Nov. 19, 1963 D. A. BARLOW 3,111,187

DIAPHRAGM FOR ELECTRO ACOUSTIC TRANSDUCER

Filed Nov. 23, 1959

Fig. 1.

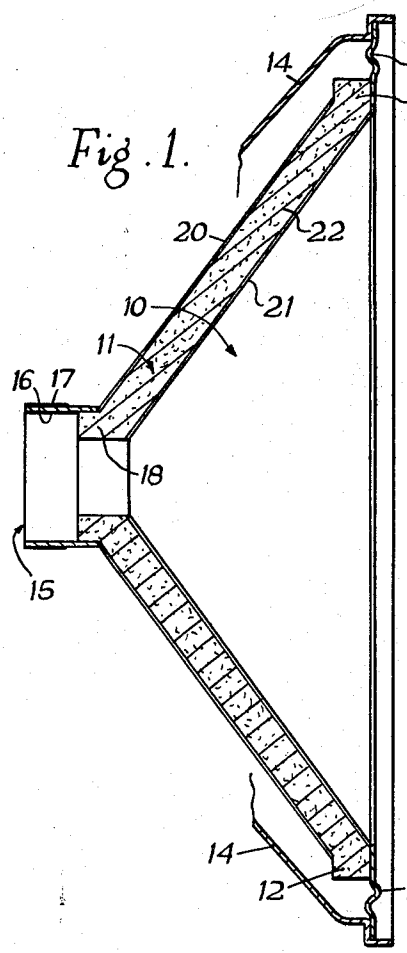


Fig. 2.

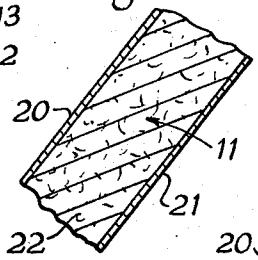


Fig. 3.

Fig. 5.

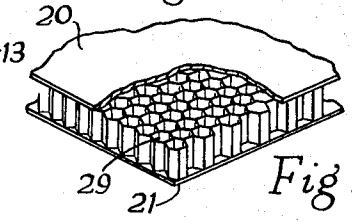
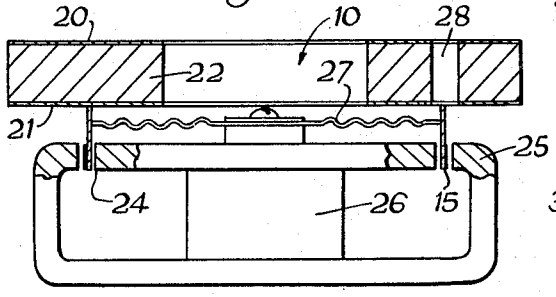


Fig. 6.

Fig. 4.



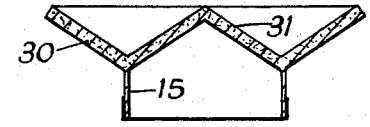
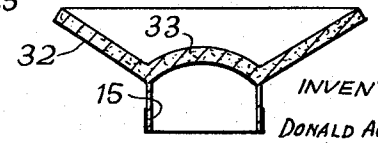


Fig. 7.



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DIAPHRAGM FOR ELECTRO ACOUSTIC TRANSDUCER

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This invention relates to electro-mechanico-acoustic transducers, commonly known as electro-acoustic transducers such as loudspeakers and microphones and is more particularly concerned with an improved construction of the sound radiating or sound receiving element or diaphragm employed in such devices.

One object of the invention is to provide an improved form of such sound radiating or sound receiving element for such transducer devices having greatly enhanced stiffness for a given total weight thereby avoiding or reducing certain disadvantageous effects present in known forms of such elements.

Another object of the invention is the provision of a novel sandwich construction for the sound radiating or sound receiving element of electro-acoustic or mechanico-acoustic transducer devices.

A further object of the invention resides in the construction of a diaphragm for a mechanico-acoustic transducer comprising a body of sandwich construction having first and second skins of metal or other stiff material separated from one another by an intermediate core having a thickness at least several times that of either of said metal skins and formed of low density material, said core material being firmly secured to the inner surfaces of each of said skins to form a unitary structure.

In order that the nature of the invention may be more readily understood a number of embodiments thereof will now be described with reference to the accompanying drawings in which:

FIG. 1 is an axial cross-section through a diaphragm in accordance with the invention for use in a moving coil type loudspeaker.

FIG. 2 is a fragmentary sectional view, drawn to an enlarged scale, showing the sandwich construction employed in the diaphragm of FIG. 1.

FIG. 3 is an axial cross-section, similar to FIG. 1, of a modification.

FIG. 4 is an axial cross-section through an electro-mechanico-acoustic transducer embodying a further modified form of diaphragm in accordance with the invention.

FIG. 5 is a perspective view of an alternative form of sandwich construction in accordance with the invention while

FIGS. 6 and 7 are diagrammatic views illustrating further embodiments of the invention.

Referring first to FIG. 1, **10** indicates generally a sound radiating diaphragm for a moving coil loudspeaker and comprising a conical portion **11** terminating outwardly in a flange **12** for attachment, as by an adhesive, to a flexible suspension member **13** of annular and preferably corrugated form as shown. The outer edge of such suspension member is secured, as by an adhesive, to a suitable mounting region of a supporting chassis indicated in part at **14**. At the inner, apical end of the conical portion **11** is secured the customary voice coil indicated generally at **15** and comprising a cylindrical former **16**

carrying the coil winding **17**. To facilitate connection of the former **16** to the portion **11**, the latter may conveniently be formed with an axially directed sleeve portion **18** shaped to fit within the former **16**, the two parts being firmly secured to one another by adhesive.

In conventional forms of similar diaphragms, the portion **11** is usually made of felted paper-like material which may be of relatively soft character or of stiffer nature to provide increased rigidity to the conical portion as a whole. In order to increase the stiffness or rigidity it is already well known to impregnate the material of the conical portion with a hard-setting varnish or with synthetic plastic materials while it is also known to employ relatively dense and stiff materials such as metal or moulded plastic as the diaphragm-forming material. The use of stiffening corrugations and ribs is also common practice with a view to making the diaphragm portion operate as a rigid piston-like member moving backwards and forwards in an axial direction under the influence of the oscillatory forces provided by the voice coil **15** when energised.

In all of the known constructions the diaphragm portion, while it may operate as a rigid piston-like member at relatively low audio frequencies in the order of, say, 25 to 100 cycles per second, sooner or later ceases to operate as a rigid piston as the oscillation frequency is raised and at frequencies of the order, usually, of 200/300 cycles per second, a so-called "break-up" phenomenon occurs in which the diaphragm itself flexes and becomes distorted from its original shape giving rise to resonances within the diaphragm with resultant adverse effect upon the reproduced sound.

In order to increase the stiffness of the diaphragm portion without at the same time so increasing its weight as to render it useless as a sound radiating or receiving element, the present invention resides in the use of a sandwich construction for at least the sound radiating portion **11**, such sandwich construction being shown to an enlarged scale in cross-section in FIG. 2 and comprising a first outer skin **20** of metal or other stiff material separated from a second outer skin **21** also of metal or other stiff material by a core or filling **22** which is, relatively speaking, many times the thickness of either skin, **20**, **21** but which is of low density and preferably cellular material, such core material being firmly secured to the inner surfaces of both of the skins **20**, **21**.

Preferably the skin material has a thickness less than 0.001 inch while the thickness of the core is at least 100 times greater than the thickness of either skin. The density of the core material is desirably not more than 2 lbs./cu. ft. and is preferably much less than this figure.

For the outer skins **20**, **21** the material employed is one affording as high a modulus/density ratio as possible. As a practical constructional material, aluminium is probably the most suitable although the metals beryllium, molybdenum, ruthenium and rhodium have higher modulus/density ratios but are less practical.

For the core **22** a low density material having maximum stiffness rather than maximum strength is required and from the materials at present available an expanded plastic, such as an expanded phenolic having a density of the order of 0.3 lb./cu. ft. or expanded polystyrene having a density of the order of 1 lb./cu. ft., is preferred.

The proportions of the sandwich are important as

there is an optimum ratio of skin thickness to core flexural thickness for achieving maximum stiffness for a given weight.

The optimum skin thickness, *Sopt*, in inches is given by:

$$Sopt=w\left[\frac{\sqrt{g-1}}{2K+2e(\sqrt{g-1})}\right] \quad (1)$$

where

w=weight of 1 sq. in. of sandwich in lbs.
K=weight of 1 cu. in. of core material in lbs.
e=weight of 1 cu. in. of skin material in lbs.

$$g=\frac{1-Ea/Es}{1-K/e}$$

Ea=core modulus in lbs./sq. in.
Es=skin modulus in lbs./sq. in.

The optimum core thickness, *Aopt*, in inches is given by:

$$Aopt=\frac{w-2eSopt}{K} \quad (2)$$

In one particular constructional example, an 8 inch diameter cone of 95° angle constructed of a sandwich material consisting of an expanded polystyrene core 0.37 inch thick clad on each side with an aluminium skin 0.00054 in. thick has a theoretical flexural stiffness nearly 3000 times that of a similar size and shape cone of conventional soft paper 0.022 inch thick while having the same weight of 10 grammes.

A similar cone if made with a core of expanded phenolic (0.33 lbs./cu. ft.) 1.13 ins. thick clad on each side with a skin of beryllium 0.0008 in. thick would have a theoretical flexural stiffness some 150,000 times that of the same paper cone.

The required sandwich formation may be consrtucted in various ways. The core element may be moulded first to the desired shape and dimensions, with any required inner and outer connection flanges or the like and the two outer metal skins then separately attached thereto by means of a suitable adhesive. The skins may be in the form of a flat sheet of appropriately developed shape so that when bent and applied to the surfaces of the moulded core they each fit snugly thereon. Some measure of overlap of any meeting edges of the skin parts is desirable and such overlapping regions also firmly secured as by adhesive. Alternatively the skins may be constituted by preshaped members conforming to the surface contour of the core element to which they are to be attached. A further form of construction is to apply the metal skins by electro-plating or electro-deposition methods while another possible manner of construction is to line the core-forming mould with the preshaped skin members and then to inject the core-forming material. With such last method it is essential that effective adhesion or bonding shall be set up between the expanded core material and the outer skins. A further method of construction is to apply the metal skins by spraying with molten metal or by vacuum vapour deposition. Another method of construction is to mould the core with such materials and under such conditions that a thin skin of solid plastic having the requisite flexural stiffness forms on the outer, mould contacting, surfaces of the core. In yet another method plastic or other skins may be applied in the form of a lacquer or paint film provided the resultant skin-forming layer has the requisite high flexural stiffness.

Although the invention has been described with relation to conical loudspeaker diaphragms it has equal application to other shapes of loudspeaker diaphragms and to diaphragms for microphones and other like electro-mechanico-acoustic transducers. The same sandwich construction is similarly applicable to diaphragms for horn loaded loudspeakers and to earphones and sound-boxes and by virtue of the greatly enhanced stiffness/weight ratio permits the construction of a diaphragm of much reduced weight for a given stiffness as compared with existing forms of construction.

The core or skin thickness may also be varied between different regions of the diaphragm according to the stress distribution. One embodiment of this nature is illustrated in FIG. 3 where the thickness of the core **22** in the vicinity of the voice coil is made appreciably greater than the thickness of such core adjacent the outer marginal edge.

The increased stiffness/weight ratio made possible by the sandwich construction of the invention is of advantage in permitting the use of diaphragm shapings which are inherently less rigid than the relatively acute angle cone already described. Thus the cone apex angle may be increased even to the limit where the diaphragm is a flat disc or annulus. FIG. 4 illustrates one embodiment of this form in which the diaphragm **10** is flat annular shape having inner and outer metal skins **20, 21** separated by a relatively thick core **22**. A large diameter voice coil **15** of a diameter equal approximately to the mean diameter of the diaphragm annulus is rigidly secured to the latter and operates within an annular magnetic flux gap **24** of a magnetic flux system **25** including a central permanent magnet **26**. The voice coil and diaphragm assembly may be supported by a central suspension member **27**. Appropriately located holes as indicated at **28** may be provided in the annular diaphragm at suitable positions to permit the temporary insertion of spacing or centering feelers for centering the voice coil in the flux gap during assembly.

Such a flat annular diaphragm shaping is particularly suited to the employment of an alternative form of core material as shown in FIG. 5 where the opposing metal skins **20, 21** are secured to and spaced apart by a honeycomb structure **29**. Such honeycomb structure may be of metal or plastic impregnated paper.

A number of other diaphragm sections particularly useful in conjunction with the sandwich construction of the invention are shown in FIGS. 6 and 7. In FIG. 6, the voice coil **15** is made approximately one half the overall diameter of the diaphragm **10** and is interconnected with the latter at the junction of oppositely directed inner and outer conical parts **30, 31**, both of which are of sandwich form as already described. FIG. 7 shows a somewhat similar form in which the outer diaphragm part **32** is of conical shape and the inner part **33** of part-spherical or domed shape, the voice coil **15** being attached to the junction region of the inner and outer parts.

Although a metal is the preferred material for forming each of the outer skins on account of the high modulus/density ratios thereof other skin materials are possible provided they have the required characteristics. For example mica or appropriate forms of plastic sheet material and possibly glass may be used. Similarly methods of applying and/or bonding the outer skins to the core, other than those specifically described previously may be employed.

I claim:

1. A diaphragm for an electro-acoustic transducer which comprises a body of sandwich construction having first and second skins of thin sheet metal spaced apart by a distance at least one hundred times greater than the thickness of either of said skins and an intermediate core filling of low-density material in the space between the opposing inner surfaces of said skins, said core material being firmly secured to the inner surfaces of each of said skins to form a unitary structure therewith.

2. A diaphragm for an electro-mechanico-acoustic transducer which comprises parallel first and second skins of thin sheet metal separated from one another by a distance at least one hundred times the thickness of either of said sheet metal skins and a filling of material having a density less than two lbs./cubic foot in between said skins,

said filling material being firmly secured to the inner surfaces of each of said skins to form a unitary structure.

3. A diaphragm for an electro-acoustic transducer which comprises a rigid body of expanded material having a density less than two lbs./cubic foot and shaped to provide an extended sound transmitting or receiving area and first and second skins of thin sheet metal firmly secured to each of the opposite extended area surfaces of said body, said metal skins each having a thickness less than one hundredth of the thickness of said expanded material body.

4. A diaphragm for an electro-acoustic transducer which comprises a conical shaped body of expanded polystyrene having a density less than two lbs./cubic foot and a thin metal skin rigidly secured to each of the opposite conical surfaces of said body, said body having a thickness dimension at least one hundred times greater than the thickness of either of said skins.

5. A diaphragm for an electro-acoustic transducer comprising a conical shaped body of expanded polystyrene having a density less than two lbs./cubic foot, a first skin of thin aluminium firmly secured to one conical surface of said conical body and a second skin of thin aluminium firmly secured to the opposite conical surface of said body, each of said aluminium skins having a thickness dimension less than 0.001 inch and said body having a thickness dimension not less than 0.25 inch.

6. A diaphragm for a mechanico-acoustic transducer which comprises a body of sandwich construction having first and second skins of aluminium of thickness not greater than 0.001 inch separated from one another by an intermediate core having a thickness at least one hundred times that of either of said aluminium skins and formed of cellular material having a density less than two lbs./cu. ft. said core material being firmly secured to the inner surfaces of each of said skins.

7. A diaphragm for a mechanico-acoustic transducer which comprises a body of sandwich construction having first and second skins of beryllium separated from one another by an intermediate core having a thickness at least one hundred times that of either of said metal skins and formed of low-density cellular material having a density less than two lbs./cubic foot, said core material being firmly secured to the inner surfaces of each of said skins.

8. A diaphragm for an electro-accustic transducer which comprises a body of sandwich construction having first and second skins of aluminium spaced apart by a distance at least one hundred times greater than the thickness of either of said skins and an intermediate core filling the space between the opposing inner surfaces of said skins and formed of expanded phenolic material having a density less than two lbs./cubic foot, said core material being firmly secured to the inner surfaces of each of said skins to form a unitary structure therewith.

9. A diaphragm for an electro-acoustic transducer which comprises a body of sandwich construction having first and second skins of beryllium spaced apart by a distance at least one hundred times greater than the thickness of either of said skins and an intermediate core filling the space between the opposing inner surfaces of said skins and formed of expanded phenolic material having a density less than two lbs./cubic foot, said core material being firmly secured to the inner surfaces of each of said skins to form a unitary structure therewith.

10. A diaphragm for an electro-mechanico-acoustic transducer which comprises parallel disposed first and second skins of thin metal having a high modulus/density ratio separated from one another by a distance at least one hundred times the thickness of either of said sheet metal skins and a core filling of expanded plastic material having a density less than two lbs./cubic foot in between said skins, said core filling being firmly secured to the inner surfaces of each of said metal skins to form a unitary structure.

11. A diaphragm for an electro-acoustic transducer which comprises a rigid conical body of expanded plastic material having a density less than two lbs./cubic foot and first and second skins of metal having a thickness at least 100 times less than the thickness of said body firmly secured to and covering each of the opposite conical side surfaces of said body.

12. A diaphragm for an electro-acoustic transducer which comprises a planar body of expanded plastic material having a density less than two lbs./cubic foot and first and second skins of metal having a thickness at least 100 times less than the thickness of said body firmly secured to and covering each of the opposite planar side surfaces of said body.

13. A diaphragm for an electro-acoustic transducer which comprises a rigid body of light weight honeycomb construction having a density less than two lbs./cubic foot and shaped to provide an extended sound transmitting or receiving area and first and second skins of metal having a thickness at least 100 times less than the thickness of said rigid body firmly secured to and covering each of the opposite extended area sides of said body.

14. A diaphragm for an electro-acoustic transducer which comprises a conical shaped body of expanded polystyrene having a density less than two lbs./cubic foot and first and second thin metal skins rigidly secured by adhesive to each of the opposite sound radiating surfaces of said body, said body having a thickness dimension at least one hundred times greater than the thickness of either of said skins.

15. A diaphragm for an electro-acoustic transducer which comprises an annular shaped body of expanded polystyrene having a density less than two lbs./cubic foot and first and second thin metal skins rigidly secured by adhesive to and covering each of the opposite planar surfaces of said body, said body having a thickness dimension at least one hundred times greater than the thickness of either of said skins.

16. A diaphragm for an electro-acoustic transducer comprising a conical shaped body of expanded polystyrene having a density less than two lbs./cubic foot, a first skin of thin aluminium firmly secured by adhesive to and covering one side of said conical body and a second skin of thin aluminium firmly secured by adhesive to and covering the opposite side surface of said body, each of said aluminium skins having a thickness dimension less than 0.001 inch and said body having a thickness dimension not less than 0.25 inch.

17. A diaphragm for an electro-acoustic transducer comprising an annular shaped body of expanded polystyrene having a density less than two lbs./cubic foot, a first skin of thin aluminium firmly secured by adhesive to and covering one side of said body and a second skin of thin aluminium firmly secured by adhesive to and covering the opposite side surfaces of said body, each of said aluminium skins having a thickness dimension less than 0.001 inch and said body having a thickness dimension not less than 0.25 inch.

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