June 24, 1958 H. SCHOENGOLD 2,840,177

LOUDSPEAKER DIAPHRAGM SUPPORT

Filed July 28, 1955 2 Sheets-Sheet 1

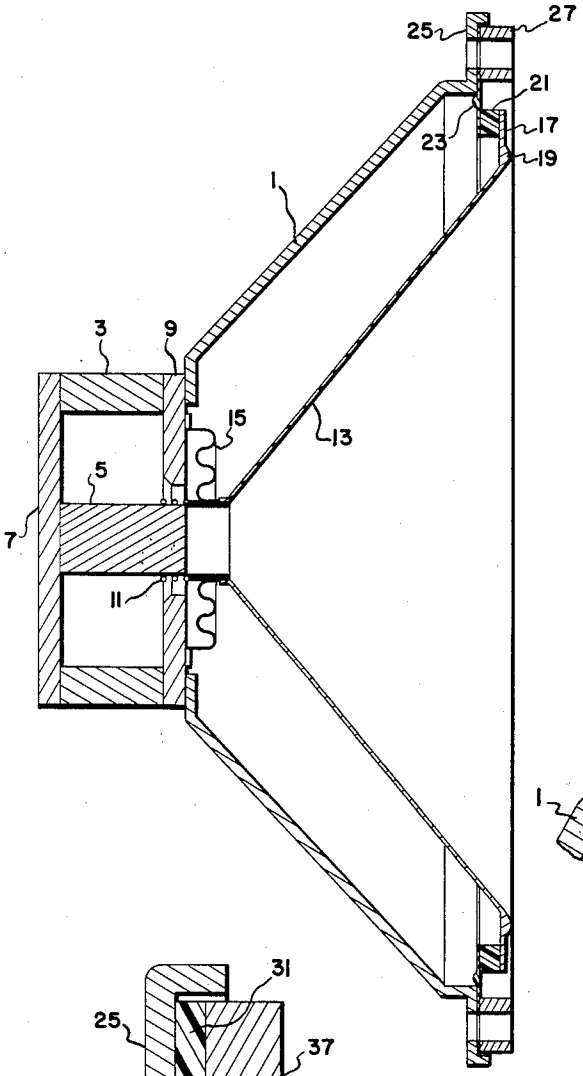


FIG. 1.

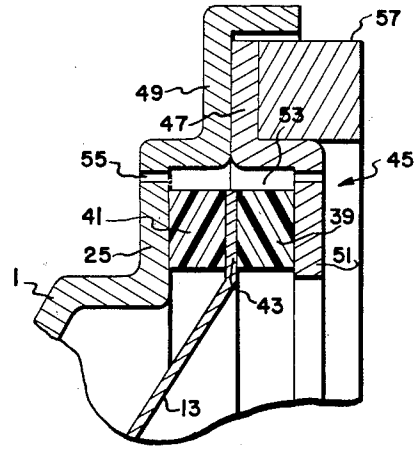


FIG. 3.

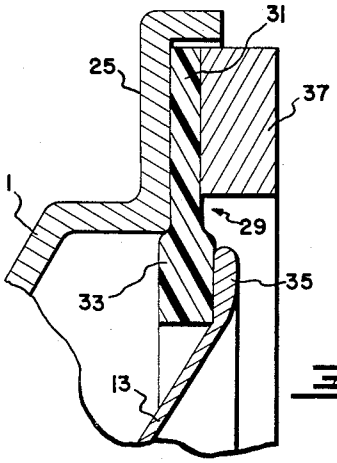
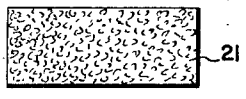


FIG. 2.

FIG. 4.



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LOUDSPEAKER DIAPHRAGM SUPPORT

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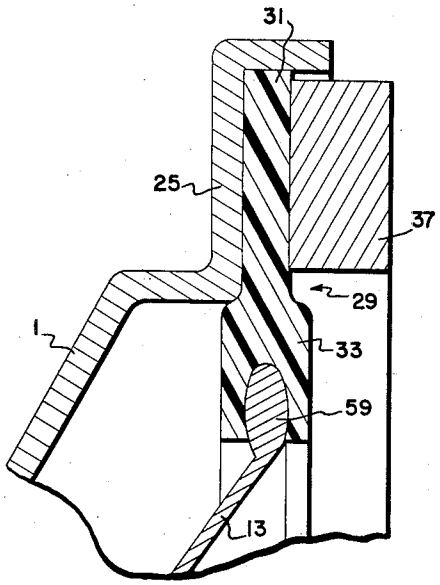


FIG. 5

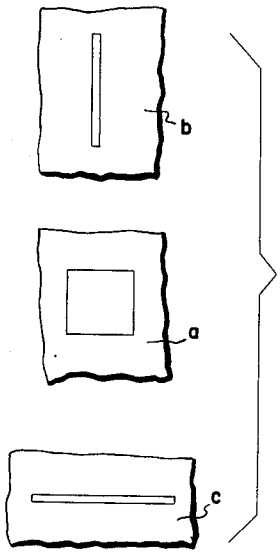


FIG. 6.

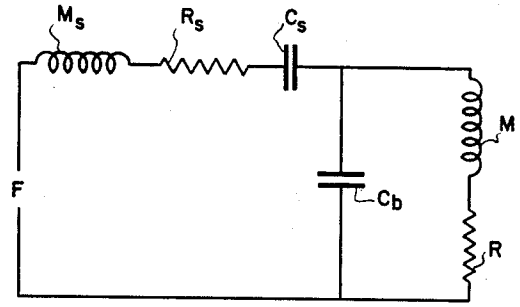


FIG. 7.

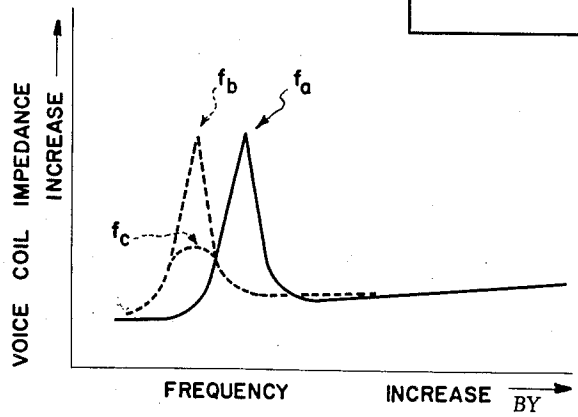


FIG. 8.

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LOUDSPEAKER DIAPHRAGM SUPPORT

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Application July 28, 1955, Serial No. 524,879

6 Claims. (Cl. 181—31)

This invention relates broadly to the loudspeaker art and in its more specific aspects it relates to a novel support or suspension means for loudspeaker diaphragms which provides greater unrestrained motion while having a high damping action which produces a substantially extended low frequency reproduction with substantially reduced distortion when compared with prior art support or suspension methods; and the nature and objects of the invention will be readily recognized and understood by those skilled in the art to which it relates in the light of the following explanation and detailed description of the accompanying drawings illustrating what I at present believe to be the preferred embodiments or mechanical expressions of my invention from among various other forms, arrangements, combinations and constructions, of which the invention is capable within the spirit and scope thereof.

My invention concerns an improvement in loudspeakers of the paper cone type and particularly to an improved suspension method permitting greater amplitudes of excursion, better damping, reduction of rim reflections, and other attending advantages.

Normally, the maximum axial travel of a diaphragm in a conventional loudspeaker is limited by the stiffness of the moving system, and this stiffness or mechanical impedance is usually incorporated into the compliant beads or corrugations at the periphery of the cone. In such conventional loudspeakers the elastic limit of such compliance may be reached at low frequencies before the cone has moved to the ultimate peak as required by the input or exciting current in the voice coil. This results in a limiting action accompanied by severe distortion, such distortion being referred to as suspension non-linearity.

The basic requirements of a linear vibrating system, i. e., one where the displacement is proportional to the applied force, in this case voice coil energy, are the combination of linear compliance and a fixed mass. In practice such systems are not simple for large magnitudes of vibration. The compliant beads or corrugations at the edge of the cone together with the centering spider act as a spring, but like most springs are linear for only a limited range of displacements.

In accordance with this invention, greater freedom of excursion is provided without appreciably affecting the stability of the voice coil with respect to the air gap. Further improvements in this invention lie in the damping quality of the suspension which reduces what is known in the trade as "rim hickey" which is caused by reflection from the frame or supporting basket. Such reflections which are due to sound waves traveling through the cone, being reflected back by the supporting frame thus causing cancellation or out-of-phase conditions at specific frequencies usually in the mid-range portion of the audio-spectrum. Another contributory value of this invention lies in the damping or resistive component added to the moving system which effectively serves to reduce the undesirable distorted peak amplitude at the resonant frequency. The combined effect of these improvements is to provide for a substantially extended low frequency reproduction containing less distortion than is obtained from hitherto existing suspension methods.

A loudspeaker may be considered a practical vibrating system and becomes resonant at some low frequency. At resonance the reactive components of mechanical impedance are zero, namely, the reactances due to inherent stiffness and inherent mass are cancelled leaving an impedance which is purely resistive. This resistive component in a conventional suspension is small because it is due to slight friction of fibres and molecules of the paper stock, therefore, the diaphragm exhibits excessive sensitivity at resonance not consistent with its sensitivity at frequencies above or below resonance. The cone attempts to reach extreme excursions at this resonant frequency, yet cannot do so because of the final restraints of the rim corrugations. Another disadvantage lies in the large rise in electrical impedance of the voice coil at resonance causing the power drawn from the amplifier to be disproportionate and small compared to the power drawn at other frequencies. This over-sensitized condition at the resonant frequency results in distortion, boom and hangover, giving a lack of distinctiveness and coloration to bass instruments and other low frequency impulses.

In order to increase the resistive component and so reduce the inordinate behaviour at resonance, it has been the practice in the art to paint the rim corrugations with a compound such as "Viscaloid" or a latex mixture, but such damping treatments are only of very minor effect as can be shown by simple impedance and frequency response measurements. Damping by inherent characteristics of the moving system is rare and at best is usually loaned by external factors such as the baffle or specialized enclosure design.

This invention incorporates a special material giving greater unrestrained motion yet having a high damping action which reduces the peak amplitude and high counter E. M. F. at the resonant frequency. Such a dissipative or resistive force likewise prevents the reflection of sound waves which travel through the cone material from being reflected back from the supporting basket; thus it reduces or eliminates the "rim hickey" or cancellation effect at mid-frequencies.

The material which I have found endows a loudspeaker with many desired and highly advantageous characteristics when used as a support or suspension means for the loudspeaker diaphragm is one which is inherently pliable or compliant and is substantially non-resilient at least partly because of its cellular structure, and after deformation returns slowly to its normal configuration. Such a material having these necessary inherent characteristics is preferably of open cellular structure having a mechanical inertance so that when it is compressed the air is driven out of the cells and when released from compression the air attempts to re-enter but because of the mechanical inertance of the material, the cells remain constricted for an appreciable time, the air being drawn only slowly back into the cells. There is thus no substantial motion imparted by the material itself resulting from its own momentum or stored energy. As one example a polyvinyl chloride open-cell formulation will produce a plastic foam which is pliable and endowed with the aforementioned desired characteristics when used as a suspension means for the diaphragm. It is within my contemplation to also use a closed cell foam as the suspension means for the diaphragm.

With the foregoing general objects, features and results in view, as well as certain others which will be apparent from the following explanation, the invention consists in

certain novel features in designs, construction, mounting and combination of elements, as will be more fully and particularly referred to and specified hereinafter.

Referring to the accompanying drawings:

Fig. 1 is a view in cross section illustrating a loudspeaker having the diaphragm supported in accordance with this invention.

Fig. 2 is a detailed view in section of a modified form of my invention, with parts thereof broken away.

Fig. 3 is a detailed view in section of a further form of my invention, with parts thereof broken away.

Fig. 4 is a section through a strip of the compliant plastic foam material constituting the suspension means for the diaphragm and illustrating the cellular structure thereof.

Fig. 5 is a detailed view in section illustrating yet another form of my invention, with parts thereof broken away.

Fig. 6 is an enlarged schematic view of a single cell of the compliant cellular material and its reactions when the diaphragm which it suspends is at rest (*a*), under tension (*b*), and when it is under compression (*c*).

Fig. 7 is a graph illustrating the numerical relationship between voice coil impedance and frequency, sometimes referred to as the motional impedance characteristic.

Fig. 8 is an electrical analog to the acoustic properties of this loudspeaker.

Referring to Fig. 1 of the accompanying drawings wherein I have illustrated one form of my invention which includes a supporting basket or frame **1** for the loudspeaker which has the usual open areas for the release of the back pressure and is provided with a conventional magnet structure formed by a ring magnet **3**, a center pole **5**, a backplate or return keeper **7** and an outer annular pole piece **9**.

The center pole piece **5** and the outer pole piece **9** leave an annular air gap in which the magnetic flux is concentrated. The voice coil winding **11** wound on a cylindrical form is attached to the apex of a paper cone **13**, usually of conical or curvilinear shape. This cone or diaphragm **13** is the essential piston generating sound. A centering spider **15** having large flexibility in the axial direction but large stiffness in a lateral direction serves to maintain the voice coil properly centered in the air gap yet capable of extreme axial motion.

The cone or diaphragm **13** terminates in a peripheral edge having a flat or flanged section **17** which is formed with a stiffening bead **19**. Fixed to the inner side of flange providing section **17** by cementing or in any other suitable manner is an annular or ring suspension element **21** which is formed of a compliant material of open cellular structure. This annular suspension element **21** which is particularly illustrated in Fig. 4 may be a polyvinyl chloride open cell formulation which is characterized by being deformable but following deformation an appreciable time lapse occurs before it assumes its normal shape. It is thus mechanically inert and has no tendency to impart any motion of its own due to momentum or stored energy as would be the case with rubber or any other "springy" substance. The compliant material may be an "open-cell" foam wherein each cell is open to adjacent cells by some form of small passageway, usually through a reduced or constricted opening. Thus in the compliant material there is a random system of cells and open doors running in all directions. The term "open cell" is used to mean a material which is porous out to the atmosphere and permits the passage of air in any direction, albeit with some resistance. This resistance is at a minimum and becomes greater when under compression or tension.

The annular suspension means **21** being formed of a material having the aforementioned characteristics may resemble in appearance and have the feel of foam rubber but with a porosity permitting a flow of air through its radial width.

In order to mount the annular suspension means **21** in the combination I fix the opposite surface thereof by cementing to the projecting surface of a semi-rigid paper annulus **23** which is cemented to the seating flange **25** of the basket. A rim gasket **27** may be employed as shown which functions to take up small irregularities of the mounting surface of the baffle or cabinet in which the speaker is installed.

The cone **13** moves as a rigid body, the stiff edge **17** preventing eccentric motion of the peripheral rim. The pliable material **21** contributes compliance or freedom to the cone vibrations. In addition to possessing compliance by being capable of expansion and compression, the material of suspension number **21** performs an acoustic purpose in that it permits passage of air through its cells. Air passing through the open cells presents a form of viscous damping to the mechanical motion of the cone. The open cell construction of the annulus **21** allows the confined air of the cabinet or baffle to flow through these cells, and since the dimensions of these openings are small the air flowing through them assumes an appreciable velocity. Since the velocity or energy in the flow is a function of cone amplitude, the effect of damping of the material **21** will be automatic. Since large amplitudes are encountered in the region of resonance, a self-damping action is exerted where it is most needed. This is a pneumatic form of operation.

The tiny cross-sectional openings together with their random and tortuous paths create a high mass inertance and a high degree of viscous resistance. It is this magnitude of mass inertance and high resistance which prevents cancellation of front radiation by the rear wave. This can be explained by reference to the analog diagram of Fig. 8 wherein the speaker is assumed to be installed in a cabinet or baffle of conventional proportions. In Fig. 8 M*s*, R*s*, C*s*, represent the mass, resistance and stiffness, respectively, of the moving system. C*b* is the compliance of the air in the enclosure, M represents the mass due to the inertance of the pores of the suspension material, R is the resistance or friction of the passage of air through this material. If M and R are small in value, as for instance by large pores or open areas then a severe shunting effect takes place. When M and R are high, negligible shunting exists as in the case of this invention.

Across C*b* acoustic cancellation may occur between front and rear waves. By selecting M and R so that their values are relatively high, then acoustic short-circuiting is avoided. In practice M and R are selected in terms of material porosity and density so that the acoustic cancellation will be just avoided for the smallest cabinet volume with which the speaker is likely to be associated. Thus a balance is observed between the conflicting requirements of damping and acoustic non-interference.

In Fig. 2 I have illustrated a further form of my invention and have used the same reference numerals to designate parts which are the same as those disclosed in Fig. 1. In this form of my invention I provide an annular suspension member designated in its entirety by the numeral **29** and this suspension member is formed of the same compliant material of cellular structure which has been described above in connection with the suspension member **21**. The suspension member **29** is formed to provide a supporting body portion **31** and a depending free portion **33** which is of greater thickness than the body portion **31**. The radial dimension of the suspension member or annulus **29** is greater than the same dimension of basket flange **25** so that the depending portion **33** will be free of and out of contact with the flange when body portion **31** is in operative position cemented to flange **25**. The cone or diaphragm **13** is provided with a thickened or reinforced rim **35** which is cemented to the free depending portion **33** of suspension member **29** to thereby suspend the diaphragm. The mounting gasket **37** is attached by cementing it against the body portion **31**

of the suspension member **29** as clearly illustrated in Fig. 2.

A further form of my invention is illustrated in Fig. 3 of the drawings and the same reference numerals have been used to describe similar parts of the loudspeaker. In this form of my invention I use two suspension members, an outer suspension member **39** and an inner suspension member **41**. Each of these members is, of course, of annular form, and is formed of a compliant cellular material such as that used in suspension members **21** and **29**. The diaphragm **13** is formed with a flange-like rim **43** which extends in substantial perpendicular relation with respect to the axis of the cone or diaphragm. The rim **43** is mounted between compliant suspension members **39** and **41**, the member **41** being in abutment with, and, if desired, cemented to flange **25** of basket or frame **1**, and if desired the rim **43** may be cemented to the two suspension members. The outer suspension member **39** is clamped in operative position by means of a flanged clamping ring designated generally by the numeral **45**. This clamping ring includes a body portion **47** which abuts against and is fixed to an extension **49** of flange **25** and also includes a depending skirt portion **51** which clamps against suspension member **39**. With the various elements mounted and arranged as described it will be recognized that an annular air space **53** is provided about the suspension members and that this air is vented to the exterior by vent holes **55** which are provided in seating flange **25** and the skirt portion **51** of clamping ring **45**. It may be noted that under operation of the loudspeaker one of the suspension members will be in compression while the other will be in tension. The usual rim gasket **57** may be used in the organization of this form of my invention.

The form of my invention which I have illustrated in Fig. 5 is broadly similar to that illustrated in Fig. 2; however in this form of my invention the reinforced rim **59** of the cone or diaphragm **13** is embedded by molding or by other means into the free inner edge of the free depending portion of the compliant suspension member **29**.

This invention while offering a suspension having high linearity and high damping, yet remains original and ingenious in that its operation is related to the acoustic system in which it is enclosed and is further pneumatically self-controlled by the cone amplitudes.

I am aware that compliant materials have been used before; however, materials such as foam rubber frequently employed, have a high mechanical reaction, it will store energy and has negligible dissipating quality and as a result will encourage high peaks of resonance to the point of self-oscillation. Prior art designs may possess high compliance, or damping control but these are of a fixed nature, their behaviour is independent of the acoustical characteristic of the enclosure, and they fail to vary the degree of damping as a function of cone amplitude.

The material which is used by me as the support or suspension means for the diaphragm obtains its compliance or flexibility by the deformation of the minute cells which are provided, the compliance therefore is not based on bending but principally on compression and tension or expansion.

In the present invention the suspension member has its maximum porosity when the cone is at rest or when undergoing relatively small vibrations. As the amplitude of vibration is increased, this material is alternately stretched and compressed to a degree where the porosity is reduced due to shrinkage and change of the open cellular areas. This shrinkage of open cells exists for both modes. Under vibration of the cone, at extreme peaks, the cells assume an elongated or rectangular cross-sectional shape as shown in Fig. 6. Since the viscosity of a fluid or gas is related to its proximity to the walls of the container, the effect of an elongated section is to increase the friction between the moving stream of air and the walls. Fig. 6*a* shows the assumed cross section of a cell at rest; in 6*b* we see the deformation under tension, and in 6*c* under compression. The resistance to flow of a gas will be greater in the cases of 6*b* and 6*c* than in the case of 6*a*. In actuality the deformations of 6*b* and 6*c* will be more complex because of their random inter-connecting nature, but the net effect is to substantially increase the resistance to flow relative to the condition of rest.

This cellular material aids in lowering the resonant frequency in that

(1) It adds to the effective mass of the moving system, and

(2) Its stiffness is reduced.

Both these factors have a downward shift of the resonant frequency. Reference to the relationship of

$$f_o = \frac{1}{2\pi}\sqrt{\frac{S}{M}}$$

wherein

fo is the resonant frequency,
S the mechanical stiffness,
M the mass,

shows we have reduced the numerator term S and increased the denominator term M, thus establishing *fo* at a lower value, which is one of the objectives of this design.

In Fig. 7 the velocity of the cone motion is shown as a function of frequency. Curve *fa* represents the cone motion of a conventional suspension. In this curve resonance occurs at *fa*. When the suspension incorporates both additional weight and compliance as in the present invention the resonance will move downward as shown by curve *fb*.

This is a very desirable lowering of the frequency of resonance.

However, if at the same time this compliant material which forms the suspension has high mechanical resistance as in the case of this invention, the amplitude of the resonant peak is suppressed as in curve *fc* and as has been previously indicated, it reduces the distortions and performance aberrations attributable to high resonant peaks.

It will now be appreciated that the suspension means which I have devised for the cone or diaphragm of a loudspeaker will endow the apparatus with many highly desirable and advantageous characteristics.

I claim:

1. A loudspeaker including a frame, a vibrating diaphragm having a rim and means for suspending said vibrating diaphragm from said frame, said means including an annulus of compliant material of open cellular structure connected with said frame and fixed to the rim of the diaphragm and extending therebetween, said compliant material being substantially non-resilient and mechanically inert.

2. A loudspeaker including a frame, a vibrating diaphragm having a rim and means for suspending said vibrating diaphragm from said frame, said means including a strip of deformable material of open cellular structure connected with said frame and fixed to the rim of the diaphragm and extending therebetween, said material being deformable under the action of the vibrating diaphragm and characterized by compression and tension of the cells when the said material is deformed.

3. A loudspeaker in accordance with claim 2 wherein said deformable material is substantially non-resilient and mechanically inert.

4. A loudspeaker including a frame, a vibrating diaphragm having a peripheral rim and means for suspending said vibrating diaphragm from said frame, said means including an annulus of compliant material of open cellular structure connected with said frame and fixed to the peripheral rim of said diaphragm and extending therebetween, said compliant material being deformable by compression and tension of the cells thereof under the

action of the vibrating diaphragm and air being driven radially outwardly of said material when the cells are compressed and stretched.

5. A loudspeaker including a frame, a vibrating diaphragm having a rim and means for suspending said vibrating diaphragm from said frame, said means including an annlus of compliant material of open cellular structure connected with said frame and fixed to the rim of the diaphragm and extending therebetween, said compliant material being characterized by a high damping action due to the cellular structure thereof whereby the amplitude and high counter E. M. F. at the resonant frequency are reduced.

6. A loudspeaker including a frame, a vibrating diaphragm having a rim and means for suspending said vibrating diaphragm from said frame, said means including an annulus of compliant material of open cellular structure connected with said frame and fixed to the rim of the diaphragm and extending therebetween, said cellular compliant material after deformation thereof being substantially without stored energy whereby the material returns slowly to its normal configuration.

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