

March 17, 1959

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TRANSDUCERS

2,878,323

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2 Sheets-Sheet 1

FIG. 1.

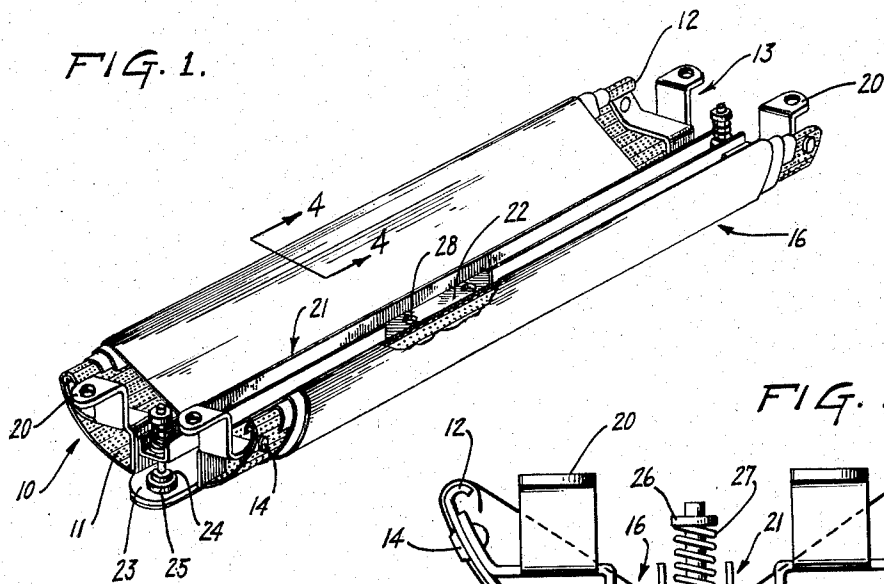


FIG. 2.

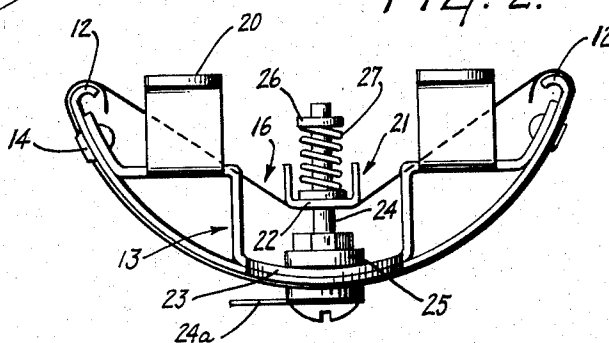
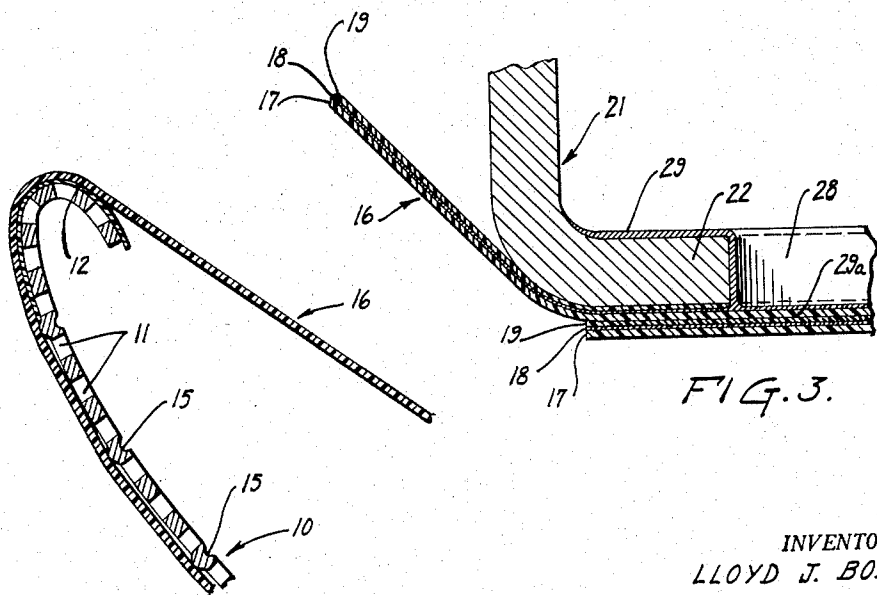


FIG. 3.

FIG. 4.

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2 Sheets-Sheet 2

FIG. 7.

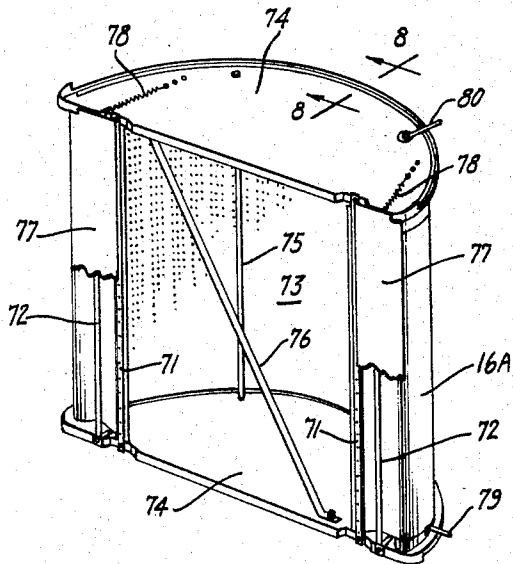


FIG. 8.

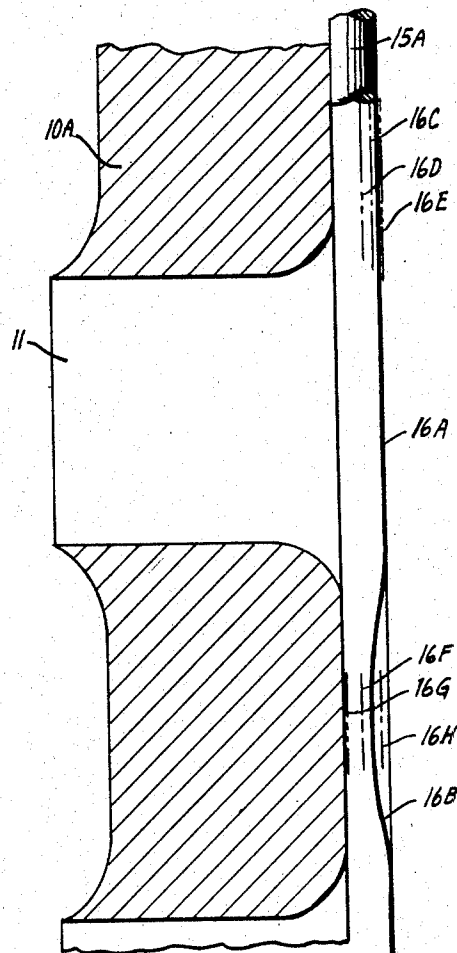


FIG. 5.

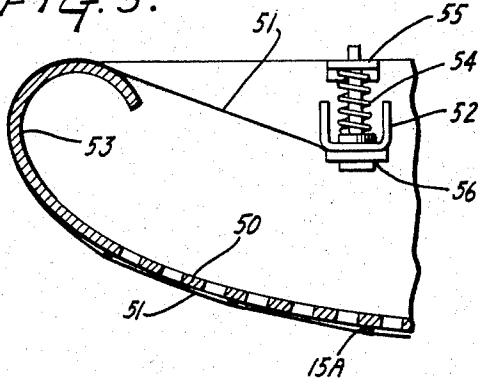
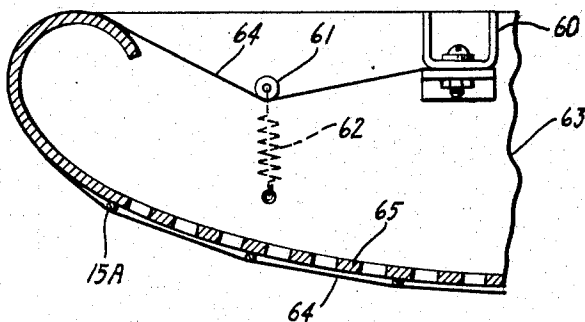


FIG. 6.



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Application January 29, 1957, Serial No. 636,891

5 Claims. (Cl. 179—111)

This invention relates to electro-acoustic transducers of the type best known as electrostatic loudspeakers. This is a continuation-in-part of my copending application Serial No. 425,607, filed on April 26, 1954.

The invention is concerned with the membrane or diaphragm member of such a speaker and more especially with the tensioning of this member in different areas thereof. It is well known that the tension under which the membrane is held affects the acoustic performance of the speaker; and this is particularly so where the membrane is desirably thin and closely spaced from the cooperating speaker element or so-called backing plate. Heretofore, local irregularities of this tension were frequently encountered; and they were often manifested by wrinkles, formed in the membrane. It is a point of importance for the present discovery or invention that the complexities of acoustic performance, which are great in any event, were aggravated by such irregularities.

Accordingly it is a primary object of this invention to avoid such irregularities, in order to improve the acoustic performance of a speaker.

A particular object is to minimize or eliminate the wrinkling of a thin membrane, held under substantial tension.

It was found that in order to achieve these objects, it is necessary to modify certain parts of a speaker, and desirable to modify others; and particularly, changes are indicated in the devices which electrically and mechanically connect the electrically conductive membrane element to the more basic structure. It appears that major irregularities of tension are likely to be caused by otherwise desirable features of such connecting devices. In addition, certain particular features of arrangement are desirable as to the membrane-supporting members or so-called "pips" and as to other elements of a speaker. The details will best be explained in connection with the following description, taken together with the accompanying drawing in which preferred embodiments of the invention are illustrated.

In the drawing, Figure 1 is a perspective view of a first electrostatic sound reproducer embodying the principles characteristic of my invention; Figure 2 is an end elevational view illustrating on a larger scale apparatus of the kind shown in Figure 1; Figure 3 is a fragmentary sectional view on a greatly enlarged scale, illustrating certain features of the diaphragm tensioning means; and Figure 4 is a fragmentary sectional view of other features, taken generally in the direction indicated by the lines 4—4 applied to Figure 1 and drawn on a scale intermediate those of Figures 2 and 3.

Figures 5 and 6 are fragmentary sectional views generally similar to Figure 4 but showing fragments of a second and a third modification, respectively; Figure 7 is a perspective view of a fourth electrostatic sound reproducer, embodying the principles of my invention; and Figure 8 is a fragmentary, sectional detail view taken along line 8—8 in Figure 7, on a scale larger than that

2

of Figure 3 to show proportions of parts more realistically.

The speaker of Figures 1 to 4

Now making more detailed reference to the drawing and initially to Figure 1 thereof, it will be seen that the speaker comprises a curved foraminous backing plate 10 having a concave side and a convex side. This plate is metallic, electrically conductive, substantially rigid, and provided with a large number of small perforations 11. Desirably, as shown in Figure 8, the diameter of each aperture is large as compared with the actual length of the perforation, the latter being defined by the thickness of the sheet. As shown in Figure 2, the sheet terminates in rolled edges 12 at the sides thereof. It is provided at each of its ends with a bracket member 13, suitably secured thereto as by rivets 14.

As shown in Figure 4 at 15 the backing plate 10 may be provided with a series of elongated, parallel ridges or membrane spacers or "pips," extending along the axis of curvature of the plate and projecting from the convex side of the plate. These ridges may be integral with the plate and may be formed for instance by embossing the plate or in other suitable ways known to the art. Desirably they project from the plate a distance of an order of magnitude either similar to or preferably smaller than the diameter of a perforation 11, for example about .002"; see Figure 8 where a similar spacer appears at 15A. Thus they minimize the spacing of the thin membrane 16 or 16A from the backing plate 10 or 10A and the corresponding signal voltage required. This in turn increases the acoustic sensitivity and fidelity of the speaker, particularly when irregularities of this minute spacing are avoided, as will now be explained.

The diaphragm 16 employed in the embodiment of Figure 1 is a continuous sleeve disposed about the backing plate 10, closely encircling the convex side of the plate and extending across the concave side of the plate at a distance therefrom, as clearly shown in Figure 2. Desirably and as schematically indicated in Figure 3, the diaphragm comprises as a base element a very thin sheet 17 of elastic dielectric material such as that made from the type "A" polyester manufactured by E. I. du Pont de Nemours & Co. and known under the designation Mylar. The plate 10 may typically have a thickness of .02 or .03 inch, whereas the sheet 17 may typically have a thickness of only .00025", that is, substantially less than is shown in Figures 1, 3 and 4; see Figure 8 for the approximate proportions of typical elements. An even thinner, electrically conductive coating 18 is applied to sheet 17, as schematically shown in Figure 3; it may have for instance a thickness of about .0000015" and may be deposited on the outer surface of the sleeve-like Mylar sheet. An outermost, protective, varnish-like coating 19 may cover this conductive layer.

The backing plate 10 serves as one electrode of a condenser, while the coating 18 forms the other electrode and is insulated from the first electrode, in the areas 15 of the closest approach thereto, by the plastic sheet 17. An electrical potential is impressed on the backing plate by one or more conductive lugs 20, shown in Figures 1 and 2 as forming part of a bracket 13. On the other hand a combined connecting and tensioning device 21, Figures 2 and 3, serves to establish electrical contact with the conductive coating 18 of the membrane 16.

In accordance with the present invention the tensioning apparatus 21 places and maintains the vibratile membranous diaphragm 16 under regulated tension, it being a particular feature of this new tensioning means that it minimizes such irregularities of tension as were hereto-

fore caused by membrane gripping, clamping and connecting devices.

As a tensioning apparatus, the member 21 must impart a certain degree of mechanical stiffness to the diaphragm 16, in opposition to the electrostatic forces cyclically acting between elements 10 and 18. This stiffness must be sufficient to provide certain acoustic characteristics and to prevent the cyclically energized and correspondingly vibrating diaphragm from approaching too closely to the backing plate; on the other hand the tension must not be too great, since otherwise the frequency range would be curtailed at the low end and the sensitivity of response would be decreased at all frequencies.

In further connection with these principles, attention is now directed to the fact that, whenever a very thin membrane is tensioned while having a pressure force or reaction applied to some part of the surface thereof, as by spacers 15 or mainly by the tensioning and connecting apparatus 21, wrinkles tend to occur in the membrane, adjacent the areas of pressure. The presence of wrinkles involves the existence of zones of different tension, adjacent one another, some of which have different resonant frequency and strength and therefore tend to develop phase differentials which ultimately impair the frequency response of the membrane; it is therefore most desirable to minimize any such wrinkling. This has been achieved by the new tensioning apparatus 21, illustrated in Figures 2 and 3. Said apparatus comprises a channel structure, approximately as rigid as the backing plate 10, with a web 22 bearing against an exterior surface portion of the membrane 16 and applying pressure to said surface portion; the channel and the contacted surface portion being arranged to confront the concave side of the backing plate 10 and being spaced from said plate along the membrane or diaphragm.

Certain preferred details of the tensioning device should now be noted and, as a first preferred feature, the orientation of the tensioning device may be mentioned. As illustrated, the portion of diaphragm 16 confronting the backing plate 10 is urged toward the concave side of said plate and into a similarly concave shape; this arrangement being preferred at least in connection with a deeply curved or semi-cylindrical plate, as it conserves useful space.

A further preferred feature is that member 22 serves both as an electrical connector and as a mechanical tensioner. For the latter purpose, member 22 is shown as resiliently mounted upon the backing plate 10, opposite ends of this member 22 being secured to lugs 23 which project from the brackets 13 at the ends of the speaker assembly, with screw members 24 passing through said lugs and engaging said opposite ends of the member 22, as shown in Figures 1 and 2. A non-conductive grommet 25 maintains the screw member 24 out of conductive relation with each lug 23, while electrical contact to the screw member and to the tensioning member is provided for by a terminal 24A. The screw member may be fastened to the lug 23 by a nut overlying the resilient grommet 25. The upper end of the screw member 24 is shown as having a collar 26 threaded thereon, providing a shouldered portion against which a coil spring 27 reacts to urge the tensioning member 22 downwardly, thereby applying resilient pressure to the diaphragm surface area underlying this member. This maintains the diaphragm under the necessary tension, particularly between the supporting "pips" 15. Adjustments of shoulder 26 on screw 24 make it possible to adjust the resilient pressure between the tensioning member 22 and the surface of the diaphragm 16.

As further shown in Figure 3 the tensioning member 22 bears directly against the protective coating 19 on the conductive layer 18; and means are provided to establish electrical contact through local surface portions of this protective layer, without breaking this layer however on

other surface portions of the membrane. To this end, as shown in Figures 1 and 3, the web 22 is provided with a longitudinal series of apertures 28; and a conductive medium 29 extends through each aperture 28, in contact with web 22 and with the conductive diaphragm layer 18 in an area 29A. This conductive medium may comprise for instance a metal paint, such as silver paint, with a solvent base such as acetone or methyl ethyl ketone. On application of such a paint, underlying portions of the protective diaphragm layer 19 are dissolved by the solvent and an excellent conductive path is established between the web 22 and the conductive layer 18 by the particles of metal paint 29.

Operation of the speaker of Figures 1 to 4

The apparatus as described has been found to provide certain advantages, as explained in the parent case, and also to minimize wrinkling and related irregularities of diaphragm tension and of acoustic performance. Effectively regulated tension is maintained in the active, vibratile part of the membrane, between the "pips" 15 of the backing plate 10.

It may be noted that even when such regulation is used, the tension in the membrane is not uniform in every respect. The tension decreases from the outermost pips 15, adjacent the edge of the backing plate, toward the central pip 15. However, tension is kept uniform at least longitudinally of each pair of pips. This is achieved by the particular, new arrangement of the tensioning apparatus 21, as described. By contrast, vibrating membranes were heretofore exposed to serious wrinkling, indicating much irregularity of stress and of strain and even the possibility of local "cold flow." In addition, diaphragm tensions varied from time to time in many of the speakers which were known heretofore; this was due to temperature changes and the like. These latter irregularities are automatically compensated by the resilient support for the tensioning member 21, provided by the coil springs 27.

Tendencies to create wrinkles are often unavoidable, even in the new device. This applies particularly to the vicinity of each aperture 28 of the tensioning and connecting member 21. Wrinkling is caused in this region as the pressure loading of membrane areas directly underlying apertures 28 differs from the corresponding loading of the areas underlying the solid material of web 22. While major wrinkles, caused in this manner, may sometimes be eliminated simply by wiping the membrane in a direction parallel to the pips 15, residual or newly formed wrinkles are still sufficient to interfere materially with the acoustic performance of the membrane if they are allowed to extend into the active vibratile portion thereof; however, according to this invention such wrinkles exist only in a membrane portion which is spaced, along the membrane itself, from the active vibratile portion overlying the convex side of the backing plate 10.

Some small tendency towards formation of wrinkles and related irregularities of tension and vibration may be encountered also because of structural features other than the electrical connecting means mentioned; even the internal structure of the membrane itself may contribute to such tendency. In practice, however, the membrane can be kept substantially flat and under regulated tension, free of variation longitudinally of the supporting pips, so long as major sources of irregularity, such as localized clamping means or localized connector means 28, are spaced along the diaphragm 16 from the vibratile diaphragm portion extending between pips 15.

Modified speakers

The principles of the present invention are applicable in many types of speakers, wherein a diaphragm or membrane is supported on elongated pips or the like. This is usually the case in so-called single-ended electrostatic

speakers, including the speaker of Figures 1 to 4; however, the improvement is available also in combination with other speaker designs, single-ended or otherwise.

For instance, a second speaker in accordance with the invention is schematically and fragmentarily shown in Figure 5. Here a backing plate 50 has a membrane 51 tensioned thereover by either one or more tensioning channels or bars 52, although only one of these bars is illustrated. Such a bar may extend for instance adjacent and along the rounded side edge 53 of the backing plate, while a similar bar, not shown, may extend along the opposite side edge. Springs 54 may react against such bars and against rigid abutments 55 to apply tension to the membrane 51, an end of which may be pressed against the bar 52 by a clamping means 56. The tensioning and connecting channel or bar 52 is again spaced, along the diaphragm 51, from the acoustically active diaphragm section overlying the plate 50.

According to Figure 6 the unitary connecting and tensioning members 21 and 52 (Figures 2 and 5) are replaced by the combination of an electrically connecting bar or channel 60 and a mechanically tensioning bar or rod 61, the latter being held resiliently by spring means 62 anchored in base plate means 63. Either one or several systems of such connecting and tensioning members 60, 61 may be provided, as in Figure 5; and again each system of such members is spaced, along the diaphragm 64, from the acoustically vibrating diaphragm portion, tensioned over a backing plate 65.

The exact measurements of such spacing may differ widely, in the different forms of the new speaker. Such as Figures 2, 5 and 6. I have found it to be preferable that the distance from the tensioning apparatus 21 or 52 or 61 to the vibrating membrane section should equal at least several times the spacing between any two co-operating, mutually adjoining pips 15, employed for the support of said vibrating section. Thus an acoustically inactive diaphragm section, or a plurality thereof, is mechanically utilized for minimizing or smoothing unavoidable wrinkles in the diaphragm; and this inactive section is several times as wide as each sound radiating portion of the diaphragm. It is a matter of lesser importance how far the tensioning bar 61 is spaced from the connecting bar 60, in Figure 6; but I have found it convenient to make this spacing approximately equal to that between the tensioning bar 61 and the active membrane section.

As to said active section, a further modification is indicated in Figures 5 and 6, with respect to the pips or diaphragm spacers. These members are here shown in form of threads or wires 15A, tensioned over the plate 50 or 65 in a direction parallel with the axis of curvature. The minute and accurate spacing required can sometimes be improved by such an expedient.

Figure 7 shows a further modification, certain details of which have also been described and claimed in an application filed by Wilbur B. Reed and Henry E. Johnston on July 30, 1956, under Serial No. 600,896; and features of similar devices are additionally shown in an application of Maurice E. Swift, Serial No. 620,893, filed November 7, 1956. Said applications are assigned to the assignee of the present invention. In the present embodiment a membrane 16A is connected to and tensioned by bar means 71, 72, adjacent each side edge of a backing plate 73, in a way somewhat similar to that shown in Figure 6; and the plate 73 and connectors 71 are held in rigid position, against distorting tendencies caused by the tension of the membrane, by a reinforcing system which may include a pair of support plates 74 and a plurality of posts and/or braces 75, 76 therebetween. Acoustic absorption means 77 may be employed, as described in the Reed-Johnston application. The tensioning rods 72 may be held by springs 78; and suitable potentials are impressed on plate 73 and mem-

brane 16A by terminals 79, 80, respectively, as described in said application.

The embodiments of Figures 1 and 7 will generally differ as to their respective sizes and frequency ranges. The device of Figure 1 is most suitable as a so-called tweeter operating for instance in a frequency range from 7000 to 20,000 cycles per second. Such a tweeter can be relatively small. The device of Figure 7 can effectively radiate sound of intermediate as well as high frequency, for instance from 2,000 to 20,000 cycles, and it is made correspondingly larger. In typical embodiments the vibratile membrane area of such a tweeter according to Figure 1 may measure for instance about ten to twenty square inches whereas the corresponding area of such a speaker according to Figure 7 may measure up to about ten times as much, or even more. These differences in size have further results, as to the maintenance of suitable tension conditions and acoustic quality in accordance with this invention.

Referring particularly to the smaller speaker of Figures 1 to 4, the ratio of the height to the width of the active vibratile membrane area has been found to be preferably about 2:1, or possibly up to about 3:1, the height being measured along the pips and the width across the same, from one edge 12 to the other. By contrast, the corresponding ratio in the larger speaker of Figure 7 may well be about 1:2; and in speakers of frequency ranges and sizes intermediate those of Figures 1 and 7, this proportioning may be modified according to principles well understood by persons skilled in the art. Thus it may be said that in general the ratio of height to width of the vibratile membrane area in a speaker according to the present invention ranges between 3:1 and 1:2; and preferably between 2:1 and 1:2.

One of the reasons for the indicated high ratio of 3:1 or 2:1 in the small speakers is that the use of a membrane elongated along the supporting pips is preferable, in lieu of elongation transversely thereof; it being possible in accordance with the present invention to insure regularity of tension along the pips, whereas it is difficult or impossible to maintain uniformity of tension across the pips, because of the inherent difference in pressure reactions applied to pips which are more or less remote from the ultimate source of tension. The upper or 3:1 limit for this height to width ratio has to do with the fact that the provision of suitable rigidity in various directions, in the backing plate, would no longer be convenient if this ratio were increased further.

Among the reasons why the larger speaker unit of Figure 7 desirably uses a lower aspect ratio, such as 1:1½ or 1:2, there is the fact that this unit, being large, is desirably designed in compact form. The most compact form would be cubical; and the nearest approach to such a form, practical for an electrostatic speaker, is that of a half cylinder having a height which approximately equals the diameter, as discussed in greater detail in the Swift application. In such a unit, the vibratile area is about one and a half times as wide as it is high.

The operation of the speaker membrane 16A can best be explained in connection with Figure 8. As shown by line 16A, this membrane is relatively flat; however it is shown as incorporating one of the aforementioned, relatively minor wrinkles, which is shown in cross section at 16B and which may for instance have a rise over the flat configuration of the membrane of about half a mil or one mil, in typical cases. The full-line position of the membrane is that which prevails when the speaker is electrically de-energized. In operation, a biasing voltage is applied, preferably so as to attract each radiating part of the membrane to an inwardly arched position 16C.

A signal voltage is then impressed to vibrate the membrane from position 16C toward and away from the backing 10A, with a normal amplitude of vibration which may for instance be calculated to involve inward

excursions to position 16D and outward excursions to position 16E.

The actual amplitude of vibration, at each point, depends on the mean distance from the membrane to the backing plate; therefore, as clearly noted at 16F, 16G, 16H, the amplitude of vibration is relatively great adjacent a wrinkle 16B mechanically bulging toward the backing plate and normally biased into a position 16F. On the other hand, of course, the corresponding amplitude is relatively small in a wrinkle bulging in the opposite direction. Thus it is clear that vibratory conditions in one and the same membrane may differ widely, depending on whether and how the various parts of the membrane are wrinkled. For instance the existence of relatively major wrinkles adjacent the side edges of the backing plate, which was unavoidable in prior constructions, involved acoustical conditions which tended to greatly distort the theoretical and desired acoustic condition. Such distortion is minimized by the more regular tension conditions in the membrane, provided by the present invention.

Still another advantage of the practically wrinkle-free membrane, provided by this invention, has to do with certain dangers of depolarization. If a vibration such as that shown at 16G—16H were allowed to occur, a strong signal would cause contacts between the membrane 16A and the charged plate 10A, thereby transferring charges to the membrane, reducing the polarizing voltage and, after some time, completely destroying the frequency response. This danger is avoided by the elimination of wrinkles in the membrane 16A.

While only some single-ended speakers embodying the invention have been described, it should be understood that the specific details disclosed are not to be construed as limitative of the invention, except insofar as set forth in the following claims.

I claim:

1. In an electrostatic loud-speaker, a backing plate curved in the approximate form of an arc of a cylinder; pip members extending longitudinally along the convex side of said arc; a membranous, electrically conductive sheet, disposed about and adjacent said convex side but spaced therefrom by the pips and extending beyond said convex side; and a tensioning structure comprising a pair of members substantially parallel to and coextensive with said pips but separate therefrom and from said convex side, one of said members electrically coupled with said membranous electrically conductive sheet and the sec-

ond member reacting against the surface of said sheet to insure regulated tension in the sheet tensioned over the pips and to provide a portion of said sheet, tensioned between said structure and said convex side, for smoothing wrinkles in said sheet.

2. In an electrostatic loud-speaker, a backing plate having curved shape between lateral edges; a vibratory speaker membrane disposed about the convex side of said plate and slightly spaced therefrom by pips extending along said side, the lateral extension of said membrane exceeding that of said side; and membrane tensioning apparatus, including: bar means spaced from and extending substantially parallel to and coextensively along said lateral edges and electrically and mechanically connected to the membrane, and similarly extending elongated structure disposed between said bar means and said lateral edges, laterally spaced from the latter, and reacting against adjacent membrane surface portions laterally spaced from said edges, for tensioning the membrane between said pips and said bar means.

3. In an electrostatic loud-speaker, a backing plate having a ratio of height to width no greater than three to one and no smaller than one to two and having cylindrical-segmental curvature about an axis parallel with the height of the plate; elongated diaphragm spacers on the convex side of the plate extending parallel with said axis; an electrically conductive membrane disposed about and adjacent the convex side but spaced therefrom by the spacers; and an elongated diaphragm tensioning structure extending parallel to said axis and reacting against a surface of the diaphragm which surface is spaced along the diaphragm from said convex side.

4. Apparatus in accordance with claim 3, wherein said ratio is approximately two to one and the area of the membrane is approximately ten to twenty square inches.

5. Apparatus in accordance with claim 3, wherein said ratio is approximately one to two and the area of the membrane is approximately a hundred to two hundred square inches.

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