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H. C. HAYES

2,064,911

SOUND GENERATING AND DIRECTING APPARATUS

Filed Oct. 9, 1935

FIG.1.

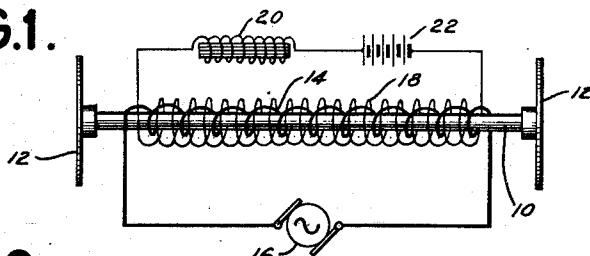


FIG.2.

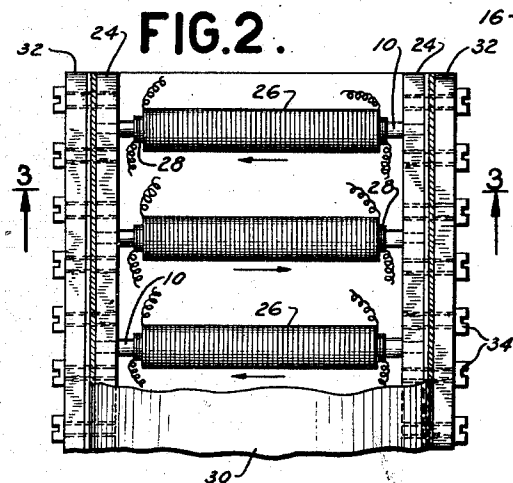


FIG.3.

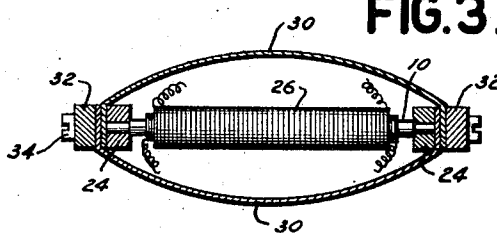


FIG.5.

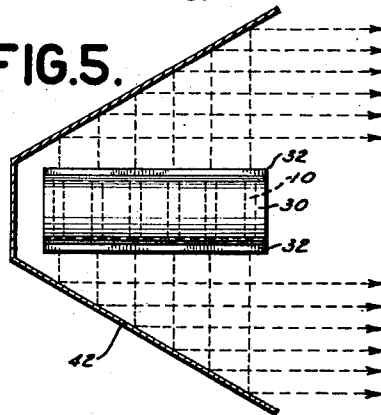


FIG.4.

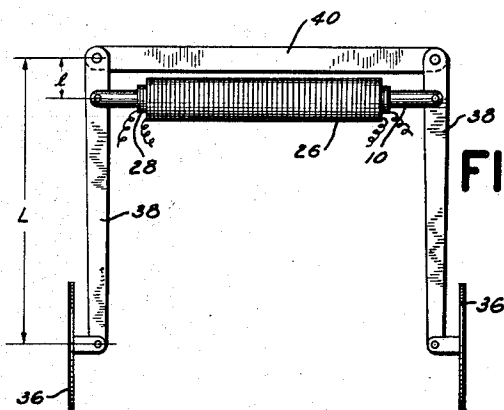


FIG.6.

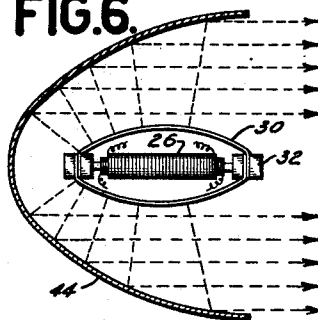
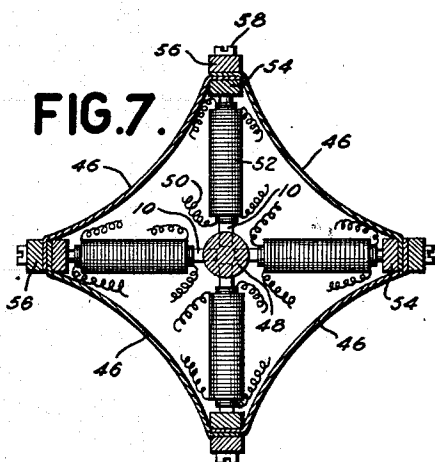


FIG.7.



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SOUND GENERATING AND DIRECTING
APPARATUS

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6 Claims. (Cl. 181—0.5)

(Granted under the act of March 3, 1883, as
amended April 30, 1928; 370 O. G. 757)

This invention relates to sound generating apparatus and more particularly to apparatus in which a sound emitting member or members are vibrated through the application of the principle of magnetostriction. The primary object of the invention is to provide a sound generating device of this type particularly well suited for emitting audible sounds in a medium such as air.

A further object of the invention is to provide a device which will concentrate sound waves in a given direction or plane, and a still further object is to provide a sound generating device in which exceptionally large forces are present for restoring the vibrating element or elements to their natural position.

It has long been known that certain solid materials, particularly some of the pure metals and their alloys, change their dimensions when subjected to a magnetic field. With certain materials, such as pure iron, the metal elongates in the direction of the field when the field is weak, but as it is strengthened a point is finally reached when the metal contracts along the direction of the field. In the case of cobalt there is a tendency for the metal to contract in weak magnetic fields and to expand in the stronger field, the expansion and contraction being along the direction of the field. Nickel contracts along the direction of the field for all field strengths. Such expansion or contraction of materials associated with a magnetic field is termed "the magnetostriction effect". If the two ends of a rod of magnetostrictive material are clamped firmly in position and the rod is subjected to a magnetic field parallel to its axis, then the tendency for the rod to change its length will set up forces tending to slide the clamps, of the same magnitude and sense as would be required to mechanically stretch or compress the rod the same amount as it would suffer if the ends were not clamped. It is evident that the changing length of such a rod or tube caused by varying the magnetic field can be employed to vibrate a diaphragm to generate sound energy.

So far as is known there is no other type of drive for oscillating diaphragms where such great restoring forces are inherently brought into play as is the case with the magnetostrictive type and therefore the scheme of making the inertia of all or part of the moving members more effective than they normally would be and without the use of levers becomes particularly valuable in combination with such magnetostrictive drive.

In accordance with this invention an apparatus has been provided by means of which certain masses are caused to vibrate by utilizing magnetostriction so that audible sounds are readily

transmitted in a predetermined direction or plane and through a medium such as air.

For a better understanding of the invention, reference may be had to the accompanying drawing in which

Fig. 1 is a diagrammatic view illustrating the principles of the invention;

Fig. 2 is a plan view, partly in section, of a sound generating device comprising one form of the invention;

Fig. 3 is a sectional elevation taken on line 3—3 of Fig. 2;

Fig. 4 is a plan view of another form illustrating certain principles of the invention;

Fig. 5 is a sectional elevation illustrating certain directional features;

Fig. 6 is a sectional plan view showing a different mounting; while,

Fig. 7 is a sectional elevation through another embodiment of the invention.

The methods and means for effectively generating sound energy in any medium are dependent on the physical characteristics of the medium. If the medium is highly incompressible like water, it becomes difficult or impossible to drive a diaphragm against it to a large amplitude and the nature of the driving force required is therefore one that has small amplitude but great magnitude, while if the medium is highly compressible like air the diaphragm can be driven against it to considerable amplitude by comparatively small forces and the nature of the driving force then required is one that is small in magnitude but which can operate through considerable amplitude. The work per second done on the medium by the diaphragm-driving forces is proportional to the value of the force times the amplitude through which it acts and to the number of cycles through which the force acts per second. It will, therefore, be seen that only small amplitudes are required to do work on a water medium because the force factor must be made great, while in the case of air the amplitude must be made great, and so only small force is required. The nature of magnetostrictive forces is better adapted for generating sound energy in water than in air because they are great in magnitude and small in amplitude.

In Fig. 1, number 10 represents a magnetostrictive rod of length 21 and cross-section (a) and numerals 12 represent two like discs or sound radiators of mass (m) attached to either end of the rod. Numeral 14 represents an electrical coil wound around the rod 10, the circuit being closed through a source of alternating current 16 of variable frequency. Numeral 18 represents another winding around the rod 10, the circuit including a choke coil 20 and a source of direct current 22, to prevent reversal of the magnetic field through the rod 10. If the frequency of the

circuit 14 is adjusted to a proper value (N), then the rod 10 with the mass (m) attached to either end will be driven to oscillate at its natural frequency and the value of (N) will be related to the dimensions of the rod, the masses involved, the elasticity of the metal, etc. by the following well-known equation:—

$$N = \frac{1}{2\pi} \sqrt{\frac{Y \cdot a}{m \cdot l}}$$

Where Y is Young's modulus of the magnetostrictive material.

Suppose now that reasonable values be assigned to the factors on the right hand side of the equation, such as:—

$a = 1$ sq. cm. $Y = 22 \times 10^{11}$, $m = 100$ gr. $l = 10$ cm. then

$$N = \frac{1}{2\pi} \frac{22 \times 10^{11} \times 1}{100 \times 10} = 71,000 \text{ cycles}$$

a pitch that is far above the audible range.

It is obvious that (N) can be made smaller by increasing the value of (m) but since the effectiveness of change of (m) only operates as the square root it will require that (m) be increased by a factor 10^4 to bring the value of (N) down to 710—a value well into the audible range. This means that a mass of 10^6 grams must be placed on each end of the rod. It is also obvious that the same effect can be obtained by making (l) ten thousand times as long, or by making (a) one ten-thousandths as large, but in each case the values become impractical. Of course, a combination of these changes can be made, but it will be found that even then some or all of the dimensions will be impractical.

The above example is given to show that the magnetostrictive forces are impractical for generating audible sounds when employed directly as shown in Fig. 1. Also, as stated hereinbefore, such forces are not suited for generating sound in air because of their small amplitude of action. The formula for (N) shows that the reason for this lies in the large value of Young's modulus, Y, which value, however, is set by nature and cannot be much modified, and as a result little or no use has been made of magnetostrictive forces for generating audible sounds in any medium, particularly in air. This invention also permits the use of such forces for this purpose and makes possible the development of simple, cheap, rugged and efficient sound generators embodying unique and desirable properties as will now be shown.

The principle of operation of the device is described in connection with Figures 2 and 3 which illustrate one form of the invention. The device in this embodiment consists of one or more rods or tubes of magnetostrictive material again indicated by numeral 10 which are connected rigidly between two stiff, transversely arranged bars 24. Each magnetostrictive member 10 is surrounded by magnetizing coils 26 and 28, these coils corresponding respectively to the coils 18 and 14 of Figure 1. The bar members 24 are preferably made of some magnetic material such as iron or steel and the sense of the direct current windings or coils 26 is preferably such that the magnetic flux will flow about the several magnetic circuits in the direction of the arrows shown in Figure 2 while the alternating current coils 28 are so connected that a current in one direction will strengthen the D. C. field at all points and when reversed will weaken the D. C. field at all points. Unless the sense of the several coils have

this relation the rods 10 and the bar members 24 will not oscillate in phase. The sound radiators or diaphragms consist of two curved sheets of metal 30, 30 which are rigidly clamped along two of the side edges between the bars 24 and members 32, the last mentioned members being secured to the bars 24 by means of suitable bolts 34. The magnetostrictive rods 10 are so positioned along the bars 24 that the same effective mass is carried by each of the rods so that each rod will have the same natural frequency (N) and the whole system will vibrate in phase. The several D. C. and A. C. coils can be connected respectively in series, in parallel or in series-parallel to the desired impedance without affecting the acoustical efficiency of the device.

This type of sound generator operates at its highest efficiency when the frequency of the electrical current circuit is tuned to equality with its natural mechanical frequency and this is the operating condition preferred, but its overall efficiency has proved to be well above that of other sound generators even when the electrical A. C. circuit is not tuned.

No difficulty is experienced in designing the apparatus so as to give pitches well down in the audible range and the reason for this can be understood in connection with Figure 4 in which it is shown that the effectiveness of a mass in determining (N) is proportional to the amplitude through which the oscillator causes it to move. This can readily be shown where levers are used as in Fig. 4. The use of levers is impractical, however, where such small movements are involved but in accordance with this invention the disadvantages of the levers are avoided by securing the amplification of diaphragm motion through curvature of the diaphragm. In Figure 4 a pair of radiating members 36 with their effective mass (m) are illustrated as carried on the ends of two like levers 38 which for simplicity of explanation may be considered weightless. The other ends of the levers 38 are pivoted to the ends of a heavy rigid cross-bar 40 and the magnetostrictive member 10 is also pivoted at its ends to the levers 38 at a distance (l) which is small compared with the length (L) of the levers. From the principles of mechanics it is obvious that the effectiveness of the mass (m), so far as determining the natural frequency of the system caused by setting up periodic strains in the rods 10 is equivalent to a mass (M) equal to

$$\frac{L}{l} \cdot m$$

placed directly on the ends of the rods 10 as shown in Figure 1. It is also obvious that the amplitude of motion of the radiating surfaces 36 of Figure 4 as compared with that of Figure 1 is also equal to the ratio

$$\frac{L}{l}$$

It follows that the effective value of any mass (m) so far as affecting the formula

$$N = \frac{1}{2\pi} \sqrt{\frac{Y \cdot a}{m \cdot l}}$$

is equal to the actual mass (m) multiplied by the ratio of the amplitude mass to that of the driving force. In the light of this demonstration it becomes obvious that the mass of the radiating diaphragms 36 becomes very effective in decreasing the value (N), particularly as their

radius of curvature is made greater because their amplitude of motion then becomes very great compared with that of the magnetostrictive rod 10. Obviously the distance (l) could be increased or decreased if it were desired to decrease or increase, respectively, the amplitude of vibration of the diaphragms or masses 36.

The device described in connection with Figures 2 and 3 is designed to utilize a comparatively small mass, i. e., the curved diaphragms 30, so effectively that magnetostrictive forces can be used for producing audible sounds. It accomplishes this by making these masses oscillate through an amplitude great as compared with that of the forces driving them. It will be recalled that an efficient generator of sound in air or any other highly compressible medium requires that the radiating surfaces should have a relatively high amplitude of motion. In the device described the masses in question have been made to be the radiating diaphragms themselves, and as a result the same conditions that serve to produce sufficiently low pitched sounds for signalling purposes also serve to make the device an effective generator of sound signals in air.

The sound energy generated by a vibrating surface or diaphragm is proportional to the square of the amplitude of motion and to the area of the surface. A method and means for oscillating a sound generating surface at large amplitude has been described. It will now be noted that the invention permits of increasing the radiating area to almost any desired value. In the first place both diaphragms oscillate outward and inward in phase so that one cannot act as a sink for the other as a source, and the full energy is thus radiated outward. The radiating area is therefore normally double that of most sound generating devices. But it is evident that the device can be designed for almost any desired length or breadth by increasing the length and/or the number of the magnetostrictive rods 10. It therefore offers a means for generating sound energy of almost any desired amount, a feature that is not common to most sound generators.

It is a well known fact that the intensity of a sound at different points equally distant from a generating source may vary greatly, particularly when the dimensions of the sound generating area are large as compared with the wave length of the sound. Under these latter conditions this sound energy is more or less confined into a diverging beam, the axis of which is perpendicular to the generating surface at its central point. It can be shown that the sine of the angle of spread of the sound beam is proportional to the ratio of the wave length of the sound to the diameter of the sound generating area. The larger this ratio is made, the smaller becomes the divergence of the sound beam. Therefore, since the device forming this invention permits of using large sound generating surfaces it thereby permits of generating directive signals without the use of horns. This fact offers definite advantages particularly in the case of certain fog signals where definite shoals or other dangerous areas are to be outlined. There is one type of directivity which is desirable for practically all types of sound signals. Since the sound source and the receiver are located in practically the same horizontal plane it becomes desirable to concentrate the sound in this plane. In this way the sound energy that is wasted in

the air above the plane of the sound generator and receiver and which under certain conditions gives deceptive echoes from low lying clouds and fog banks, could be utilized to increase the signal strength in the direction where it is desired and at the same time increase the reliability of direction of the sound source. It will now be explained how this can be accomplished.

It has been stated that the divergence of a sound beam from a plane radiating surface increases as the ratio of the diameter to the wave length of sound decreases, and that when the radiating surface is circular this ratio determines the sine of the angle of divergence. It can be shown that a similar relation holds for rectangular-shaped radiating surfaces. Let (a) and (b) represent the length and breadth, respectively, of the plane radiating surface. Then the spread of the beam in a direction parallel with (a) will be less than the spread parallel with (b) and the cross-section of the beam becomes somewhat rectangular with its short and long dimension parallel respectively with the long and short dimensions of the radiating surface. Therefore, if a rectangular-shaped radiating surface is mounted to face in a horizontal direction and dimensioned so that the vertical length is large compared with the wave length of the signal, so as to make the vertical spread of the beam small, and the horizontal breadth is made much smaller so as to favor the spread of the beam in a horizontal direction, then the sound will be concentrated in a horizontal plane. In case of the form of transmitter described in Figs. 2 and 3, where two opposite radiating surfaces are employed, the horizontal dimension can readily be made such that the sound from each plate diverges 180 degrees in horizontal plane so that substantially equal intensity is given for all directions about the azimuth. This is the condition desired for fog signals on most light ships where, due to changing winds and tidal currents the ships may point in almost any direction of the compass. It is obvious that a sound generator of the type described can be mounted with its long dimension in a horizontal instead of a vertical direction so as to direct the sound through a definite azimuth angle. Under such conditions only a portion of the sound has a horizontal direction. If in addition the transmitter is surrounded by a cone-shaped reflector 42, as shown in Figure 5, or if it is mounted with the long axis vertical and is placed in a parabolic-cylindrical reflector 44 having its axis vertical, as shown in Figure 6, substantially all the sound can be directed in horizontal direction and concentrated in a definite azimuth angle. Means for supporting the sound generating devices within the reflectors has been omitted to simplify the illustration.

It is obvious that the best shaped radiating surface for concentrating the sound energy in a plane so that the intensity will be equal at all points equi-distant from the generator would be a circular cylinder, but so long as the wave length is large with respect to the breadth of a face, the polygon cross-section serves about as well and by using such a form the radiating surface can be made larger than in the design shown in Figures 2 and 3. Figure 7 shows a design carrying four equal radiating surfaces that embodies certain favorable features. In Figure 3 it will be noted that the members 24 and 32 vibrate 180° out of phase with the radiating surfaces 30. It is true that the amplitude of the bar members 24 and 32 is small as is also their radiating area but

they do generate some sound and this small amount, because of the phase relation, must cancel by interference an equal amount of the sound generated by the radiators 30. This defect can be remedied when the section is polygonal, as can be seen in Figure 7 where the four radiating surfaces 46 are curved inward toward the center axis instead of outward as in Figure 3. In this embodiment four sets of magnetostrictive rods 10 are arranged in the form of a cross and are rigidly connected at their inner ends to a bar 48 coinciding with the longitudinal axis of the device. Each rod 10 is surrounded by A. C. and D. C. coils 50 and 52 respectively, these coils again corresponding to the coils 14 and 18 of Figure 1. The outer ends of the rods 10 are rigidly connected to transverse bars 54 and the edges of the radiating members 46 are held against these bars 54 by means of other bars 56 and suitable bolts 58. These connections are substantially the same as those involving elements 24, 32 and 34 shown in Figures 2 and 3.

It is obvious that the entire surface comprising the four radiators 46 and the bars 56 shown in Figure 7 moves outward and inward in phase and that this condition can be made to prevail with a polygonal section of any desired number of sides. This type of sound generator has the double advantage that it all oscillates in phase and that the radiating surface can be given any desired area without affecting the directivity perpendicular to the axis, whereas with the embodiment shown in Figures 2 and 3 this cannot be done without increasing the breadth of the two sides to lengths so great with respect to the wave length that each face would concentrate its energy into an azimuth angle less than 180° thereby having "dead areas".

Obviously, many modifications and variations of the invention, as hereinbefore set forth, may be made without departing from the spirit and scope thereof, and therefore only such limitations should be imposed as are indicated in the appended claims.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

I claim:

1. In a sound generating device, a plurality of rods of magnetostrictive material arranged in parallel, a pair of bars each of which is rigidly secured to one end of each of said rods, a second pair of bars adapted to be clamped against and in alignment with said first mentioned bars, a pair of substantially rectangular sound radiating diaphragms each of which is outwardly convex in curvature, each of said diaphragms being provided with flanges along two of its parallel edges, said flanges being clamped between said first and second mentioned bars, and electrical magnetic means surrounding said rods for vibrating said rods longitudinally by magnetostriction.

2. In a sound generating device, a plurality of rods of magnetostrictive material arranged in parallel, a pair of bars each of which is rigidly secured to one end of each of said rods, a second pair of bars adapted to be clamped against and in alignment with said first mentioned bars, electrical magnetic means surrounding said rods for vibrating said rods longitudinally by magnetostriction, and means for converting the longitudinal movements of the rods into sound waves having greater amplitude as compared to the

amplitude of vibration of said bars comprising a pair of substantially rectangular sound radiating diaphragms each of which is curved in a transverse direction, each of said diaphragms being provided with flanges along two of its parallel edges, said flanges being clamped between said first and second mentioned bars.

3. In a sound generating device, a plurality of rods of magnetostrictive material, a central supporting member, said rods being disposed in parallel groups and said groups being arranged uniformly and radially around said member with the inner end of each rod rigidly secured to said member, and an enveloping diaphragm secured to the projecting ends of said groups of rods, the portions of said diaphragm between adjacent groups of rods being uniformly concave, and electrical magnetic means for simultaneously vibrating all of said rods longitudinally by magnetostriction.

4. In a sound generating device, a plurality of rods of magnetostrictive material, a central supporting bar, said rods being disposed in parallel groups and said groups being arranged in the form of a cross with one end of each rod secured rigidly to said bar, a plurality of sound radiating diaphragms, each of said diaphragms being substantially rectangular and slightly curved throughout its length, means for securing parallel edges of said diaphragms to the projecting ends of adjacent groups of rods, the curvature of said diaphragms being concave, and electrical magnetic means for simultaneously vibrating said rods longitudinally by magnetostriction.

5. In a sound generating device, a plurality of rods of magnetostrictive material, a rigid supporting bar, said rods being arranged parallel in groups and said groups being disposed uniformly and radially around said bar with the inner end of each rod rigidly secured to said bar, a connecting member rigidly secured to the projecting ends of the rods of each group, a plurality of sound radiating diaphragms, each of said diaphragms being substantially rectangular and slightly curved about its longitudinal axis, the longer parallel edges of each of said diaphragms being provided with flanges, means for securing the flanges of each of said diaphragms to said connecting members of adjacent groups of rods, the curvature of said diaphragms being concave, and electrical magnetic means for simultaneously vibrating said rods longitudinally by magnetostriction.

6. In a sound generating device, a plurality of rods of magnetostrictive material arranged in parallel, a pair of bars each of which is rigidly secured to one end of each of said rods, a pair of substantially rectangular sound generating diaphragms each of which is outwardly convex in curvature and is secured along two of its edges to said bars, means for vibrating said rods by magnetostriction including a magnet coil surrounding each of said rods and a source of alternating current for energizing said coils, and means for directing the sound waves emitted from said device in a predetermined horizontal direction and concentrated in a definite azimuth angle, comprising a parabolic-cylindrical reflector disposed around said device with the axis of said reflector arranged vertically and the open side facing toward the desired direction, said device being disposed with its longitudinal axis vertical and its transverse axis pointing in the desired direction.

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