Feb. 10, 1948. W. P. MASON 2,435,595

HIGH POWER COMPRESSIONAL WAVE RADIATOR

Original Filed Feb. 19, 1942

FIG. 2

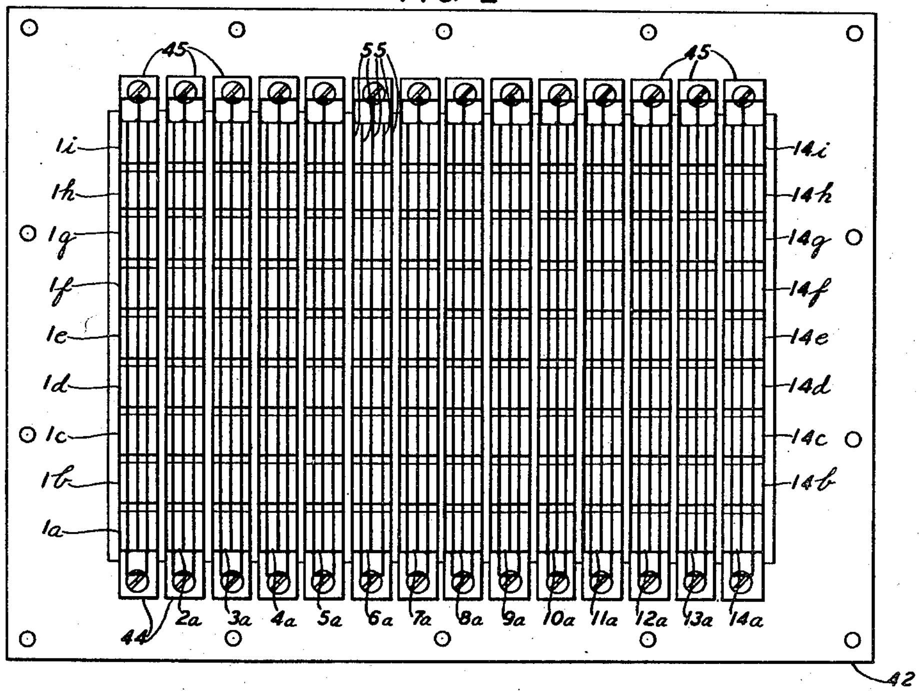


FIG. 3

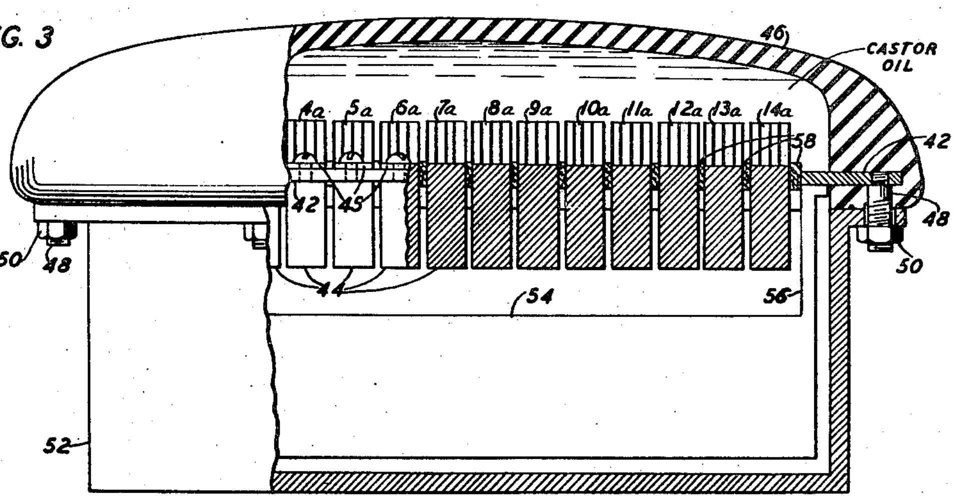
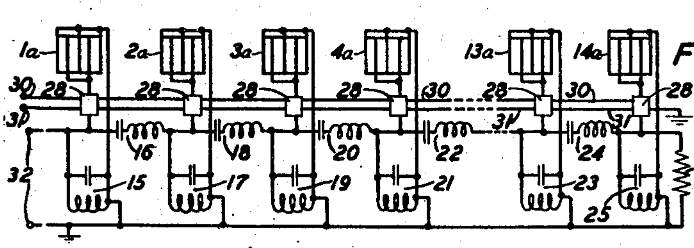


FIG. 1



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HIGH-POWER COMPRESSIONAL WAVE RADIATOR

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1 Claim. (Cl. 177—386)

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This invention relates to high power compressional wave radiating devices. More particularly, it relates to methods and apparatus arrangements for eliminating or substantially reducing the power limitations imposed upon compressional wave radiating devices by the phenomenon known as "cavitation."

This application is a division of my copending application Serial No. 431,558, filed February 19, 1942, which issued on July 23, 1946, as United States Patent 2,404,391.

When a vigorously vibrating mechanical element, such as a piezoelectric or magnetostrictive vibrating element, is employed in certain liquids, such as sea water, to radiate substantial amounts of compressional wave energy, it has been found that the amount of energy radiated increases directly with the increase in the power applied to the vibrating member up to a particular value, which value varies somewhat with the specific liquid and with temperature variations of the liquid and the vibrating element. As the power input is increased beyond this particular value, the phenomenon designated "cavitation" is observed.

This phenomenon is evidenced by the formation of bubbles of vapor or gas on the surface of the vibrating element and the amount of energy radiated per unit of further increase in energy applied to the vibrating element becomes much less than for power levels below the cavitation point. In many instances, indeed, no increase in radiated power, or even a decrease in the total radiated power, will result from an increase in applied power once the phenomenon of "cavitation" has become evident.

This application is accordingly directed to the discovery that if the vibrating element is immersed in a highly viscous fluid the phenomenon of "cavitation" does not become evident until much higher power levels are reached.

For example, cavitation occurs in kerosene when the power input is sufficient to create an acoustic pressure of from .85 to .90 atmosphere at the surface of the vibrating member, whereas in highly viscous liquids, such as castor oil, olive oil, linseed oil, and the like, it has been found that cavitation does not take place until an acoustic pressure at the surface of the vibrating member in the order of five atmospheres, or greater, has been established.

Since the radiated power is proportional to the square of the acoustic pressure, the maximum output power which can be radiated by employing the highly viscous liquid is in the order of

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twenty-five times that which can be radiated when the vibrating element is immersed in kerosene.

Cavitation in sea water begins at an acoustic pressure of approximately one atmosphere. It is necessary, therefore, in employing arrangements of the invention to provide for spreading the radiated power so that at the surface of contact with the sea water the effective acoustic pressure does not exceed one atmosphere. This is accomplished by enclosing the vibrating member or members within a cap which is filled with a highly viscous liquid, the cap being appropriately shaped and proportioned to provide the desired spreading of the power radiated from the vibrating member or members over a sufficiently large area before contact with and transmission into the sea water from the exterior of the cap takes place.

The principles of the invention are applicable with particular advantage to piezoelectric radiators employing Rochelle salt crystals, since, as discussed at length in my copending application Serial No. 413,429, filed October 3, 1941, entitled "Compressional wave radiators and receivers," Patent No. 2,414,827, the heating of a Rochelle salt crystal from any cause to a temperature of 40° C. or higher is most objectionable because it reduces the leakage resistance of the crystal to such a low value that further heating and ultimate destruction of the crystal is very likely to result. Naturally the substantial dissipation of energy accompanying cavitation rapidly overheats the crystal and accelerates its destruction. On the other hand, if this difficulty can be substantially eliminated Rochelle salt crystals are greatly to be preferred for submarine signaling compressional wave radiators since they are much cheaper than other types of piezoelectric crystals and the natural frequency and impedance characteristics of these crystals are more convenient for use in submarine signaling systems.

A principal object of this invention is to provide methods and apparatus for eliminating or reducing the phenomenon of "cavitation" adjacent compressional wave radiating surfaces.

Another object is to provide methods and apparatus for greatly increasing the power which can be efficiently radiated from compressional wave radiators.

A further object is to provide piezoelectric Rochelle salt crystal radiators capable of efficiently radiating high power compressional energy waves.

Other objects will become apparent during the course of the following description and from the appended claim.

The principles of the invention will be more readily apparent from the description of the illustrative embodiment shown in the accompanying drawing, in which:

Fig. 1 indicates in schematic diagram form the electrical connections of the radiator of Figs. 2 and 3; and

Figs. 2 and 3 show the principal mechanical features of a multicrystal piezoelectric high power compressional wave radiator employing the principles of the invention.

In more detail, in Fig. 1 a plurality of groups of four piezoelectric crystals in each group, namely, groups 1*a*, 2*a*, 3*a*, etc., are shown associated with a multisection band-pass electrical wave filter comprising shunt arms **15**, **17**, **19**, etc., and series arms **16**, **18**, **20**, etc. Successive groups of the crystals are connected electrically in shunt with successive shunt arms of the filter, respectively, as shown in Fig. 1. The right end of the filter is terminated in a resistive impedance **26** which is appropriately related to the impedance of the adjacent filter section over the transmitting band of the latter as will be described hereinafter. If the arrangement is to be used as a radiator, electrical energy comprising frequencies within the pass-band of the filter is introduced through the terminals **32** at the left end of the filter. When used as a receiver the compressional wave energy is converted by the crystals into electrical energy which may be drawn from terminals **32**.

The crystal groups 1*a*, 2*a*, 3*a*, etc., are preferably aligned with a distance between centers which is less than half the wavelength of the highest frequency to be radiated or received. This is necessary in order that a single direction of transmission or reception will obtain for each frequency. As wavelength is the quotient of velocity of propagation divided by the frequency the nature of the propagating medium must be taken into consideration.

In general, the directivity of such a device for both radiation and reception in any particular plane will vary with the dimension of the device parallel to that plane. For sharp directivity a dimension in the order of at least five wavelengths of the lowest frequency employed is desirable.

The phase shift of an electrical wave filter section of the type employed in the filter illustrated in Fig. 1 is well known in the art. For example, see the textbook "Transmission Networks and Wave Filters," by T. E. Shea, published by D. Van Nostrand Company, Inc., New York, 1929, pages 215 and 216, Figs. 106 and 107. It varies from $-\pi$ at the lower cut-off, to $+\pi$ at the upper cut-off, passing through zero in the mid-frequency of its transmission band. Thus any desired phase shift, between the above-stated limits, per filter section can be obtained by selecting the frequency in the pass-band corresponding to the desired phase shift. Of course, for each particular phase shift per section the array of crystal groups will transmit or receive energy with greatest efficiency at a particular angle since each crystal group differs in phase from adjacent groups by the phase shift of one filter section.

If two or more different frequencies, within the pass-band of the filter sections, are introduced into the device of Fig. 1, each frequency will be transmitted in a particular direction, different for each frequency, respectively, since the phase shift per filter section will be different for each frequency.

Conversely, for the reception of energy of a particular frequency within the pass-band of the filter sections the arrangement illustrated in Fig. 1 will respond with maximum efficiency only if the energy approaches from a particular angle which is dependent upon the phase shift per section of the wave filter at that frequency.

The arrangement of Fig. 1, therefore, normally has "prismatic" properties as defined above.

Relay switches **28** are provided to operate on voltage placed on conductor **30** and to disconnect the ungrounded conductors of the crystal groups from their respective filter sections and to connect them to a common conductor **31** so that all crystal units may be operated in phase at all frequencies in the event that prismatic characteristics are not desired. Radiation will then be broadside or normal to the longitudinal axis of the array for all frequencies.

Figs. 2 and 3 show the salient mechanical design features of a device, the electrical schematic of which can be that shown in Fig. 1. To permit the radiation of greater power, and to increase the vertical directivity characteristics of the device, each of the crystal groups **1*a***, **2*a***, **3*a***, etc., of Fig. 1 is further expanded by adding eight similar groups of four crystals each, connected electrically in parallel with the original group so that the complete radiator of Figs. 2 and 3 comprises fourteen vertical rows of crystal groups, each row comprising nine groups and each group comprising four crystals, i. e., thirty-six crystals per row and five hundred and four crystals for the complete radiator. The nine groups of each row, for example, groups **1*a*** to **1*i***, inclusive, or **14*a*** to **14*i***, inclusive, as shown in Fig. 2, can conveniently have common electrodes (**55** of Fig. 2) running the entire length of the row. Five electrodes are, of course, required, one between each pair of adjacent crystals and one on the outer surface of the two outside crystals of each group. The electrodes **55** can be of metal foil and are cemented or otherwise attached to the adjacent crystal surfaces.

The groups of crystals of each row are in turn cemented to their respective mounting strips **45**, a thin insulating spacer being interposed between the crystal groups and the metal mounting plate to afford high insulation resistance. Ceramic spacers of low dielectric constant and a cement also of low dielectric constant and unusually strong adhesive properties have been found most suitable for this purpose, since lower values of capacity to ground as well as higher breakdown voltages are thus obtained. These features are of especial importance for devices which are to radiate high power. The crystal groups are equally spaced along the mounting strip with a small interval between groups to afford appropriate directivity in the vertical plane as described hereinafter. The mounting strips **45** are screwed to a mounting plate **42**, which is assembled, as shown in Fig. 3, to clamp the edges of a composition rubber cover **46** tightly against a casing **52** by means of bolts **48** and nuts **50**. The composition rubber cover is preferably of a material recently developed by one or more of the large rubber manufacturers to have substantially the same velocity of propagation of compressional wave energy as sea water and thus to increase the efficiency of energy transfer to or from the water.

A multisection filter, such as is illustrated in the schematic diagram of Fig. 1, is mounted in a case 54 attached to mounting plate 42 by brackets 56. As the successive rows of crystals are directly shunted across successive shunt arms of the filter the effective electrical impedance of the rows of crystals and the distributed capacity in the wiring thereto should be taken into consideration in the filter design as an integral part of its associated filter arm impedance. The use of 45-degree Y-cut crystals again is very advantageous in this connection, since the capacity of such crystals varies very little with temperature changes and will not, therefore, appreciably impair the filter's characteristics with temperature changes normally encountered in submarine signaling. As a practical matter the provision of small trimming capacities whereby the resonance of the arms may be exactly adjusted after final assembly will be found advantageous.

Gaskets 58 of rubber or oil-proofed felt or the like are placed between the mounting strips 45 of adjacent rows and the space between the rubber cap and the crystals is filled with castor oil or some other highly viscous fluid, such as olive oil or linseed oil, which will eliminate cavitation at the power level to be employed and will serve to efficiently transmit compressional wave energy. The viscous fluid should be of such character that it can be "dried" conveniently to exclude moisture from the crystal surfaces.

The mounting strips 45 include a backing block of metal 44 for each group of crystals. The crystal groups are mechanically one-quarter wavelength high and the backing blocks are likewise mechanically one-quarter wavelength high, the difference in height between the crystals and the backing blocks arising from the difference in the velocity of propagation of compressional wave energy in the two materials. This type of mounting is discussed in detail in my above-mentioned copending application Serial No. 413,429 and its purpose is to produce a node of motion at the mounting strip 45 so that energy from the crystal groups in one row will not be transmitted to groups of adjacent rows or to the mounting plate 42 and casing 52. If transmitted to adjacent rows such energy can impair or destroy the desired directive effects by introducing energy of other than the desired phase and if transmitted to the mounting plate and case it can result in substantial dissipation and in the radiation or reception of energy from the sides or rear of the device, thus again impairing the efficiency and the directive properties of the device. For a well balanced assembly in which the backing blocks and crystals are accurately proportioned the fourteen mounting strips 45 can be replaced by a single mounting plate and the backing blocks 44 for each row can be replaced by a single bar running the length of the row, thus eliminating gaskets 58 and reducing the amount of milling work required on the backing blocks.

Casing 52 should provide adequate clearance between backing blocks 44 and the filter case 54 as well as the casing 52 itself so that substantially no energy will be lost or radiated in undesired directions from the sides or the rear of the assembly. In exceptional cases the casing 52 may be evacuated to prevent the transmission of compressional wave energy across it. As pointed out in my above-mentioned copending application, the reception of energy through the sides or rear of a directional receiving device is particularly undesirable in submarine detecting systems for use on naval craft since the propeller and engine noise from the craft itself will then be very likely to mask the relatively weak sound waves from a distant submarine. Wiring between the crystals and filter, etc., is not shown in Figs. 2 and 3 as it would, it is felt, render the drawing obscure. Also relay switching devices 28 of Fig. 1 are not shown in Figs. 2 and 3 but the necessary arrangements, including appropriate wiring, can, of course, readily be inserted in accordance with the diagram of Fig. 1 by one skilled in the art.

In addition to affording increased radiation the inclusion of nine crystal groups in each row broadens the radiation or response pattern of the device of Figs. 2 and 3 in the plane of the row. Since the device will normally employ its prismatic properties in the horizontal plane, the broadening just mentioned will occur in the vertical plane. For submarine detection work this is desirable as it will compensate for the roll of the vessel upon which the radiator or receiver is carried.

For high power submarine radiators, 45-degree Y-cut Rochelle salt piezoelectric crystals, or some cut of Rochelle salt crystal approximating the 45-degree Y-cut, offer substantial advantages as described in my above-mentioned copending application Serial No. 413,429. As mentioned above, the practicable maximum power output limit for crystal radiators is a point below that at which cavitation begins to take place. For a crystal submerged in an ordinary liquid, such as kerosene, for example, it has been discovered that cavitation will begin to occur at acoustic pressures of .85 to .90 atmosphere. When submerged in a highly viscous liquid, such as castor oil for example, it has been discovered that cavitation will not begin until an acoustic pressure in excess of five atmospheres has been reached. The adsorbed water of the crystal surfaces should, of course, be carefully removed and the castor oil or other highly viscous medium should be carefully "dried" as explained in my above-mentioned copending application Serial No. 413,429.

Since the power is proportional to the square of the acoustic pressure, the output power capacity of the crystal which can be realized without destruction of the crystal is increased in the order of twenty-five times by immersing it in a highly viscous liquid.

The greatly increased power which may be radiated with crystals immersed in a highly viscous liquid probably results from the sluggishness of the liquid, which flows so slowly that no cavities form during the short intervals in which negative pressure exists.

The increased power capacity of the individual crystal thus realized may be employed to advantage in constructing compressional wave radiators which will transmit in the order of twenty-five times the power of prior art radiators of like physical dimensions or it may be employed to obtain a given power radiation with a greatly reduced number of crystals and a much smaller over-all radiator structure than is required with prior art devices.

It is important that the cap enclosing the crystals provide a sufficient volume and a cross-sectional area of the viscous fluid within it parallel to the radiating surfaces of the crystal. The cross-sectional area should expand substantially as the distance from the radiating surfaces is increased, so as to "spread" the power to an extent such that the acoustic pressure transmitted to the water in contact with the cap is somewhat less than an atmosphere. If effective spreading of the power is not realized, cavitation in the water with consequent loss of power will take place adjacent the outer surface of the cap and the efficiency of the radiator can be seriously impaired. This requirement of spreading the power is more readily satisfied for radiators of the type described in my copending application Serial No. 407,457, filed August 19, 1941, entitled "Radiating systems," Patent No. 2,411,551, in which, to reduce "minor-lobe" radiation (i. e., radiation at angles other than that of maximum radiation) the more central units of a multicrystal radiator are driven with greater power than the peripheral or end crystals. However, in any type of radiator the cap may readily be proportioned to afford an adequate spreading of the power and reduction of pressure to avoid cavitation at the cap's outer surface of contact with the water or other medium into which it is to radiate energy. In the structure of Figs. 2 and 3 the spacings between the crystal groups and between the rows of crystal groups provide in effect an immediate expansion of the cross-sectional area through which the energy is to be transmitted in the viscous fluid. Furthermore, the fact that the successive rows of crystals are driven in differing phase relation, as described above, reduces the maximum effective pressure at the surface of contact with the sea water.

In radiators of the above type in which the successive groups of radiating elements are connected at corresponding points of successive sections of a wave filter, respectively, in order to obtain the particular desired distribution of the radiated power between the successive groups of radiating elements the impedance of the successive filter sections can be adjusted. For the purposes of this specification this process is designated as tapering the filter impedance and a filter so adjusted is designated as a tapered filter. For example, in the radiator illustrated in Figs. 1, 2 and 3, if it is desired to drive each of the fourteen groups of crystals by substantially equal amounts of power, it is necessary to compensate for the attenuation in the filter structure and the absorption of power by the successive radiating groups as power is transmitted from the input terminals 32 toward the terminating resistance 26. The diminution of energy is, of course, principally a function of the dissipation of the filter sections and the absorption of power by the successive crystal groups in the sequence. In a particular model it was found satisfactory to increase the impedance of each section by approximately five per cent of the impedance of the preceding filter section to provide substantially equal power radiation from all fourteen rows of crystals. In this instance the impedance of the first section was 6000 ohms and the impedances of the successive sections were 6,320 ohms, 6,710 ohms, 7,100 ohms, 7,600 ohms, 8,140 ohms, 8,770 ohms, 9.480 ohms, 10,320 ohms, 11,350 ohms, 12,600 ohms, 14,130 ohms, and 16,100 ohms, respectively.

Of course, if a distribution of power in which the more central units are to be driven with more power than the peripheral units is de-

sired, for instance, to obtain smaller minor-lobe radiation, the impedance of the successive sections should increase more rapidly than above from the input end to the central unit and then either remain substantially the same or even decrease again to the end or terminating unit, depending upon the power distribution desired. The principles involved are, of course, those discussed in my above-mentioned copending application on Radiating systems, Serial No. 407,457, coupled with the well-known principle that the power which a load of a given impedance will absorb is a function of the impedance of the circuit from which the power is to be drawn.

The above arrangements are preferred illustrative embodiments of the principles of the invention. Numerous other arrangements within the spirit and scope of the invention will readily occur to those skilled in the art. For example, while the above illustrative embodiments employ groups of piezoelectric vibrators, it is obvious that magnetostrictive, electromagnetic or other vibrating members could be substituted therefor and the prismatic properties, the increased power radiation and the like improved performance characteristics can be realized. The scope of the invention is defined in the following claim.

What is claimed is:

A high power compressional wave radiator comprising an electromechanical vibrating element adapted to develop at its radiating surface acoustical pressures in excess of one atmosphere, an envelope enclosing said vibrating element said envelope being filled with a liquid of sufficiently high viscosity that the phenomena of cavitation will not take place on the radiating surfaces of the vibrating element at the acoustical pressures developed, the proportions of said envelope being sufficiently large that the acoustical pressure developed at its surface is less than one atmosphere.

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