May 7, 1946. A. R. MORGAN 2,399,820

PIEZOELECTRIC APPARATUS

Filed Sept. 2, 1942

Fig. 1.

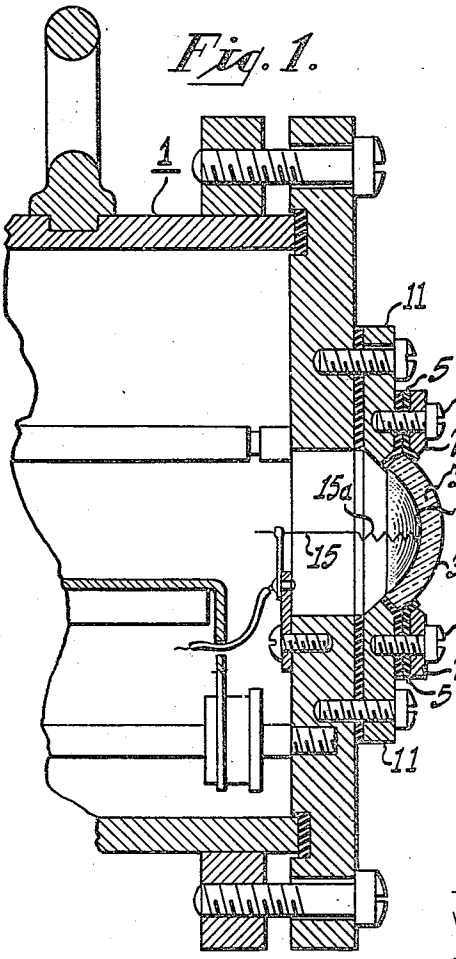
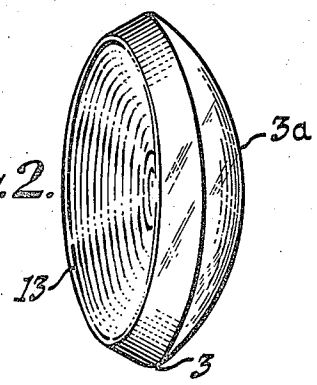


Fig. 2.



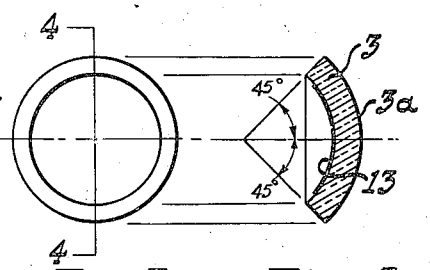


Fig. 3. Fig. 4.

Fig. 5.

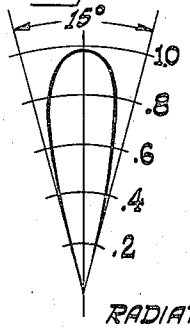
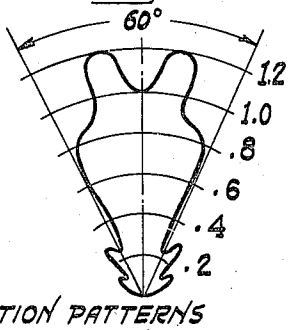


Fig. 6.



RADIATION PATTERNS

FLAT CRYSTAL CURVED CRYSTAL

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PIEZOELECTRIC APPARATUS

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7 Claims. (Cl. 177—386)

This invention relates to piezoelectric apparatus and has special reference to the provision of an improved form of crystal and holder for use in underwater signaling systems.

In the usual underwater signaling system, a quartz resonator converts electric oscillations of a given frequency (usually about 40,000 cycles per second) into elastic waves of the same frequency. These elastic waves are reflected back after impact on a distant obstacle, are amplified by the resonance phenomenon and then translated into electric signal energy.

The higher limit of frequency employed in such signaling systems is fixed by the distance to be traversed or, stated another way, by the absorption that can be allowed. The general rule is: penetration of the waves in water is inversely proportional to the square of the frequency. Thus, it is known that for 100,000 cycles per second the total energy is decreased to one-third of its initial value at 5 kilometers, while the corresponding distance of 40,000 cycles per second is 30 kilometers. (In air, the absorption would be approximately about 2,000 times larger, and at 100,000 cycles per second the energy would be reduced to one-third at 2 meters.)

The above considerations point toward an upper limit of 70,000 cycles per second for the frequency, on a basis of a reduction of energy to one-third at a distance of 10 kilometers. There are, however, numerous applications for underwater signaling systems of a very much more limited range and it would appear, in view of the foregoing, that any desired short range could simply be achieved by a proper selection of the crystal frequency. Such, indeed, is the case. However, it must be borne in mind that when an ordinary quartz plate is employed the radiated energy is localized in a narrow cone perpendicular to the plate, and of a half-angle A given by the formula:

$$\sin A = 1.2\frac{\lambda}{d}$$

where d is the diameter of the piezoelectric plate and λ is the wave length. Hence, one selecting a conventional crystal of a relatively high frequency for use in a signaling system of limited range has heretofore been obliged to accept the very narrow radiation pattern peculiar to a flat plate of that frequency. This, of course, is not always desirable since practical considerations may dictate the use of a relatively wide radiation pattern.

Accordingly, the principal object of the present invention is to provide an improved piezoelectric crystal which, when used in an underwater signaling system, will exhibit a radiation pattern considerably wider than that exhibited by present day crystals of the same frequency and diameter.

As will hereinafter more fully appear, the crystal employed in achieving the foregoing object is preferably in the form of a circular portion of a spherical shell. Therefore, a related object of the invention is to provide a suitable mounting arrangement for such an odd-shape crystal and one which will permit the crystal to be vibrated, subaqueously, in its intended mode and at its maximum practical efficiency.

Other objects and advantages will be apparent and the invention itself will be best understood by reference to the following specification and to the accompanying drawing wherein:

Figure 1 is a fragmentary sectional view of an underwater signaling unit incorporating a piezoelectric crystal assembly within the invention.

Figure 2 is a view in perspective of a quartz piezoelectric crystal cut in accordance with the principle of the invention, and similar to the crystal shown in Fig. 1.

Figure 3 is a plan view of the crystal of Fig. 2.

Figure 4 is a sectional view of the crystal taken on the line 4—4 of Fig. 3.

Figure 5 is a graph showing a narrow radiation pattern characteristic of prior art crystals, and

Figure 6 is a graph showing the wide radiation pattern characteristic of crystals cut in accordance with the principle of the present invention.

The broad objects of the invention may be achieved in an otherwise conventional underwater signaling unit, indicated generally at 1 (Fig. 1), by substituting a suitably mounted concavo-convex piezoelectric element 3 for the usual flat plate crystal or crystals of the prior art. As shown in Fig. 1, the crystal 3 forms a part of the end wall of the watertight casing 1 and it is the convex surface 3a of the crystal which is presented to the sea water or other ambient medium surrounding the casing. It is this arrangement of the electrode faces of the crystal which gives rise to the later described broad radiation pattern. The crystal 3 is preferably supported about its periphery in a rubber or similar gasket 5 with the seal rendered watertight as by a clamping force applied to the gasket by means of a removable clamping ring 7 having screws 9 which engage a mounting plate 11 on the end of the casing 1.

When, as during normal operation, the crystal

3 is in contact with sea water, but a single electrode 13 need be used in its excitation. (In this case the water may be said to comprise the second electrode, the circuit being completed through the water, which is conductive, to the casing 1.) This electrode 13 is preferably in the form of a silver or other metallic coating applied to the inner or concave face of the crystal and electrically connected to the voltage supply (not shown, but which may include an amplifier mounted within the casing 1) by means of a wire 15 which may be biased as by means of a loop or bend 15*a* into engagement with the said metalized concave face of the crystal.

As shown more clearly in Figs. 2, 3 and 4, the piezoelectric element employed in carrying the invention into effect preferably comprises a circular portion of a spherical shell. This "dished" vibratile element 3 preferably comprises an X-cut quartz element cut to respond to a fundamental frequency which is a function of its thickness dimension. That is to say, a crystal exhibiting a "longitudinal" type of vibration (as does an X-cut crystal) is to be preferred to one exhibiting a "shear" type of vibration and, where the desired frequency can be achieved with either a "thickness-mode" or a "contour-mode" crystal element, the "thickness-mode" element should ordinarily be used.

As previously indicated, the frequency to which the piezo-electric element is cut will ordinarily be dictated by the distance to be traversed by the elastic waves it sets up in the sea water or other ambient medium in which the device is to be operated. In one practical embodiment of the invention wherein the frequency employed was of the order of 500,000 per second, (i. e. 500 kilocycles) the crystal specifications were as follows: The crystal was an X-cut quartz element of the form shown in Figs. 2, 3 and 4 wherein it will be noted (see especially Fig. 4) that the vertex half-angle of the cone whose base is the spherical outer convex surface of the crystal, and whose vertex is its center of curvature, is substantially 45 degrees. The greater diameter of the said crystal was 1.25", the radius of its outer or convex surface was 0.885" and the radius of its concentric inner or concave surface was 0.660", hence its thickness was uniform at 0.225" as measured along different radii. The said crystal when vibrated, subaqueously, set up a radiation pattern similar to that shown in Fig. 6 wherein the elastic waves are shown as spanning an arc of 60 degrees. This radiation pattern is approximately four times as wide as the pattern (shown in Fig. 5) achieved with a conventional flat-surfaced crystal tested in the same apparatus.

Various modifications of the invention will suggest themselves to those skilled in the art of piezoelectricity. By way of example, the size and the curvature of the crystal may be greater or less that given in the foregoing example, as determined by the exact pattern desired. Further it is not essential to the practice of the invention that the crystal be of uniform thickness, since in some cases the desired pattern may be achieved with a circular crystal of a more or less tapered construction. Further, the invention is not to be limited to a vibrator incorporating a single crystal element since, where an extremely wide radiation pattern is required, it is entirely practical to employ a bank or mosaic of crystals. Accordingly, the foregoing description of one practical embodiment of the invention should be interpreted as illustrative and not in a limiting sense except as required by the prior art and by the spirit of the appended claims.

What is claimed is:

1. A vibratile element comprising a piezoelectric crystal in the form of a circular portion of a spherical shell and wherein the vertex half-angle of the cone whose base is the spherical surface of said crystal, and whose vertex is its center of curvature, is substantially 45 degrees.

2. The invention as set forth in claim 1 and wherein the thickness of said piezoelectric element is substantially uniform as measured along different radii of said spherical shell.

3. The invention as set forth in claim 1 and wherein said piezoelectric crystal is constituted of quartz and is adapted to respond to a predetermined fundamental thickness-mode frequency.

4. The invention as set forth in claim 1 and wherein said piezoelectric crystal comprises an X-cut quartz element adapted to respond to a predetermined fundamental thickness-mode frequency of the order of several hundred kilocycles per second.

5. A signaling device comprising a fluid-tight casing constituted in part by a piezoelectric crystal cut in the form of a concavo-convex element, the convex face of said piezoelectric crystal being presented to the ambient surrounding said casing, and means for vibrating said piezoelectric element.

6. The invention as set forth in claim 5 and wherein the inner concave face of said piezoelectric element is provided with a metallic electrode coating, the outer convex face of said element being uncoated.

7. An underwater signaling unit comprising a water-tight casing constituted in part by an X-cut piezoelectric quartz crystal element cut in the permanent form of a circular portion of a spherical shell, the convex face of said crystal element being presented to the aqueous medium normally surrounding said casing, and means comprising an electrode presented to the inner concave surface of said element for vibrating said quartz at a frequency which is a function of its thickness dimension.

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