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SOUND REPRODUCING MEANS

Filed Jan. 9, 1930

2 Sheets-Sheet 1

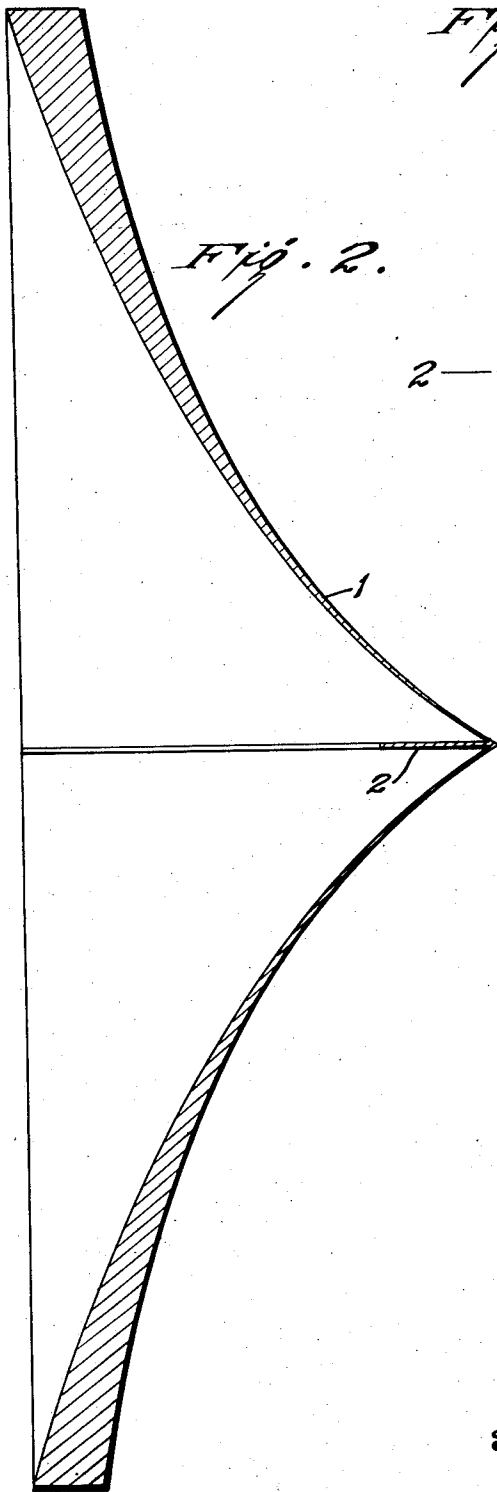


Fig. 1.

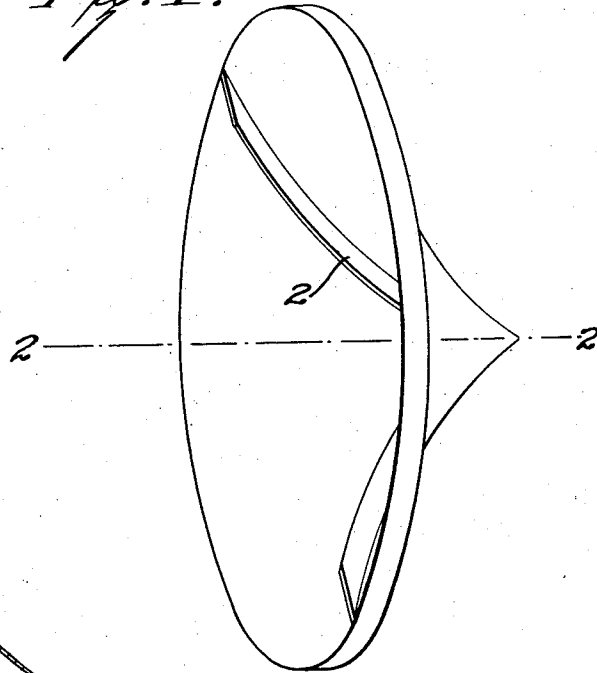
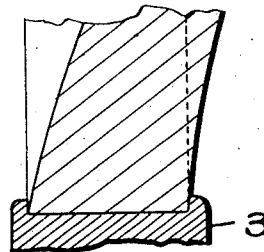


Fig. 3.



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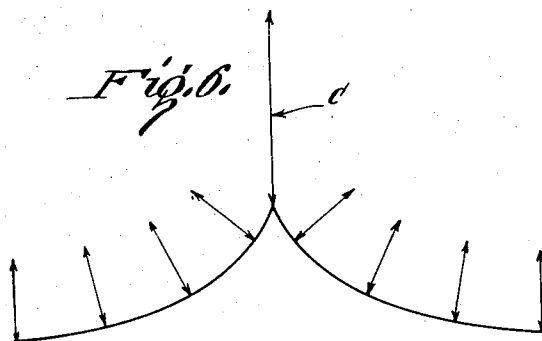
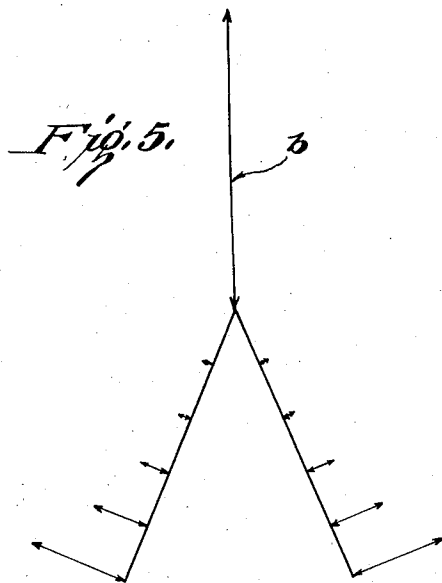
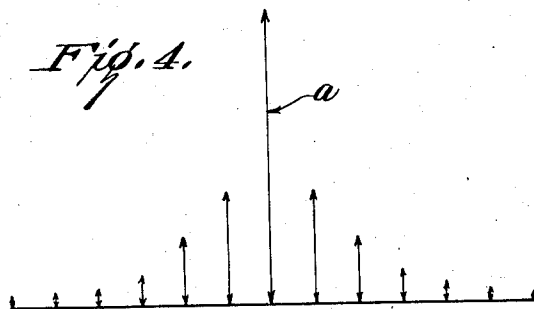
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SOUND REPRODUCING MEANS

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2 Sheets-Sheet 2



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SOUND REPRODUCING MEANS

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This invention relates to loud speakers; and it comprises a sound reproducing diaphragm having equal distribution of energy emission for equal circumferential zones, said diaphragm having approximately the shape of a belled cone or a coned diaphragm thinner at the center than at the edges; the surface advantageously following a curve corresponding to a Neilian or semi-cubical parabola and the thickness at any point varying with the square of the radius of a plane section; all as more fully hereinafter set forth and as claimed.

While a large number of empirical facts are known concerning the emission of sound from a diaphragm, the theory of the emission is not well understood. It is probably for this reason that no entirely satisfactory apparatus has yet been developed for the transformation of electrical impulses into sound or vice versa. The development of methods for the transmission and amplification of the electrical impulses themselves has far outstripped the development of the reproducing mechanism.

Faithful reproduction of sound requires that a diaphragm vibrate in a complex manner; the vibrations corresponding exactly in character and in amplitude to those of the source of sound. As a rule a diaphragm does not do this, its own resonance qualifying the impressed vibration. Placed in vibration by impressed energy, any of the usual diaphragms develop a complex series of vibrations including the forced vibration, the natural or free vibrations and the reaction products of the two. The sound delivered is mutilated, distorted or covered by noise to that extent.

By free vibration of a diaphragm as distinguished from forced vibration is meant such vibration as results from striking the diaphragm a single blow and producing a tone which continues after the impelling force is withdrawn, whereas by forced vibration is meant the response of a diaphragm to each vibration or series of vibrations impressed upon it which does not continue after the impelling force has ceased.

If a diaphragm or sound producing body

is made of heavy material such as metal, the free vibration will predominate to such an extent that forced vibrations are overwhelmed, whereas the lighter the material the less the tendency for the body to vibrate in free vibration and the more adaptable it becomes to the impulses of forced vibrations. For example, a bell when struck will give forth a certain definite tone specifically belonging to that bell. Even under forced vibrations of other frequencies the tone of the bell will predominate.

The lighter the material, however, the greater the ratio of its responsiveness in forced vibrations to that in free vibration.

A diaphragm tends to vibrate in segments with development of nodes; the period of any particular segment depending upon (a) the thickness of the material and (b) the square of the distance from the center. This is represented by the equation

$$\text{Frequency} = \frac{\text{thickness}}{\text{radius}^2}$$

The range of frequencies to which a diaphragm of uniform thickness is resonant in free vibration thus depends upon the diameter of the diaphragm. Further, the range of frequencies to which a diaphragm of a given diameter is responsive in free vibration may be increased by thinning the diaphragm from the center outwardly, or it may be diminished by increasing the thickness from the center outwardly; that is, the area of the diaphragm that is responsive in free vibration to any one frequency may be enlarged or reduced by increasing the thickness of the diaphragm from the center outwardly or by reducing the thickness from the center outwardly.

Also the volume of sound at any frequency per unit of vibratory energy may be increased or diminished by reducing or enlarging the area of the diaphragm which is responsive to that frequency. Increase of the volume of sound may be obtained by increasing the amplitude of vibration. The range of frequencies to which the diaphragm is responsive is not changed thereby. It is known, however, that distortion of reproduction in

the usual diaphragm is greatly increased as the amplitude of vibration is increased. Consequently, the efficiency of the diaphragm in the emission of the energy impressed upon it becomes important.

It is known that the efficiency of emission of a disc diaphragm is low due to the fact that the center of the disc does most of the work; that is the energy is rapidly dissipated from the center toward the circumference. This appears to be due to the fact that the center of the disc is not sufficiently stiff to transmit the energy to the outer sections, without appreciable loss.

I have found that efficiency of emission of sound requires that the surface of the diaphragm follow a curve; and that the center of the diaphragm be sufficiently stiff to transmit the energy to the outer sections without great loss. The most effective method which I have found of accomplishing this result is to make the diaphragm of a certain shape which may be most easily explained by reference to the accompanying figures in which,

Fig. 1 represents a perspective view of a diaphragm;

Fig. 2 is a section along the line 2—2 of Fig. 1;

Fig. 3 is a fragmentary view showing marginal clamping;

Fig. 4 is a diagrammatic representation of the distribution of energy emitted from a disc diaphragm;

Fig. 5 represents the emissive energy distribution of a conical diaphragm; and

Fig. 6 represents the emissive energy distribution of my improved diaphragm.

An advantageous shape for my diaphragm is illustrated in Figs. 2 and 6. In Fig. 6 the arrow *c* represents the direction and magnitude of an impressed force which causes the vibration. This is a rectilinear force in one dimension which is transformed by the diaphragm into three dimensional motion. The smaller arrows along the contour of the diaphragm represents the energy emitted at the corresponding circumferential zones. From the shape of the contour it is evident that this diaphragm has a considerable stiffness close to the point of application of the exciting force, at least in the direction of vibration. This causes a considerable portion of the energy to be distributed outwardly along the diaphragm without appreciable loss. Near the outer edges the diaphragm is free to vibrate in a plane which is essentially perpendicular to the direction of the applied force; that is the major component of the vibration is parallel to the vibration of the applied force. I have found that the combination of the stiffness at the center and the curvature as shown produces a most efficient diaphragm in the emission of sound. The explanation appears to reside in the fact that the emitted

energy for equal circumferential zones is equal, from the center outwardly. This is indicated by the equal length of the arrows along the contour. What I regard as the best surface curvature for my diaphragm, is, or approximates to, that of a Neilian or semi-cubical parabola of rotation (Williamson, "Integral Calculus," Longmans, London, 1880, page 224). While this exact shape is advantageous, any other contour approximating it in general form is useful.

The equation of this curvature may be represented by the equation $X^2 = KY^3$, in which *K* is constant. For balsa wood I have found that the best value of *K* is about one-fifth.

Fig. 4 illustrates the emission of energy from a disc diaphragm, *a* representing the magnitude and direction of the applied force. It is seen that the energy of emission is concentrated at the center and practically disappears at the edges.

Fig. 5 represents the conditions existing in a cone diaphragm. Here the diaphragm is stiff for its entire length and the major portion of the energy is transmitted to and emitted from the very edge of the diaphragm. The face of the diaphragm, moreover, is not perpendicular to the direction of the applied force and hence energy is lost. The applied force tends to move the diaphragm bodily rather than cause it to merely vibrate.

A flat disc of even thickness over-emphasizes the high notes in sound reproduction, while a conical diaphragm over-emphasizes the lower notes;—especially those notes that come within the range of the free vibration response of such diaphragms. My new diaphragm gives an even response over the whole audible range.

The range of frequencies to which a diaphragm is sensitive is changed by tapering its thickness. I have found two tapers to be severally advantageous in each of which the thickness of the diaphragm varies with the square of the radius. With a thin center and thick edge, the above equation showing the relation between frequency, radius and thickness, indicates that a taper section varying directly as the square of the radius of a plane section passing through the axis should produce a constant or single frequency. I have confirmed this conclusion by experiment. Mathematically such a diaphragm has essentially a single natural frequency, or in other words is homophonic. It might be expected that this single resonant frequency would interfere with reproduction but I have found that, where the diaphragm is relatively large and is made of balsa wood, paper pulp or other light material, the natural frequency is unimportant and does not interfere with impressed vibrations of any audible frequency. Apparently the energy required for the diaphragm to vibrate as a

whole is too great to permit emission of this frequency with the power available in ordinary reproducing units. The diaphragm reproduces vocal and instrumental notes with their full complement of overtones and in their natural ratio, making the timbre of different instruments clearly distinguishable and the voice natural, without mutilation, distortion, noise or mushiness.

The phonic homogeneity of my thin center, thick edge, single frequency diaphragm prevents substantial disturbance by clamping, and such a diaphragm may be mounted in almost any convenient manner. Edgewise clamping is desirable. In addition I ordinarily employ a full diameter, rigidly attached hard wood rib.

The particular construction of my thin center thick edge diaphragm is shown in Figures 1 to 3.

The bell shaped body 1, Fig. 2, may be integral or built up and may be made of any suitable material. The contour curves gently outward away from the conical, leaving the inner surface slightly convexed and the outer surface slightly concaved. The two surfaces have somewhat different curvatures, being separated by a thickness of material which increases gradually along the line of curvature from the center outwardly. For best results the increase in thickness is directly as the square of a radius of a plane section vertical to the axis of rotation, that is, in the case of a curvature approximating that of a semi-cubical parabola, which is the optimum curvature, the thickness increases at the square of the axis at right angles to the axis of rotation. This vertical axis may be called the "semi-cubical" axis or the axis which varies as the square root of the cube of the other axis. A diaphragm with a peripheral radius twice as great would be four times as thick at the edge. A typical diaphragm under the present invention may be of balsa wood and 24 inches in diameter on a plane section, with a marginal thickness of 1 inch. At a midway point where the diameter of a plane section is twelve inches the diaphragm has a thickness of $\frac{1}{4}$ inch. With other woods, paper pulp, cardboard, etc., the thicknesses will vary; but the general rule is followed that the increase of thickness outward shall be as the square of a plane section radius. With these materials this increase of thickness necessarily increases the mass of material in a cross section of the diaphragm in the same ratio, that is, the diaphragm has a cross section progressively increasing both in width and in weight of material with distance from the apex and the rule of variation in proportion to the square of the plane section radius applies to the weight as well as to the thickness.

As shown, the diaphragm is provided with a transverse rib 2, rigidly united to the dia-

phragm. Its function is to apply vibratory energy. In Fig. 3 I have shown a convenient method of mounting the diaphragm, the edge being clamped by support 3 which may be of a board panel or may be a spider-carried metal annulus.

An interesting result seems to follow when the diaphragm is built in the shape described. The phone unit may be applied at the center of the diaphragm or at any point along the rib with almost equally good results. While this fact is of value in the practical construction of radio or phonograph loudspeakers it is of especial interest as tending to indicate that this form of diaphragm will function correctly even under seemingly adverse conditions.

By reversing the taper of the diaphragm, making it thin at the periphery and thick at the center but still allowing the thickness to vary with the square of the radius, quite another and interesting result is obtained. Instead of being homophonic, the natural tendency existing in any diaphragm to vibrate in segments with intervening nodes is reinforced. This tendency is increased by any taper which is thicker at the center than at the edges, but a taper which varies with the square of the radius has been found advantageous in producing a large range of natural frequencies for a conveniently sized diaphragm. Thus, with a balsa wood diaphragm one inch thick at the center and $\frac{1}{8}$ inch at the periphery, a 22 inch diaphragm will give natural frequencies covering about ten octaves, or more than an 80 inch ordinary cone, speaker will do. The areas, however, responding to any particular frequency are very small. Such a diaphragm has portions which tend to go into free vibration at almost any frequency that is found in audible sounds while the amount of the free vibration is not very great. Such a diaphragm gives good reproduction of speech and music with very little noise of its own. Instead of having a small range of frequencies which affects the sound to be reproduced, it has a multiplicity of minor natural frequencies, in the audible range. One advantage of this is that a small diaphragm can be made as effective in reproduction as much larger diaphragms of uniform thickness. The distortion due to the resonance of the diaphragm can be spread over a range of ten octaves or more—with the result that it is hardly noticeable to the ear.

While I have described the diaphragm more particularly for reproducing sound it may be equally used for the reverse purpose of picking up sound as in microphones for radio transmission, record making devices and the like. The principles herein explained may be used in making musical instruments.

The source of energy or the exciting unit is usually positioned at the apex of the dia-

phragm and may comprise the motor unit of a telephone, radio, phonograph, etc.

What I claim is:—

1. A diaphragm having approximately the shape of a belled cone with a thickness varying with the square of the radius of a plane section.
2. A diaphragm having approximately the shape of a belled cone being thin at the center and thick at the edge with intermediate thickness varying with the square of the radius of a plane section.
3. A diaphragm having approximately the shape of a belled cone being thick at the center and thin at the edge with intermediate thicknesses varying with the square of the radius of a plane section, the contour curving gently from the apex to the edge.
4. A homophonic sound amplifying diaphragm having approximately the shape of a belled cone and made of material thinner at the center than at the periphery, the contour of the diaphragm curving gently from the apex to the periphery, the outer surface being slightly concave and the inner surface slightly convexed, and the thickness of the material increasing with the radius of curvature of the contour.
5. A diaphragm having approximately the shape of a belled cone; the contour being concave from the apex to the edge; the thickness increasing as the square of the distance from the apex on a plane section.
6. A diaphragm having the general shape of a belled cone but having a curved surface with a contour following a curve corresponding to a semi-cubical parabola of rotation and having walls increasing in thickness from the apex to the base.
7. A diaphragm useful with radio reproducing units and resonant in free vibration to approximately but one frequency, said diaphragm being thin at the center and thick at the edge with intermediate thicknesses varying with the square of the radius on a plane section and being of a mass too great to be set into free vibration at said frequency by the motor unit.
8. A diaphragm resonant in free vibration to but approximately one frequency, said diaphragm being thin at the center and thick at the edge with intermediate thicknesses varying with the square of the radius on a plane section, and said diaphragm having the general form of a belled cone with a contour following a curve corresponding to a semi-cubical parabola of rotation.
9. A diaphragm resonant in free vibration to approximately but one frequency, said diaphragm being thin at the center and thick at the edge with intermediate thicknesses at intermediate points and having a curved surface, the contour being in the form of a parabola.
10. A diaphragm having approximately

the shape of a belled cone, and having a radial rib rigidly united to said diaphragm.

11. In a sound reproducing device, a diaphragm receiving near its center forced vibrations from a transmitting unit and being resonant in free vibration to approximately but one frequency, said diaphragm being of a radially tapered transverse section, said section increasing in width from the center to the outer edges, said increase being in proportion to the square of the radius of a plane section.

12. A sound amplifying diaphragm resonant in free vibration to substantially but one vibrational frequency, said diaphragm being of moderately large size and of a curved conical shape externally concave and internally convex, the diaphragm thickness progressively increasing from the center to the periphery with the radius of curvature.

13. In a sound-reproducing device, a diaphragm receiving near its center forced vibrations from a transmitting unit and being resonant in free vibration to approximately but one frequency, said diaphragm having the shape of a belled cone with a cross section progressively increasing in weight from the center outwardly, the mass of material in successive annular sections varying in proportion with the square of the radii of plane sections taken at right angles to the axis.

14. In sound reproducing means, an amplifying diaphragm of moderately large size and resonant in free vibration to approximately but one frequency, said diaphragm having the shape of a belled cone with its inner surface convex and its outer surface concave and with the weight of material in the diaphragm cross section increasing regularly from the apex to the base along the line of the bell curvature.

In testimony whereof, I have hereunto affixed my signature.

ADRIAAN NAGELVOORT.