United States Patent

Kato et al.

[15] **3,697,789**

[45] **Oct. 10, 1972**

[54] **MECHANICAL OSCILLATOR**

[72] Inventors: **Yoshiaki Kato**, Higashimurayama; **Hideki Ohuye**, Urawa, both of Japan

[73] Assignee: **Citizen Watch Co., Ltd.**, Tokyo, Japan

[22] Filed: **June 21, 1971**

[21] Appl. No.: **155,195**

[30] **Foreign Application Priority Data**

Sept. 9, 1970 Japan 45/79093
June 23, 1970 Japan 45/61921

[52] **U.S. Cl.**..................**310/9.5,** 58/23 TF, 310/8.2, 310/9.6, 310/25

[51] **Int. Cl.** **H01v 7/00**

[58] **Field of Search**..............310/8, 8.1, 8.2, 8.3, 8.9, 310/9.1, 9.4, 9.5, 9.6, 25; 84/459, 409; 58/23 TF

[56] **References Cited**

UNITED STATES PATENTS

299,956	6/1884	Butterworth	84/457
1,937,583	12/1933	Norrman	84/409 X
2,376,131	5/1945	Dunlap et al.	310/25
2,971,104	2/1961	Holt, Jr.	310/25 X
2,838,698	6/1958	Holt, Jr.	310/25
2,666,196	1/1954	Kinsley et al.	310/8.2 X
2,323,719	7/1943	Mallina	310/8.2 UX
2,247,960	7/1941	Michaels	310/25 X

Primary Examiner—J. D. Miller
Assistant Examiner—Mark O. Budd
Attorney—William D. Hall et al.

[57] **ABSTRACT**

An improved vibrating element and a novel construction of an oscillator unit employing the vibrating element. The vibrating element is formed into a shape such that its vibrating part is divided into at least two prings with a slit therebetween. The width of the slit is uniform along the greater extent of said vibrating part from the open end thereof and is then gradually reduced substantially at a constant rate towards its closed end to thereby improve the shock resisting property of the vibrating element.

10 Claims, 21 Drawing Figures

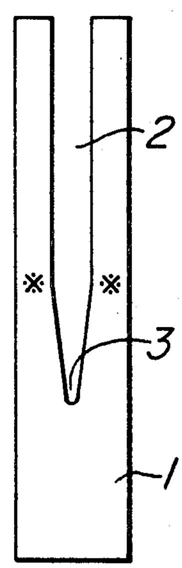
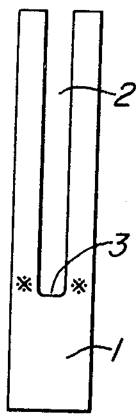
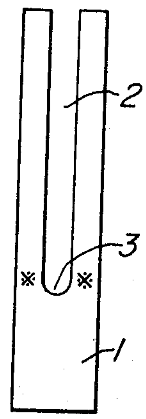


FIG. 1a



PRIOR ART

FIG. 1b



PRIOR ART

FIG. 2

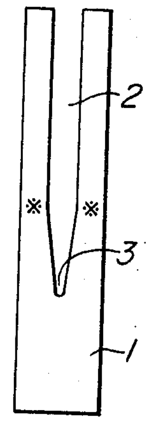
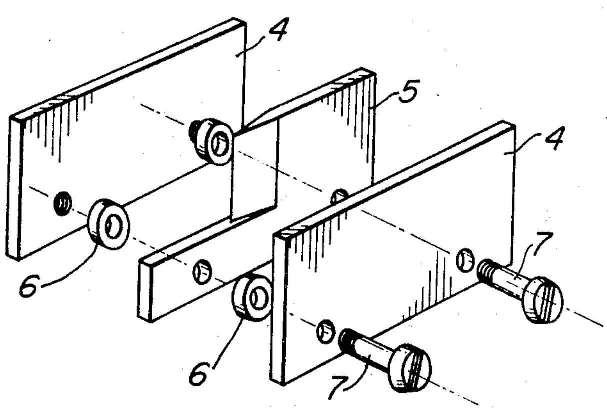


FIG. 3



INVENTOR

Yoshiaki Kato

Hideki Ohuye

ATTORNEY

FIG. 4a

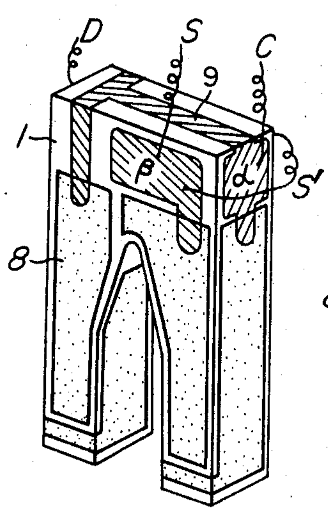


FIG. 4b

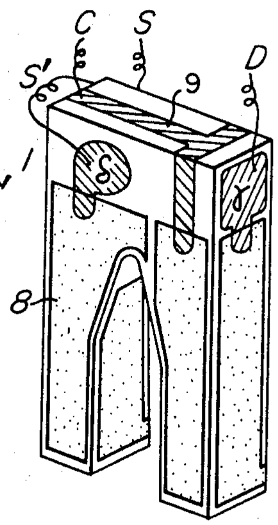


FIG. 5

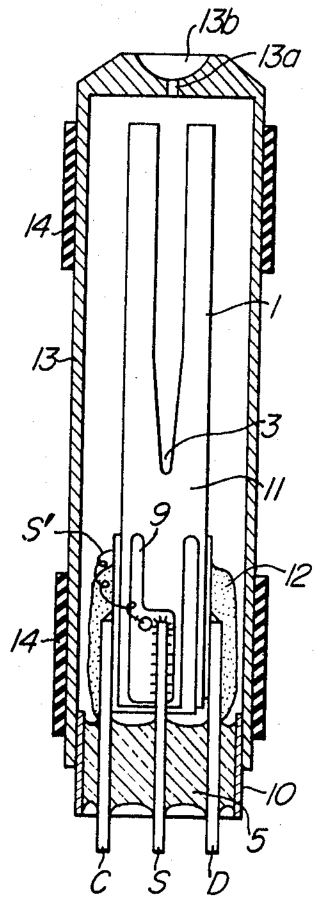


FIG. 4c

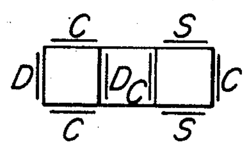
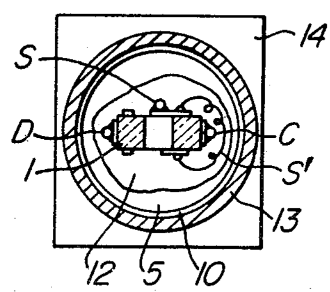


FIG. 6



INVENTOR

Yoshiaki Kato

Hideki Ohuye

ATTORNEY

FIG. 7a

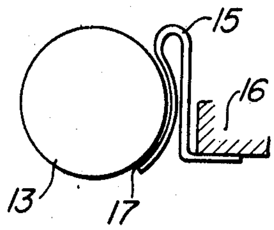


FIG. 7b

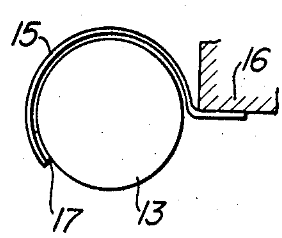


FIG. 8a

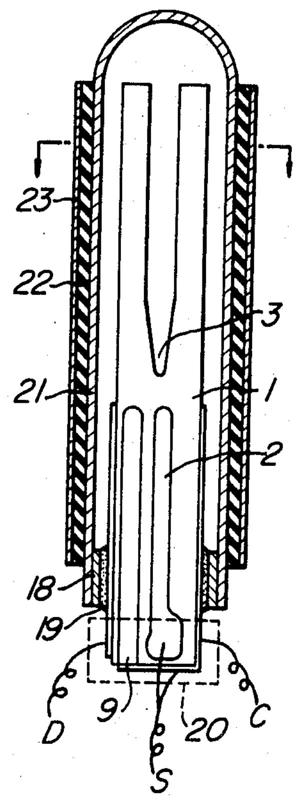


FIG. 8b

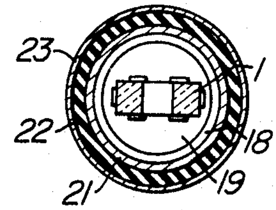
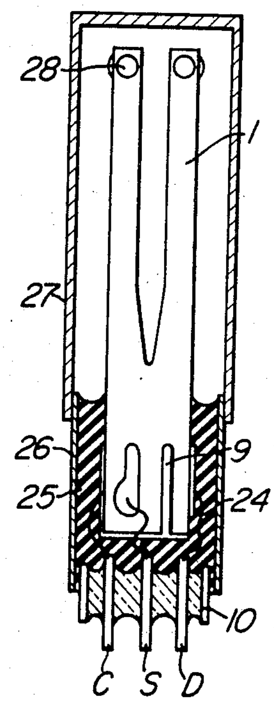


FIG. 9



INVENTOR

Yoshiaki Kato

Hideki Ohuye

ATTORNEY

FIG. 10

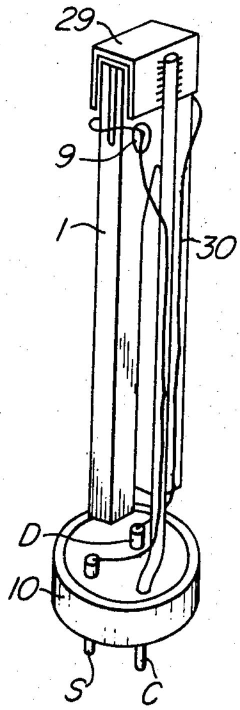


FIG. 11a

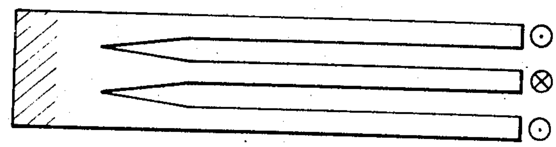


FIG. 11b

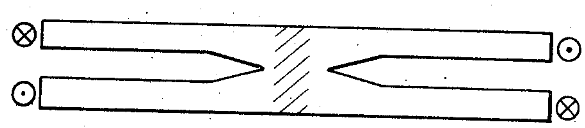


FIG. 11c

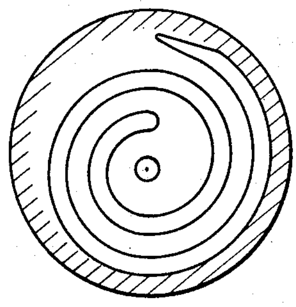
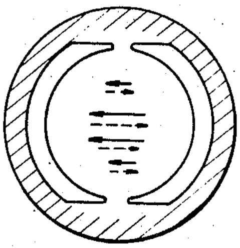


FIG. 11d



INVENTOR

Yoshiaki Kato
Hideki Ohaye

ATTORNEY

MECHANICAL OSCILLATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a mechanical oscillator comprising a mechanical vibrating element of the type whose vibrating part is divided into at least two prongs with a slit therebetween.

The present invention also relates to the construction of oscillator units of the type having hermetically sealed containers holding the improved vibrating elements therein.

2. Description of the Prior Art

Heretofore relatively low-frequency crystal oscillators have been constructed employing a free-free bar type or tuning fork type quartz crystal vibrator. In the development of crystal wrist watches, the microminiaturization of such crystal oscillators and an improvement of their shock resisting properties to the maximum possible extent have been required However, with the conventional oscillators of the type employing a free-free bar type vibrator, while their microminiaturization has not necessarily been impossible, there has been a certain limit in the improvement of their resistance to shock, since the free-free bar type vibrator must be supported by means of very fine wires so that once the watch has been inadvertently dropped, for example, its efficiency can no longer be ensured. On the other hand, with conventional oscillators of the type employing a tuning fork type vibrator, their microminiaturization is also possible and at the same time relatively rugged supporting wires can be employed due to the large area of the node of vibration. However, experiments have shown that the use of excessively rigid supports cause the tuning fork prongs to be easily broken because of the impact acceleration, whereas the use of flexible supports also causes the prongs to be easily broken since the tips of the prongs tend to strike the inner surface of the vacuum container when subjected to the impact. Thus, it is apparent that with an improvement in the strength of such tuning fork prongs against breaking, a tuning fork type crystal oscillator can be employed to produce a crystal wrist watch having a good shock resisting property.

SUMMARY OF THE INVENTION

It is a main object of the present invention to provide improved mechanical strength for a mechanical oscillator to improve the shock resisting property of the oscillator to withstand large shocks to which it may be subjected.

It is another object of the present invention to provide an improved relatively low-frequency microminiature crystal oscillator which is superior both in the frequency stability and the resistance to shock upon impact, which is simple in construction and suited for mass production, and which is, in particular, suited for use as a source oscillator for crystal wrist watches.

These objects are realized in the present invention through the provision of a tuning fork type mechanical vibrating element having a plurality of prongs which are separated from one another by at least one slit, with the width of the slit being uniform over the greater extent of said slit from the open end of said vibrating element, and with said width then gradually decreasing at a constant rate toward the closed end of said slit.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1***a* and **1***b* are plan views showing the shapes of the conventional tuning forks.

FIG. **2** is a plan view showing the shape of a tuning fork used with the oscillator unit according to the present invention.

FIG. **3** is a perspective view showing the structure of a tool employed for processing the tuning fork of FIG. **2**.

FIGS. **4***a* and **4***b* are perspective views showing the arrangement of exciting electrodes for a crystal tuning fork.

FIG. **4***c* is a diagram showing the polarities of the exciting electrodes for the prongs of the tuning fork of FIGS. **4***a* and **4***b*.

FIG. **5** is a longitudinal sectional view of an embodiment of the oscillator unit of the invention having the tuning fork of FIG. **2** rigidly supported within a hermetically sealed container.

FIG. **6** is a cross-sectional view of the oscillator unit of FIG. **5**.

FIGS. **7***a* and **7***b* illustrate by way of example different methods of supporting the outer can of the oscillator unit shown in FIG. **5**.

FIGS. **8***a* and **8***b* respectively illustrate a longitudinal sectional view and a cross-sectional view of another embodiment of the present invention in which the tuning fork of FIG. **2** is mounted within a sealed container and hermetically secured at the open end of the container.

FIG. **9** is a longitudinal sectional view of a further embodiment of the present invention in which the tuning fork of FIG. **2** is resiliently supported within a hermetically sealed container with rubber material being filled around the surface of the node of vibration.

FIG. **10** is a perspective of a further embodiment of the present invention in which the node portion of the tuning fork of FIG. **2** is resiliently supported by a pin of a hermetic terminal; and

FIGS. **11***a*, **11***b*, **11***c* and **11***d* are plan views showing still further embodiments of the present invention in which the principle of FIG. **2** is applied to certain vibrating elements other than tuning forks.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be explained with reference to the accompanying drawings.

In the past, as shown in FIGS. **1***a* and **1***b*, tuning forks cut and finished from such hard and brittle materials as rock crystal have been limited to only two kinds of geometric shapes, that is, the shape of FIG. **1**a in which the shape of a closed end portion **3** of a slit **2** separating the two prongs of a tuning fork member **1** is rectangular, and the shape of FIG. **1**b in which the shape of the closed end portion **3** is semicircular. While these conventional tuning forks have been generally satisfactory when the tuning forks are suspended with fine supporting wires and used as the frequency standards for stationary oscillators, it has been recently discovered by the inventors that, when used as the source oscillators for wrist watches, these conventional crystal tuning forks are not generally satisfactory in every respect.

In other words, in order to ensure an accuracy in terms of the daily rate of the order of 0.1 to 0.2 second, and a strength comparable to those of the latest mechanical wrist watches, which are requisites for a crystal wrist worthy of the name the following two essential conditions must be satisfied:

1. The oscillation should not be interrupted even for a moment by such a degree of shock as may be caused when a watch fitted around the wrist is inadvertently struck directly against a desk or the like.
2. The vibrating element should not be caused to be broken even when a watch is inadvertently dropped onto the floor from a height of not less than one half of one's stature. The interruption of oscillation as mentioned in (1) above is attributable to the fact that the vibrating element is moved to hit against the inner wall of the hermetically sealed oscillator container or the supporting structure of the vibrator when the watch is struck against the desk, and thus this difficulty can be solved by reinforcing the supports of the vibrating element to improve its rigidity so that the vibrating element may not easily come into contact with the surrounding structure. However, this permits the impact acceleration to directly act on the vibrating prongs so that the prongs may be easily broken when subjected to the impact mentioned in (2) above. This type of breaking occurs only at or near the base of vibrator prongs as indicated by marks * in FIGS. **1***a* and **1***b*, and it is attributable to the fact that in these portions the maximum bending moment acts on the prongs and hence the maximum stresses are produced, and there is the effect of stress concentration caused by a sudden change in section, at the slit end.

Among the solutions which have hitherto been proposed to overcome the foregoing difficulty, none has been superior to the tuning fork of FIG. **1***b* wherein the closed end portion **3** of the slit has the form of a semicircle to reduce the concentration of stress to some extent.

According to the present invention, the closed end portion **3** of the slit is V-shaped as shown in FIG. **2**. In this way, when subjected to the same acceleration, the resulting bending stress will be much smaller due to a slight and gradual increase in the sectional areas of the prongs, although the bending moment acting on the prongs at the base thereof will be much the same as in the conventional shapes. The rate of decrease of stress differs depending on the direction of accelerations, but even in the worst case (i.e., when the direction of acceleration is perpendicular to the prongs and the plane of the U-portion of a tuning fork) the decreasing rate of stress will be equal to the rate of increase in the width of the prongs at the base thereof. In this case, the rigidity of the prongs at the root thereof will also be increased with the resulting tendency toward somewhat increasing the natural frequency of the tuning fork, though this deficiency can be overcome by slightly increasing the length of the prongs.

By intuition one might consider that, since the radius of curvature at the top of the V-shape necessarily tends to be smaller than the radius of curvature in the conventional tuning fork shown in FIG. **1***b*, the effect of stress concentration would be considerably greater in the structure of the present invention than in the conventional structure. This is not true according to the tests conducted by the inventors, which have also shown that the present invention is effective in improving the resistance of the vibrating prongs to shock.

Next, the method of manufacturing tuning forks according to the present invention will be explained. Ultrasonic machining methods are widely employed for processing hard and brittle materials such as crystal blanks. FIG. **3** illustrates by way of example the construction of a tool which is believed to be best suited for use with the present invention. The tool comprises a laminated structure of sheets in which plates **4** are provided for cutting both sides of a tuning fork, a plate **5** is provided for cutting a central slit, and these plates are assembled by means of screws **7** with intervening spacers **6** spacing the plates away from one another by a distance equal to the prong width. The bottom face of this assembly is soldered to the top of an amplitude amplifying horn of an ultrasonic machine. The upper surface of the assembly constitutes a cutting surface by which three parallel open groves in the form of a " |‌|| " are cut in a blank. The upper and lower sides may be cut crosswise by means of a thin diamond cutter to cut out a finished tuning fork. To improve the production efficiency, a large number of the plates **4** and **5** may be alternately arranged so that a plurality of tuning forks are cut and finished simultaneously. The V-shaped slit end portion according to the present invention may be readily formed by providing the plate **5** with a knife-edge as shown in FIG. **3**. Furthermore, the thickness of the plates **4** and **5** and of the spacers **6** may be advantageously finished preliminarily to extremely accurate dimensions by means of a lapping process, for example, to thereby improve the accuracy of natural frequency of a finished tuning fork and of the balance in the vibrations of the two prongs.

Next, the exciting electrode pattern for a crystal tuning fork will be explained with reference to FIGS. **4***a*, **4***b* and **4***c* in which numeral **1** designates a crystal tuning fork whose contours are indicated with thin lines and dotted portions **8** outlined with thick full lines indicate an electrode pattern deposited by means of evaporation. Hatched portions **9** represent silver coated surfaces formed by applying a silver paste to those portions and then firing them prior to the evaporation process. These silver coated surfaces and the evaporation deposited surfaces are partially superimposed to provide electrical connections therebetween.

FIGS. **4***a* and **4***b* illustrate the two different external appearances of the crystal tuning fork before and after it has been turned through **180** degrees about its vertical axis. Among the silver coated surfaces, the larger surface portions designated as α, β, γ and δ are provided with deposits of solder to which lead wires are connected. The external lead wires may be connected to terminals C, S and D. The surfaces β and δ are interconnected by an internal conductor S'.

FIG. **4***c* illustrates the tuning fork as seen from the side of the upper ends of its prongs so as to show the ultimate interconnections among the deposited electrode coatings around the prongs and the respective terminals. The terminals C, S and D are respectively connected to the common terminal, input terminal and output terminal of an oscillating circuit so that the tuning fork is excited to develop bending vibrations. Of course, the electrode pattern as well as the terminals described above are illustrative only and the form of the electrode pattern and the number of the terminals may differ depending on the kinds of piezo-electric material used, the orientation of cut of the tuning fork, the types of oscillating circuit and so on.

Next, an embodiment incorporating the improved vibrating element will be explained.

The low frequency crystal oscillators which have hitherto been used comprise either a crystal rod or tuning fork suspended within a vacuum container by means of supporting wires. With this type of construction, there have been frequent troubles where the crystal was broken by hitting against the wall of the container, or the supporting wires were detached when subjected to a large mechanical shock.

According to the present embodiment of the invention, an oscillator unit of a novel construction is incorporated with the resultant remarkable improvement in the strength of the oscillator unit.

Referring now to FIG. **5** illustrating the embodiment, numeral **1** designates a crystal tuning fork, and **9** designates silver coated surfaces as shown in FIGS. **4*a*** and **4*b***, but the corresponding deposited electrode pattern is not shown. Numeral **10** designates a cylindrical outer frame of a material such as "Kovar" alloy; **5** is a glass material filled into the frame **10**; and C, S and D are insulated pins of "Kovar" or the like which extend through the glass layer. These components together constitute a hermetic terminal. The other ends of the leads C, S and D and an internal conductor S' are soldered to the corresponding silver coated surfaces **9** in a similar manner as explained in connection with FIGS. **4*a*** and **4*b***. In this way, the tuning fork can be externally excited through the hermetic terminal and at the same time the node portion of vibration of the tuning fork, i.e., a portion **11** connecting the two vibrating prongs, has its end firmly secured to the hermetic terminal in a manner as if mechanically it were almost integrally formed with the hermetic terminal by means of the sufficiently thick lead wires. If necessary, this portion of the unit may be further reinforced by applying an adhesive material **12** therearound.

Numeral **13** designates a hermetically sealed case of a material such as metal, glass or ceramic which is fitted on the hermetic terminal and completely sealed by joining its open end and the outer frame **10** together with a solder, adhesive or the like. This process may be carried out in a vacuum, or alternatively a small hole **13*a*** may be preliminarily provided so that when a recessed portion **13*b*** has been sealed with a solder, indium alloy or the like in a vacuum, the tuning fork is placed in a vacuum and is thus enabled to always oscillate in an ideal manner.

The tuning fork of this embodiment is characterized by the fact that the tuning fork is rigidly secured to the outer can, whereas the tuning fork is resiliently supported in the conventional unit. For this reason, even when the prongs of the tuning fork or the hermetically sealed case is more or less caused to bend under external force, a sufficient gap exists between the tuning fork and the case and prevents them from contacting against each other so that no breaking of the prongs occurs. It is to be noted here, however, that such external force acts directly on the prongs and therefore in some cases, in addition to the fact that a closed end portion **3** of the slit is formed into a V shape, the following countermeasure may preferably be taken to prevent the prongs from being broken. That is, instead of being rigidly secured to the base plate, the hermetically sealed case may be supported through the intermediary a resilient member **14** such as silicon rubber, for example, so that such external force is transmitted to the vibrating element only in a damped form.

The tests conducted by the inventors have shown that by virtue of the effects of the above-mentioned two measures, no breaking of the vibrating prongs occurred even when the watch was dropped on to a stone surface from a height of more than **1** m, and the resultant variations in the frequency were also satisfactorily small. Furthermore, when subjected to relatively small shocks, the vibrating element and the case wall did not contact against each other to cause any temporary stoppage of oscillations as heretofore experienced in the conventional units.

The tests have also shown that the rigid connection of the tuning fork tends to somewhat increase the leakage of vibrations as compared with the conventionally supported vibrators with resultant small changes in frequency due to the modification of the supporting conditions. However, these deficiencies may be overcome by the following countermeasures to such an extent that there will be no practical inconvenience:

1. Detect, with a sufficiently high degree of accuracy, the difference in natural frequencies between the two vibrating prongs by measuring variations in the value of Q of the vibrating element, the phase difference between the vibrations of the two prongs and so on, and then adjust in a manner to reduce the difference in the natural frequencies.
2. Arrange that the distance between the soldered portions and the lower end of the slit, i.e., the height of the base portion **11** constituting the node of vibration, becomes sufficiently larger than the total width of the tuning fork, for example, thereby preventing any damping substance, such as a solder and an adhesive from being deposited on those portions where vibration strains are present.
3. Employ the cushion members **14** for the purpose of stabilizing the supporting conditions of the vibrating element.

Referring to FIG. **6**, there is illustrated a sectional view of the oscillator unit of FIG. **5** and in this figure the identical reference numerals designate the corresponding parts. The resistance of the prongs to breakage is weak in the directions normal to the plane of the U portion of the tuning fork and this the members **14** are made somewhat thicker in these directions.

FIGS. **7*a*** and **7*b*** show two types of resilient supporting structures for the vibrating element in which leaf springs are employed in place of the rubber members **14**. In these figures, numeral **13** designates a case; **15** designates a leaf spring or a wire spring which is corrugated in FIG. **7*a*** and cylindrical in FIG. **7*b***; **16** designates a foundation such as a base plate; and **17** designates a joint connecting the spring and the case. With these structures, space-saving resilient supports can be provided. In addition, some stoppers may be mounted on the periphery of the can.

In this connection, the hermetic lead wires need not always be soldered directly onto the surfaces of the tuning fork, and relatively short intermediary members may be used. Alternatively, the tuning fork may be secured within the hermetic container by separate means so that fine lead wires can be connected to the tuning fork later. (In other words, the lead wires have nothing to do with the mechanical support of the crystals.) Moreover, in addition to such tuning fork type units, the present invention can also be applied to other oscillator units having a relatively large node of vibration (e.g. a unit employing a cantilever rod crystal which is wider at its base and a thickness-shear unit).

Next, another embodiment of the construction of a crystal oscillator unit incorporating the improved tuning fork of the present invention will be explained with reference to FIGS. **8*a*** and **8*b***. A tuning fork **1** is first connected with a metal ring **18**, and is hermetically sealed thereto with a filler material **19**, such as a glass sealing material and an adhesive. In this state, the upper ends or lower ends of the prong portions are adjusted to balance the vibrations of the two prongs (i.e., to adjust the two prongs so that the two prongs oscillate at the identical natural frequency and thus the reactions of the vibrations are cancelled to thereby prevent the vibrations from leaking out) and to adjust the unit to the desired frequency. Exciting electrodes may be deposited in a pattern similar to that shown in FIGS. **4*a*** and **4*b***, and the necessary external connections for the electrodes are provided by means of a deposited conductor pattern **9** connecting a surface **20** of the tuning fork exposed outside the lower end of the metal ring **18** and the prong surfaces. Numeral **21** designates a cylindrical container of a metal or glass which is hermetically joined with the metal ring **18** with a solder, a soft metal such as indium or an adhesive. The joining is accomplished in a vacuum or alternately the unit is evacuated after the completion of the joining to finish the oscillator unit in the form of a semi-permanent vacuum tube.

The results of the tests conducted on the effects of the present invention will be explained hereunder.

Tuning forks were cut from crystal blanks 0.8 mm thick and were finished to specified dimensions so that they had the total width of 1.9 mm. The prong length was 7 mm, and the ratio of the prong width to the slit width was almost 1 : 1 excepting the closed end portion 3 of the slit. Some of the tuning forks had their slit bottoms formed to be semicircular as shown in FIG. **1*b*** and the remaining tuning forks had their slit bottoms formed as shown in FIG. **2**. The latter had a V-shaped bottom and the width of each of the prongs thereat was greater by one third of the maximum slit width, with the slit bottom being formed into the shape of a semicircle with a diameter of about one third of the maximum slit width taking into consideration the danger of stress concentration and the wear of the processing tool. The height of the V portion was about two times the prong width. The inclined sides of the V portion were actually not plane surfaces, but they happened to somewhat bulge outwardly, and the bottom portion was approximately in the form of a semiellipse. When the two types of the tuning forks were subjected to loads applied to the tops of the prongs and acting towards the tops of the mating prongs, even in an example in which the least difference was recorded, the conventional tuning fork failed at the load of 270 g, whereas the breaking load of the novel tuning fork was 350 g. Thus, it is apparent that the strength of the tuning fork according to the present invention is greater than that of the conventional type by more than 30 percent. In the case of the tuning fork according to the present invention, the prongs were broken at the portions near the upper end of the V as indicated by marks * in FIG. **2** and not at the base of the prongs as with the conventional tuning forks. Thus, it was proved that the stresses produced in the base of the prongs were satisfactorily small in the tuning fork of the present invention.

Then, oscillator units constructed as shown in FIG. **8*a*** were assembled employing the same two types of tuning forks. These units were housed in cases similar to wrist watches and were subjected to drop tests. When the units employing the conventional tuning forks were dropped on to stone flooring, they were frequently broken even when the height of the fall was only **50** cm, whereas the units with the novel tuning forks were found to be in good order even after they had been dropped from a height of 100 cm. When an oscillator tubular member **21** which was enclosed by a layer of rubber **22** and covered by a cylinder **23** was housed within the case, the unit did not break even when it was dropped from a height of 150 cm. Moreover, when units of this type were allowed to drop while they were oscillating, the recorded fluctuations of the vibration caused by the shock were such that there was no substantial inconvenience which would prevent their practical use.

The unit employing the tuning fork of the present invention was also rather superior to the unit with the conventional tuning fork in terms of the value of Q which was a quality factor of the oscillator units, and it was assumed that this could be attributed to the improved distribution of strains caused by the vibrations. Furthermore, as compared with the conventional oscillator units, a larger percentage of the oscillator units according to the present invention could oscillate at a desired frequency without any subsequent adjustment after their assemblage. When it is desired to slightly reduce the oscillation frequency without destroying the equilibrium of the vibrations of the two prongs which have been balanced, the sides of the slit at the center thereof are slightly ground by means of a tool, such as a diamond file. For such a working operation, the device of the present invention has proved to be advantageous since its V-shaped slit bottom easily guided the file to to the central portion of the slit. On the contrary, the conventional units were often unbalanced since one of the two prongs tended to be ground to a greater extent cut than the other.

In summary, the device of the present invention is advantageous in that an improved oscillator unit is provided without increasing the dimensions of the vibrating element, and this improved unit is rather superior to conventional units in terms of machinability and vibration characteristic and, more specifically, it has an improved mechanical strength.

While there have been described some embodiments in which the crystal tuning forks are rigidly supported within the hermetically sealed containers, the advantage of an improved strength can be equally ensured with the improved tuning fork type vibrating element of the present invention even when such a tuning fork is resiliently supported within a hermetically sealed container. In other words, while a resiliently supported tuning fork tends to strike against the inner wall of a container in which it is supported when subjected to an impact exceeding a certain limit, there is less danger of the tuning fork being broken it if it reinforced as shown in FIG. 2. FIGS. **9** and **10** illustrate further embodiments of this type of the present invention.

Referring first to FIG. **9**, numeral **1** designates a crystal tuning fork; **10** designates a hermetic terminal as shown in FIG. **5**; C, S and D are pins; **24** designates relatively resilient lead wires interconnecting the pins and conductive film electrodes **9** deposited on the surface of the vibrating element; **25** is a mass of rubber into which the base portion of the tuning fork is embedded; and **26** and **27** provide a vacuum container when assembled with the hermetic terminal **10** by soldering, for example. In addition, although not a characteristic feature of the present embodiment alone, numeral **28** designates silver in paste form preliminarily applied to the upper ends of the prongs and then fired. By adding a very small amount of solder, for example, to the fired silver paste, or by removing the solder which has been applied in advance to the fired paste, an adjustment to the desired frequency can be effected very accurately. The adjustment by the removal technique is easier and the removing methods may include removing by mechnical abraison, removing by a soldering iron and the use of heat ray or a laser beam focused to melt and volatilize the solder. When the vacuum container is transparent, the last-mentioned method may be advantageously employed to externally effect the required fine frequency adjustment of a vibrating element which has been previously housed within the vacuum chamber.

Referring to FIG. **10**, numeral **1** designates a crystal tuning fork; **9** designates a conductive film deposited on the surface of the tuning fork; **29** designates a C-shaped metal mounting securely soldered onto a portion of the conductive film; **10** designates a hermetic terminal; and C, S and D pins. One of the three pins is extended and is secured to the metal mounting **29** by welding so that the pin resiliently supports the tuning fork and also serves as one of the exciting electrodes. The remaining short pins and the remaining conductive film portions are interconnected by long lead wires **30**. The vacuum container is not shown in this figure, since it is identical with the one shown in FIG. **9**.

While the preferred embodiments of the present invention have been described in which the invention is shown applied to the tuning fork type vibrating elements, the present invention can be equally applied to other forms of vibrating elements. FIGS. **11***a* through **11**d illustrate various forms of vibrating elements each of which is cut from a single blank and then slitted to specified dimensions. As previously described in connection with the tuning fork type vibrating elements, the slit in each of these elements can also be adjusted to gradually reduce the width of the slit towards its closed end to thereby increase the resistance to breakage. The illustrated vibrating elements are; (*a*) a triple prong reed, (*b*) an H-shaped vibrating element, (*c*) a vortex vibrating element whose free end is located in the central portion, and (*d*) a disk type vibrating element integrally formed with a supporting ring and designed to oscillate in the thickness-shear mode of vibration. In these figures, the hatched portions indicate the positions at which the vibrating elements are mounted on the holders, and the arrows indicate the directions of displacement of the free end at specified moments.

We claim:

1. A mechanical oscillator comprising a tuning fork type mechanical vibrating element having a plurality of prongs which are separated by at least one elongated slit, said slit being open at one end of its ends and closed at its other end, the width of said slit being uniform for more than half the length of said slit from the open end thereof and then gradually decreases in width at substantially a constant rate toward the closed end of said slit.

2. A mechanical oscillator according to claim **1**, in which the width of the gradually decreasing portion of said slit at the closed end of said slit is about one-third the width of the uniform portion of said slit.

3. A mechanical oscillator according to claim **2**, in which the apex of said gradually decreasing portion, at the closed end of said slit, is semicircular.

4. A mechanical oscillator according to claim **1**, in which the length of said gradually decreasing slit portion is about two times the prong width adjacent the uniform portion of said slit.

5. A mechanical oscillator according to claim **1**, in which said prongs merge into a base portion of the vibrating element, constituting the node of vibration, the height of said base portion being greater than the total width of two adjacent prongs of the tuning fork.

6. A mechanical oscillator according to claim **1**, comprising a hermetic enclosure for hermetically housing said vibrating element, and means for resiliently supporting said enclosure.

7. A mechanical oscillator according to claim **3**, comprising a hermetic enclosure for hermetically housing said vibrating element, and means for resiliently supporting said enclosure.

8. A mechanical oscillator according to claim **1**, comprising a hermetic enclosure for hermetically housing said vibrating element, said prongs merging into a base portion of said vibrating element, means for making electrical connections to said base portion for exciting said vibrating element, the base portion of said vibrating element protruding from said enclosure into the space exterior of said enclosure to render said portion for electrical connection accessible from outside said enclosure.

9. A mechanical oscillator according to claim **6**, in which said prongs merge into a base portion of said vibrating element, the base portion of said vibrating element, to which external electrical connection is made for exciting said vibrating element, extending to the exterior of said enclosure to render said portion for electrical connection accessible from outside said enclosure.

10. A mechanical oscillator according to claim **7**, in which a base portion of said vibrating element, to which external electrical connection is made for exciting said vibrating element, extends to the exterior of said enclosure so that said portion for electrical connection is accessible from outside said enclosure.

* * * * *