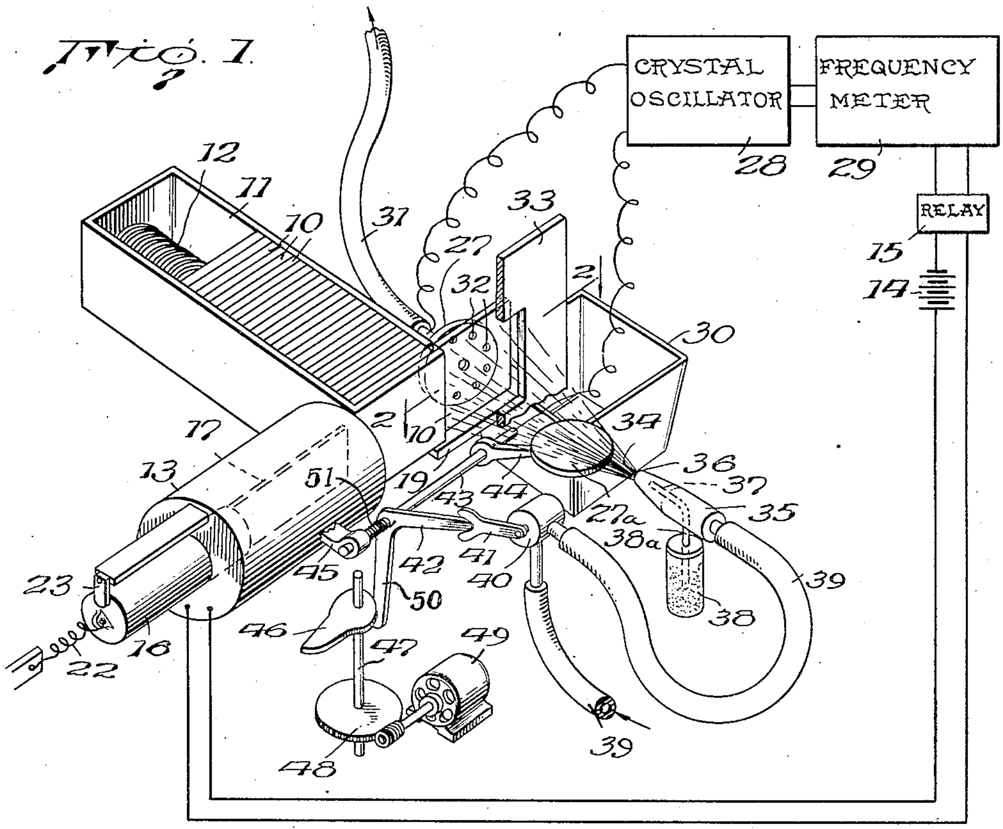
April 4, 1944. J. M. WOLFSKILL 2,345,648

PIEZOELECTRIC CRYSTAL APPARATUS

Filed April 28, 1941 2 Sheets-Sheet 1

FIG. 1.



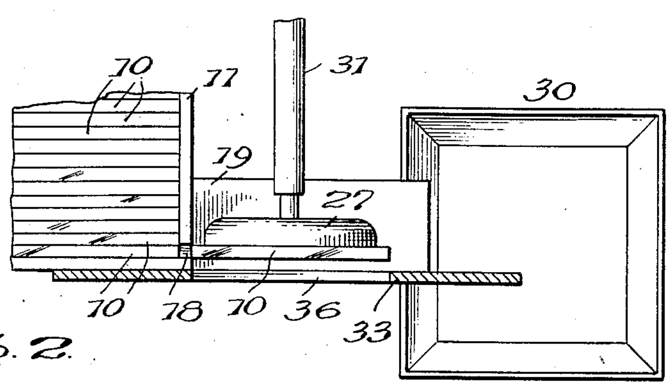


FIG. 2.

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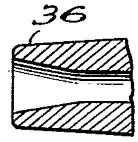

FIG. 3.

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PIEZOELECTRIC CRYSTAL APPARATUS

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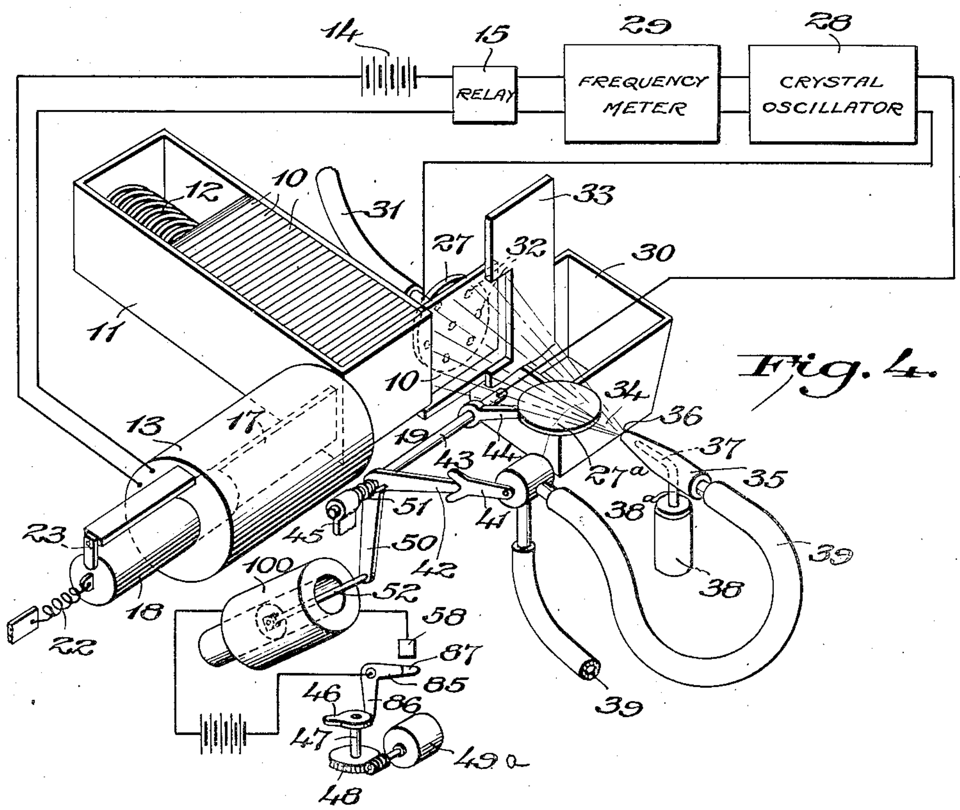
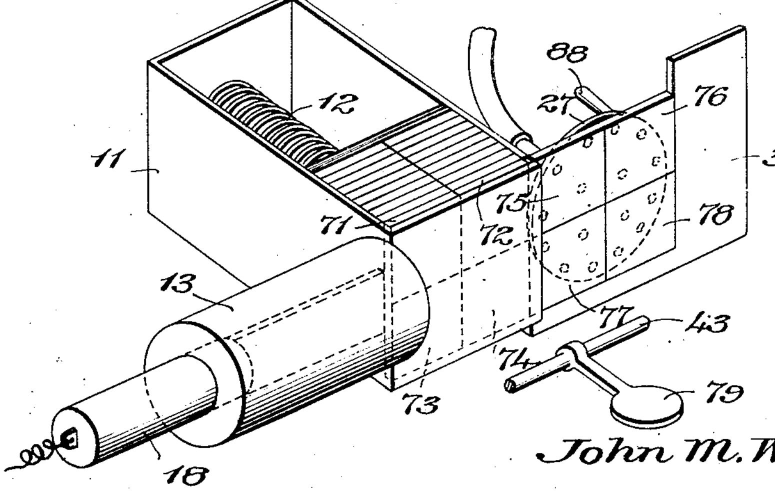


Fig. 4.

Fig. 5.



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Patented Apr. 4, 1944

2,345,648

UNITED STATES PATENT OFFICE

2,345,648

PIEZOELECTRIC CRYSTAL APPARATUS

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Application April 28, 1941, Serial No. 390,829

13 Claims. (Cl. 51—8)

This invention relates to piezo-electric crystal apparatus, and more particularly to a method of adjusting a quartz crystal to certain specified frequencies by means of a greatly improved method which eliminates the necessity for a highly skilled operator, and also facilitates a more rapid adjustment.

It is an object of this invention to provide a method whereby the final adjustment of the frequency of a quartz crystal is done by automatic means.

It is a further object to provide a method whereby the characteristics and performance of the crystal are greatly improved because of the inherent accuracy of the method of adjustment of the crystal.

It is a further object to provide a method whereby the final frequency adjustment over a range of from zero to one hundred or more kilocycles is done in such a manner that the frequency change is under complete control of the operator.

Another object is to provide a method of frequency adjustment in which the operation is completely automatic.

Another object of this invention is to provide a means for maintaining a specific or definite contour of the crystal while moving the crystal to its desired frequency.

A further object of this invention is to provide a means for moving the frequency of a crystal with a special convex contour without changing the said contour even to a slight degree.

Still a further object of this invention is to provide a means for moving the frequency of high or ultra-high frequency harmonic crystals.

Another object of this invention is to provide a process for finishing piezo-electric crystals to a desired frequency consisting of lapping the crystal to a frequency somewhat below the desired frequency, edge grinding the crystal until single frequency response of maximum activity is obtained, and then sandblasting the crystal to the desired frequency.

Another object of this invention is to provide a method of finishing piezo-electric crystals by sandblasting according to a time-frequency curve for definite abrasive grains and grades and sandblast pressures; wherein each of said crystals is exposed to the sandblast for a time interval determined from the time-frequency curve, and then the rate of frequency change with time is determined for the actual amount the frequency is moved, and from this is computed the additional time of exposure necessary to move the crystal to the desired frequency.

In the prior art of adjusting quartz crystals to final specified frequencies, it has been the practice to grind the crystals to a certain specified thickness by means of lapping machines to within 5–50 kilocycles or more of the final frequency, depending on the frequency range. The lapping process is entirely mechanical, and the crystals are generally lapped to dimension rather than to frequency. As a result, very definite limits are imposed on the closeness to which a group of crystals may be lapped and still make certain that all the crystals are below the desired specified frequencies.

It is well known in the art that there is no practical means for reducing the frequency of a plate type of crystal once it has been carried past the desired frequency. As a result, the lapping operation is always done in such a way as to make sure that all of the crystals in a group are well below the desired frequency. Because of this, and because of certain dimensional variations over the lapping plate, and also because of small variations in the thickness coefficient of the crystals themselves, it is necessary to control the lapping process fairly closely. At best, however, it is difficult to machine lap crystals in groups to closer than possibly one ten-thousandth of an inch. One ten-thousandth of an inch represents a frequency change for what is known in the art as an A or AT cut, of 14 kilocycles for a 3 megacycle crystal. As the frequency is increased, the frequency change with thickness increases as the square of the frequency. In other words, at 6 megacycles a change of 56 kilocycles for one ten-thousandth of an inch change would be obtained. This change varies with different cuts, depending on the frequency thickness coefficient, and is given by the equations

$$\Delta F = \frac{-F^2 \Delta T}{K}$$

where ΔF is the frequency change, F is the frequency, ΔT is the change in thickness, and K is the thickness coefficient. For various cuts known to the art, the X-cut has a thickness coefficient of 1.13×10^5, A or AT cut has a thickness coefficient of $.655 \times 10^5$, a B or BT cut has a thickness coefficient of $.995 \times 10^5$, and a C cut has a coefficient of 1.97×10^5. Dimensions are in inches and frequency in cycles per second.

As mentioned before, one ten-thousandth of an inch represents a practical limit on machine lapping tolerances, but with care and precise machinery, of course it is possible to lap closer. This, however, is not a particular problem, since the final finishing of a crystal to a specified frequency has always in the prior art had to be done by hand, and the frequency had to be measured as the grinding or hand lapping process proceeded. This final operation is done on the basis of frequency rather than mechanical measurements, and there are certain small uncontrollable factors which enter into the process, such as small frequency jumps and spurious oscillations which by virtue of the inherent inaccuracy of the method make their appearance and are hard to control. This final operation, then, requires a highly skilled operator, and even at best, what might be considered a perfect crystal cannot be made. This has resulted in considerable confusion in the art as to performance standards of quartz crystals.

By means of this present invention, it is possible to produce what might be considered practically perfect crystals from a performance, as well as a mechanical, standpoint. This will be evident from the following discussion. Crystal blanks which have been mechanically lapped to within the above mentioned tolerance of one ten-thousandth of an inch can be made exceptionally flat over the surface and parallel between the two faces by the mechanical lapping process. They are, however, flat and parallel at a frequency which is still far removed from the final desired operating frequency. Crystal surfaces can be held flat and parallel by this mechanical lapping process to ten millionths of an inch without difficulty, and if the crystal could be held to these standards and moved to the desired operating frequency, a practically perfect crystal would result. It is the purpose of this invention to describe a practical method of accomplishing this.

This present invention consists of a process of cutting, grinding or abrading portions of a piezo-electric element either uniformly over a surface or face thereof, or with a special contour, by means of sandblasting apparatus in which very fine grains of quartz, "carborundum," aluminum oxide or other abrading material suitable for cutting surfaces of the quartz piezo-electric element, are used in the air blast. Very fine sharp grains of cutting or abrading material of microscopic proportions are preferred since these will leave an even, satin-like finish on the sandblasted surface of the piezo-electric element free from even microscopic pits or cavities. This is desirable where the piezo-electric element is finished or cut to the desired frequency by the sandblast.

However the sandblast may be used for rough grinding of the piezo-electric element prior to lapping the element as explained above and in that case a coarser grain may be used.

Various air pressures in the sandblast may be used and in general the finer the grain of the cutting material the higher the air pressure required to cut the quartz piezo-electric element, since the kinetic energy of the cutting grains and therefore the cutting force of said grains is proportional to the mass thereof. If the mass of the grains is reduced the velocity thereof must be increased so that the cutting action of the individual grains will not be too much reduced or impaired. Of course when finer grains are used more of them contact the surface being cut, however, the individual grain actually does the cutting and therefore the kinetic energy of each grain is the determining factor in that respect.

After the quartz piezo-electric element is cut by the sandblast it may be washed to remove all of the particles embedded in the surfaces thereof and for this purpose a water bath may be used.

Where desired the nozzle of the sandblast gun may be made so that an uneven spray will be obtained and crystal elements with a convex contour obtained or tapered or bowed crystal elements such as described in my patents, Nos. 2,240,449 and 2,224,700 may be cut.

In cases where the sandblast is to be controlled manually, time-frequency curves may be plotted for cutting materials of different grains and grades and air-blast pressures, so that the operator can determine with fair accuracy approximately how long a time is required to adjust the frequency of a crystal element of a given cut. Time-frequency curves however, are not necessary in this invention since the frequency of the crystal is measured at frequent intervals automatically by the frequency measuring apparatus, and the crystal is ejected from the sandblast as soon as it is adjusted to the desired frequency.

The air blast gun is provided with a nozzle that is highly resistant to wear, and such a nozzle may be made of the so-called hard metal alloys, such as "Carboloy," tungsten carbide, tantalum carbide and the like, or it may be lined with rubber.

In the specification and claims the terms "sand blast" and "sand blasting" are intended to define air blasting with any abrasive. Various grains, such as No. 220 up to No. 400 or No. 500 or even finer grain of aluminum oxide abrasive may be used depending upon the type of finish desired and the rapidity with which the frequency of the crystal is moved.

Various other features of this invention will be apparent from the following specification, claims and drawings in which, briefly:

Fig. 1 is a view of the apparatus of my invention;

Fig. 2 is a sectional view taken along the line 2—2 of Fig. 1; and

Fig. 3 is a sectional view of a modified form of the nozzle of the air blast gun.

Fig. 4 shows a modified form wherein a special solenoid controls the movement of the electrode and application of the sand blast.

Fig. 5 shows an arrangement wherein a plurality of crystals are sandblasted at the same time.

Referring to Fig. 1 of the drawings in detail, reference numeral 10 designates a plurality of lapped crystal element blanks arranged side by side in the box 11. A spring 12 is employed for pushing the crystal blanks 10 toward the feeding side of the box from which they are fed upon the support 19 by means of a feeding plunger or blade 17 which is actuated by the armature 16 of the solenoid 13. Each time a new crystal blank is to be fed upon the support 19, the solenoid 13 is energized so that the armature 16 thereof is pulled into said solenoid and the blade 17 caused to force the next crystal blank out of the box 11 through the slot 18 to a position in front of the suction electrode 27. Air is sucked into the electrode 27 by means of a suction hose 31 attached thereto, through the holes 32 formed in the face of the electrode 27, and this suction functions to hold the crystal blank upright in front of the electrode. The inside of the electrode 27 is hollowed out for this purpose and is connected by means of a passage to the suction tube 31 to which is connected a suitable suction or evacuating pump or chamber.

A suitable spring 22 is attached to the solenoid armature 16 for withdrawing this armature from the solenoid when the latter is de-energized. A stop 23 is attached to the housing of the solenoid 13 to limit the outward movement of the armature 16.

A suitable mask or shield 33 made of rubber or similar material that is highly resistant to the cutting abrading action of the sandblast is positioned in front of the crystal element being sandblasted. The purpose of this shield or mask is to permit the use of a sandblast spray 34 having a solid angle several times the size that would normally be required to cover the face of the crystal being sandblasted. The hole formed in the mask 33 is of a size such as to permit the whole crystal face to be sandblasted by an even and uniform abrasive blast corresponding to the center of the blast spray 34. The uneven fringe or outer portions of the spray 34 fall on the mask 33 and do not reach the face of the crystal element. This mask 33 functions to protect the apparatus from the action of the sandblast. As a further protection the portions of the apparatus which are likely to be exposed to the sandblast may be given a coating of rubber which is highly resistant to such action.

The sandblast spray gun 35 is of conventional design except that the nozzle 36 thereof may be made of wear-resistant material composed of a hard metal alloy such as, tungsten carbide, tantalum carbide or the like. The spray gun 35 is provided with an abrasive container 38 and a pipe 38*a* is connected between this container and the nozzle of the gun so that air passing through the gun from the flexible hose 39 sucks the abrasive from the container 38 through the pipe 38*a* and forces this abrasive out in the form of a spray 34. The gun 35 may be adjusted so that different forms of abrasive sprays may be obtained. For example this may be accomplished by moving the end of the abrasive feeding pipe 38*a* different distances from the mouth of the nozzle 36. Different nozzle shapes also may be employed and a nozzle with a gradually expanding mouth opening may be employed to produce a uniform abrasive spray.

A valve 40 is connected into the hose 39. This valve 40 is provided with a lever 41 to open and close the valve in accordance with the operation of the motor-driven cam 46 which is connected to the valve lever 41 by means of the bell crank 42. This bell crank 42 is pivoted on the shaft 43 which is supported by the bearing 45 and rotates this shaft 43 through an angle of approximately 90 degrees. The second, solid, electrode 27*a* is also attached to the shaft 43 by means of the arm 44 so that this electrode is rotated and moved up to the sandblasted face of the crystal 10 by the shaft 43 when the bell crank 42 is rotated and the valve 40 turned off thereby. Thus the sandblast is turned off when the crystal electrode 27*a* is moved into operative position to the crystal. The respective electrodes 27 and 27*a* are connected to the crystal oscillator circuit 28 so that the crystal between these electrodes is set into oscillation during the interval when the sandblast is interrupted, and the frequency of the crystal is determined by the frequency meter 29 connected to the crystal oscillator 28. If the crystal is of the desired frequency, the frequency meter energizes the relay 15 which connects the battery 14 to the solenoid 13 and this solenoid is energized so that the plunger 17 is caused to eject another crystal from the box 11 upon the support 19. Thereupon the sandblasted crystal is pushed into the container 30 by the crystal being ejected from the box 11.

A motor 49 is employed for driving the worm gear arrangement 48 and this in turn drives the cam 46 which is mounted on the shaft 47. Cam 46 engages arm 50 of bell crank 42.

By employing different forms of nozzles on the spray gun, crystals of different shapes may be produced. For example if it is desired to produce a tapered crystal such as disclosed in my Patent No. 2,240,449 the nozzle 36 is arranged to spray the crystal face with gradually increasing intensity toward one end of the crystal so that the proper taper is produced. On the other hand if a crystal of bowed configuration is desired such as is disclosed in my Patent No. 2,224,700, the nozzle 36 is arranged so that the central part of one of the faces of the crystal is sandblasted with greater intensity than the two ends. The other face of the crystal is sandblasted so that the two ends are cut away to a greater extent than the central part of the crystal which results in an arcuate crystal element. Crystals of stepped configuration also may be produced simply by sandblasting the crystal in steps.

Various electrical circuit arrangements for controlling the electrodes, the solenoid 13 and the motor 49, such as illustrated in my co-pending application Serial No. 386,938, may be employed. Where desired, as shown in Fig. 4, the electrode 27*a* may be actuated by means of a second solenoid 100 controlled by a suitable timing mechanism and this same solenoid may be used for operating the valve 40, as by link 52. The timing mechanism may have a constant speed motor 49*a* such as the motor 49.

A suitable coil spring 51 may be wound around the shaft 43 with one end fixed to said shaft and the other end to the bearing 45, said spring functioning to return the shaft to the position shown in the drawings after the bell crank 42 is disengaged by the cam 46. In this position the valve 40 is open so that compressed air is fed to the spray gun 35 and the electrode 27*a* is in its downward position out of the way of the abrasive spray. The valve 40 is turned off and the electrode 27*a* is advanced to the corresponding crystal face once during each revolution of the cam 46. If desired a small air-gap may be left between the electrode 27*a* and the crystal face. The crystal would then be calibrated with this small air-gap.

Furthermore several crystals which are lapped to the same nominal frequency may be sandblasted at the same time and in this case the frequency of only one of the sandblasted crystals need be measured. For this purpose lapped crystals are grouped into different frequency groups and then all of the crystals of one frequency are arranged to be sandblasted in one operation. Such an arrangement is shown in Fig. 5. All of the crystals may be arranged manually on a large suction electrode such as electrode 27 and then sandblasted simultaneously. If desired the electrode 27 may be made of sufficient size to accommodate several crystals at the same time and also may be rotatable with respect to the box 11 so that the solenoid 13 may feed crystal blanks to this rotatable electrode. In Fig. 5, which shows a modification of a part of the apparatus of Fig. 1, the crystals are arranged in receptacle 11 in layers of four, as 71, 72, 73, 74, and are ejected in such arrangement by blade 17 on to electrode 27. An ejected layer of four crystals 75, 76, 77, 78, is shown in exposed position on electrode 27. The electrode 27 may be rotated by handle 80. However, ordinarily it is satisfactory to measure only one crystal as 77 by applying electrode 79 thereto, and electrode 79 is not arranged to be applied to the crystals occupying other positions on the electrode 27.

Various other modifications may be made without departing from the spirit and scope of this invention and therefore I do not desire to limit this invention to the exact details shown except in so far as those details that may be defined by the claims.

What I claim is as follows:

1. Apparatus for adjusting the frequency of oscillation of a piezo-electric crystal, comprising: a sandblast, means for supporting a piezo-electric crystal in said sandblast, and an electric circuit comprising an oscillator and a frequency meter and electrodes, and means for intermittently moving said electrodes into and out of electrical operative position with reference to said piezo-electric crystal for indicating the frequency of said crystal.

2. The method of producing quartz piezo-electric elements, comprising the steps of cutting a quartz piezo-electric element of a desired angle, selecting the desired frequency for said piezo-electric element, lapping the piezo-electric element to dimensions such that said element will oscillate at a frequency below the desired frequency, and sandblasting a surface of said element until the frequency thereof corresponds to the desired frequency.

3. The method of producing quartz piezo-electric elements, comprising the steps of cutting a quartz piezo-electric element of a desired angle, selecting the desired frequency for said piezo-electric element, lapping the piezo-electric element to dimensions such that said element will oscillate at a frequency below the desired frequency, sandblasting a surface of said element until the frequency thereof corresponds to the desired frequency, and periodically measuring the frequency of said element, and removing it from sand blasting exposure as soon as such measurement shows that the crystal has attained said desired frequency.

4. The method of producing quartz piezo-electric elements, comprising the steps of cutting a quartz piezo-electric element of a desired angle, selecting the desired frequency for said piezo-electric element, lapping the piezo-electric element to dimensions such that said element will oscillate at a frequency below the desired frequency, sandblasting a surface of said element, periodically interrupting said sandblasting, and measuring the frequency of said element until the frequency thereof corresponds to the desired frequency.

5. Apparatus for producing piezo-electric crystal elements, comprising: abrasive means for cutting a plurality of piezoelectric crystals to desired frequencies, an air blast for projecting said abrasive means against a face of said crystals, frequency indicating means, electrodes for at least one of said crystals connected to said frequency indicating means, and timing means for moving one of said electrodes to and away from the corresponding crystal face and adapted for interrupting the air to said air blast while said movable electrode is in operative position with said crystal.

6. Apparatus for producing piezo-electric crystal elements, comprising: compressed air impelled abrasive for cutting piezoelectric crystals to desired frequencies, electrically actuatable means for feeding said crystals to said abrasive means, frequency determining means adapted to be connected to the crystal so fed to such abrasive means, and a control circuit between said feeding means and said frequency determining means and actuatable upon a predetermined condition of said frequency determining means for actuating said feeding means.

7. Apparatus for producing piezoelectric crystal elements, comprising: powdered abrasive for cutting piezoelectric crystals to desired frequencies, an air blast means for projecting said abrasive against a face of said crystals, frequency indicating means, electrodes for at least one of said crystals connected to said frequency indicating means, a valve for cutting off said air blast means, and timing means adapted for moving one of said electrodes to and away from the corresponding crystal face and for operating said valve to cut off said air blast means while said movable electrode is in operative position with said crystal.

8. Apparatus for producing piezoelectric crystal elements, comprising: abrasive means for cutting piezoelectric crystals to desired frequencies, an air blast means for projecting said abrasive means against a face of said crystals, frequency indicating means, electrodes for at least one of said crystals connected to said frequency indicating means, timing means adapted for moving one of said electrodes to the corresponding crystal face for placing said frequency indicating means in electrical operative relation with said crystal, a valve for controlling said air blast means, and means adapted for connecting said valve to said timing means for interrupting the air to said air blast while said movable electrode is in electrical operative relation with said crystal while the frequency of said last mentioned crystal is being measured.

9. Apparatus for producing piezoelectric crystal elements, comprising: abrasive for cutting piezoelectric crystals to desired frequencies, compressed air means for projecting said abrasive against a face of said crystals, frequency indicating means, electrodes for at least one of said crystals connected to said frequency indicating means, a shaft for supporting one of said electrodes and moving the same into and out of electrical relation with said crystal, a valve for controlling said compressed air, valve operating means for operating said valve connected to said shaft, a substantially constant speed motor for periodically rotating said shaft, said electrode supported on said shaft and said valve operating means having arranged for interrupting the air to said air blast while said supported electrode is in electrical operative relation with said crystal while the frequency of said last mentioned crystal is being measured.

10. In apparatus for adjusting the frequency of a piezoelectric crystal element, a sand blast, holding means for holding said crystal element exposed to said sand blast, frequency measuring means for measuring the frequency of said crystal element comprising circuit elements in electrical relation with said crystal element, and frequency actuatable displacing means connected to said frequency measuring means and actuatable

upon the indication of a predetermined desired frequency to displace said crystal element from said holder and out of exposure to said sand blast.

11. In an apparatus for adjusting the frequency of piezoelectric crystal elements, a holder for holding a crystal element in exposed treatment position, said blast means for applying a sand blast to a crystal element so held in said holder, sand blast control means for controlling the application of said sand blast means, a pair of electrodes normally positioned adjacent said holder in electrical relation with the crystal element held therein, movable support means for moving a first one of said electrodes into and out of electrical relation with the crystal element in said holder, frequency measuring means connected to said electrodes, cyclically operating common control means arranged to cause movement of said first one of said electrodes into electrical relation with a crystal element in said holder when said sand blast control means is turned off, and to cause movement of said first one of said electrodes out of electrical relation with a crystal element in said holder when said sand blast control means is turned on, and electrically actuatable crystal element displacing means connected to said frequency measuring means and adapted to displace a crystal element from said holder when the frequency of said crystal element measured when said first electrode is in electrical relation therewith attains a predetermined desired value.

12. In an apparatus for adjusting the frequency of piezoelectric crystal elements, a holder for holding a crystal element in exposed treatment position, electrically actuatable feeding means for feeding crystals from a stack successively into said holder and adapted for displacing one crystal element from said holder when another element is fed thereto, sand blast means for applying a sand blast to a crystal element so held in said holder, sand blast control means for controlling the application of said sand blast means, a pair of electrodes normally positioned adjacent said holder in electrical relation with the crystal element held therein, movable support means for moving a first one of said electrodes into and out of electrical relation with the crystal element in said holder, frequency measuring means connected to said electrodes, and cyclically operating common control means arranged to cause movement of said first one of said electrodes into electrical relation with a crystal element in said holder when said sand blast control means is turned off, and to cause movement of said first one of said electrodes out of electrical relation with a crystal element held in said holder when said sand blast control means is turned on, said frequency measuring means being connected to said feeding means and being adapted to actuate said feeding means to feed a new crystal element to said holder and to displace therefrom a measured crystal element when the measured frequency of a crystal element held in said holder attains a predetermined desired value.

13. In apparatus for producing adjusted piezoelectric crystal elements, holding means for simultaneously holding a plurality of piezo-electric crystals in exposed position, abrasive means for cutting said crystals to desired frequencies, an air blast which simultaneously projects said abrasive means against adjacent exposed faces of said crystals while so held in said holding means, frequency indicating means, electrodes for one of said crystals and positioned in electrical relation therewith while said one crystal is so held in said holding means and being connected to said frequency indicating means, and timing means for moving one of said electrodes to and away from the corresponding face of said one crystal and for interrupting the air to said blast while said movable electrode is in operative position with said one crystal.

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