May 1, 1951 J. F. MARQUIS 2,551,447

ELECTRODYNAMIC SPEAKER

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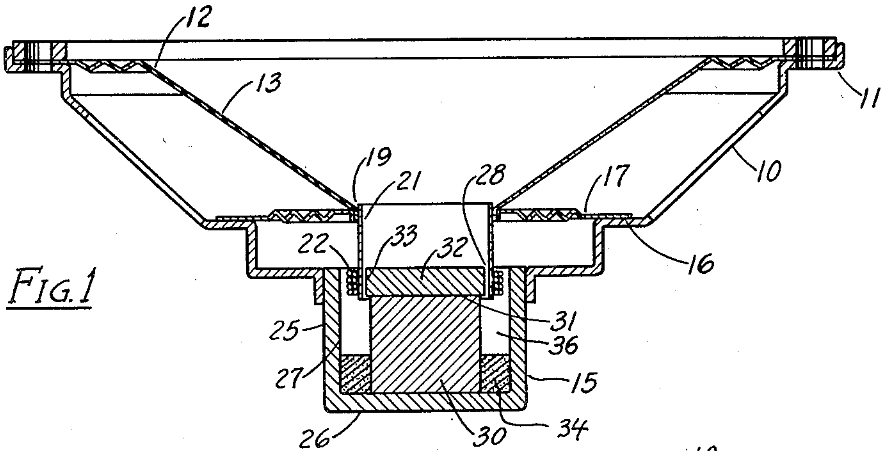

FIG. 1

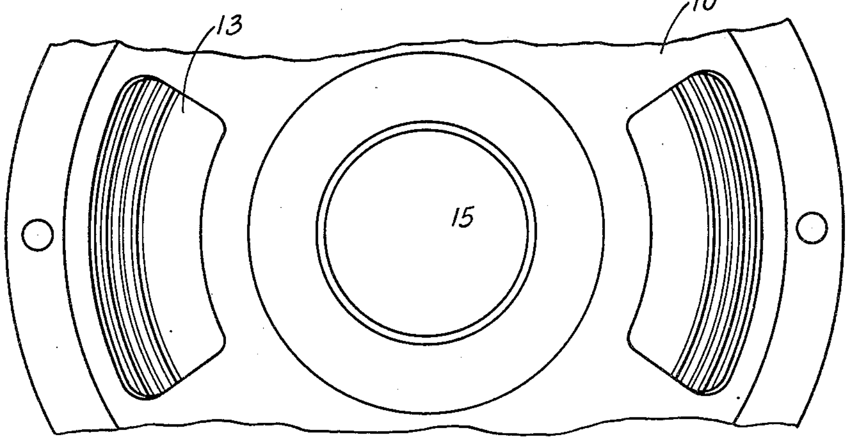

FIG. 2

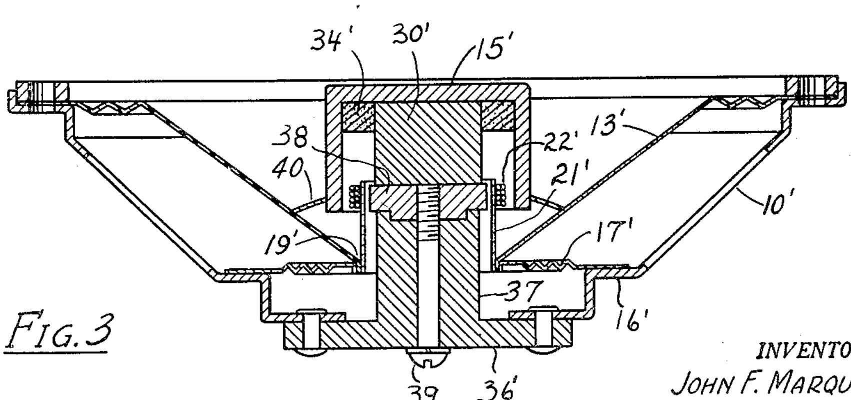

FIG. 3

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ELECTRODYNAMIC SPEAKER

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5 Claims. (Cl. 179—119)

1

This invention relates to an electrical apparatus and particularly to a permanent magnet type of loud speaker. The invention has particular application to dynamic speakers employing permanent magnets of such materials as Alnico 5 or 6 or similar anisotropic material having a preferred axis of a magnetization.

Permanent magnet types of dynamic speakers have generally provided a length of permanent magnet cooperating with a pot of the open or closed type. The open type has generally consisted simply of a U-shaped piece while the closed type of pot used a cylindrical pot.

In order to render the use of permanent magnets efficient in such speaker structures, it is generally the practice to dispose the permanent magnet at the central core. In some instances, the annular air gap within which a voice coil operates has been formed by one end of the permanent magnet and in other instances a pole piece has been used. The end of the permanent magnet remote from the voice coil has been disposed in abutting relation to the pot or in an aperture or recess in the pot bottom.

Such conventional speakers have been designed so that the pot volume had a certain ratio to the volume of the magnet. In general, the ratio of volume defined by the entire magnetic structure, usually called motor volume, has been quite high in comparison to the volume defined by the permanent magnet surface exposed to free air or other non-magnetic material. This high ratio has resulted in the rim of the pot being located at such a distance from the free end of the permanent magnet or pole piece as to require a gap plate. Such gap plate has been attached to the rim of the pot and the gap plate itself has generally defined the annular air gap within which a voice coil operates.

In certain types of prior art speakers, particularly where the end of the permanent magnet remote from the voice coil went into an aperture in the pot, the ratio of volume of the entire magnetic structure called the motor volume, divided by the volume of the entire permanent magnet may have been as low as 4. Conventional speakers have generally used ratios up to as high as 11. Where a volume ratio of 4 existed, this being with an apertured pot, the efficiency of the magnet was reduced when compared to the efficiency of a permanent magnet speaker where the pot had a solid bottom and the magnet abutted against the inner surface of the pot bottom. To compensate for this loss of efficiency it

2

was necessary to use larger permanent magnets to obtain the desired output.

In the design of the magnetic structure of a speaker both in the prior art and in the practice of the present invention, certain fundamental considerations apply. Thus a characteristic curve of the permanent magnet material must be available. This characteristic curve—usually two curves—consists of the so-called energy product curve and demagnetization curve. In both of these, the Y axis shows induction in kilogauss. The X axis for the energy product curve shows external energy consisting of the product of B_dH_d. In this curve B_d represents the flux density of the magnet corresponding to the operating point on the demagnetization curve while H_d represents the magnetizing force of the magnet corresponding to the operating point on the demagnetization curve. The X axis for the demagnetization curve shows demagnetizing force in a suitable unit as oersteds.

In the use of such curves, certain empirical formulae are relied upon.

$$L_m=\frac{B_gL_g}{H_d}$$

$$A_m=\frac{B_gA_g}{B_d}$$

It is assumed that H_g equals B_g in air. In the above formulae L_m is the magnet length in centimeters; L_g is the length in centimeters of the air gap parallel to flux line; B_g is flux density in gauss desired in the air gap; H_d is the magnetizing force in oersteds of the magnet corresponding to the operating point on the demagnetization curve; A_m is the area in square centimeters of magnet perpendicular to direction of magnetization; A_g is the cross sectional area in square centimeters of the air gap perpendicular to the flux line; and B_d is the flux density in gauss of the magnet corresponding to the operating point on the demagnetization curve.

It is assumed that for speaker purposes, a simple magnet shape will be used. The curves and formulae for designing a magnet for a speaker may be found in many hand-books and advertising circulars of companies manufacturing and selling permanent magnet materials. In addition, reference is made to circular number C448 of the National Bureau of Standards issued August 10, 1944.

In prior art permanent magnet speakers, the air gap has generally been made as small as possible and will vary with the size and rating of the speaker. In such prior art speakers the magnet volume was selected on the basis of supplying the proper flux lines at the air gap. Such a magnet requires, of course, iron for completing the magnetic circuit. It is in connection with such additional iron that the ratio of motor volume to magnet volume has been utilized, this assuming arbitrary distribution of magnetic losses throughout the magnetic circuit. As a result, in such prior art structures, the motor had a certain volume for a particular speaker rating and the volume in general was substantial and rendered such speakers bulky as well as expensive.

The general objective in designing most speakers using expensive magnet materials has been to use the magnet at its highest efficiency. Thus, the magnetic efficiency of a speaker may be defined as the magnetic energy in the air gap times 100 divided by the magnetic energy within the magnet proper. The energy in the gap is

$$\frac{B_g^2 A_g L_g}{8\pi}$$

The energy in the magnet is

$$\frac{B_d H_d V_m}{8\pi}$$

where V_m is the volume of the magnet.

The magnetic efficiency of standard type speakers having volume ratios up to 11 generally ranges from about 43% to about 48%. Such speakers have the permanent magnet provided with a soft iron pole piece at the air gap and have the other end of the permanent magnet abut the pot surface. In those instances where the permanent magnet itself extended into the air gap and the other end extended into a recess in the pot (the volume ratio being about 4) the efficiency went down to 35% or even less. By eliminating the recess in the pot the efficiency was improved to 40% or less.

I have discovered that it is possible to provide a permanent magnet type of speaker of the dynamic type having a motor volume substantially lower than what has hitherto been considered necessary as compared to prior art speakers of equal rating. In a speaker embodying my invention, it is frequently possible to use a smaller magnet volume than what has hitherto been considered necessary for speakers of comparable rating. I have discovered that a permanent magnet dynamic type of speaker having a motor volume to magnet volume of the order of about 4 and particularly 3 or 3½ is possible, providing the following structural details are present. One such detail is the provision of a soft iron pole piece at the voice coil end of a permanent magnet being magnetically anisotropic. The other detail is the provision of the permanent magnet abutting against the inside surface of the pot and in no case extending into any recess or aperture made of soft iron, in the pot.

As the result of such a low ratio, the inside surface of the pot side is spaced at such a short distance from the opposing magnet surface as to eliminate the necessity for a gap plate. It will be evident that the pole piece for the magnet must be larger than the diameter of the magnet so as to extend beyond the magnet side. Thus an annular air gap will be defined by the opposing pole piece and the inner pot surface.

In the utilization of this invention in a speaker it is first necessary that the permanent magnet have magnetic directivity of the order of that of Alnico 5 or 6. Secondly, in the design of a speaker utilizing this invention, the design formulae previously indicated will be used in conventional manner to obtain maximum magnet efficiency. It will therefore be possible to design a speaker utilizing the present invention, which speaker will have at least as great and generally greater magnetic efficiency than a prior art speaker of equal rating with the additional advantage that the improved speaker will have a far lower motor volume and will thus have less weight, less metal and will be more compact than prior art speakers of equal rating.

By virtue of the invention herein, the efficiency of a speaker may be made at least equal to the efficiency of the best designed prior art speakers and have a range of 43 to 48% and in many instances may be made greater, while at the same time reducing the amount of magnetic material and iron and over-all speaker size.

This low ratio of volumes and close disposition of pot side and permanent magnet surface results in a substantially different distribution of losses in the magnet circuit than is true for conventional speaker structures. However, the total of all the magnetic losses of a speaker embodying the present invention is no more and may be substantially less than the sum total of all losses in the magnetic circuit of a conventional permanent magnet speaker of equal rating. In a speaker embodying the present invention, the reluctance of the air leakage paths is reduced as compared to the corresponding paths in a conventional speaker structure. However, I have found that the reluctance of the ferromagnetic circuit is also reduced in my improved speaker as compared to a conventional speaker with the result that the leakage factor is not adversely affected and is generally improved.

A speaker embodying the present invention has highly desirable characteristics such as a more compact and smaller magnetic motor structure as compared to a conventional speaker. My improved speaker requires no gap plates and thus reduces the manufacturing and assembly problems which have arisen in connection with the use of a gap plate and the necessity for maintaining the gap plate rigidly in position. It must be remembered that in a conventional speaker structure, the annular air gap within which the voice coil operates is defined by the gap plate and the free end of the permanent magnet or pole piece. Numerous difficulties have arisen in connection with maintaining these gap defining parts rigidly in position so that the voice coil will at all times be properly positioned. By elimination of a gap plate and utilization of the pot as one portion for defining an annular air gap it has been found that substantial manufacturing economies are possible. Such economies in manufacturing economies are possible. Such economies are possible. Such economies in manufacture and reduction in the number of steps in the manufacture of a speaker are of substantial importance. In addition to the saving resulting from the simple reduction of manufacturing steps and in the amount of magnet and iron used, there is also a saving due to the reduced possibility of dirt and metal particles being lodged in the air gap. In conventional speakers, after the gap plate has been positioned on the pot, it is difficult to remove dirt and foreign matter lodging inside of the motor structure. In a speaker embodying the present invention, the region within the pot is more accessible even though smaller as compared to a conventional speaker structure. A substantial advantage accruing from the use of this invention is the increased magnetic efficiency arising from the elimination of the magnetic discontinity between the gap plate and pot side of a conventional structure. As is well known, even accurately ground metal surfaces provide a magnetic discontinuity which may be expressed in terms of an equivalent air gap. Hence the elimination of such joints is beneficial.

A saving in material is accompanied by a saving in processing due to the fact that smaller magnets and pots may be utilized in a speaker embodying my invention as compared to a conventional speaker of equal rating.

By virtue of my invention, it becomes possible to construct speakers having smaller axial dimension and in particular it becomes possible to provide a compact speaker wherein the motor lies within the volume defined by the conical diaphragm. Other advantages will become apparent to those skilled in the art as the invention is described.

Referring therefore to the drawings, Figure 1 shows a sectional elevation of one form of speaker embodying the present invention. Figure 2 is a back plan view of the structure shown in Figure 1. Figure 3 is a sectional elevation of a modified speaker embodying the present invention.

Referring first to Figures 1 and 2, basket 10 of conventional form is provided. Basket 10 is usually of sheet metal and has rim 11 supporting the large end 12 of conical diaphragm 13. Basket 10 is rigidly attached in any suitable manner to motor pot 15. Basket 10 has attached thereto as at 16 corrugated flat washer 17 of flexible material. Washer 17 is attached at its inside edge to small end 19 of the conical diaphragm.

Attached at 19 is bobbin 21 of suitable material. Bobbin 21 is in the form of a thin cylinder and carries thereon voice coil 22. Voice coil 22 consists of a number of turns of wire generally on the outside of the bobbin. Leads from voice coil 22 are disposed on washer 17 and carried to suitable terminals for connection to a source of audio frequencies. The structure thus far is conventional except for pot 15.

Pot 15 is preferably of the so-called closed type having side 25 and bottom 26. Side 25 has inside surface 27. The upper portion of surface 27 defines annular air gap 28 in which voice coil 22 operates.

Disposed against the inside surface of bottom 26 is permanent magnet 30. This magnet is preferably of Alnico 5 or similar anisotropic material having the same order of magnetic directivity. In the case of Alnico 5, it is customary to heat the alloy, orient the molecules of the alloy in a powerful magnetic field along a desired magnetic axis and permit the alloy to cool while in this condition. Permanent magnet 30 preferably has a circular cross section. Magnet 30 has pole face 31 against pole piece 32 of soft iron. Pole piece 32 has a thickness suitable for the purpose and has outer cylindrical surface 33 defining the inner boundary of annular air gap 28.

Various means for maintaining pole piece 32 and magnet 30 rigidly in position with respect to the pot may be used. The simplest way is to solder the pole piece and magnet in position. Thus solder, glue or other suitable material may be provided at 34 for maintaining the magnet in position. It is understood that the pot surface defining the annular air gap will be accurate for the required purpose.

In accordance with this invention, the pot volume is so selected with reference to the magnet volume as to provide for a ratio of the order of 3 or 4 and preferably about 3 or 3½. By virtue of this ratio, annular region 28 within the pot between the oppositely disposed pot and magnet surfaces becomes small and relatively short along the axis of the permanent magnet.

It will be noted that in order to utilize this low volume ratio, it is necessary that permanent magnet 30 have its end abut against bottom 26 of the pot and have the other end thereof provided with a pole piece of suitable dimension. This pole piece must be thick enough to provide sufficient iron along the axis of the permanent magnet as to permit the lines of force from the end of the magnet to curve around within the pole piece.

Referring now to Fig. 3, a modified structure is shown with corresponding parts carrying like primed numbers. In this construction, basket 10′ is disposed in substantially the same relation to diaphragm 13′ as in Fig. 1. Small end 19′ of the diaphragm is coupled to disc 17′ and voice coil bobbin 21′ in generally the same manner as shown in Fig. 1 except that the voice coil and bobbin extends into the space enclosed by the large diaphragm. Stepped portion 16′ of the basket is riveted to stud 36′ of steel or soft iron. Stud 36′ has cylindrical portion 37 extending toward the voice coil and carries at the end thereof pole piece 38 of soft iron. Pole piece 38 and portion 37 of the stud are preferably shaped in any desired manner as with an annular step so that the pole piece may be accurately and rigidly positioned upon the stud. Bolt 39 passing through a suitable bore in stud 36′ engages threads tapped in pole piece 38 to maintain this assembly tightly in position.

Magnet 30′ is suitably soldered or rigidly attached to pole piece 38. Magnet 30′ and pot 15′ are rigidly maintained in predetermined relative position by solder 34′ or other material such as glue.

Felt ring 40 is provided to function as a dust cap and is cemented or glued between the diaphragm and pot. Excepting for the relative proportions of permanent magnet and the remainder of the motor consisting of the volume defined by the pot, this being 15′ in Fig. 3, the construction shown in Fig. 3 is quite conventional.

In general, it is possible to utilize the magnetic structure disclosed herein in various types of permanent magnet dynamic speakers or other devices of the permanent magnet dynamic type wherein a member moves in an annular gap.

In the practical design of a speaker using the present invention it is assumed that the designer will provide sufficiient iron in the pot and pole piece at the voice coil end of the magnet so that the iron as a whole does not operate generally at excessive flux densities. In particular, it is undesirable to saturate any substantial amount of iron since that increases leakage. The permanent magnet itself will generally have a circular cross section.

With anisotropic magnet materials, such as Alnico 5, while the magnetic directivity is great, it is not great enough to reduce the clearance between the magnet side and inside surface of the pot to the order of the usual dimensions for a voice coil gap. In the design of a speaker involving the present invention it is found that gradually reducing the clearance between the magnet side and opposed inside surface of a pot results in little increase in magnetic leakage until a critical clearance is reached. A further reduction in the clearance below this critical point generally results in a sharp increase in leakage flux and thus results in a sharp drop in overall magnet efficiency.

Thus as an example, a ¾ oz. Alnico 5 magnet having a length of about ½'' and a diameter of about ½'' was designed with a spacing of .090''. A larger magnet of 1.5 ozs. of the same material having a length of .6'' and a diameter of about .8'' could be used with the same clearance between the pot and magnet side.

In the above examples, the clearance of .090'' was about three or four times that required for an average voice coil. Thus in general the clearance at the magnet side while larger than at the pole piece is still in the same order. The pole piece at the voice coil end of the magnet had a diameter large enough to reduce the clearance with the inside of the pot to about .025'' or the like.

In the event that a magnet material is developed having substantially greater anisotropic properties than Alnico 5, it may be possible to reduce the clearance between the magnet side and pot side to about that required for a voice coil. However, this would require accurate grinding of the magnet surface in order to prevent excessive magnetic losses. The clearance of .090'' given as an example is large enough so that substantial tolerances are possible in the magnetic surface without impairing efficiency.

The length of the pole piece at the voice coil end in general will be determined by the axial length of the voice coil gap. It is understood that the above dimensions and the minimum clearances and voice coil gaps are merely by way of example. Thus there may be special types of voice coils requiring either larger or smaller gaps than customary. In addition, variations in magnet size and dimensions as well as variations in magnetization of a magnet will have substantial effect upon the permissible minimum clearance. In general, this permissible minimum clearance may be obtained by simple experimentation and is part of the design procedure in engineering a speaker.

It is possible that in certain exceptional cases where reduction in weight is of paramount importance, such as for example in aircraft, and efficiency is secondary, that the clearance between magnet side and pot side may be reduced somewhat below the desirable border line limit. In such a case, a small and light weight speaker having substantial power will result, such speaker of course having an efficiency somewhat below the optimum value.

What is claimed is:

1. In a permanent magnet dynamic type speaker, a solid cylindrical permanent magnet having a preferred axis of magnetization along the cylinder axis of the order of that of Alnico 5, said magnet having both ends smooth, a soft iron pot whose volume is not more than about 4 times the magnet volume, said magnet being disposed to form a central core for the pot and having one pole face abutting against the pot bottom, said pot bottom being flat and free of any recess for the magnet so that said magnet contacts the pot

only at the one pole face thereof, a soft iron pole piece for the other magnet pole face contacting the magnet only at the pole face and not overhanging the magnet sides and extending beyond the magnet side, the pole piece and opposing inside pot surface adjacent the pot rim defining an annular air gap for voice coil operation, said pot and magnet and pole piece being designed for efficient use of the magnet whereby a compact, light weight speaker having an efficiency in excess of 48% results.

2. The speaker according to claim 1 wherein a conical diaphragm is provided and wherein the pot lies substantially within the volume defined by the diaphragm cone.

3. The speaker according to claim 1 wherein the ratio of pot volume to magnet volume is in the range of 3 to 3½.

4. In a permanent magnet dynamic speaker, a straight solid permanent magnet having smooth ends and being of a material having a preferred axis of magnetization of the order of Alnico 5 and a soft iron pole piece at one end of the magnet contacting the magnet only at the pole face and not overhanging the magnet sides, a soft iron pot abutting the other end of the magnet, said pot having straight sides, the inside surface of the pot side being sufficiently close to the sides of the pole piece so that an annular air gap between the inside surface of the pot near the rim is formed with said pole piece and said pot bottom being flat and free of any recess for the magnet, said construction being free of magnetic discontinuities other than the ends of the permanent magnet, the spacing between the sides of the permanent magnet and inside surface of the pot being sufficiently close to provide for a ratio of volume of motor to magnet of the order of about 4 or less and the magnetic circuit as a whole having an efficiency of more than 48%.

5. The structure according to claim 4 wherein the clearance between magnet side and opposed pot surface is of the order of the annular gap formed at the side of the pole piece, whereby a gap plate between the edge of the pot and pole piece is rendered unnecessary.

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