

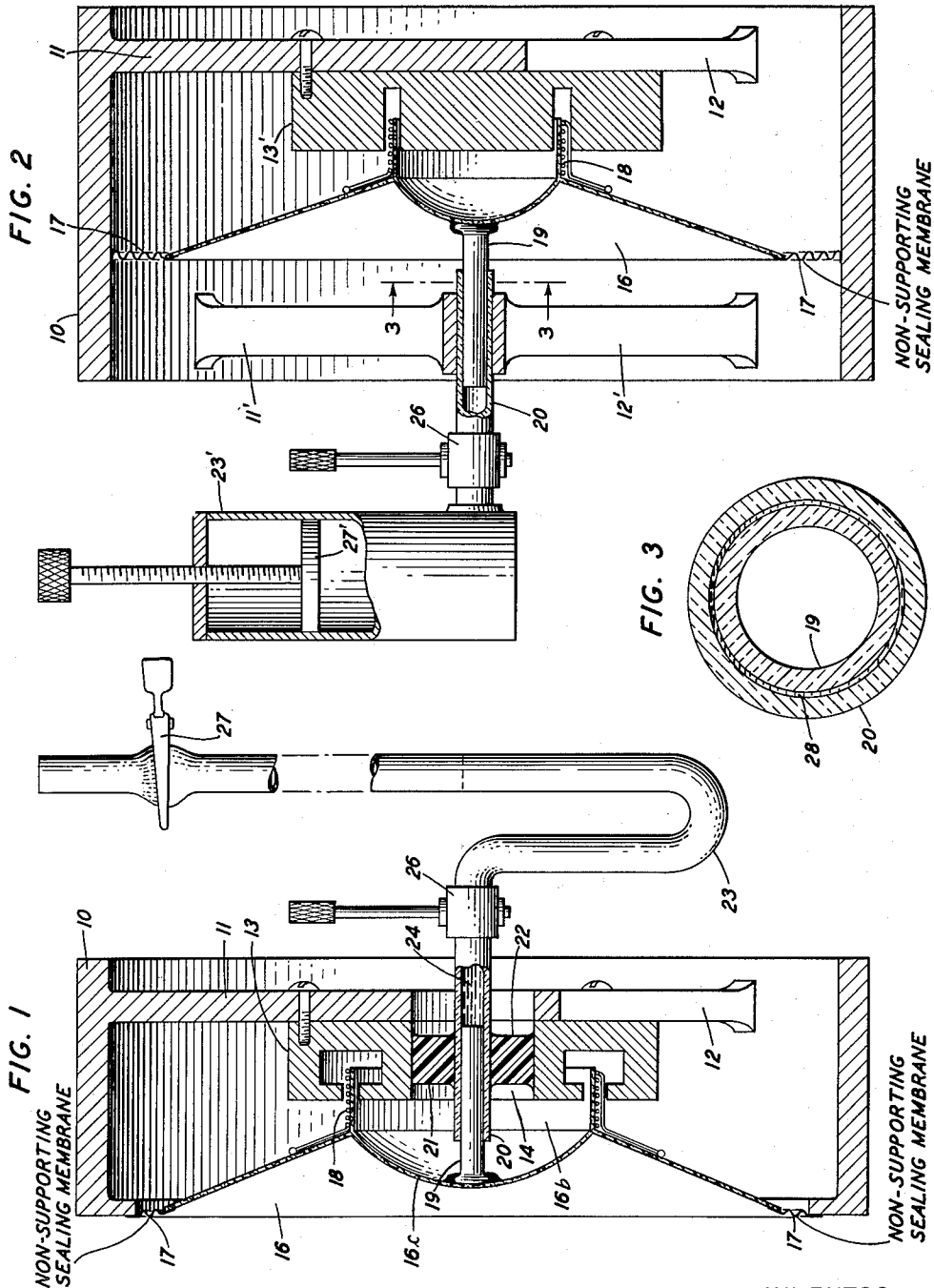
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LOUDSPEAKER SYSTEM

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LOUDSPEAKER SYSTEM

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This invention relates to loudspeaker systems and more particularly to new structure for supporting the transducing element therein and for providing convenient control over the characteristics thereof.

Loudspeaker systems translate electric signals into acoustic vibrations. Such systems generally include a movable, substantially conical diaphragm, a voice coil secured to the apex portion of the diaphragm, a magnet structure, and appropriate radial, resilient, support elements for holding the diaphragm in a predetermined rest position with respect to the magnet. Axial restoring forces for returning the voice coil to its normal rest position after each displacement thereof are supplied by the resilience of the radial supports. Suitable terminating devices, such as enclosures or horns of various types, may also be employed for enhancing the quality of sound produced by the system.

It is generally recognized that a truly ideal loudspeaker arrangement would include four principal features: (1) a linear relationship between the force applied to the diaphragm and the resultant displacement thereof; (2) means for adjusting the force-displacement relationship; (3) means for adjusting the system resonant frequency; and (4) construction which permits useful coupling of any one of a variety of suitable terminations to either side, or to both sides, of the diaphragm. However, no prior art speaker system includes all of these features.

Much of the distortion which takes place in prior art loudspeakers may be attributed to characteristic nonlinearities in the force-displacement relationship of the resilient, radial supports heretofore employed for suspending the diaphragm in a predetermined rest position. The reason is that low frequency sounds are produced by large diaphragm displacements at a low rate of movement while high frequency sounds are produced by relatively small diaphragm displacements at a high rate of movement. In prior art flexible suspensions, the force required to accomplish each unit of displacement increases as the total displacement increases. This nonlinear force-displacement relationship requires a larger driving force to be applied to produce a low frequency sound of given intensity than is required to produce a high frequency sound of the same intensity. Consequently, a system tends either to distort the high frequencies due to overdriving or to suppress the low frequencies due to underdriving. Furthermore the prior art suspensions do not permit the system force-displacement ratio or the system frequency response to be adjusted to match the output characteristics of different amplifiers or to match the response characteristics of different terminations. The industry has labored over the years with a multitude of variations in diaphragms and diaphragm support structures, but each prior art effort has been encumbered by diaphragm supports of the resilient radial type previously described.

Accordingly, it is one object of the invention to improve loudspeaker systems.

An additional object is to increase the utility of loudspeaker systems.

Another object is to overcome the problem of nonlinearities in diaphragm-coil supporting means.

A further object is to control adjustably the frequency

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response and the displacement characteristics of a loudspeaker system.

Yet another object is to introduce apparatus embodying new principles for supporting loudspeaker diaphragms and for controlling the characteristics of loudspeaker systems.

These and other objects of the invention are realized by employing a fluid in a variable coupling device for supporting a loudspeaker diaphragm in its proper relationship with respect to other components of a loudspeaker system. One embodiment of the invention employs a co-operating cylinder and piston of small diameter compared to the diaphragm diameter to couple the diaphragm to stationary structure in the speaker system. A liquid of predetermined viscosity occupies the clearance between the piston and the cylinder to influence the response of the system and to provide lubrication therebetween as required. The piston is secured to a central portion of the diaphragm; and the cylinder is secured to the speaker magnet structure. A compartment of adjustable length is acoustically coupled to the inside of the cylinder and provides control over the force-displacement relationship of the system. A valve at the coupling point provides control over the frequency response of the system.

This loudspeaker embodiment is characterized by a diaphragm force-displacement relationship which is both adjustable and substantially linear. Frequency response is also adjustable, and the two surfaces of the diaphragm are essentially unobstructed so that suitable terminations may be coupled to either or both of them.

A more complete understanding of the invention and of the various objects and advantages thereof may be obtained from a consideration of the following detailed description together with the attached drawing in which:

FIG. 1 is a side view partly in section of a loudspeaker system including the present invention;

FIG. 2 is a side view partly in section of another embodiment of the invention; and

FIG. 3 is a magnified cross section view taken at the line 3-3 in FIG. 2.

FIG. 1 shows a portion of a loudspeaker enclosure 10 which may be of generally cylindrical configuration with inwardly extending radial ribs 11 and 12 which support an annular magnet 13 inside housing 10. Complete details for housing 10 are not disclosed here since they are not relevant to a description of the invention and they may include a wide variety of horns or enclosures coupled to either side of the housing or to both sides. It need only be pointed out that the radial ribs 11 and 12, as well as other ribs not visible in the section drawing of FIG. 1, serve only to support magnet 13 and do not substantially restrict acoustical access to the interior of housing 10 from the right-hand side thereof as illustrated.

A diaphragm 16 is in the general shape of the frustum of a cone and includes an inner convex diaphragm 16c. A flexible membrane 17 loosely connects the periphery of diaphragm 16 to housing 10 to prevent acoustic coupling between the front and rear surfaces of diaphragm 16 around the edges thereof. Membrane 17 does not, however, provide any significant support for diaphragm 16. A voice coil 18 is wound upon a cylindrical rearward extension 16b from the apex portion of diaphragm 16 in the usual manner. Diaphragm 16 is suspended in a rest position such that coil 18 is in an annular air gap of magnet 13, and the suspending structure will now be described.

In accordance with one aspect of the present invention a coupling device with a fluid link supports diaphragm 16. A piston 19 is one member of the device

and is secured to the inner diaphragm 16c. Piston 19 extends rearwardly from diaphragm 16 along a line which is substantially parallel to the intended direction of diaphragm movement. Piston 19 will generally be constructed of nonmagnetic material.

A cylinder 20 is the other member of the coupling device and is co-operatively arranged in telescopic engagement with piston 19 throughout a substantial portion of the length thereof. Cylinder 20 is supported by radial members 21 and 22 in fixed relationship with respect to magnet 13 in a centrally located port 14 through magnet 13. For the sake of convenience, the diameter of cylinder 20 and piston 19 should be much smaller than the diameter of diaphragm 16 or of coil 18. The minimum cylinder diameter is influenced by the weight of the diaphragm-coil combination.

Cylinder 20 is vented into a fluid-enclosing chamber which in FIG. 1 is a flexible rubber tube 23 containing air. Coupling between cylinder 20 and tube 23 is accomplished by any suitable valve mechanism such as valve 26 which also permits adjustment of the coupling passage diameter. Valve 26 effects a capacitive type of adjustment which accomplishes a change in the compliance of the moving portions of the loudspeaker system and thereby changes the resonant frequency of the system.

The effective length of tube 23 is fixed by a clamp 27 which may be located at different places along the length of tube 23 to adjust the volume of the chamber and thus change the force-displacement relationship of the diaphragm-piston combination. It is well known that ideal gaseous fluids have a substantially linear isothermal pressure-volume relationship defined by Boyle's law. In accordance with this invention, that same relationship is the basis for the relationship between the force exerted on the diaphragm 16 and the resulting diaphragm displacement under the control of piston 19, cylinder 20, and tube 23. Consequently, in the structure of FIG. 1, piston 19, through its co-operation with cylinder 20 and tube 23, can support diaphragm 16 and help to control its displacement without injecting significant nonlinearities in the signal-to-sound translation.

The effect of moving the position of clamp 27 can be demonstrated in a simplified manner by assuming ideal conditions. A continuously applied force F tending to displace diaphragm 16 and piston 19 could result from the electromotive interaction between magnet 13 and coil 18. Force F moves piston 19 thereby changing the volume of air enclosed in cylinder 20 and tube 23 until the resulting change in air pressure acting on the end of piston 19 equalizes the forces acting on the piston. For a piston of uniform diameter, the pressures on each end would then be equal. By employing the mentioned pressure-volume relationship for an isothermal change:

$$F/A_p = P_o \frac{V_o}{V_o - V_d} = P_o \frac{V_o}{V_o - A_p d}$$

where A_p is the cross sectional area of the piston, P_o and V_o are the initial pressure and volume, respectively, inside cylinder 20 and tube 23 before the application of force F , and V_d is the change in cylinder volume due to the movement of piston 19 through a displacement d . This relation reduces to

$$F/A_p = \frac{P_o}{1 - \frac{A_p d}{V_o}}$$

which shows that in order to equalize pressures when the force F is applied, the initial pressure must change by a factor which is dependent upon both the initial volume V_o and the displacement d . For example, V_o can be increased by moving clamp 27 upward in FIG. 1 and thereby increasing the effective volume in tube 23. However, that change decreases the factor operating upon P_o so that the applied force F must now act through a greater displacement d in order to equalize pressures.

In other words, the piston-diaphragm force-displacement relationship is changed by changing V_o , the initial combined volume of cylinder 20 and tube 23.

The inside of tube 23 is normally filled with an elastic fluid such as air. However, in order to assure uniform operation of valve 26 in spite of ambient temperature variations, a suitable liquid 24 may be included in cylinder 20 and in the portions of tube 23 which are either at or below the level of cylinder 20 when the tube is arranged as illustrated in FIG. 1. No structure is shown for supporting tube 23 in any particular position since its location is not at all critical to the successful operation of the invention unless a liquid is used as described above.

Piston 19 and cylinder 20 must have a minimum engagement length which will assure substantially straight line operation of diaphragm 16 and will not cause any significant misalignment between piston 19 and cylinder 20. If the engagement length is substantially greater than piston diameter, satisfactory operation is obtained.

A lubricant, such as an intermediate grade of machine oil, is the fluid link in the coupling device supporting diaphragm 16. The oil occupies the clearance between piston 19 and cylinder 20 and also provides freedom of movement with substantially no noise. In this embodiment the requirement governing viscosity is that it should be low enough to present substantially uniform impedance to relative movements of piston 19 and cylinder 20 throughout the range of frequencies to be translated by the loudspeaker. A modification of this requirement will be discussed subsequently in connection with FIG. 3.

In summary with respect to FIG. 1, diaphragm 16 is supported in a predetermined radial relationship with respect to magnet 13 by the co-operative engagement through a fluid of two members, piston 19 and cylinder 20, no other supporting structure being required. The elastic properties of the fluid in cylinder 20 and tube 23 provide substantially uniform resistance to the displacement of diaphragm 16 and piston 19 and likewise supply the necessary force required to restore the diaphragm and piston to their normal rest position following any given displacement.

Clamp 27 may be adjusted along tube 23 to increase or decrease the volume enclosed within tube 23 thereby changing the force-displacement relationship imposed upon diaphragm 16 without, however, altering the linearity of that relationship.

Valve 26 may be adjusted to control the rate of fluid exchange between cylinder 20 and the interior of tube 23 thereby altering the compliance of the system and the resonant frequency thereof.

In FIG. 2 there is shown a further embodiment of the invention wherein a diaphragm supporting arrangement, which is similar to that shown in FIG. 1, is applied to the front of the diaphragm rather than to the rear thereof. In this figure, elements which are similar to those shown in FIG. 1 have been designated by the same or similar reference characters. FIG. 2 demonstrates that the invention may be employed in connection with magnet structures 13' which may not be centrally ported as was the magnet structure 13 in FIG. 1. Housing ribs 11 and 12 are here shown as extending all the way to the middle of the housing since it is not necessary to provide the central aperture which was utilized in the embodiment of FIG. 1.

Housing ribs 11' and 12' are provided to support cylinder 20 in fixed relationship with respect to housing 10 and in engagement with piston 19. A rigid cylindrical chamber 23' has replaced the tube 23 and is provided with an adjustable plunger 27' for changing the effective volume of the chamber to control the force-displacement ratio of the loudspeaker system.

FIG. 3 is a magnified cross sectional view of piston 19 and cylinder 20 at line 3-3 in FIG. 2. It can be seen in the magnified view of FIG. 3 that a liquid 28

fills the clearance between piston 19 and cylinder 20. As previously mentioned in connection with FIG. 1, liquid 28 has a viscosity such that it presents a substantially constant impedance to movements of piston 19 in the frequency range of interest when a fluid chamber is employed in connection with the supporting piston 19 and cylinder 20 of the invention. If, however, the viscosity of liquid 28 is increased to a value that might be characteristic of some grades of castor oil, for example, the influence of the viscous liquid upon the speaker system changes markedly. The new viscosity is such that the fluid presents a much higher impedance to relative movements of piston 19 and cylinder 20 at high frequencies than at low frequencies. That is to say, the short, high frequency displacements occur at a high velocity which is impeded by the higher viscosity of liquid 28 while the relatively longer, low frequency displacements occur at a lower velocity which is not so severely impeded.

Thus, while valve 26 provides a capacitance type of control over system frequency response, viscosity offers an inductive type of control over that response. The two controls may be used singly or together to shape system response. For example, piston 19 and cylinder 20 may be replaced by two similarly movable elements which are not required to provide support. The elements would be coupled by a fluid with a viscosity which overbalanced the effect of valve 26. A conventional radial supporting structure could be employed for the diaphragm. The fluid impedance to displacements would tend to compensate the force-displacement relationship of the support so that the system force-displacement relationship would be nearly constant over the audible range of frequencies. Thus, by employing a high viscosity liquid together with a stronger system driving force than has normally heretofore been employed, both the low frequency and the high frequency diaphragm displacements may be accurately produced without overdriving for the high frequency displacements or underdriving for the low frequency displacements.

Although the present invention and its governing principles have been described in connection with particular operative examples, it is to be understood that additional examples and modifications thereof which will be obvious to those skilled in the art are included in the invention.

What is claimed is:

1. Electroacoustic transducing means comprising electromotive driving means adapted to be actuated by electric signals, a member mechanically connected to be driven in oscillatory motion by said driving means for generating acoustic representations of said signals, and pneumatic means for restoring said driven member to a predetermined rest position after each oscillatory excursion thereof, said pneumatic means comprising a piston secured to said driven member to be driven thereby in a direction which is parallel to the principal axis of said piston, the area of engagement between said piston and said driven member comprising only a small portion of the area of one side of said member, a cylinder telescopically engaging said piston, an enclosure, means coupling pressure variations between the interior of said enclosure and the interior of said cylinder, and means attached to said enclosure for adjusting the volume thereof to change the force-displacement ratio of operation for said member.

2. The electroacoustic transducing means in accordance with claim 1 in which said member is a movable diaphragm, said piston is secured to one side of said diaphragm with its axis being substantially coincident with the axis of said diaphragm.

3. The electroacoustic transducing means in accordance with claim 1 in which said member is a substantially conical diaphragm, and said piston is secured to the central portion of said diaphragm with its axis substantially concurrent with the axis of said diaphragm.

4. The electroacoustic transducing means in accordance with claim 1 in which supporting means are provided for maintaining said cylinder stationary, and said supporting means comprises the sole support for said piston and said driven member.

5. The electroacoustic transducing means in accordance with claim 1 which comprises acoustic terminating means supporting said driving means, and nonsupporting sealing means connecting the periphery of said member to said terminating means for preventing acoustic vibrations generated on one side of said driven member from interfering with vibrations generated on the other side thereof.

6. The electroacoustic transducing means in accordance with claim 1 in which said enclosure is a flexible tube.

7. The electroacoustic transducing means in accordance with claim 6 which comprises in addition means adjusting the effective length of said tube for thereby changing the force-displacement relationship for said driven member.

8. The electroacoustic transducing means in accordance with claim 6 which comprises in addition means adjusting the minimum diameter of said tube for thereby changing the resonant frequency of said transducing means.

9. The electroacoustic transducing means in accordance with claim 8 which comprises in addition means adjusting the effective length of said tube for changing the force-displacement relationship of said driven member.

10. The electroacoustic transducing means in accordance with claim 8 in which a liquid is confined in a portion of said tube including said diameter adjusting means.

11. In a loudspeaker system comprising a diaphragm, a voice coil secured thereto, a magnet arrangement in electromotive relationship with said coil for driving said diaphragm to generate acoustic vibrations in response to the electrical excitation of said system, the improvement which comprises a fluid, support means including said fluid and providing the sole radial support for said diaphragm.

12. A loudspeaker system in which useful sound waves may be projected from either side of its diaphragm, said system comprising said diaphragm, a voice coil secured thereto, a magnet structure arrangement in electromotive relationship with respect to said coil for driving said diaphragm and coil in response to electrical excitation of said system, an enclosure of adjustable effective volume and adjustable minimum diameter, a cylinder, means communicating between the interior of said cylinder and said enclosure, and a piston secured to said diaphragm and arranged in telescopic engagement with said cylinder for altering the pressure within said enclosure in response to movements of said diaphragm.

13. In a loudspeaker system comprising a diaphragm, a voice coil secured thereto, a magnet arranged in electromotive relationship with said coil for driving said diaphragm to generate acoustic vibrations in response to the electrical excitation of said system, the improvement which comprises a viscous liquid, a coupling device including two relatively movable members separated by said liquid, and means securing said members to said diaphragm and to said magnet, respectively, for providing the sole support for said diaphragm.

14. The loudspeaker system in accordance with claim 13 in which said members comprise a piston and a cylinder telescopically engaging said piston, a tube having only one end thereof open is acoustically coupled at its open end to said cylinder whereby movements of said piston alter the pressure within said cylinder and within said tube, and the diameter of said piston is much smaller than the diameter of said diaphragm.

15. A loudspeaker system comprising a diaphragm having substantially the configuration of the frustum of a

cone, a voice coil wound upon a cylindrical form secured to the apex portion of said diaphragm, an annular magnet structure surrounding the outer surface of said voice coil and having a cylindrical pole portion extending within the interior of said form, said pole portion having an axial aperture therethrough, a piston secured to the apex portion of said diaphragm and extending substantially coaxially therewith through said voice coil and into said aperture, the length of said piston being substantially greater than the diameter thereof, a cylinder telescopically engaging a substantial portion of said piston with clearance therebetween, means supporting said cylinder in fixed relationship with respect to said magnet so that said cylinder in turn maintains said piston in a substantially fixed radial relationship with said magnet, said cylinder extending through at least a portion of said cylindrical pole piece, a flexible tube connected to the end of said cylinder and acoustically coupled to the interior thereof, a clamp adjustable along the length of said tube for changing the effective volume thereof with respect to said cylinder, and means connected to said effective portion of said tube volume for changing the minimum diameter thereof.

16. In a loudspeaker system comprising a diaphragm, a voice coil secured thereto, and a magnet arranged in an electromotive relationship with said coil for driving said diaphragm to generate acoustic vibrations in response to the electrical excitation of said system, the improvement which comprises a first member fixed to said diaphragm, a second member fixed to said magnet for variably engaging said first member, and a fluid film arranged between said members.

17. In a loudspeaker system comprising a diaphragm, a voice coil secured thereto, and a magnet arranged in an electromotive relationship with said coil for driving said diaphragm to generate acoustic vibrations in re-

sponse to the electrical excitation of said coil, the improvement which comprises a first member secured to said diaphragm, a second member secured to said magnet, a liquid coupling said members together, and said liquid having a viscosity such that in the frequency range of interest for said system said liquid presents a much higher impedance to relative movement of said members for translating frequencies in the upper part of said range than for translating frequencies in the lower part of said range.

18. In a loudspeaker system comprising a diaphragm, a voice coil secured thereto, and a magnet arranged in an electromotive relationship with said coil for driving said diaphragm to generate acoustic vibrations in response to the electrical excitation of said system, the improvement which comprises a first member secured to said diaphragm, a second member secured to said magnet, a fluid coupling said members together, and said fluid having a viscosity such that in the frequency translating range of interest for said system said liquid presents substantially constant impedance to the relative movement of said members with respect to one another for translating electrical signals to acoustic vibrations.

19. The loudspeaker system in accordance with claim 18 in which said members and said fluid comprise a coupling device which provides the sole means of support for said diaphragm.

20. The loudspeaker system in accordance with claim 19 in which said members comprise a piston and a cylinder in telescopic engagement with one another, pneumatic control means are acoustically coupled to the interior of said cylinder for adjusting the force-displacement relationship for movements of said diaphragm, and means are connected to said control means for adjusting the compliance of said system.

No references cited