Jan. 31, 1933. L. G. BOSTWICK 1,895,441

SOUND TRANSLATING DEVICE

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FIG. 1

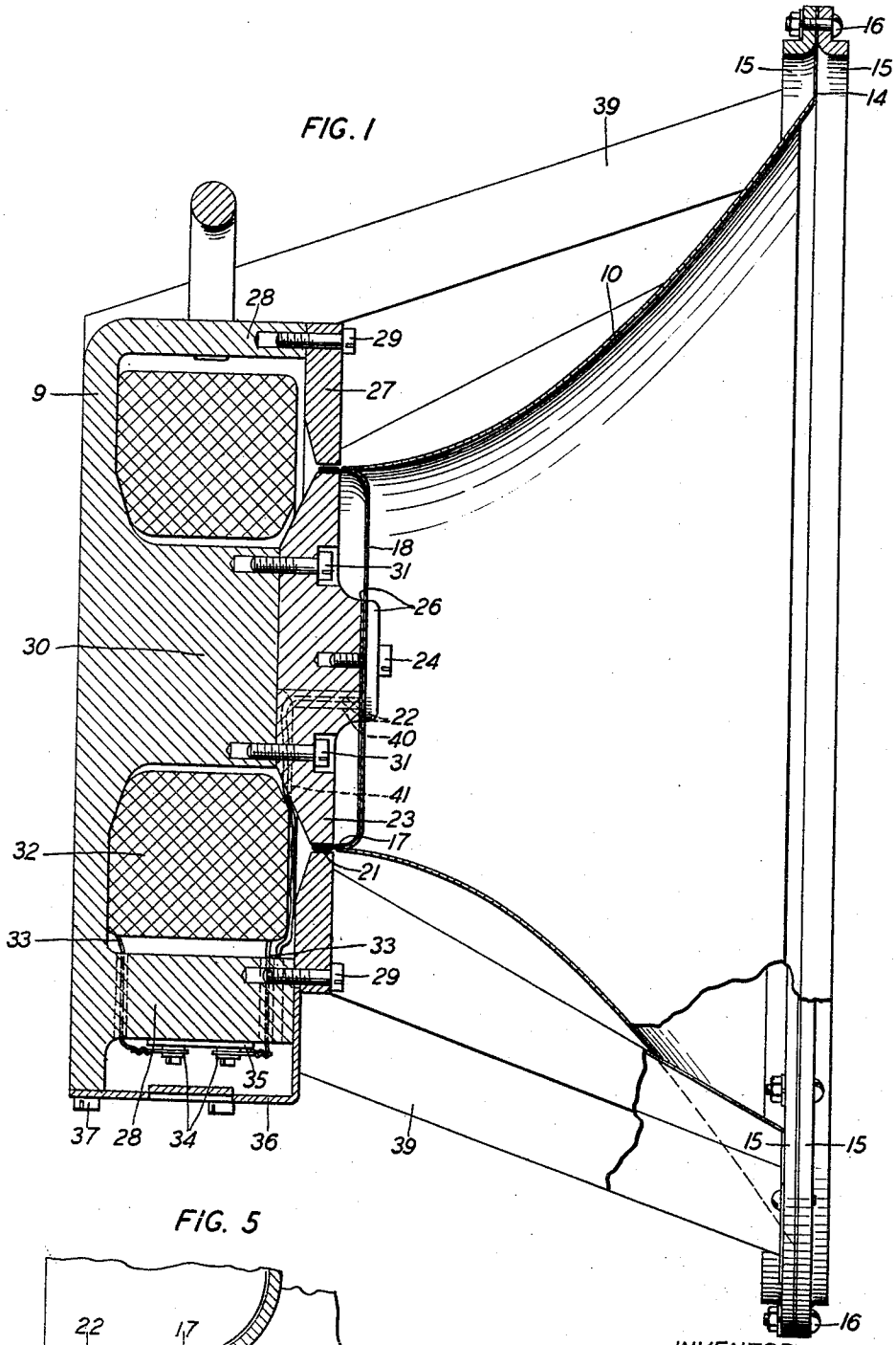

FIG. 5

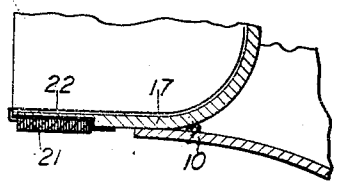

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FIG. 2

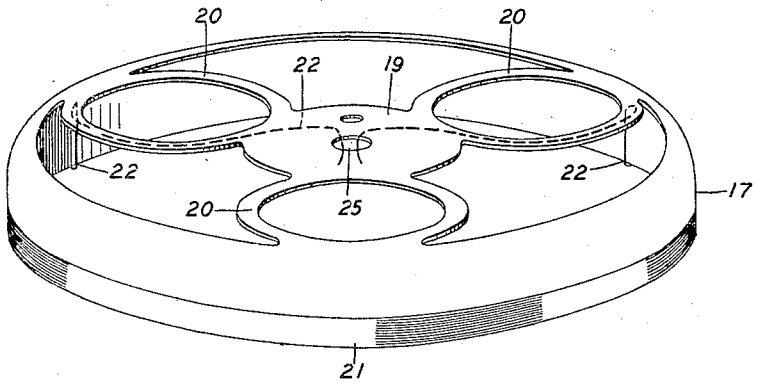

FIG. 4

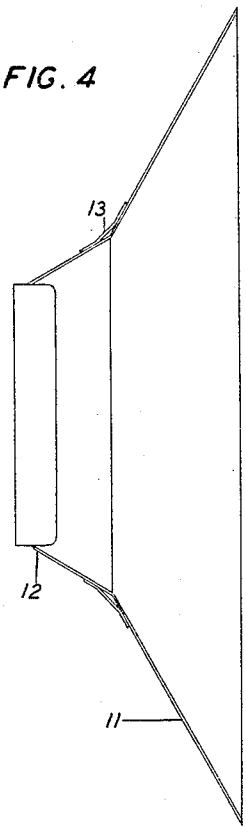

FIG. 3

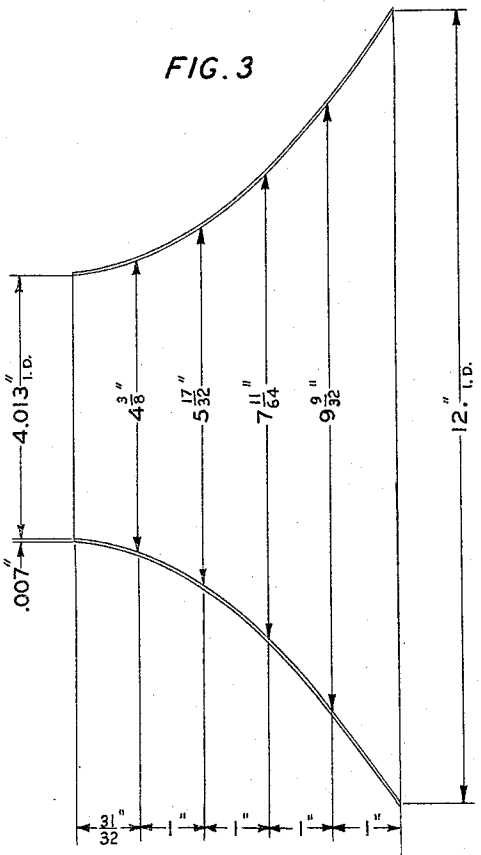

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FIG. 6.

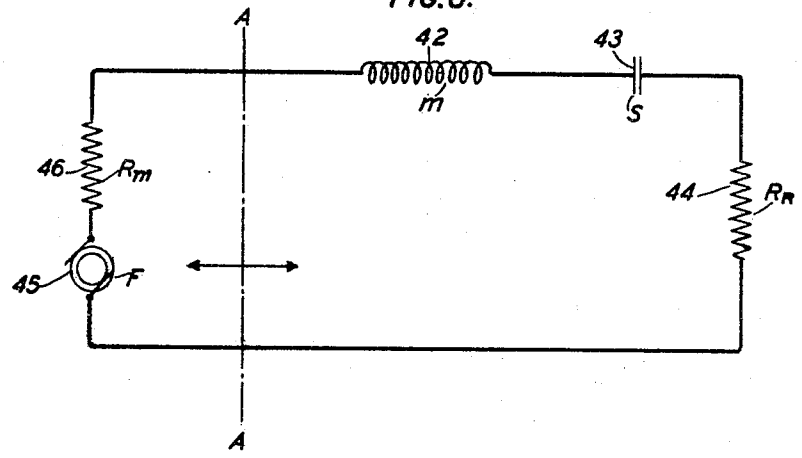
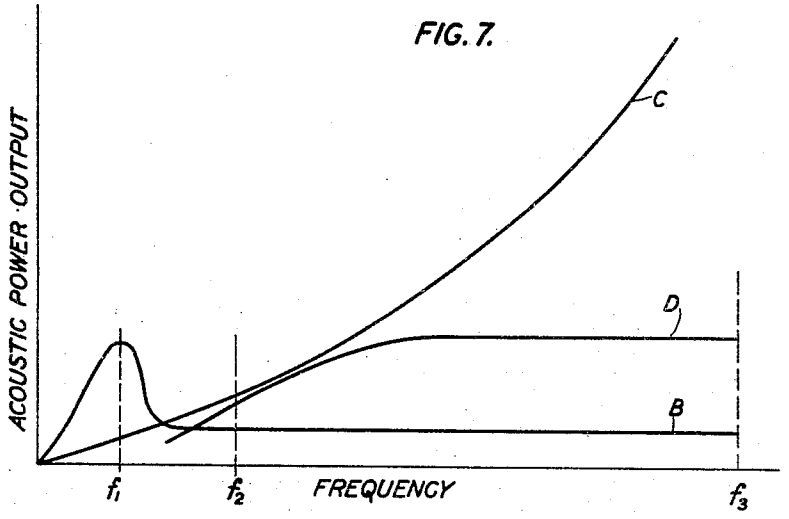


FIG. 7.



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Patented Jan. 31, 1933 1,895,441

UNITED STATES PATENT OFFICE

LEE G. BOSTWICK, OF EAST ORANGE, NEW JERSEY, ASSIGNOR TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

SOUND TRANSLATING DEVICE

Application filed October 4, 1930. Serial No. 486,381.

This invention relates to sound translating devices and more particularly to loud speakers employing a moving coil actuated, direct acting diaphragm.

The diaphragm in loud speakers of this type is usually designed to vibrate substantially as a piston over the lower portion of the frequency range, say below 800 cycles, and as a wave type radiator in the upper frequency range. To radiate uniform acoustic power with constant electrical supply over the lower frequency range, it is necessary that the vibrational velocity vary inversely as the frequency. This relation is obtained in present day loud speakers by allowing the mass reactance of the vibrating system to be the predominating vibratory impedance, resulting in what is generally termed a "mass controlled" device. Such a loud speaker has two distinct disadvantages. First, the efficiency must inherently be low because most of the actuating force is expended in accelerating the vibratory system and but little is useful in producing sound radiation; secondly, the dissipation or resistance must be so small that the diaphragm vibration is poorly damped resulting in either an undesirable resonance period and a poor reproduction of transient sounds or the necessity of locating the resonance period outside the translated frequency range.

An object of this invention, therefore, is to improve the efficiency of loud speakers and to translate sound uniformly over a wide frequency range.

In accordance with one feature of this invention the mechanical impedance of the vibratory system and the mechanical motional resistance at the driving coil associated with the diaphragm are so related that the diaphragm is substantially "resistance controlled" instead of "mass controlled" below a certain frequency well within the frequency range it is desired to translate. This results in an improved efficiency over a desired frequency range and makes possible a mechanical motional resistance of sufficient magnitude to critically damp the vibrating system and to completely suppress the main diaphragm resonance.

In accordance with another feature of this invention a loud speaker diaphragm is formed of some plastic material, such as cellulose acetate or phenol condensate, so that it will have a continuously curved radiating surface and is further so proportioned that it may be vibrated as a whole with substantially uniform efficiency and response over a desired portion of the audio frequency spectrum.

In accordance with still another feature of this invention the vibratory element in a loud speaker of the moving coil type is so mounted that substantially no restraint is offered to true linear displacement of an edge of the diaphragm and an annular driving coil affixed thereto.

These and other features of this invention will be more clearly understood from the following detailed description with reference to the accompanying drawings in which

Fig. 1 is an elevational view mainly in cross-section of a loud speaker made in accordance with this invention;

Fig. 2 is an enlarged detail view in perspective of the spider for carrying the actuating coil and supporting the diaphragm as shown in Fig. 1;

Fig. 3 is a dimensioned cross-sectional view of a preferred form of a diaphragm proportioned in accordance with this invention;

Fig. 4 is an elevational view of an alternative form of diaphragm;

Fig. 5 is an enlarged fragmentary view in cross-section of the spider shown in Fig. 2, illustrating the method of mounting the actuating coil and the leading-in wires therefor;

Fig. 6 shows diagrammatically an electrical circuit analogous to or equivalent to the mechanical vibratory portion of a moving coil loud speaker of the type shown in Fig. 1; and

Fig. 7 shows characteristic output curves for a "mass controlled" and a "resistance controlled" loud speaker, and a characteristic output curve for a combined "mass and resistance controlled" loud speaker in accordance with this invention.

Referring now to Fig. 1 of the drawings,

the loud speaker of this invention comprises a frusto-conoidal diaphragm 10 preferably of some plastic material, such as cellulose acetate or phenol condensate, which may be easily molded and formed to desired dimensions, and which in its final state possesses appreciable inherent stiffness and rigidity. The diaphragm 10 is adapted to vibrate substantially as a whole over a substantial range of frequencies, say up to the point where the radiation resistance thereof approaches a constant, and it has been found that the response characteristic of the loud speaker may be improved by forming the diaphragm as a frustum of a surface of revolution, the diameter of which varies non-linearly between the two bases of the diaphragm. In a preferred embodiment the diaphragm as shown in Fig. 3 is frusto-conoidal and has a continuously curved substantially hyperboloidal or paraboloidal surface. The ratio of the diameters of the bases is substantially, and preferably, three to one. It is to be understood that although specific dimensions of a diaphragm are shown in Fig. 3, the invention is not limited thereto and any diaphragm proportioned similarly to that shown in Fig. 3 is contemplated within the scope of this invention.

In another embodiment, in accordance with this invention, the diaphragm, as shown in Fig. 4, comprises a plurality of frusto-conical sections 11 and 12 of lightweight material such as cellulose acetate or phenol condensate, the larger base of one section being joined to the smaller base of the other section. The junction of the two sections is reinforced by a ring 13, cemented or otherwise suitably attached to each of the sections, so that the rigidity of the diaphragm is increased and the diaphragm will vibrate as a piston throughout the desired portion of the audio frequency spectrum. Although the diaphragm shown in Fig. 4 comprises but two frusto-conical sections, it is to be understood that any number of joined sections may be used without departing from the scope of this invention.

The larger base of the diaphragm 10 is connected to a supporting frame by a thin annulus 14 of flexible material such as limp leather, silk or the like which is cemented or otherwise suitably attached to the edge of the diaphragm 10 and is clamped between two flanged ring members 15 held together by bolts 16. The smaller base of the diaphragm 10 is suitably affixed to the flange 17 of a spider 18.

The spider 18, as shown more clearly in Fig. 2, comprises a thin metallic stamping of lightweight non-magnetic material such as duralumin or aluminum, having an annular flanged portion 17, a central hub portion 19, and three equally spaced annular arms 20 joining the flange 17 and the hub 19. The lower outer portion of the flange 17 is recessed, as shown more clearly in Fig. 5, and an annular driving coil 21 consisting of a flat ribbon conductor wound edgewise and having an insulatory coating of lacquer, varnish or the like is set in the recessed portion and fastened therein by a suitable adhesive or cement. Leading-in wires 22 for the driving coil 21 are cemented or otherwise suitably affixed to the inner surface of the flange 17 and may be similarly attached along arms 20 of the spider 18.

The spider 18 is mounted on a central pole piece 23 by a bolt 24 passing through a central opening 25 in the hub 19 and through two non-metallic washers 26. The pole piece 23 is of slightly smaller diameter than the flange 17 so that the driving coil 21 is reciprocally disposed in a narrow annular air gap formed by the pole piece 23 and an outer pole piece 27.

When the driving coil 21 oscillates in the air gap, it is desirable that it move with true linear displacement and at all times be out of contact with the pole pieces 23 and 27. As the coil 21 oscillates the flange 17 of the spider 18 also oscillates and the annular arms 20 are slightly stretched along a radius of the spider so that they do not vibrate as cantilever beams, but function rather as extensible links between the hub 19 and the flange 17. Consequently no tilting force is exerted upon the flange 17 and as a result the coil 21 oscillates substantially without restraint along a straight line instead of through a short arc as would be the case were the arms 20 rigid and inextensible.

The pole piece 27 is mounted on an outer pole 28 of a rectangular shaped magnetic structure 9 having a circular core or inner pole 30, by bolts 29 and the pole piece 23 is mounted on the inner pole 30 by bolts 31. An energizing winding 32 encircles the inner pole 30 and is provided with leading-in wires 33 which extend through bores in the outer pole piece 28 and are connected to the terminals 34 mounted on an insulating terminal block 35, positioned in a recessed portion in the pole 28. A sheet metal cap member 36 is affixed to the pole 28 by bolts 37, only one of which is shown, and closes the recess in which the terminal block 35 is mounted. A plurality of angular supports 39 are bolted or otherwise secured to the outer pole 28 and are likewise bolted to the rings 15.

The leading-in wires 22 for the driving coil 21 extend through an opening 40 in the pole piece 23, pass through a recessed portion 41 in said pole piece and are connected to terminals, not shown, mounted on the terminal block 35.

In order to improve the efficiency of moving coil loud speakers throughout the lower portion of the audio frequency spectrum and to insure suppression of the main diaphragm

resonance in accordance with this invention, the mechanical motional resistance at the driving coil 21 is made substantially equal to the mechanical impedance of the vibratory element, comprising the diaphragm 10, the spider 18, the driving coil 21 and the annulus 14, at some frequency within the lower portion of the audio spectrum and above the lowest frequency it is desired to translate. The advantages of this feature will be more clearly evident from a brief consideration of the characteristics of moving coil loud speakers, reference being had particularly to Figs. 6 and 7.

Referring to Fig. 6, that portion of the circuit to the left of the line A—A is the electrical equivalent of the mechanical motional resistance and the driving force in a moving coil loud speaker and that portion of the circuit to the right of the line A—A is the electrical equivalent of the vibratory system of the loud speaker. The vibratory system has an effective mass m, represented by the inductance 42, a compliance S, represented by the capacity 43, and a radiation resistance R_R, represented by the resistance 44. The mass m, is the summation of the radiation mass and the combined effective mass of the diaphragm, the spider, the driving coil, and the flexible annular mounting. The compliance S, is the compliance of the spider and the annular mounting. The actuating force F, that is the force resulting from the passage of signal currents through the driving coil is represented by a source of E. M. F. 45, and the mechanical motional resistance R_m, of the driving coil is represented by a resistance 46.

The mechanical motional resistance at the driving coil may be expressed algebraically as

$$R_m = \frac{B^2 \pi a d n}{2\rho}$$

where

B = flux density in the air gap in which the driving coil vibrates

a = cross-sectional area of each conductor of the driving coil

d = diameter of the driving coil

n = number of turns in the driving coil

ρ = resistivity of each conductor

The mechanical impedance of the vibratory element throughout that portion of the audio frequency spectrum in which the diaphragm acts as a piston may be expressed algebraically as

$$Z_d = R_R + j\omega m + \frac{S}{j\omega}$$

In "mass controlled" loud speakers, the mass is so large with respect to the compliance, the mechanical motional resistance, and the radiation resistance that for all frequencies below that at which the diaphragm breaks up, the mass reactance is the dominating and substantially the sole factor determining the acoustic output of the loud speaker with respect to the frequency of vibration. Under a condition of constant applied driving force, the output characteristic is similar in form to that indicated by the line B in Fig. 7. Although such a characteristic is desirable in view of the uniformity of the output with respect to frequency, the efficiency of the loud speaker is inherently low since most of the actuating force is expended in accelerating the vibratory mass. Furthermore, the vibratory system may have an undesirable resonance at some frequency f_1 in the lower portion of the frequency spectrum.

If in an acoustic system, such as is represented in Fig. 6, the mechanical motional resistance is increased and the mass reactance decreased until the combined resistance $R_m + R_R$ is large in comparison with the combined impedances 42 and 43, the vibration would be substantially "resistance controlled" and the output of the speaker would vary somewhat as shown by the curve C in Fig. 7. If the several factors are properly proportioned the efficiency of such a loud speaker, that is a "resistance controlled" speaker, would be relatively high. However, the nonuniformity of the response is objectionable.

It has been found that if the mechanical impedance of the vibratory system and the mechanical motional resistance at the driving coil are properly correlated, the desirable properties of a "mass controlled" and a "resistance controlled" loud speaker may be combined. If the mechanical motional resistance at the driving coil and the mechanical impedance of the vibratory system are made substantially equal at some frequency between the lowest frequency f_2, it is desired to translate and the frequency f_3, at which the diaphragm breaks up, the acoustic power will vary somewhat as indicated by curve D in Fig. 7. The specific magnitude and form of the acoustic power characteristic will of course, be dependent upon the magnitude of the physical constants involved and the particular frequency at which the mechanical motional resistance and the mechanical impedance of the vibratory system are made substantially equal. It has been found desirable to select this frequency between 100 and 400 cycles.

It has been found further that when the mechanical motional resistance and the mechanical impedance of the vibratory system are correlated as hereinbefore described, the mechanical motional resistance at the driving coil can be made approximately the same magnitude as the critical damping resistance which results in the complete suppression of the main diaphragm resonance. In order that this may be the case, it is necessary that the frequency at which the mechanical mo-

tional resistance at the driving coil and the mechanical impedance of the vibratory system are made substantially equal be greater than twice the apparent resonance frequency of the diaphragm as determined algebraically by

$$f=\frac{1}{2\pi}\sqrt{\frac{S}{m}}$$

In the particular embodiment of my invention illustrated in the drawings, for example, a satisfactory efficiency and response may be obtained with a diaphragm proportioned as shown in Fig. 3, a driving coil having a diameter of substantially 4″ and comprising 50 turns of copper wire ribbon .002″ by .02″ and a flux density of approximately 15,000 gausses. In this particular embodiment the diaphragm breaks up between 600 and 1000 cycles and the lowest frequency it is desired to translate is about 60 cycles. The mechanical impedance of the vibratory system and the mechanical motional resistance at the driving coil are made substantially equal at approximately 150 cycles. The effective mass of the vibratory system is approximately 30 grams. It is to be understood, however, that these values are merely illustrative of the invention and that the invention is not limited thereto.

The loud speaker of this invention may be used in conjunction with a baffle board or a short horn which may be so designed as to its loading characteristic as to compensate for the drooping of the "mass-resistance controlled" curve at low frequencies as indicated by curve D in Fig. 7.

What is claimed is:

1. A sound translating device comprising a vibratory element adapted to vibrate as a whole over the lower portion of the audio-frequency spectrum, and electro-dynamic means for actuating said vibratory element, the mechanical motional resistance of said means and the mechanical impedance of said vibratory element being substantially equal at a frequency between the lowest frequency it is desired to translate and the approximate frequency at which the vibratory element ceases to vibrate as a whole.

2. A sound translating device comprising a vibratory element, and electro-dynamic means for actuating said vibratory element, the mechanical motional resistance of said means being substantially equal to the mechanical impedance of the vibratory element at a frequency between 100 and 400 cycles.

3. A sound translating device comprising a vibratory element, and means for actuating said vibratory element, the mechanical motional resistance of said means and the mechanical impedance of said vibratory element being substantially equal at a frequency such that said mechanical motional resistance will be approximately of the same magnitude as the critical damping resistance of said vibratory element.

4. A sound translating device comprising a vibratory element, and means for actuating said vibratory element, the mechanical motional resistance of said means and the mechanical impedance of said vibratory element being substantially equal at a frequency greater than twice the apparent resonance frequency of said vibratory element.

5. A sound translating device comprising a vibratory element, and means for actuating said vibratory element, the mechanical motional resistance of said means and the mechanical impedance of said element being substantially equal at a frequency such that the vibratory element will be substantially resistance controlled up to said frequency and will be substantially mass controlled between said frequency and the frequency at which the vibratory system ceases to vibrate as a whole.

6. A sound translating device comprising a vibratory element including a frusto-conoidal diaphragm, and means including a driving coil associated with said vibratory element for actuatng it, the mechanical motional resistance of said means and the mechanical impedance of said element being substantially equal at a frequency between 100 and 400 cycles.

7. A sound translating device comprising a vibratory element including a diaphragm of plastic material, said diaphragm being formed so that it will vibrate as a whole over a substantial portion of the lower audio-frequency spectrum, and means for actuating said vibratory element, the mechanical motional resistance of said means and the mechanical impedance of said vibratory element being substantially equal at a frequency between the lowest frequency it is desired to translate and the frequency at which the diaphragm ceases to vibrate as a whole.

8. A sound translating device comprising a support, a vibratory element including a diaphragm, flexible means connecting said diaphragm to said support, and means for actuating said vibratory element, the mechanical motional resistance of said means and the mechanical impedance of said vibratory element being substantially equal at a frequency between 100 and 400 cycles.

9. A sound translating device comprising a support, a magnet having concentric pole pieces forming an annular air gap, a vibratory element including a diaphragm, flexible means connecting said diaphragm and said support, flexible means connecting said diaphragm and one of said pole pieces, and an annular coil disposed in said air gap and associated with said diaphragm for driving it, the mechanical motional resistance at said

coil being substantially equal to the mechanical impedance of said vibratory element between 100 and 400 cycles.

10. A sound translating device comprising a support, a magnet having concentric pole pieces forming an annular air gap, a vibratory element including a frusto-conoidal diaphragm of plastic material adapted to vibrate as a whole over a substantial portion of the lower audio-frequency spectrum, flexible means connecting the larger end of said diaphragm and said support, a spider member mounted on the inner of said pole pieces and connected to the smaller end of said diaphragm, and a coil mounted on said spider member and disposed in said annular air gap, the mechanical motional resistance at said coil being substantially equal to the mechanical impedance of said vibratory element at a frequency above the lowest frequency it is desired to translate and below the frequency at which the diaphragm ceases to vibrate as a whole.

11. A sound translating device in accordance with claim 10 in which the mechanical motional resistance at the driving coil and the mechancal impedance of the vibratory element are substantially equal at a frequency greater than twice the apparent resonance frequency of said vibratory element.

12. A sound translating device in accordance with claim 10 in which the mechanical motional resistance of the coil and the mechanical impedance of the vibratory element are substantially equal at a frequency such that the vibratory element will be substantially resistance controlled up to said frequency and will be substantially mass controlled between said frequency and the frequency at which the diaphragm ceases to vibrate as a whole.

In witness whereof, I hereunto subscribe my name this 3rd day of October 1930.

LEE G. BOSTWICK.