

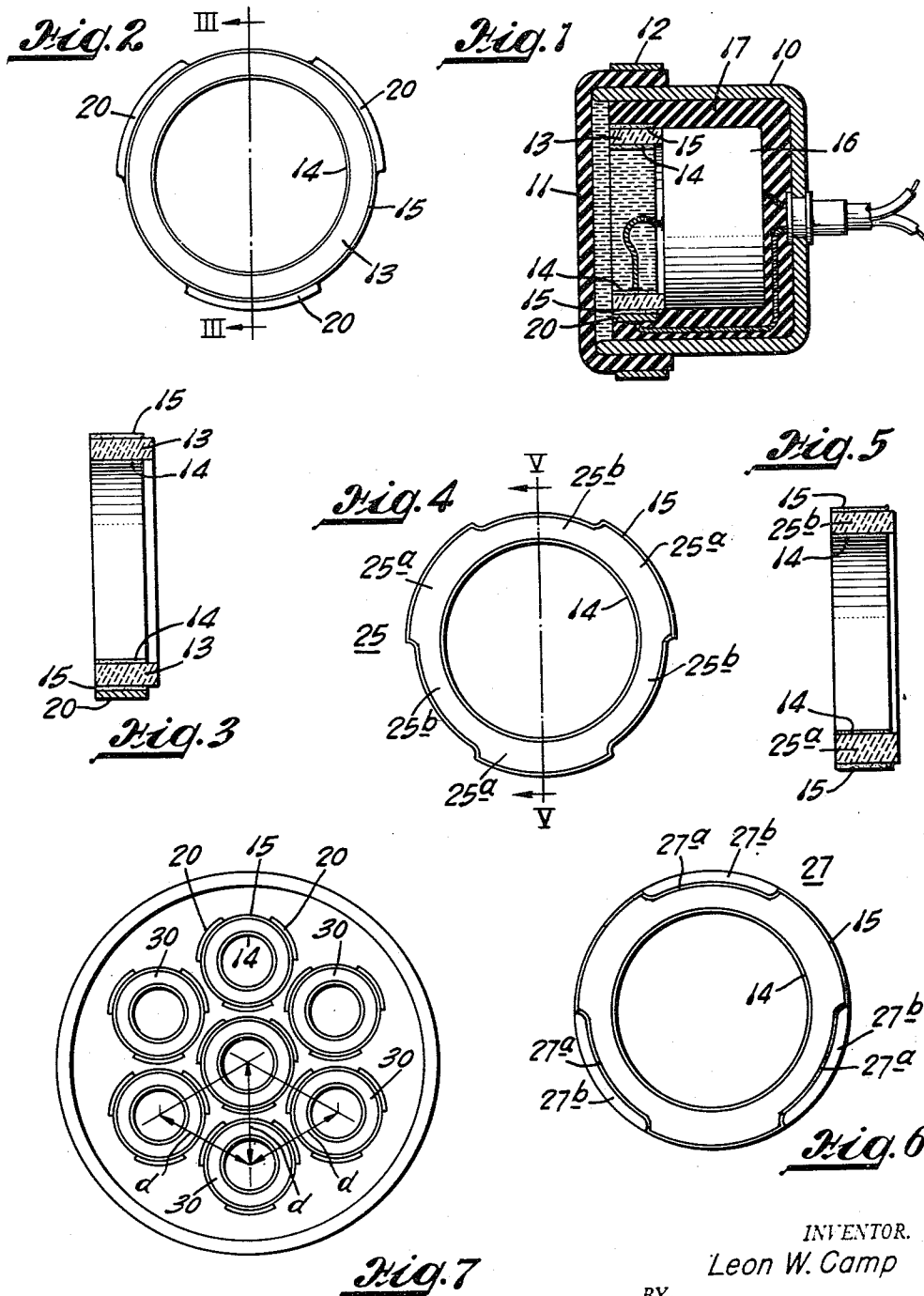
Dec. 18, 1956

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2,774,892

ANNULAR VIBRATOR WITH LUMPED LOADING

Filed May 29, 1951



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ANNULAR VIBRATOR WITH LUMPED LOADING

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Application May 29, 1951, Serial No. 228,956

7 Claims. (Cl. 310—8.1)

This invention relates to electro-mechanical vibrators of annular or ring shape intended to vibrate radially at their resonant frequency, the resonant frequency being a function of the dimensions of the ring and the mechanical characteristics of the material. Such vibrators are useful as transducers for producing compression waves in fluids in response to electrical oscillations, and, vice versa, for producing electrical oscillations in response to compression waves in fluids.

In general, the resonant frequency of such a ring varies inversely with its diameter, and to attain lower frequencies, the diameter must be increased. Such increase in diameter is sometimes objectionable or even impossible because of space limitations, as when an array of rings in a transducer must have a prescribed close spacing between the centers of the rings in order to obtain desired directional transmission characteristics.

An object of the invention is to lower the resonant frequency of radial vibration of a ring vibrator without increasing its diameter.

This object is achieved in accordance with the invention by increasing the mass of the ring at circumferentially spaced regions relative to the mass of the portions intermediate said regions. It is recognized that the resonant frequency can be decreased by uniformly increasing the mass of the ring throughout its circumference, but the decrease in frequency obtained by lumped, spaced masses is proportionately greater than that obtained by a uniform increase in the mass. The explanation is that the desired radial vibration is accompanied by a circumferential expansion and contraction, the frequency of which is determined largely by the greater mass in the spaced regions and the lesser restoring force of the portions of the ring intermediate the regions of greater mass.

The lumped masses should be symmetrically disposed circumferentially and at least three in number to discourage local vibration of segments of the ring out of phase with the desired vibration. The lumped masses may be of the same material as the rest of the ring and formed therewith, or they may be of a different material, preferably having a greater density.

A full understanding of the invention may be had from the description to follow with reference to the drawing in which:

Fig. 1 is a longitudinal sectional view of a transducer incorporating a ring vibrator in accordance with the invention;

Fig. 2 is an end view of the vibrator;

Fig. 3 is a cross section in the plane 3—3 of Fig. 2;

Figs. 4 and 5 are views corresponding to Figs. 2 and 3 respectively showing an alternative construction;

Fig. 6 is a view similar to Fig. 2, showing a third alternative construction; and

Fig. 7 is a face view of a transducer having an array of rings in accordance with the invention.

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Referring to Fig. 1, the transducer therein illustrated comprises a cup-shaped case 10 with a rubber end cap 11 secured in water tight relation over the open end of the casing by a band clamp 12. Positioned within the case 10 is a ceramic vibrator ring 13, having inner and outer electrodes 14 and 15, respectively, which electrodes may consist of silver coatings on the ceramic ring. The ring 13 is backed by a solid member 16 of substantial size, which may be made of some material, such as steel or aluminum, having good sound transmission characteristics and specific acoustic impedance much greater than that of water. The diameter of the backing member 16 is substantially the same as that of the ceramic ring 13 and both are supported within the casing 10 by a mass of some sound insulating material 17, such as Coroprene or air cell rubber. The entire space between the front end of the member 16 and the rubber window 11 is filled with some fluid, such as castor oil, which has substantially the same sound propagation characteristics as water.

The direct or primary mechanical motion produced in the ceramic ring 13 by potential between the electrodes 14 and 15 is radial, but there is a secondary resultant circumferential movement which determines the resonant frequency, it being approximately equal to the frequency corresponding to one wave length of sound in the material. The radial vibration of the outer face of the ceramic ring 13 is not utilized, it being reflected by the sound insulating material 17. The radial vibration of the inner surface of the ring 13 is transmitted to the fluid therewithin, developing sound waves which are transmitted through the fluid to the window 11, and through the window to the water or other fluid exterior thereof.

Referring to Figs. 2 and 3, the ceramic ring 13 has bonded thereto at equally spaced regions three bodies 20 of a material preferably having a density greater than that of the ceramic material composing the ring 13. These bodies 20 may be of uniform radial thickness, and each may be of sixty degrees extent and spaced from the other two bodies by sixty degrees. It is to be understood, however, that there is no hard and fast rule as to the circumferential dimensions and spacing of the bodies 20 and their arcuate extent may be less or greater than 60 degrees.

It is desirable that not less than three bodies 20 be employed, as a lesser number is more apt to produce undesired parasitic vibrations of the ring which would decrease its efficiency. However, the number may be increased beyond three to any desired extent. In general, it is simpler and satisfactory to employ three bodies or only a small additional number.

The bodies 20 may consist of metal and it is convenient to form them of solder, or other readily fusible alloy, which can be bonded directly to the silver coating 15 on the outer circumferential surface of the ring 13.

In Figs. 1, 2 and 3, the additional bodies 20 are positioned on the exterior circumferential surface of the ring 13, because the inner surface of the ring is the working surface. Applications of vibrating rings are known in which the exterior surface is the working face, and in that case the additional masses should be placed on the inner surface.

In a uniform ring, vibrating at the resonant frequency of circumferential expansion and contraction, the frequency is roughly in accordance with the formula:

$$f = \frac{\sqrt{K}}{C} \rho$$

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where

f =resonant frequency

K =elastic modulus or material

ρ =density of the material

C =mean circumference of the ring

Since the physical properties of the material in a simple ceramic ring are not controllable to any great extent, a lower frequency is obtainable only by increasing the circumference.

However, when a plain ring, such as the ring 13 is lump loaded as disclosed in Figs. 2 and 3 with additional mass, the foregoing formula no longer applies, and the resonant frequency of circumferential expansion and contraction and of the resultant radial vibration is substantially lower than for the plain ring.

As an example, a plain ring of barium titanate ceramic material having an internal diameter of 0.910 inch, an external diameter of 1.110 inches and a length of 0.270 inch was measured and found to have a maximum admittance at 52.239 kc. and a minimum admittance at 53.189 kc., giving a difference between the maximum and minimum admittances of 0.950 kc. and a maximum to minimum impedance ratio of 29.0 decibels. Such a ring had a weight of 7.7608 grams.

The same ring was then loaded with three bodies of solder, symmetrically distributed as shown in Fig. 2, and weighing 1.6212 grams. With this loading, the ring had a maximum admittance at 48.102 kc., and a minimum admittance at 49.008 kc., giving a difference between the maximum and minimum admittances of 0.906 kc., and a maximum to minimum impedance ratio of 20.5 decibels. It will be noted that the addition of the loading reduced the frequency over 4 kc. or about 8%. The loading reduced the Q , as evidenced by the change of the maximum to minimum impedance ratio from 29.0 decibels to 20.5 decibels. This reduction in Q is often an advantage in a transducer since it produces more uniform transmission over a band of frequencies.

A similar ring loaded with three bodies of solder weighing 4.78 grams had its frequency reduced from 52 kc. to 43.4 kc., a reduction of 16.5%. Reductions of 20% have been obtained, and even greater reductions are probably obtainable.

It is not necessary, in order to obtain the advantages of the invention, to make the lumped loading in the form of a different material of greater density. In some instances, improved results can be obtained by making the ceramic ring itself of different mass at different circumferentially spaced regions. Such a construction is shown in Figs. 4 and 5, in which a ceramic ring 25 is provided with sections 25A, of larger radial dimensions than the intermediate sections 25B. As has been previously pointed out, the reduction in frequency is not merely because of the greater mass of the sections 25A, but the result of this greater mass in combination with the reduced restoring force of the material in the sections 25B of smaller radius.

In most applications, there is no objection to having protuberances on the non-working face of a ring vibrator, such as occur in the constructions shown in Figs. 2 and 3 and in Figs. 4 and 5. However, there may be instances where it is desirable to have the ring of uniform dimensions throughout. The advantages of the invention can be utilized in a ring of uniform dimensions by employing the construction shown in Fig. 6, in which the ring 27 has recesses 27a formed in its outer surface and these recesses are filled with material 27b of greater density, such as solder, or the like.

As previously indicated, the invention may be advantageously applied to multiple ring transducers employing a plurality of rings in a close array to provide highly directional transmission and reception characteristics in water. Such a transducer employing seven rings 30 is illustrated in Fig. 7. In such a transducer it is nec-

essary for the obtention of certain beam patterns that the distances d between the centers of the rings be not greater than 0.8 of the wavelength in water. In a conventional ring, the wave length in the ceramic material at the resonant frequency is the mean circumference or 3.14 times the diameter of each ring. If the rings are almost in contact, it is evident that the distance d between centers will be only slightly greater than the diameter of each ring. However, the speed of sound, and therefore the wave length is roughly three times greater in ceramic materials and metals such as are commonly used in ring vibrators, as it is in water. Hence, using conventional rings almost in contact, the minimum distance d between centers is slightly greater than

$$\frac{\lambda c}{3.14}$$

where λc is the wave length in the ceramic, or .95 λw where λw is the wave length in water. As pointed out, for some purposes distance d should be not greater than .8 λw . In accordance with the present invention, it is possible to reduce the frequency and increase the wave length by at least 20% without increasing the diameter of the rings, thereby reducing d to less than .8 the wave length in water, the maximum permissible value for the particular directional pattern mentioned.

In the particular examples given, the vibrating element has been described as a ceramic. Electromechanically responsive ceramics containing barium titanate are well known. They change their dimensions in response to an electric potential and vice versa, in this respect resembling piezo crystals. Ceramics have advantages over some other materials such as piezo electric crystals in that they are more readily formed into desired shapes, but the expression "electromechanically responsive material" as used herein means any material that alters its dimensions in response to electrical excitation or vice versa.

Although for the purpose of explaining the invention, some particular embodiments thereof have been shown and described, obvious modifications will occur to a person skilled in the art, and I do not desire to be limited to the exact details shown and described.

I claim:

1. A device of the type described, comprising: an annular, radially vibratile element containing electro-mechanically responsive material, and means for electrically coupling said element to an electric circuit; said element consisting of an even number of arcuate regions, alternate ones of which have substantially identical mass identically distributed along their arcuate dimensions and the intervening regions of which have substantially identical mass identically distributed along their arcuate dimensions, the mass of said alternate regions being greater than the mass of said intervening regions.

2. A device, according to claim 1, in which said element comprises a continuous ring of said electro-mechanically responsive material, having bonded thereto, in said alternate regions, discontinuous bodies of a material of greater density than said electro-mechanically-responsive material.

3. A device, according to claim 2, in which said ring of electro-mechanically responsive material is of uniform cross-sectional dimensions at all circumferential points.

4. A transducer comprising an array of annular radially vibratile elements of the same dimensions containing electro-mechanically responsive material positioned adjacent each other in a common plane in which each element has a plurality of circumferentially symmetrically spaced regions of greater mass than the intervening portions, whereby the resonant frequency of vibration of the elements is reduced without altering the center-to-center and the periphery-to-periphery spacing of the elements in the array.

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5. A device of the type described comprising: a continuous radially-vibratile ring of electromechanically-responsive material, and means for electrically coupling said element to an electric circuit; said ring having a plurality of circumferentially symmetrically spaced regions of greater radial thickness and greater mass than the intervening portions of the ring.

6. A device of the type described comprising: an annular radially-vibratile element containing electromechanically-responsive material and means for electrically coupling said element to an electric circuit; said element having a plurality of circumferentially symmetrically spaced regions of greater mass than the intervening portions of the element; in which said element comprises a continuous ring of said electromechanically-responsive material of greater radial thickness in said intervening portions than in said regions, and said regions have bonded thereto discontinuous bodies of a material of greater density than said electro-mechanically-responsive material.

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7. A device according to claim 2 in which said ring has inner and outer cylindrical faces and said discontinuous bodies are on said outer cylindrical face.

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