said crystal.

15. Piezoelectric crystal apparatus comprising a face mode piezoelectric quartz crystal element having conductive electrode coatings formed integral therewith, a plurality of conductive resilient wire supports for said crystal element, each of said wire supports being soldered at one end thereof to one of said crystal coatings adjacent the nodal region of said crystal element and at its opposite end being carried by a base, each of said wire supports having a mass of solder comprising a cast solder ball or globule disposed thereon intermediate said ends of said wire support, the portions of said wire supports between said solder masses and said base having bends therein comprising springs, said mass being spaced on said wire substantially at a node thereof, the length of said wire between said mass and said crystal element being a value to provide flexure mode vibrations therein of a natural frequency for said length of said wire equal to the frequency of said crystal element, and said mass being of a magnitude sufficient to terminate said vibrations.

16. Piezoelectric crystal apparatus comprising

a piezoelectric crystal, supporting spring wires for said crystal, a single massed weight suspended by each of said wires intermediate the ends thereof, the portions of said wires between said weights and said crystal being tuned to vibrate at a harmonic mode of vibration with a frequency substantially equal to the frequency

of said crystal and the remaining portions of said wires on the side of said weights that is remote from said crystal comprising bent spring wires for supporting said weights and said crystal.

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