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2,905,260

LOUD SPEAKER DIAPHRAGM

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2 Sheets-Sheet 1

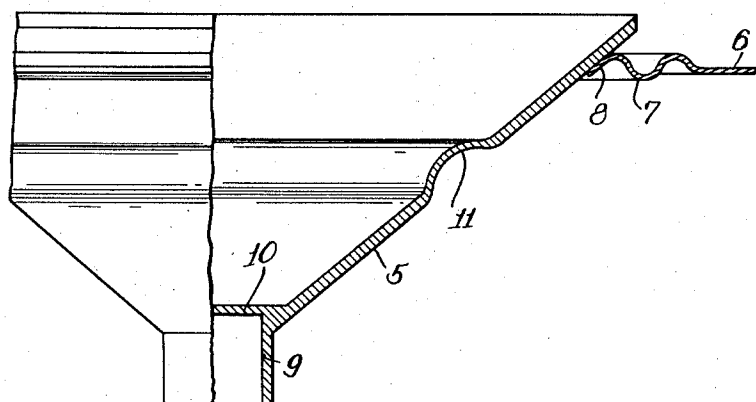
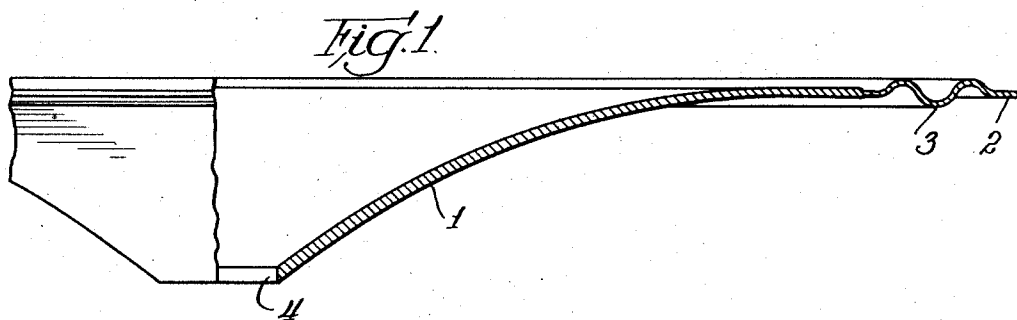
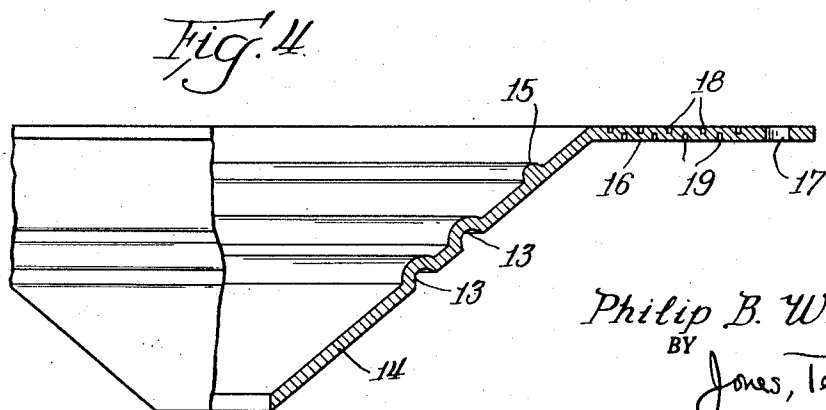
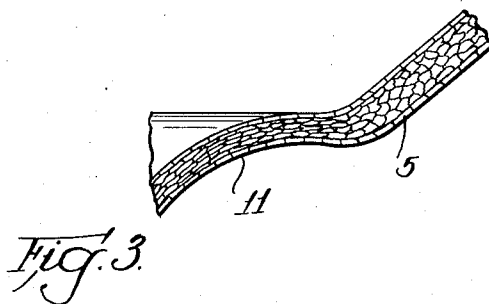


Fig. 2.



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2 Sheets-Sheet 2

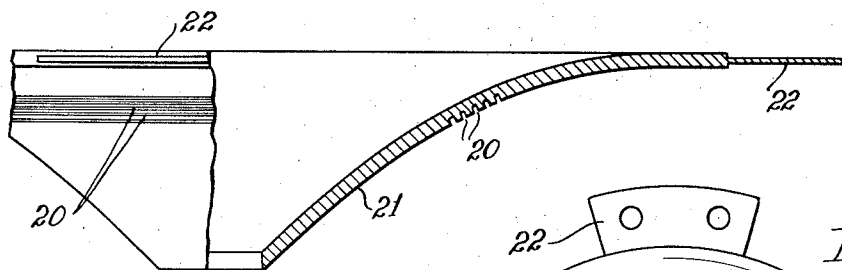


Fig. 5.

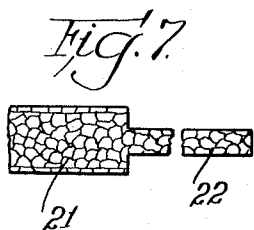


Fig. 7.

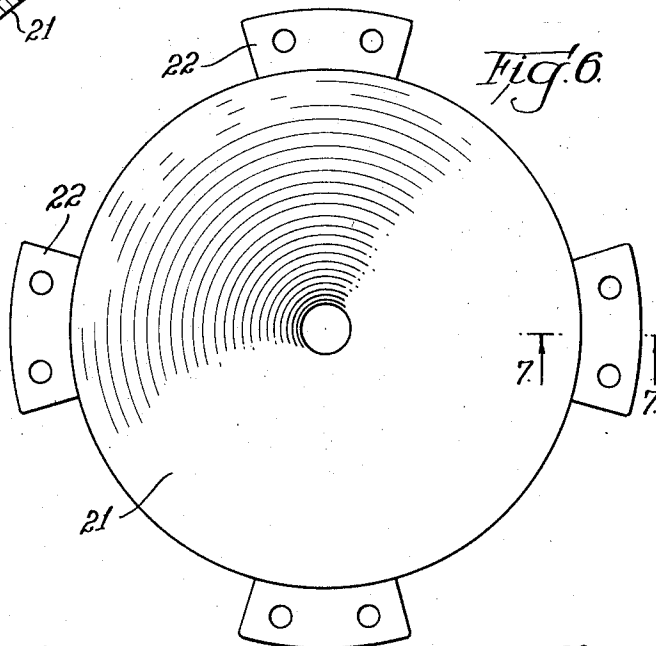


Fig. 6.

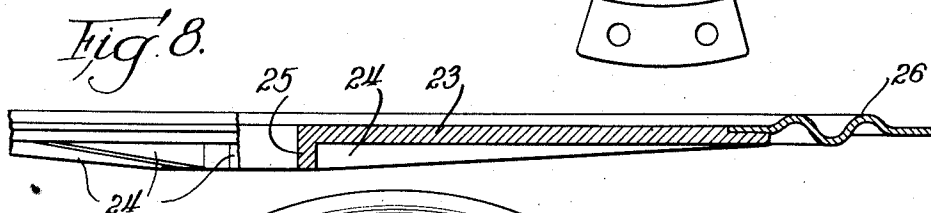


Fig. 8.

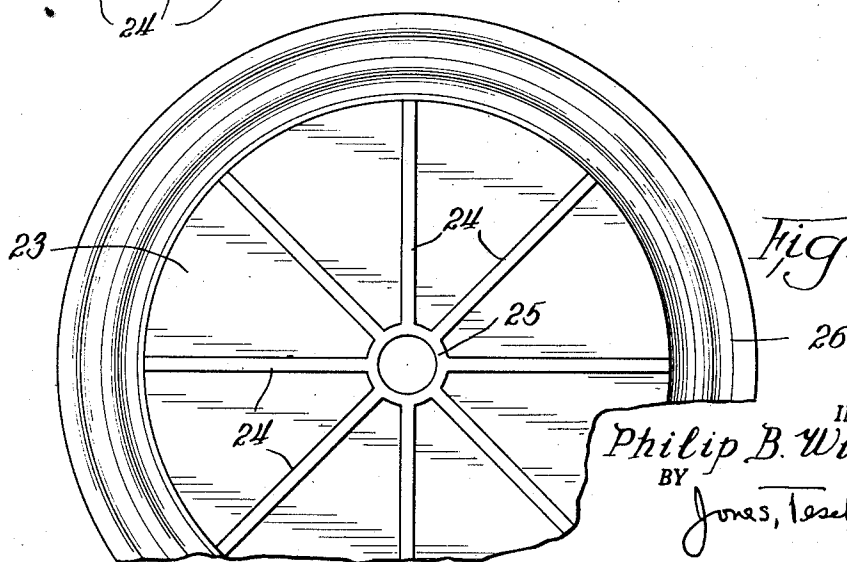


Fig. 9.

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1

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LOUD SPEAKER DIAPHRAGM

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18 Claims. (Cl. 181—32)

This invention relates to loud speaker diaphragms.

Loud speakers of both the direct radiator and horn types employ diaphragms for the transduction of electrical impulses to acoustic waves which are manifested as audible sound. These diaphragms are generally driven by an electromagnetic motor and function as pistons operating upon the air at their surfaces in the creation of sound in the atmosphere. Since the driving forces are usually applied at the centers of the customarily circular diaphragms, the most faithful and efficient production of the acoustic counterpart of the driving electrical impulses in the atmosphere results; generally speaking, when the diaphragm is so stiff that no bending occurs as a result of the application of the driving forces, and is so light that its inertia is negligible as a distorting factor in the response of the diaphragm to the driving forces.

Loud speaker diaphragms have heretofore been fabricated from paper or molded from cellulose pulp, plastic-impregnated fabric, very thin metal or plastic and other similar materials. Selection of a particular material for a particular application has generally required a compromise between stiffness, low mass, moisture resistance, and other desirable physical characteristics.

The fundamental object of the present invention is to provide a diaphragm for loud speakers which performs with substantially improved efficiency as compared with presently available diaphragm elements. A further object is to provide such a diaphragm having low mass and high stiffness and strength. Another object is to provide a loud speaker diaphragm which is substantially unaffected by ambient humidity and therefore possesses improved stability.

A further and very important object is to provide a loud speaker diaphragm structure which is susceptible of a wide variety of specific design modifications, with particular reference to the provision of local compliances or stiffening devices; rate of flare of the cone, thickness variations; and the like, to adapt the diaphragm to a wide variety of applications.

Many additional features of advantage of the invention will become apparent as the description thereof proceeds.

In the accompanying drawing:

Fig. 1 is a quarter-sectional view of a diaphragm embodying the invention;

Fig. 2 is a quarter-sectional view of a modified form of diaphragm;

Fig. 3 is an enlarged detailed view of a portion of the diaphragm of Fig. 2;

Figs. 4 and 5 are quarter-sectional views of further modified forms of the diaphragm;

Fig. 6 is a front view of the diaphragm of Fig. 5;

Fig. 7 is an enlarged detailed sectional view taken at the line 7—7 of Fig. 6;

Fig. 8 is a quarter-sectional view of another form of the diaphragm; and

Fig. 9 is a rear view of the diaphragm of Fig. 8.

All of the several forms of diaphragms contemplated by the invention are formed from a single type of material

2

which has been found to have peculiar characteristics which are highly advantageous with reference to loud speaker diaphragms, not only because of the superior operating characteristics of the finished product, but also because it is susceptible of production techniques and design variations which may be employed in the production of diaphragms giving optimum operating performance in each of a wide variety of applications. As will be shown in greater detail below, the material can furnish very stiff driving surfaces, while providing compliance rings and flexible suspensions at desired locations. Its body comprises a multiplicity of very fine, uniform discrete cells, each being a miniature bubble with very thin plastic walls which are common to adjacent cells. It is produced by expansion of gases internally of the plastic material in a manner somewhat similar to the popping of popcorn. Being light in weight, relatively thick sections can be tolerated with corresponding enhancement of stiffness. For example, thicknesses of from one-eighth to one-quarter of an inch are satisfactory. The material is extremely tough and non-friable and is quite firmly resistant to compaction.

The material in the formed diaphragm is generally referred to as expanded or foamed plastic, and the raw material used in the forming of the diaphragm is termed an expandable plastic. Provision for expansion of the plastic base material may be made by several means, as by impregnation with a foaming agent, low boiling solvent, or gas which may be activated by the application of heat, by incorporation of chemicals which react under certain conditions to evolve gases which produce the desired foaming or expansion, and by other means which will not be more fully described here. The plastic base materials may be of either the thermoplastic or thermosetting type, but the former has been found to be convenient to use in the diaphragm forming process. The expandable plastic may be in the form of a solid, such as powder, beads, or the like, or may be liquid, such as a plastisol.

Although several expandable thermoplastic products from which satisfactory diaphragms may be produced are commercially available, the preferred material is the expandable unmodified polystyrene manufactured by Koppers Company, Inc. and commercially available in the form of small beads ready for expansion by the application of heat. This material is more fully described in the pending application of Gaetano F. D'Alenio for a patent filed in behalf of Koppers Company, Inc. and entitled: "Treatment of Polymeric Materials" the specification of which is hereby incorporated by reference herein. The complete specification of the counterpart of this application was published September 5, 1956 as British Patent No. 756,654. This preferred material may be further characterized by the relationships of density of the expanded product and the temperatures and pressures which may be satisfactorily employed in their production. Under molding pressures of from 10 to 50 pounds per square inch, and temperatures of from 230° to 270° F., products having densities of from 2 to 10 pounds per cubic foot are formed.

The diaphragms of the invention may be formed from a suitable expandable plastic raw material, such as the Koppers polystyrene beads, by confining the material in a suitable closed mold while heat is applied to cause the beads to expand and fill the mold with its increased bulk, and until the expanded body is again cooled sufficiently to have attained a stable condition.

Various techniques may be employed in this process of fabrication of the diaphragm from an expandable thermoplastic raw material. A quantity of the material calculated to form a product of the desired density, usually in the preferred range of from 2½ to 3½ pounds per cubic foot, is placed in the mold. Solid material in the

form of beads or granules may be used, or the raw expandable plastic may be in sheet or liquid form. To assure structural uniformity throughout the body of the finished diaphragm, the raw material should be uniformly distributed in the mold. When beads or granules are used, an expandable mold may be employed in which the cavity, starting with minimum volume filled with the beads, is gradually increased in size at a rate which is controlled to conform with the expansion of the plastic as heat is applied. Alternatively, a coherent production mold insert may be prepared as a preform in a separate mold which may be entirely filled and heated only sufficiently to cause the beads to stick together sufficiently for handling. A further alternative technique to assure uniform distribution of the plastic in the mold is to adhere a layer of the granules to a foil backing of the same plastic and place such a composite sheet, cut to proper size, in the mold. Partially pre-expanded beads may be used.

Heat may be applied to the mold by the direct introduction of dry steam into the mold cavity, by heating the mold by means of an external steam jacket, or by means of hot air.

As is seen in the enlarged cross section shown in Fig. 3, the body of the expanded thermoplastic material produced from the expandable beads consists of a multiplicity of grains welded together at common interfaces to form a homogeneous mass. Each grain, formerly a bead of unexpanded material, comprises a rigid pulp not unlike popcorn in appearance. The surfaces of the body which were in contact with the mold during formation of the product comprise integral films of hard, dense plastic which is thicker, and therefore stronger, than the intercell films. The spaced surface films, rigidly bound together by the pulpy body material, contribute to the stiffness of a section of the expanded product.

Referring, by way of example of the invention, to the diaphragm illustrated in Fig. 1, this particular form of the device illustrates certain advantages of the invention by embodying design features made possible thereby. It comprises a flared body 1 having a flat rim 2 for attachment of the diaphragm to the supporting frame of the speaker structure. A flexible annular ring 3 supports the body of the diaphragm in vibratile suspension from rim 2. A molded or machined bore 4 of the proper diameter for reception of the tubular cylindrical support of a voice coil is provided at the center of the diaphragm. This support, not shown in Fig. 1, may be cemented or otherwise suitably affixed to the diaphragm at the bore to drive the same.

The pitch of the diaphragm may be shallower than is customary for direct radiator cones heretofore in use. This dimensional characteristic is made possible by reason of the great rigidity or stiffness of the expanded polystyrene material. The loudspeaker can be made shallower and the mass of the diaphragm for a given effective piston area is less than is the case with a deeper cone.

It will also be observed that the wall thickness of body 1 of the diaphragm decreases progressively from its center to its periphery. Also, the rate of flare increases with increased distance from the central bore of the diaphragm. Both of these characteristics, desirable as contributing to the efficiency of the speaker, are made possible by the physical properties of the material from the standpoints of fabricating technique possibilities and finished product. Since the diaphragm is molded, the flare and radial taper are readily provided by properly shaping the mold pieces. Since the load that must be carried by the body of the diaphragm decreases from its center to its periphery, thickness may be reduced and the rate of flare increased, accordingly. It will be understood that, if desired, the increasing flare design may be employed with uniform diaphragm thickness, or the thick-

ness may be diminished, as shown, with an otherwise straight conical wall.

In the diaphragm of Fig. 1, the supporting ring 2 and flexible suspension 3 are molded integrally with the body 1 of the diaphragm. The necessary flexibility is achieved by substantially reducing the thickness of the flexible support. Being tough, dependable support is provided by webs that may be as thin as one-sixteenth of an inch. Methods for imparting still greater flexibility to a given section are described below.

The thickness of the diaphragm wall, especially at its center, is sufficient to provide a surface at bore 4 of sufficient area to receive and rigidly support a voice coil bobbin cemented thereto. If desired, a suitable cylindrical voice coil support may be molded into the body of the diaphragm.

Another form of diaphragm is illustrated in Fig. 2. In this device, the body 5 is suspended from supporting loud-speaker structure by ring 6 and flexible suspension 7. The supporting ring and flexible suspension is an integral annular element which may be composed, for example, of phenolic resin impregnated cloth, and which is cemented at 8 to the rear surface of the body of the diaphragm near its periphery. Instead of a through bore at the center of the diaphragm to receive and support a separate voice coil bobbin, a tubular element 9 is molded as an integral part of the diaphragm to form a support for the voice coil. This element may be machined after forming to eliminate taper required by molding draft, if desired.

In this form of the device, a dome 10 is also provided as an integral part of body 5.

In order to produce certain desired results, particularly with respect to the reproduction of sound of both low and high frequencies, it is sometimes desirable to provide a compliance intermediate the center and the periphery of the radiating body portion of the diaphragm. Such a compliance may be provided by any of several means, one being illustrated in Fig. 2. A thin section 11 is provided at a predetermined distance from the center of the diaphragm, the balance of the diaphragm being of uniform substantial thickness. This thinner section is, as pointed out above, more flexible than the adjoining portions of the diaphragm, with the result that the driving characteristics of both the inner and outer portions of the body of the diaphragm are modified by reason of the interposition of the annular compliance. If desired, the flexibility of the compliance may be increased by curving this section, as in the manner shown.

Although the thinner section of the body of the diaphragm forming compliance 11 may be molded into the device as a part of the fabricating process, it may also be formed as a separate operation subsequent to the completion of the molding process. For example, body 5 of the diaphragm of Fig. 2, when molded, may have straight conical form of substantially uniform thickness. Then, by means of a suitable die or roller, a section of the body of the diaphragm may be compressed to provide the compliance 11. The effect of such compression is to render the section quite flexible by reason both of the resulting reduced thickness and also the crumpling of at least the transverse walls of the cells of the expanded plastic body. Rigidity of the unaltered expanded body being due to the stiffness of the interconnecting cell walls, compaction has the effect of breaking down the rigid structure in the direction of the compacting forces without simultaneous rupture which would weaken the section. If desired, the section may also be flexed to further enhance the compliancy and given a permanent curvature to the same end.

An enlarged, detailed view of the portion of the diaphragm of Fig. 2 including compliance section 11 is shown in Fig. 3, the nature of the internal structure after compaction and flexing being indicated.

Further functional design possibilities are illustrated in the diaphragm of Fig. 4. A pair of annular corrugations

5

13. in body 14 of this diaphragm serve the dual function of augmenting circumferential stiffness while interposing localized radial compliance. If circumferential stiffness, alone, is desired, an annular ridge 15 may be employed, rather than a corrugation. Radial stiffness of the diaphragm is not diminished by such a ridge.

An alternative form of flexible suspension is shown at 16. The suspension and mounting ring 17 are molded from the expandable plastic as an integral part of the diaphragm. A series of spaced concentric grooves 18 and 19 are then cut into the material to a depth approaching one-half of the thickness of the material. Grooves 18 in the front surface of the suspension and grooves 19 in the rear surface are preferably staggered to avoid excessive weakening of the suspension. They may be formed in any suitable manner, as by sawing. Preferably, the grooves are provided by actual removal of material, as well as rupture of the surface films, since the greatest degree of flexibility is thereby provided. With somewhat less satisfactory results, the grooves may be impressed by means of a suitable die or may even be molded into the diaphragm.

Compaction of the grooved suspension section further increases its flexibility, and, for maximum flexibility, the section may be kneaded, as by repeated flexing of the section.

Still further alternative features are illustrated in the embodiment of the invention shown in Figs. 5 to 7. In this flared diaphragm, a compliance is provided by cutting spaced concentric grooves 20 into the body 21 of the diaphragm from the rear surface thereof. The degree of compliance depends upon the depth, number, and spacing of the grooves. A flexible suspension 22 is provided by cutting away surface portions on both sides of the diaphragm beyond the periphery of body 21. A suitable file or rasping tool or other cutting means may be used to reduce the section of the suspension to a thickness which is quite flexible, yet retains sufficient strength and radial rigidity to properly support the diaphragm in the speaker structure. As is shown in the enlarged, detailed view of Fig. 7, the heavier surface skins are removed in forming the suspension in the manner described. Flexibility of suspension 22 results from the removal of these stiff surface films and also the thinning of the section. The suspension 22 may be in the form of a peripheral annulus, or, if desired for maximum freedom of axial vibration of the diaphragm, the suspension 22 may be limited to four sectors, as shown in the front view of Fig. 6.

Another form of diaphragm of the invention is illustrated in Figs. 8 and 9. As the drawing shows, the front of the body 23 of this diaphragm is planar. A plurality of spaced radial ribs 24 are integrally molded into the rear of the diaphragm structure, the inner ends of the ribs joining an upset portion 25 surrounding the central bore of the diaphragm. These ribs not only enhance the stiffness of the diaphragm, but also prevent undesired vibration of radially adjacent local areas of the diaphragm body, the phenomenon known as "cone break-up." A separate suspension and mounting ring 26 is cemented to the body of the diaphragm at its periphery.

The inherent stiffness of the expanded polystyrene material, augmented by ribs 24, results in a structure which is sufficiently stiff to give good results even in a flat diaphragm, such as that shown in Figs. 8 and 9. The low unit mass of the material makes possible the use of the rather bulky structure without unduly adversely affecting the efficiency of the speaker unit.

It will be appreciated by those skilled in the art that the loud speaker diaphragms of this invention offer operating efficiencies with flexibility of application not heretofore generally attainable. Particular design features, illustrated and described by way of example with reference to embodiments shown in particular figures of the drawing, are interchangeable so that a large number of combinations not specifically shown are possible. For a

6

complete comprehension of the invention, it is important to appreciate that the expanded plastic material, as it comes from the mold, is very rigid, and therefore capable of providing a desirably stiff diaphragm, and that working of any selected portion, as by compaction and/or repeated flexing, deprives such part of its stiffness and renders it quite pliant. Alternative or cumulative means for rendering a particular part relatively more flexible than the desirably stiff body portions of the diaphragm are also available and are described herein. Such means may be employed to provide flexibility at any desired location whether specifically described in connection with an intermediate compliance or the flexible diaphragm support.

Invention is claimed as follows:

1. A loud speaker diaphragm comprising a stiff, self-supporting body composed of expanded plastic material of substantial thickness wherein the bulk of the diaphragm body comprises a thin-walled cellular structure and said cellular structure is covered on both sides by continuous integral surface films, said diaphragm having a flexible annular section adjoining a body portion thereof, said section being integral with said body portion.

2. A diaphragm in accordance with claim 1, wherein the flexible annular section is kneaded.

3. A loud speaker diaphragm comprising a stiff, self-supporting body composed of expanded plastic material of substantial thickness wherein the bulk of the diaphragm body comprises a thin-walled cellular structure and said cellular structure is covered on both sides by continuous integral surface films, and an annular suspension integral with and surrounding the body portion of said diaphragm, said suspension being substantially more flexible than said body portion adjacent said suspension.

4. A diaphragm in accordance with claim 3 wherein the annular suspension is thinner than the body portion adjacent said suspension.

5. A diaphragm in accordance with claim 3 wherein the annular suspension is compacted.

6. A diaphragm in accordance with claim 3 wherein the annular suspension has a plurality of spaced grooves extending thereinto from a surface thereof, said grooves being concentric with the diaphragm.

7. A diaphragm in accordance with claim 3 wherein the annular suspension has a plurality of spaced grooves extending thereinto from both front and rear surfaces thereof, said grooves being concentric with the diaphragm, the grooves in the front surface of said suspension being staggered with respect to the grooves in the rear surface thereof.

8. A loud speaker diaphragm comprising a stiff, self-supporting body composed of expanded plastic material of substantial thickness wherein the bulk of the diaphragm body comprises a thin-walled cellular structure and said cellular structure is covered on both sides by integral surface films, said diaphragm having an annular section intermediate the center and periphery of the body portion thereof which section is thinner and more flexible than the adjoining body portion of said diaphragm.

9. A diaphragm in accordance with claim 8 wherein the annular section is compacted.

10. A loud speaker diaphragm comprising a stiff, self-supporting body composed of expanded plastic material of substantial thickness wherein the bulk of the diaphragm body comprises a thin-walled cellular structure and said cellular structure is covered on both sides by integral surface films, said diaphragm having at least one groove concentric with the diaphragm extending into the material from a surface of the body portion thereof intermediate the center and periphery of said body to provide an annular compliance therein.

11. A loud speaker diaphragm comprising a stiff, self-supporting body composed of expanded plastic material of substantial thickness wherein the bulk of the diaphragm body comprises a thin-walled cellular structure and said cellular structure is covered on both sides by integral

surface films, said diaphragm having a plurality of closely spaced grooves extending into the material from the rear surface of the body portion thereof, said grooves being concentric with the diaphragm and located intermediate the center and periphery of said body portion to provide an annular compliance therein.

12. A loud speaker diaphragm comprising a stiff, self-supporting body composed of expanded plastic material of substantial thickness wherein the bulk of the diaphragm body comprises a thin-walled cellular structure and said cellular structure is covered on both sides by continuous integral surface films, said diaphragm having an annular ridge in the body portion thereof to enhance the circumferential stiffness of said body portion.

13. A loud speaker diaphragm comprising a stiff, self-supporting body composed exclusively of expanded thermoplastic material of substantial thickness wherein the bulk of the diaphragm body consists of a thin-walled cellular structure and said cellular structure is covered by integral surface films of greater thickness than the walls of the cells of said cellular structure.

14. A diaphragm in accordance with claim 13 and including a voice coil bobbin integral therewith.

15. A diaphragm in accordance with claim 13 wherein the body portion thereof has a substantially planar front surface.

16. A diaphragm in accordance with claim 15 and including a plurality of stiffening ribs integral with the body

portion of said diaphragm and extending radially from the center thereof on the rear surface of said body portion.

17. A loud speaker diaphragm comprising a stiff, self-supporting body and flexible diaphragm suspension means at the periphery of and integral with said body, said body of said diaphragm being composed of expanded plastic material of substantial thickness wherein the bulk of the body comprises a thin-walled cellular structure and said cellular structure is covered on both sides by integral surface films and said suspension means is composed of the cellular structure without the surface film covering.

18. A loud speaker diaphragm in accordance with claim 17 wherein the flexible suspension means comprises a plurality of circumferentially spaced sectors.

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