METALLIC DIAPHRAGM FOR ELECTRODYNAMIC LOUDSPEAKERS

Filed Oct. 4, 1960

INVENTOR.
RUDOLPH T. BOZAK

ATTORNEYS.
This invention relates to an improved diaphragm for use in high fidelity electro-dynamic loudspeakers.

The ideal loudspeaker diaphragm is a perfectly rigid structure having the lowest possible mass and mounted in a manner such that it can freely move in axial direction in response to electrical signals. Attempts have been made to make a diaphragm from very thin lightweight metallic and plastic materials. However, these have not been successful primarily because the very thin diaphragms tend to vibrate internally at a certain characteristic frequency for each particular material and this seriously interferes with the sound being reproduced. Also, there is a tendency toward nodal vibrations which also interfere with the primary sound being reproduced. When damping materials were applied to the thin diaphragm to dampen out the objectionable internal vibrations, the mass of the diaphragm was so substantially increased that the increased mass caused excessive inertia which prevented the diaphragm from moving freely in correlation with the frequencies of the sounds being reproduced. This was particularly objectionable at high frequencies. For these reasons thin lightweight diaphragms especially those made from aluminum or magnesium have not been commercially successful.

I have now devised a lightweight diaphragm which gives almost perfect reproduction of sound in the frequency range from about 100 to 5000 cycles per second. The diaphragm comprises a very thin sheet of metal or plastic which has such low mass that its response over this wide frequency range is remarkably uniform. At the same time I have found a way to rigidify and dampen the diaphragm whereby no internal vibrations in the diaphragm itself can interfere with the primary sound being reproduced.

The diaphragm of my invention comprises a thin sheet of lightweight metal or plastic material which is flared generally into the shape of a cone with curved walls. The thickness of the diaphragm is very important and must not exceed about 0.015 inch. I prefer to employ sheet material which is about 0.002 to about 0.010 inch thick. At these thicknesses the diaphragm is so light that it has no apparent inertia which can interfere with axial movement of the diaphragm during sound reproduction.

It is essential that the wall of the diaphragm be curved, since I have found a way to rigidly and dampen the diaphragm whereby no internal vibrations in the diaphragm itself can interfere with the primary sound being reproduced. The curve of the wall is usually a circular arc. I prefer to form the diaphragm with a wall having a circular arc for its inner portion, and a more pronounced curve at the lower end of the diaphragm near the apex. This extremely thin diaphragm is highly susceptible to objectionable internal vibrations. Also, it is highly resilient and prone to deformation so that it has no practical value unless it is rigidified. I have found that if the outer peripheral portion of the diaphragm is bent in the general form of an annular flange the diaphragm is quite substantially rigidified particularly as to radical deformation and such flange prevents objectionable vibrations from occurring in the peripheral area of the diaphragm.

Best results are achieved with a 90° angle between the flange and the adjacent periphery of the diaphragm and the flange may be either turned up or down in relation to the diaphragm. However, a 90° angle is not an absolute requirement. In all cases the area adjacent the periphery must be bent so as to form only a single flange without the formation of a corrugation since a corrugated flange readily vibrates and would cause highly objectionable sounds in the peripheral portion of the diaphragm.

I have also found that the diaphragm must be reinforced at its lower end adjacent to the voice coil cylinder and for such purposes I bridge the internal surfaces of the diaphragm with a central reinforcing member, either separately attached to the diaphragm or formed as an integral part thereof. Preferably this reinforcing member is positioned at the point where the voice coil cylinder and the lower end of the diaphragm are joined. When the thin diaphragm has been rigidified with the annular peripheral flange and the central reinforcing member, it becomes strong enough to act as a true diaphragm piston and objectionable vibrations along the periphery and the lower end of the diaphragm are eliminated.

While the reinforced metal diaphragm of my invention has utility the wall of the rigidified lightweight diaphragm may be caused to vibrate internally at certain high frequencies and when this happens there is an objectionable ring or other sound characteristic of the particular material employed for the diaphragm. Also, local annular modes of vibration may be excited in the diaphragm wall and these interfere with the primary sound being reproduced. I have found that these objectionable vibrations can be eliminated by coating the diaphragm with a thin film of elastically pliable damping material. For best results it is important that the coating be elastically pliable for effective damping. While I do not understand the reason for this I believe that the elastically pliable damping material readily deforms with the diaphragm as the diaphragm vibrates so that every movement of the diaphragm during internal vibration is faithfully followed and blanketed by the damping material which prevents the objectionable sound characteristic of these internal vibrations from being generated.

The film is preferably applied to both sides of the diaphragm as this form gives the best results. However, the film may be applied only to one side of the diaphragm but the results will not be as good. The film should have some adherence to the material of the diaphragm in order to insure that it remains bonded and that the film has a smooth non-porous surface so that absorption of air is kept at a minimum.

The material which gives excellent results as a damping film on the diaphragm is a natural or synthetic rubber latex applied in liquid form. For example, neoprene latex and other synthetic rubbers such as styrene-butadiene and acrylonitrile-butadiene copolymers, polybutadiene, polyisoprene and polysisobutyene, dissolved or suspended in suitable solvents, may be employed. These materials may be applied either by brushing or spraying. I prefer to spray the latex on the diaphragm as this gives the thinnest possible film. In addition paper or wool fibers may be impregnated in the film of damping material on the diaphragm and solutions or dispersions of synthetic plastic materials which dry to elastically pliable films may be employed as a damping material for the diaphragm. Other conventional dampers, such as felted paper may also be employed provided the selected adhesive remains pliable and does not harden to the extent that it becomes rigid.

It is important that the film of damping material be as thin as possible so that the weight of the diaphragm will not be objectionably increased. In this connection I have found that for a diaphragm thickness within the
range specified hereinafter the thickness of the film of damping material should not exceed the thickness of the diaphragm itself. In the case of the preferred form of structure where a film of damping material is applied to both sides of the diaphragm the combined thickness of both films should not be greater than about twice the thickness of the diaphragm itself. When the film thickness is kept below this limit the increased weight of the diaphragm due to the film of damping material does not substantially interfere with the response characteristics of the diaphragm.

Since the central reinforcing member is made from the same thin lightweight material as the diaphragm itself, the reinforcing members can also vibrate at characteristic frequencies and thereby interfere with the primary sounds being reproduced. Therefore, the reinforcing material also should be dampened and for this purpose I prefer to place a disc of damping material on the side of the reinforcing member facing the open mouth of the diaphragm. The disc is permanently mounted on the reinforcing member preferably with the same elastically pliable material used to form a film on the diaphragm or if desired other nonhardenable pliable adhesives may be employed. The disc may be a hard fibrous structure such as paper or wool fibers or a mixture of the two glued together to form a rigid porous structure. Alternatively the disc may be made of soft foam rubber. For the hard fibrous structure the thickness of the disc should be approximately \( \frac{3}{4} \) of an inch and in the case of the soft foam rubber disc the thickness may vary from about \( \frac{3}{4} \) to about \( \frac{3}{4} \) inch.

Further improvements in the response characteristics of the diaphragm may be achieved by providing the diaphragm with a plurality of holes having a diameter of about 5 to 10 times the thickness of the diaphragm itself. The holes can be located in symmetrical or random arrangement throughout the diaphragm and there is no practical limit on the number of holes that may be employed. In general, I have found that the more holes that are provided the better the improvements in speaker response. Also, when the diaphragm is coated on both sides with films of damping material, the damping material merges within the holes and forms a mass of elastically pliable material which anchors the films on opposite sides of the diaphragm in the manner of rivets or bolts. Apparently, the plugs of elastically pliable material also localize any internal vibration of the diaphragm and prevent the travel of vibrations radially through the diaphragm. This could account for the improved response characteristics of the diaphragm when holes are provided therein.

Since the diaphragm of my invention is very thin and lightweight it is difficult to control its movement to perfectly linear axial movement with conventional suspension means. I have found that the movement of the diaphragm can be effectively controlled by the use of two compliant annuli. The compliant annulus is a corrugated structure which when attached to the loudspeaker diaphragm permits the diaphragm to move freely in axial direction like a floating piston. The annulus can be made from conventional materials such as linen and other cloth impregnated with phenolic resins or rubber latex. Impregnation is necessary to seal the compliant annulus against passage of air and also impart elasticity to the annulus. In the diaphragm of my invention the compliant annulus is attached to the exterior peripheral wall surface of the mouth of the diaphragm and a second annulus is attached to the diaphragm at the point where the bottom end of the diaphragm and the voice coil cylinder meet. By suspending the diaphragm in such manner with two annuli the movement of the diaphragm is perfectly controlled to true axial movement in response to the electrical signals being converted into sound. It is, of course, important that the compliant annulus itself does not vibrate and cause objectionable interference with the sound being generated by the diaphragm.

The diaphragm of my invention may be made from lightweight metal such as aluminum, magnesium and alloys thereof. Heretofore, a problem with aluminum diaphragms has been the fact that the aluminum tends to crystallize over a long period of time and the diaphragm then becomes prone to rupture or cracking. I have found that when both sides of the diaphragm are coated with the film of damping material the tendency to crystallize is substantially eliminated so that the aluminum diaphragm can be satisfactorily used over an extended period of time. In addition to metal, strong plastic materials may also be used for the diaphragm. For example plastic materials derived from cellulose esters such as cellulose acetate, cellulose nitrate, cellulose propionate, cellulose butyrate, vinyl polymers and copolymers, polypropylene, polyethylene, polyurethane, and acrylonitrile and nylon may be satisfactorily used. In all cases it is essential that the thickness of the diaphragm not be greater than the limit specified hereinafter.

For a better understanding of my invention reference will be made to the accompanying drawings in which:

FIG. 1 is a sectional view of the loudspeaker assembly employing the diaphragm of my invention.

FIG. 2 is a top plan view thereof.

FIG. 3 is a partial sectional view of the diaphragm which illustrates a damping disc in position on the central reinforcing member.

FIG. 1 shows the usual conventional rigid loudspeaker housing 10 which has a permanently magnetized pole piece 12 and core 13 with a space for receiving the voice coil 14 of a diaphragm. The voice coil has electrically conductive wires 16 wound about the exterior surface thereof. The pole piece 12 and core 13 provide a magnetic flux in the space for the voice coil and when electrical signals are conducted through wire 16 a second magnetic flux is generated. The interaction of two magnetic fluxes induces axial movement of the voice coil to which an aluminum diaphragm 18 is attached.

The aluminum diaphragm 18 has a curved wall which from the peripheral edge to about the point 20 is generally a section of a circle. From point 20 down to the voice coil 14 the curve of the wall increases sharply. This is the preferred structure of my diaphragm. The peripheral edge of the diaphragm 18 is bent upwardly to form a flange 22 positioned at about 90° to the periphery of the diaphragm. The lower end of the diaphragm preferably has a step 24 which merges into the reinforcing member 26. The reinforcing member has spaces cut out of it to decrease its weight. The wall of the diaphragm is about .004 inch thick. Both sides of the diaphragm wall are coated with films of neoprene latex 27 which have a combined thickness of about .003 inch. There are a plurality of holes 28 cut out of the diaphragm wall and the latex films merge within these holes. Compliant annulus 30 and 32 respectively are glued to the diaphragm. The compliant annuli are made from cloth impregnated with phenol-formaldehyde resin. The compliant annuli include corrugations 34 and are attached to the rigid loudspeaker housing at 36 and 38.

As can be seen in FIG. 1 the thin lightweight diaphragm is suspended in a manner that permits it to move freely from the interaction of the two magnetic fluxes in the voice coil space. The diaphragm floats so to speak within the loudspeaker diaphragm with complete freedom of movement. At the same time its movement is controlled by the two compliant annuli to a strict axial direction so that sound is perfectly generated in response to the signals transmitted through the wires 16.

The reinforcing member 26 itself can vibrate and cause objectionable interference with the sound being reproduced. As shown in FIG. 3 a soft foam rubber 40 disc is glued to the side of the reinforcing member facing the
open mouth of the diaphragm. Preferably the same neoprene latex 26 is employed for permanently seating the foam rubber disc on the reinforcing member.

It will be understood that it is intended to cover all changes and modifications of the preferred embodiment of the invention herein chosen for the purpose of illustration which do not depart from the spirit and scope of the invention.

1 claim:

1. A diaphragm for electrodynamic loudspeakers which comprises a thin lightweight sheet in the general form of an open cone with curved wall, a peripheral portion at the large open end of said generally conical sheet being bent to form a flange, a reinforcing member positioned adjacent the small open end of said conical sheet and bridging the interior wall surfaces thereof, and compliant annuli attached to the exterior wall of said sheet adjacent the periphery and lower end portions thereof.

2. A structure as specified in claim 1 in which a film of damping material is positioned on at least one side of said generally conical diaphragm.

3. A structure as specified in claim 1 which includes a plurality of holes positioned in the wall of said conical sheet.

4. A diaphragm for electrodynamic loudspeakers which comprises a lightweight metallic sheet in the general form of an open cone with curved wall, said sheet having a maximum thickness of about 0.015 inch, a peripheral portion at the large open end of said generally conical sheet being bent to form an annular flange, a reinforcing member positioned adjacent the small open end of said generally conical sheet and bridging the interior wall surfaces thereof, a plurality of holes positioned in the wall of said sheet, a film of damping material adhered to at least one side of said sheet, and compliant annuli attached to the exterior wall surface of said sheet adjacent the periphery and lower end portion thereof.

5. A structure as specified in claim 4 in which both sides of said sheet are coated with a film of elastically pliable rubber, the films merging together within said holes to lock the film on said sheet and the maximum combined thickness of the films on both sides of said sheet being not more than about twice the thickness of said sheet.

6. A structure as specified in claim 4 in which said sheet is made from aluminum.

7. A structure as specified in claim 4 which includes a layer of damping material in position on said reinforcing member.

8. A structure as specified in claim 7 in which the damping material is rubber sponge.

9. A structure as specified in claim 4 which includes a hard fibrous disc of damping material seated upon the side of said reinforcing member facing the mouth of said sheet, the thickness of said disc being about ½ inch.

10. A structure as specified in claim 1 in which the sheet is aluminum.

11. A structure as specified in claim 1 in which the sheet is made of plastic material.

References Cited in the file of this patent

UNITED STATES PATENTS

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Inventor</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,757,451</td>
<td>Crane</td>
<td>May 6, 1930</td>
</tr>
<tr>
<td>1,783,385</td>
<td>Nystrom</td>
<td>Dec. 2, 1930</td>
</tr>
<tr>
<td>2,256,270</td>
<td>Swift</td>
<td>Sept. 16, 1941</td>
</tr>
<tr>
<td>2,641,329</td>
<td>Levy et al.</td>
<td>June 9, 1953</td>
</tr>
<tr>
<td>2,905,260</td>
<td>Williams</td>
<td>Sept. 22, 1959</td>
</tr>
</tbody>
</table>