April 14, 1936. A. L. THURAS 2,037,185

SOUND TRANSLATING DEVICE

Filed March 28, 1933 2 Sheets-Sheet 1

FIG. 1

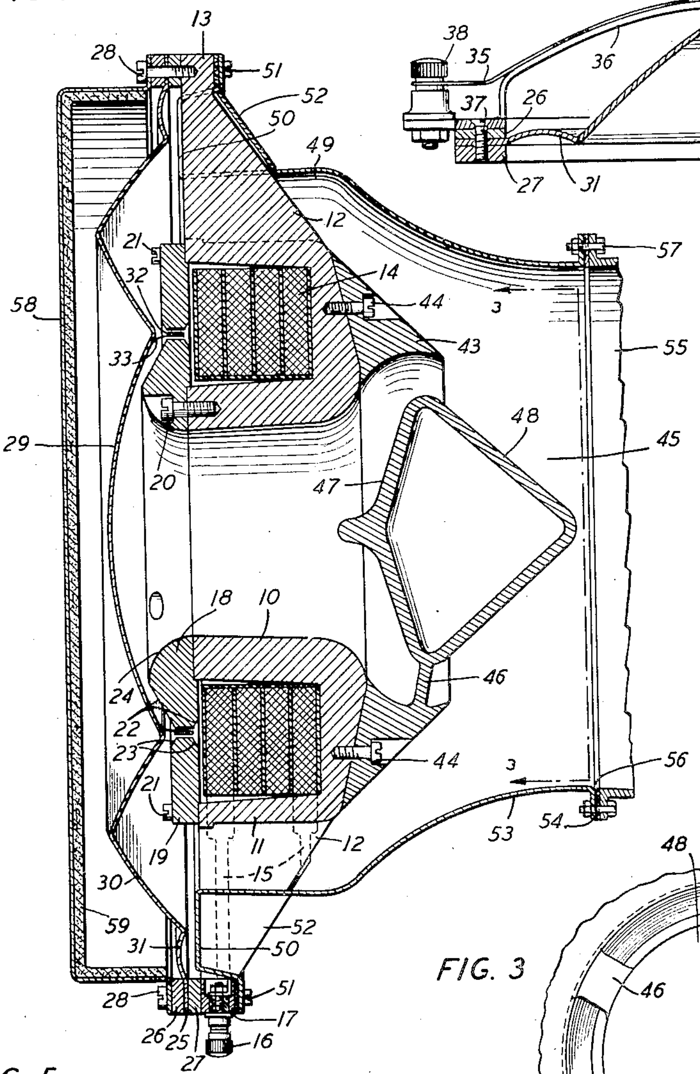


FIG. 4

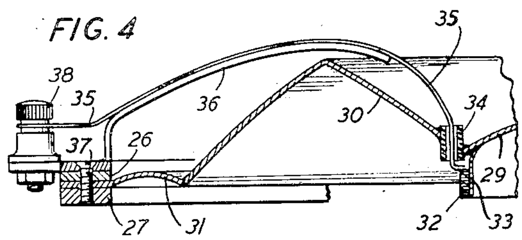


FIG. 3

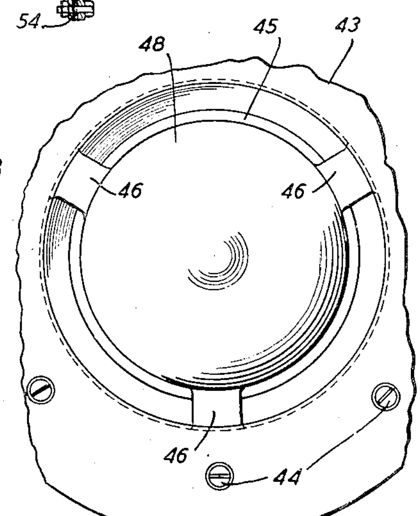
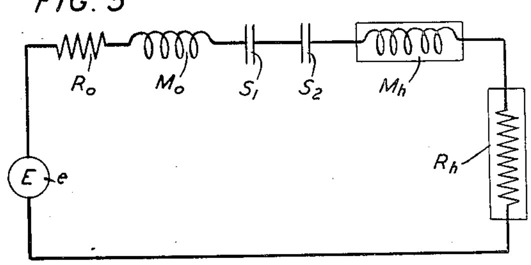


FIG. 5



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April 14, 1936. A. L. THURAS **2,037,185**

SOUND TRANSLATING DEVICE

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FIG. 2

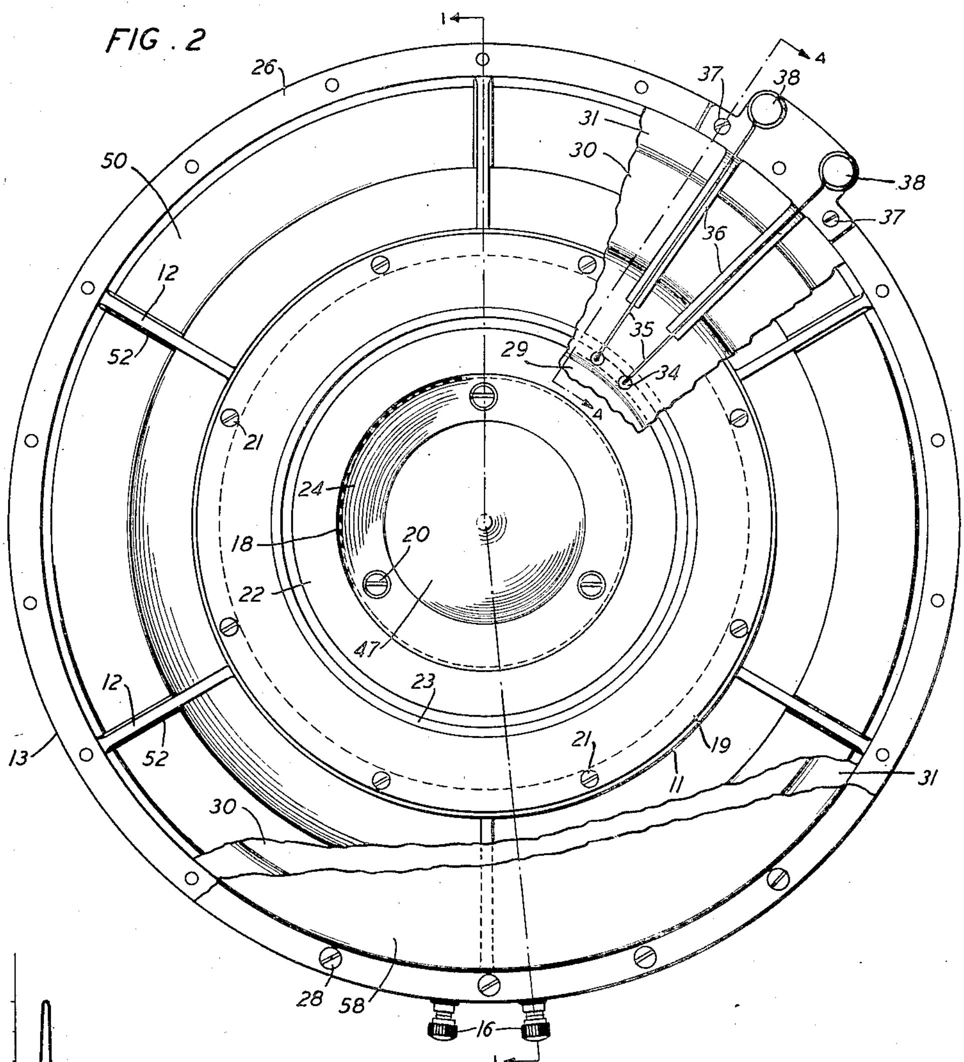


FIG. 6

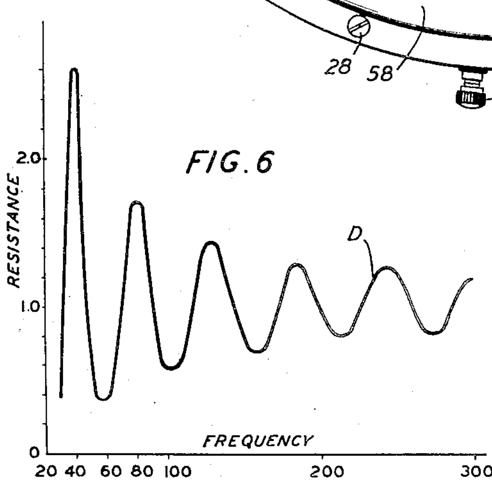
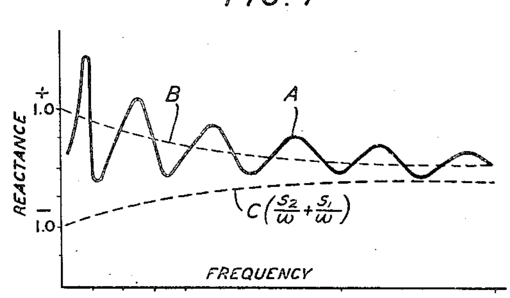


FIG. 7



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2,037,185

UNITED STATES PATENT OFFICE

2,037,185

SOUND TRANSLATING DEVICE

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Application March 28, 1933, Serial No. 663,123

7 Claims. (Cl. 179—115.5)

This invention relates to sound translating devices and more particularly to moving coil actuated loudspeakers of the horn type.

In loudspeakers of the horn type, the impedance of the horn load is of a complex character and comprises a reactance component due to the inertia of the air column vibrated by the diaphragm, and a resistance component, commonly termed the radiation resistance. Both the resistance and the reactance component are variable with respect to the frequency of the sound waves propagated by the diaphragm so that the acoustic power output of the device, which is dependent upon the horn impedance, varies with frequency. Consequently, in the reproduction of speech and music by such a loudspeaker, all the frequencies in the audio range or in the desired range to be reproduced, are not translated with uniform intensity, and as a result faithful and accurate transmission is not obtained.

One object of this invention is to improve the transmission characteristics of loudspeakers and to enable thereby the faithful and efficient reproduction of speech and music.

In one embodiment of this invention, a loudspeaker comprises a magnet having a hollow cylindrical central or inner pole, an outer pole, and concentrically disposed annular pole-pieces forming a narrow annular gap concentric with respect to the bore in the central pole-piece. A diaphragm is supported at its periphery by the magnet and is coaxially disposed with respect to the bore in the inner pole, the diaphragm being of materially greater diameter than the outer pole of the magnet. An annular driving coil is connected to the diaphragm and is disposed in the annular air gap. A hollow coupler member of substantially the same diameter as the radiating portion of the diaphragm encircles the magnet and is concentrically disposed with respect to the bore in the inner pole of the magnet. The coupler member terminates adjacent the surface of the diaphragm. The throat end of a horn is adapted to be connected to the coupler member at the end remote from the diaphragm. A tapered plug member is mounted on the magnet and is coaxially disposed with respect to the bore in the inner pole-piece. This construction provides a plurality of sound ducts of substantially equal length disposed one within the other and extending between the surface of the diaphragm directed toward the magnet and the throat of the horn. The other surface of the diaphragm may be enclosed in a casing which may be lined with a sound absorbing material such as felt.

In accordance with one feature of this invention, the coupler member, plug, and magnet are so constructed that the aggregate cross-sectional area of the several sound ducts, in planes at right angles to the paths of sound travel varies uniformly between the diaphragm and the throat of the horn. Preferably, the aggregate cross-sectional area increases exponentially from the diaphragm to the throat of the horn.

In accordance with another feature of this invention, the magnet is so constructed that a high magnetic flux, which may be in excess of 20,000 lines per square inch, is provided in the airgap in the magnet, and a driving coil of great length and large conductor area is provided whereby a high acousto-electrical efficiency is obtained.

In accordance with still another feature of this invention, the chamber adjacent one surface of the diaphragm is proportioned so that the stiffness thereof is substantially equal in magnitude to the mean reactance component of the horn load impedance throughout a range of audio frequencies, whereby the reactance component of the horn load impedance is substantially neutralized throughout this range of frequencies.

In accordance with a further feature of this invention, the resistance of the driving coil for the diaphragm, the resistance component of the horn impedance and the resistance of the source of power are so proportioned that the acoustic output of the loudspeaker is substantially constant throughout a wide range of audio frequencies.

The invention and the features thereof will be understood more fully from the following detailed description with reference to the accompanying drawings in which:

Fig. 1 is a side view in cross-section of a loudspeaker illustrative of one embodiment of this invention;

Fig. 2 is an end view of the loudspeaker shown in Fig. 1, with portions of the casing and of the diaphragm broken away to show details of the magnet and coupler member assembly more clearly;

Fig. 3 is a detail end view as seen from line **3—3** in Fig. 1 showing the association of the plug member and the magnet;

Fig. 4 is an enlarged detail view showing the manner in which the leading-in conductors for the diaphragm actuating coil are brought out to external terminals:

Fig. 5 shows diagrammatically an equivalent electrical network for the acousto-mechanical system of the loudspeaker shown in Fig. 1;

Fig. 6 is a typical characteristic illustrating the variation of the resistance component of the horn load impedance with frequency; and

Fig. 7 shows a typical horn reactance characteristic and illustrates graphically how the reactance component of a horn load impedance may be substantially neutralized throughout a range of frequencies in accordance with a feature of this invention.

Referring now to the drawings, a loudspeaker illustrative of one embodiment of this invention comprises a magnet having a hollow inner pole **10** and an outer pole **11** concentric with the pole **10**. The magnet is provided with a plurality of projections or webs **12** which extend outwardly from the pole **11** and are connected by a ring member **13** which may be integral therewith. An annular field or excitation coil **14**, which may be of the construction described in detail and claimed in my copending application, Serial No. 622,191, filed July 13, 1932, encircles the inner pole **10**. Extensions **15** of the coil **14** extend along and may be secured to one of the webs **12**, and are connected to external terminals **16** carried by the ring member **13** and insulated therefrom by insulating sleeves or bushings **17**.

A pair of annular pole-pieces **18** and **19** are secured to the poles **10** and **11**, respectively, by screws **20** and **21**, respectively, and are spaced to form a narrow annular airgap. Preferably the pole-pieces are arranged concentrically with the opening or bore in the pole **10**. The magnet assembly is preferably of sufficient dimensions, and the coil **14** of such construction, that a flux of the order of 20,000 lines per square inch can be maintained in the airgap formed by the juxtaposed faces of the pole-pieces **18** and **19**. In order to prevent fringing between the juxtaposed pole faces and thereby to confine the flux to the airgap, the pole-pieces **18** and **19** may be provided with beveled or chamfered surfaces as at **22** and **23**, respectively. The pole-piece **18** may be formed with an enlarged portion as at **24** to provide a path of uniform reluctance between the pole **10** and the pole-piece.

A diaphragm, which may be of the order of 20 inches in diameter, is mounted upon the ring member **13** and comprises a flat peripheral portion **25** secured between clamping rings **26** and **27** which are secured to the ring member **13** as by screws **28**. The diaphragm, all the surfaces of which are curved, has a relatively rigid portion adapted to vibrate as a whole analogous to a piston, including a central, dished or dome-shaped portion **29** and an annular portion **30** substantially V-shaped in cross-section and concentric with the central portion **29**. The rigid portion of the diaphragm is connected to the peripheral portion **25** by an annular bowed flexible portion **31**. The entire diaphragm may be formed in a single piece, of suitable lightweight material, such as duralumin, and may be of uniform thickness, for example, 4½ mils, or may be formed of a plurality of pieces of the same or different material. In order to insure uniform vibration of all portions of the diaphragm and particularly to insure vibration of all parts of the rigid portion of the diaphragm in phase, the diaphragm should be accurately centered in the clamping rings **26** and **27** and the flexible annular portion **31** should be of uniform curvature throughout.

The diaphragm may be actuated by an annular coil **32**, which may be of the construction described in my Patent 1,707,544, granted April 2, 1929. The coil **32**, which may be of the order of 8 inches in diameter, may be mounted on an annular supporting sleeve **33**, for example, of copper, which is secured to the diaphragm, as by cementing, at approximately the edge of the central, dished portion **29**. The diaphragm is provided with a pair of small apertures, (only one of which is shown in Fig. 4) in each of which an insulating bushing or sleeve **34** is secured. Leading-in conductors **35**, which may be integral extensions of the coil **32**, pass loosely through a corresponding one of the bushings or sleeves **34** and extend along arched supports or fingers **36** mounted on the ring member **26** by screws **37**. The conductors **35** are connected at their outer end to terminals **38**. This construction allows the conductors to move freely as the diaphragm vibrates and the stresses introduced in the conductors are distributed throughout a large portion thereof so that rupture of the conductors is prevented.

In order to prevent excessive local vibration therein, the conductors **35** may be damped, for example, by means of a thin coating of a viscous material, for example, wax, applied thereto. The conductors preferably are so designed that the natural or resonance frequency thereof is below the lowest frequency to be translated by the loudspeaker.

A metallic member, which may be of cast aluminum, comprising an annular rim portion **43** and a hollow plug designated generally as **45** connected to the rim portion **43**, as shown more clearly in Fig. 3, by a plurality of radially extending integral arms **46** is secured to the magnet as by screws **44**. The rim portion **43** and the plug **45** are preferably disposed coaxially with the opening or bore in the pole **10**. The plug **45** is formed with oppositely directed substantially conical surfaces **47** and **48**, the proportioning of which will be described in detail hereinafter.

A shell or hollow coupler member which may be of a suitable metal, for example copper, encircles the magnet and comprises a cylindrical portion **49** of but slightly smaller diameter than the rigid portion of the diaphragm, having a flange **50** secured to the ring member **13** as by screws **51**. A plurality of channel members **52** are secured one to each of the projections or webs **12** and also to the ring member **13**, and serve to lock the coupler member in position. The coupler member is provided with an inwardly curved portion **53** which terminates in an outwardly directed flange **54**. The cylindrical and inwardly curved portions are coaxially disposed with respect to the opening or bore in the pole **10**. A horn member **55**, shown in part in Fig. 1, forming a sound duct is connected at its throat to the shell or coupler member and is secured thereto, together with a washer **56**, by bolts **57**. This construction, it will be apparent, provides a plurality of coaxial sound ducts or passageways between the surface of the diaphragm toward the magnet assembly, and the throat of the horn so that the sound waves emanating from substantially all portions of the diaphragm surface are conveyed to the horn and a high efficiency is attained.

In order to insure that the sound waves originating at all points of the diaphragm reach the throat of the horn in phase, whereby suppression or neutralization of any of the frequencies propagated are prevented, the magnet, coupler member, and plug are so designed and proportioned that the sound waves emanating from all points of the diaphargm traverse paths of substantially equal length in passing to the throat of the horn. The opening or bore in the pole 10, the member 43, plug 45, and coupler member, and the outer pole 11 of the magnet are so formed that the aggregate cross-sectional area of the several sound passageways or ducts formed thereby, in planes at right angles to the paths of sound travel, varies in a desired manner. Preferably the elements aforenoted are so designed that this aggregate area of the sound passageways or ducts increases exponentially from the diaphragm toward the throat of the horn 55.

The rear surface of the diaphragm may be enclosed by a casing 58 having a lining 59 of a sound-absorbing material, such as felt, therein. This casing provides a chamber having a uniform stiffness effect over the surface of the diaphragm which decreases any tendency of the diaphragm to wabble at the low frequencies.

The acousto-mechanical system of a loudspeaker of the construction described may be represented, as is known, by an equivalent electrical network such as shown in Fig. 5. In this figure, the characters indicate the equivalent of impedances in the acousto-mechanical system of the loudspeaker as follows:

E—Source of energy connected to the actuating coil 32,

e—Voltage of the source E or force at the actuating coil,

R_0—Motionless resistance of the actuating device, i. e., the driving coil 32, plus the resistance of the source E, both referred to the acousto-mechanical system,

M_0—Mass of the vibratory element, i. e., the diaphragm, driving coil 32 and driving coil support 33,

S_1—Edge stiffness of the diaphragm,

S_2—Stiffness of the chamber formed by the diaphragm and the casing 58,

M_h—Reactance or mass component of the horn load impedance,

R_h—resistance component of the horn load impedance.

For practical purposes, in the loudspeaker described the stiffness of the chamber between the diaphragm and the horn is sufficiently small with respect to the other factors that it may be neglected.

Although a loudspeaker of the construction described hereinbefore may be utilized alone to translate speech and music, it may be used with particularly good results in sound reproducing apparatus including a plurality of loudspeakers adapted to reproduce different bands of frequencies of importance in speech and music most efficiently. If so used, a loudspeaker as shown and described may be utilized to reproduce frequencies between the lowest frequency it is desired to translate and about 300 cycles.

It is known that the horn load impedance in a loudspeaker of the horn type is of a complex character and comprises resistance and reactance components both of which are variable with frequency. Typical characteristics showing the variation of the resistance and reactance components with frequency are shown in Figs. 6 and 7, respectively. It will be apparent that in view of the non-uniformity of these components with respect to frequency, the response characteristic of the loudspeaker, which is dependent upon the horn load impedance, will not be uniform so that faithful reproduction of speech and music will not be obtained, assuming of course that the current supplied to the actuating unit, for example to the driving coil 32, is of the same magnitude at all the frequencies in the band to be reproduced.

In accordance with a feature of this invention, the effect of the variations in the reactance component of the horn load impedance is counteracted through the agency of the air chamber to the rear of the diaphragm. More specifically, the chamber is so proportioned that the stiffness of the system divided by 2π times the frequency, that is,

$$\frac{S_2}{\omega}+\frac{S_1}{\omega}$$

is substantially equal to the mean reactance of the horn load impedance throughout the range of frequencies to be reproduced by the loudspeaker. This is illustrated graphically in Fig. 7, in which curve A shows the reactance component of the horn load impedance, curve B shows the means value thereof, and curve C shows the stiffness of the chamber to the rear of the diaphragm plus the edge stiffness of the diaphragm divided by 2π times the frequency. It will be seen from these curves that the sum of the ordinates for curves B and C at any frequency is substantially zero so that the stiffness of the air chamber neutralizes to a material degree, the reactance component of the horn load throughout a wide range of frequencies. It will be understood, of course, that the ordinates of the graph in Fig. 7 are merely relative and that suitable units may be chosen as desired.

The stiffness of the air chamber may be computed from the equation

$$S_2=\frac{1.4\times10^6A^2}{V} \qquad (1)$$

where A is the area of the diaphragm and V is the volume of the air chamber. The reactance component of the horn impedance may be ascertained in ways well known to those skilled in the art.

The sound power output of the loudspeaker for a constant vibrational velocity of the diaphragm is proportional, as is known, to the resistance component of the horn impedance. From Fig. 5, it will be apparent that the power dissipated in the resistance R_h, neglecting the reactance component, is proportional to

$$\left(\frac{e}{R_0+R_h}\right)^2 R_h. \qquad (2)$$

Consequently, the sound power output of a loudspeaker of which Fig. 5 is an equivalent network will be proportional to the voltage of the source, the resistance of the horn load, and the resistance of the source and of the actuating device in the relation given in Equation 2. It follows, therefore, that a uniform output will be obtained throughout a wide range of frequencies, if R_0 and R_h are so proportioned that the change in the factor

$$\frac{R_h}{(R_0+R_h)^2}$$

with frequency is small. By differentiating this factor with respect to R_h and equating the differential to zero, it is seen that the desired proportionality is $R_0=R_h$. The optimum relationship between R_0 and R_h will depend, of course, upon the form of the resistance characteristic of the horn load, as indicated for example by curve

D in Fig. 6. Preferably R_0 is chosen between the maximum and minimum values of R_h, as indicated by this curve.

For a varying R_h, such as shown in Fig. 6, the minimum variation in sound output is obtained by equating the powers for the maximum and minimum values of R_h indicated by the characteristic curve, thus,

$$\left(\frac{e}{R_0+R_{h_{max}}}\right)^2 R_{h_{max}}=\left(\frac{e}{R_0+R_{h_{min}}}\right)^2 R_{h_{min}} \quad (3)$$

Solving this equation for R_0,

$$R_o=\sqrt{R_{h_{min}}\times R_{h_{max}}} \quad (4)$$

Thus, for a loudspeaker in which the resistance of the horn load varies as indicated in Fig. 6, using 2.6 as the maximum value of R_h and 0.4 as the minimum value, R_0 should, in accordance with equation 4, equal

$$\sqrt{2.6\times 0.4}$$

or 1.02.

For the maximum value of R_h, the sound output is proportional to

$$\frac{2.6e^2}{(3.62)^2}=2.0e^2$$

and for $R_0=R_h$, the sound output is proportional to

$$\frac{1.02e^2}{(2.04)^2}=2.4e^2$$

It will be seen, therefore, that for a loudspeaker including a horn having a radiation resistance varying by a factor of approximately 6½, as indicated by curve D in Fig. 6, the maximum variation in sound output is but 20%.

It will be understood, of course, that the various impedance values given are merely illustrative of the invention and that many other values thereof may be used, and also that modifications may be made in the embodiment of the invention shown and described without departing from the scope and spirit of the invention as defined in the appended claims.

What is claimed is:

1. A sound translating device comprising a diaphragm, means for actuating said diaphragm, a sound duct, and means coupling said sound duct to one surface of said diaphragm, said means including a plurality of annular members disposed one within another and spaced from one another to form a plurality of annular sound passageways between said surface and said duct, one of said members being a magnet operatively associated with said actuating means.

2. A loudspeaker comprising a diaphragm, means for actuating said diaphragm, a horn, a coupler member extending from immediately adjacent one surface of said diaphragm and connected to the throat of said horn, said coupler member being substantially coextensive at the end adjacent said diaphragm with the radiating portion of said diaphragm, and an annular magnet structure operatively associated with said diaphragm actuating means, disposed within said coupler member and spaced therefrom, and extending from adjacent said one surface.

3. A sound translating device comprising a magnet having inner and outer poles, the inner of said poles having a longitudinal bore extending therethrough, a diaphragm adjacent one end of said magnet and extending beyond the lateral extremities thereof, and a hollow member encircling said magnet and spaced therefrom to provide a sound passageway associated with said diaphragm.

4. A loudspeaker comprising a magnet having coaxial cylindrical poles disposed one within the other, a pair of pole-pieces on said poles spaced to form an airgap, the inner of said poles and pole-pieces having coaxial apertures extending therethrough, a plurality of webs extending outwardly from the outer of said poles, a diaphragm mounted on said webs, an annular driving coil connected to said diaphragm and disposed in said airgap, a horn having its throat in juxtaposition to the end of the magnet remote from said diaphragm, and a cylindrical coupler member coaxial with said poles, connected to said horn at one end and to said webs at the other end, said coupler member encircling said outer pole and spaced therefrom.

5. A sound translating device comprising a diaphragm, actuating means for said diaphragm, a sound duct, and means for coupling one surface of said diaphragm to said duct, said means including a plurality of annular members intermediate said surface and said duct defining a plurality of annular sound passageways disposed one within the other, one of said members being a magnet operative associated with said actuating means, said members being proportioned so that the aggregate cross-sectional area of said passageways varies exponentially between said diaphragm and said duct.

6. A loudspeaker comprising a magnet having a pair of poles disposed one within the other, the inner of said poles having a longitudinal bore extending therethrough, a diaphragm adjacent one end of said magnet and extending beyond the lateral extremities thereof, a hollow member encircling said magnet and spaced therefrom to form a passageway coaxial with the bore in said inner pole, and a plug member adjacent one end of said bore, said poles, coupler member, and bore being proportioned so that the aggregate lateral cross-sectional area of the passageways bounded thereby increases exponentially away from said diaphragm.

7. A loudspeaker comprising a magnet having coaxial poles disposed one within the other, coaxial pole-pieces for said poles spaced to form an annular airgap, the inner of said poles and pole pieces having coaxial bores extending therethrough, a plurality of webs extending outwardly from the outer of said poles, a diaphragm supported by said webs at its periphery, said diaphragm being coaxial with said bores, an annular driving coil connected to said diaphragm and disposed in said airgap, a coupler member encircling said outer pole and spaced therefrom to form a passageway coaxial with said bores, one end of said member being adjacent the peripheral portion of said diaphragm, a horn having its throat connected to the other end of said member, and a plug member having oppositely directed substantially conical surfaces one of which extends into the bore in the inner pole-piece, and the other of which terminates substantially in the plane of the throat of said horn.

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