Feb. 1, 1938. M. W. SCHELDORF 2,106,815

ACOUSTIC DIAPHRAGM AND METHOD OF MAKING SAME

Filed July 31, 1935 3 Sheets-Sheet 1

FIG. 1.

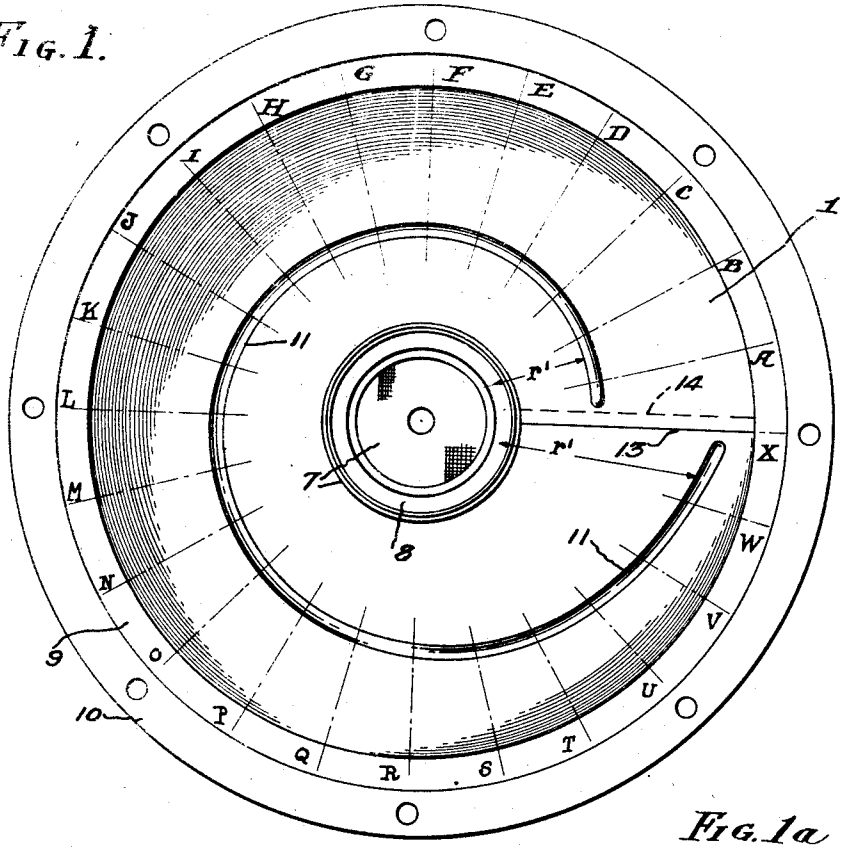


FIG. 1a

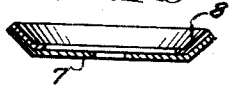


FIG. 2.

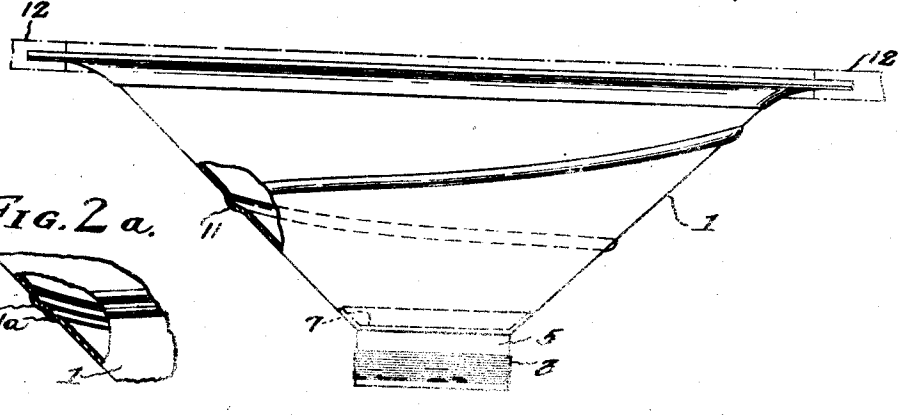


FIG. 2a.

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ACOUSTIC DIAPHRAGM AND METHOD OF MAKING SAME

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FIG. 3.

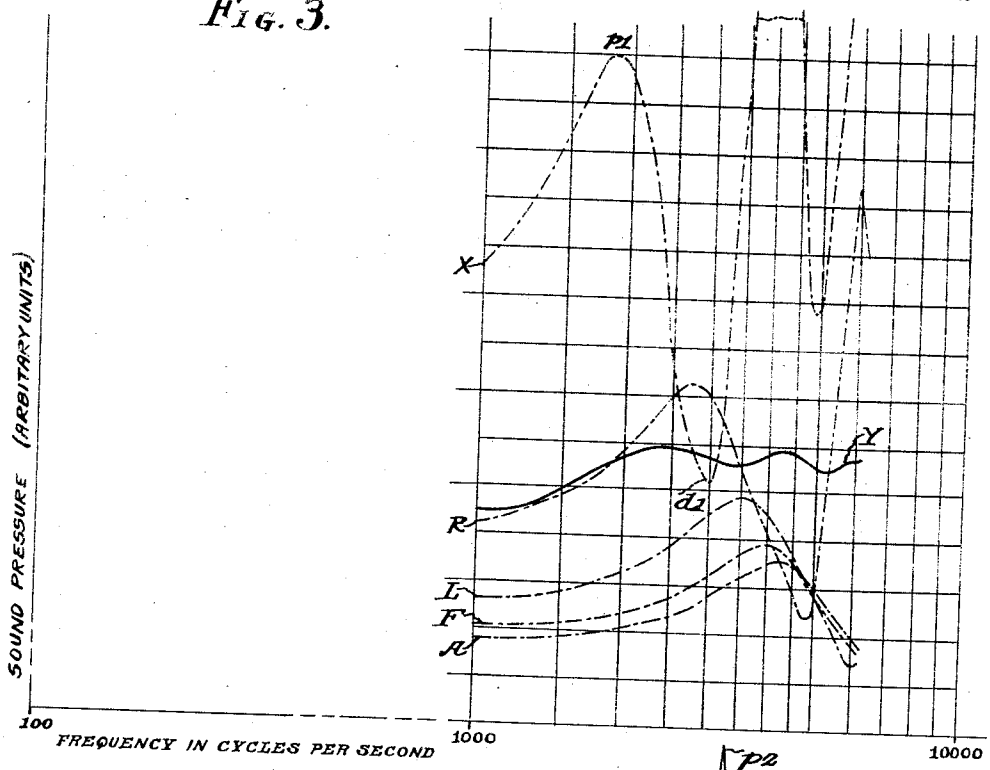
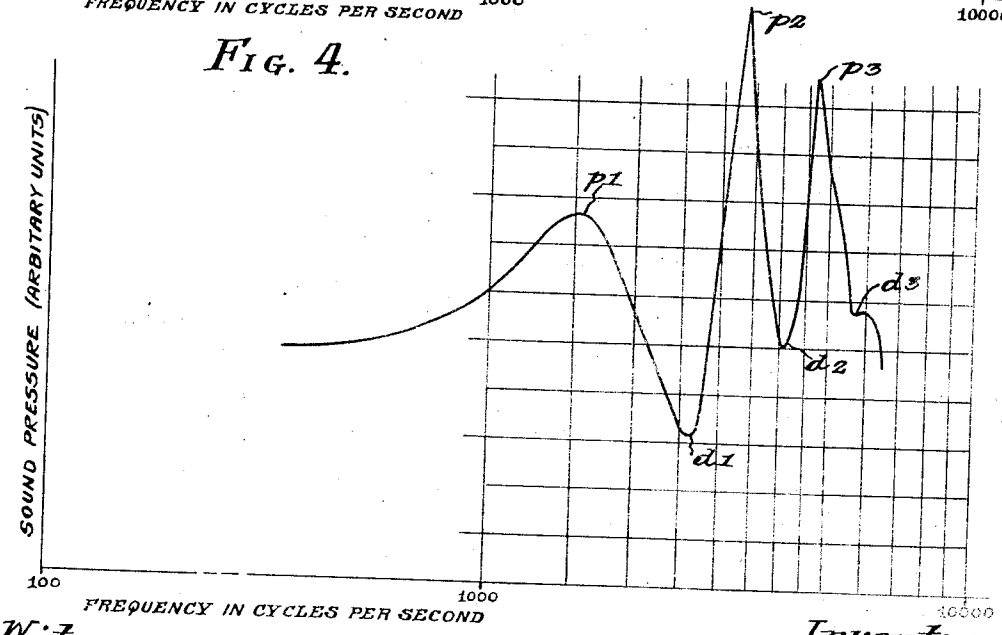


FIG. 4.



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ACOUSTIC DIAPHRAGM AND METHOD OF MAKING SAME

Filed July 31, 1935 3 Sheets-Sheet 3

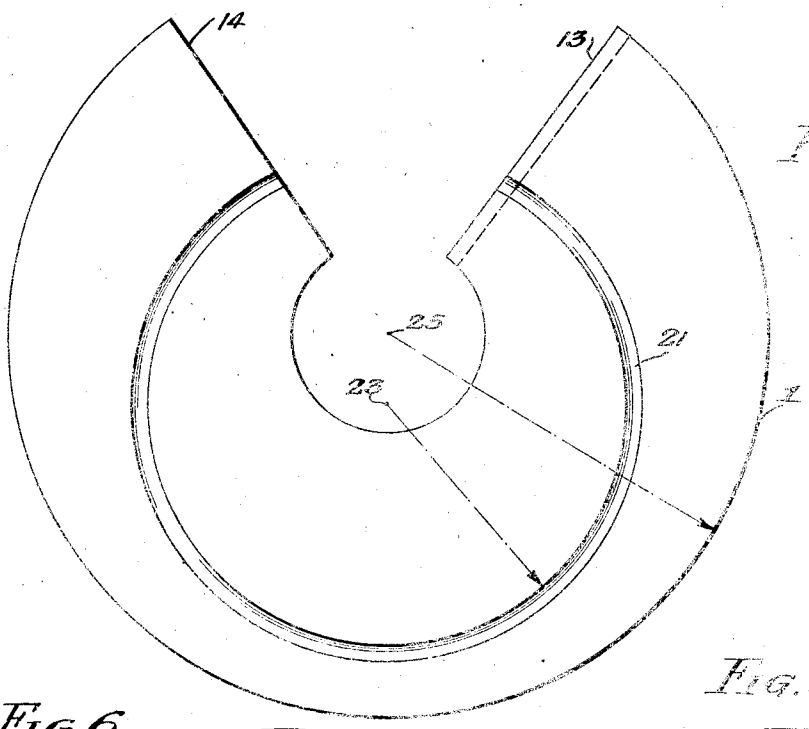


FIG. 5

FIG. 6.

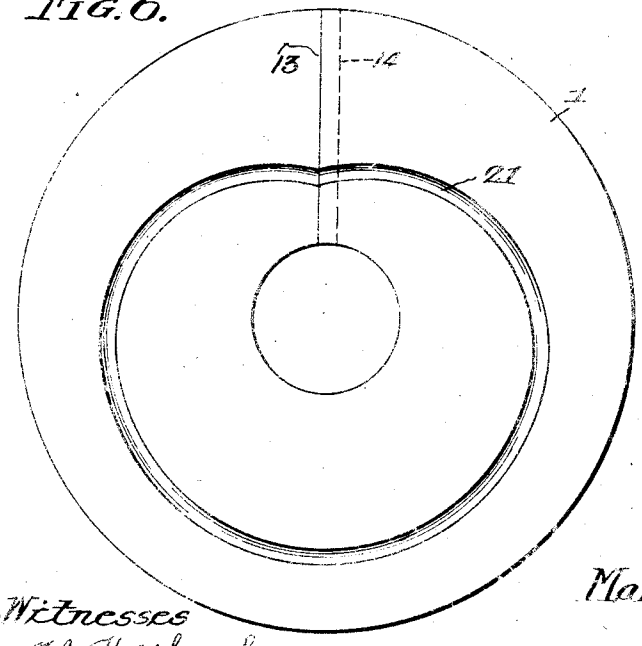
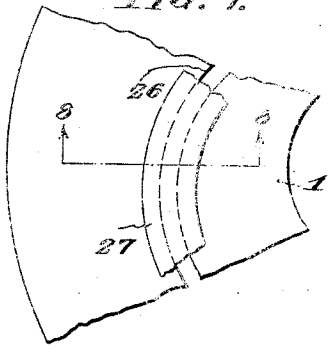


FIG. 8.



FIG. 7.



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Patented Feb. 1, 1938 2,106,815

UNITED STATES PATENT OFFICE

2,106,815

ACOUSTIC DIAPHRAGM AND METHOD OF MAKING SAME

Marvel W. Scheldorf, Haddon Heights, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application July 31, 1935, Serial No. 34,065

15 Claims. (Cl. 181—32)

My invention relates to acoustic devices and more particularly to diaphragms adapted to be used in loudspeakers of the electrodynamic type. It is, however, applicable to other acoustic devices such as microphones and the like.

In its broadest aspect an important object of my invention is to provide an acoustic diaphragm whereby electrical waves, corresponding to original sound vibrations, may be faithfully translated into sound waves without a sacrifice in efficiency of translation.

More specifically another object of my invention is to provide an acoustic diaphragm characterized by a substantially uniform reproduction of sound and freedom from resonant points, or peaks and dips, throughout a broad audio frequency response range.

A further object of my invention is to provide an acoustic diaphragm having characteristics of high fidelity of reproduction, and which is so simple in construction, that it is adapted to inexpensive quantity production methods and machinery.

A further and more specific object of my invention is to provide an acoustic diaphragm of the piston type, preferably of circular contour, successive sectors of which effectively constitute portions of different mechanical and acoustical characteristics around the circumferential expanse of the diaphragm.

A further object of my invention is to provide an acoustic diaphragm that is symmetrical in outline and arrangement for various reasons that will occur to those skilled in the art, and yet nonsymmetrical in a mechanico-acoustic sense, for improving fidelity and uniformity of reproduction in an efficient manner.

A still further object of my invention resides in an improved method of producing a conical diaphragm from fibrous sheet material, characterized by improved acoustic qualities, and adapted to simplified manufacturing operations with inexpensive materials.

In loudspeakers considerable difficulty has been experienced in covering the desired audio frequency range in such a manner that undistorted reproduction of sound occurs. In the case of diaphragms of the type that are arranged to be driven as a piston, the response characteristics have been quite irregular over the range as a result of standing wave interference caused by reflection of certain waves from the edge or base of the diaphragm. For these waves, of the higher audio frequencies, the diaphragm no longer oscillates as a whole, piston fashion, as it does for lower frequencies, but breaks up into separately vibrating, inner and outer, sections.

Various means have been heretofore devised for improving fidelity or uniformity of response over the range. For example, it has been the practice for years to employ a multiplicity of concentric circumferential corrugations in conical diaphragms, broadly in accordance with the teachings of Zimmerman Patent 1,689,513, the expressed purpose being to circumferentially stiffen the diaphragm to prevent parasitic vibrations or rattling of local sections around the diaphragm. It has been the opinion among engineers that such corrugations have inherently provided a certain desired degree of radial compliance the corrugation corresponding to capacity in an electrical filter, and the area or mass between corrugations corresponding to inductance in the filter, this probably having accounted for some of the improvement in performance as compared with the smooth surface diaphragm structure.

Ordinarily, such corrugations have, however, been placed much closer together than disclosed by Zimmerman, without special regard to any law or formulae, it having been common practice to make the spacing, if any, between corrugations equal. I do not mean to imply that there has been little design effort back of such diaphragms, for such is not the case. Considerable work, involving laborious cut and try methods, has been used to obtain diaphragms with certain desired acoustic characteristics. In production it has been found that the factors are very critical; for example, dies made from the same drawings, in different shops, have yielded different results. Cones made from one set of dies were satisfactory while those made from the others were unsatisfactory.

Considerable research work has been done in the way of providing corrugations intended to function fully as compliances for the specified purpose of breaking up the diaphragm effectively into sections, thereby preventing interference between relative outer and inner portions at the higher audio frequencies, only the inner directly driven section vibrating effectively at the higher frequencies. In this connection reference is made to Ballantine Patent 1,876,831. Reference is made also to the Rice and Kellogg paper in the A. I. E. E., April 1925, pages 470 and 471, Fig. 23, disclosing early work on the use of concentrically arranged compliant coupling between diaphragm sections that function with the compliances as filters; and Bedford 1,846,937 disclosing compliant

couplings of damping material between sections.

It has been considered that practically ideal results could be obtained by means of one or two properly designed and critically placed, corrugations of the low loss type. Work has been done to determine generally some law to determine the exact positions on a piston type diaphragm to place concentrically arranged corrugations as well as the dimensions of the corrugations so placed, in order to obtain an improvement in fidelity, the mass of the diaphragm sections and the compliances being of such nature as to constitute a mechanical filter for changing the phase of interfering waves in the higher frequency range. The factors, however, are so many, variable, and interdependent that it is an extremely complex problem, not a simple matter of placing compliant couplings here and there. There is no comprehensive method for calculating the positions and dimensions of compliant corrugations of the above type, for a given set of conditions involving all of the many factors.

While cone diaphragms of improved performance for special purposes have been made in limited numbers with properly located concentric corrugations having desired compliance characteristics, there has still existed the objectionable problem of peaks and dips in the response characteristic because of the fact that it has been found impossible to control with the necessary degree of uniformity the compliant character of the corrugations for purposes of large production. Any change in diaphragm design for different loud speakers would mean repeating the extremely complicated and time consuming methods to determine the shape and locations of the corrugations.

In accordance with my invention the above-mentioned difficulties are avoided by providing an acoustic diaphragm of the piston type, as in the form of a cone, trumpet, pan-shape, or other desirable species with an eccentrically arranged compliant path with respect to the dynamic axis or axis of revolution of the cone. In one embodiment of my invention a corrugation of compliant nature is embossed in the surface of a conical type diaphragm for use in an electrodynamic loudspeaker and is so placed that its position relative to the driving means at the small end of the diaphragm, is in the form of a single short logarithmic spiral preferably extending throughout substantially one full angle of revolution, or in other words, the circumferential expanse of the diaphragm. However, the spiral may extend further so as to overlap radially, or end short of the full circumferential expanse, without departing from the spirit of my invention. In such an arrangement the diaphragm may be considered as effectively divided into a series of imaginary sectors having continuously different mechanical and acoustic characteristics around the circumferential expanse of the diaphragm. I have found that such an arrangement is extremely simplified and easy to control in production, and is not subject to well-known critical factors that cause trouble with cones having multiple and symmetrical compliances in the form of concentric corrugations. In making the distinction between multiple corrugations and a single compliant path or corrugation, I desire it to be understood that my single compliant path may take the form of a plurality of parallel corrugations of shallower depth and closely arranged to give about the same effect as a single large corrugation. While I prefer a spiral corrugation, continuous throughout its length, it will be understood that the spirit of my invention will not be avoided by the use of a discontinuous corrugation or broken path.

The novel features which I consider characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment when read in connection with the accompanying drawings, in which:

Fig. 1 is a plan view, substantially full size, of a cone diaphragm embodying my invention,

Fig. 1*a* is an elevation view in section of a centering disc sub-assembly of Fig. 1,

Fig. 2 is a view in side elevation of the cone diaphragm of Fig. 1, with a portion broken away to more clearly illustrate my invention,

Fig. 2*a* is a view similar to the broken away portion of Fig. 2 showing a slightly modified form of my invention,

Fig. 3 shows characteristic curves of a loudspeaker diaphragm made in accordance with my invention.

Fig. 4 shows a characteristic curve of a plain conical diaphragm,

Fig. 5 is a plan view of a development of a modified form of my novel acoustic diaphragm,

Fig. 6 is a plan view of my modification corresponding to Fig. 5, looking into the concave side of the diaphragm, after forming into a cone,

Fig. 7 is a view in plan, with portions broken away, of a modification of the above forms of my invention,

Fig. 8 is a sectional view of the modification of Fig. 7 as viewed in the direction of the arrows 8—8.

Referring to Figs. 1 and 2 of the drawings, I have illustrated a preferred embodiment of my invention which comprises a frusto-conical diaphragm 1, having a translating or driving means, such as a voice coil 3 wound on a coil form 5, attached to the small end of the diaphragm, and adapted to form part of an electrodynamic type loud speaker, for example, shown in Kellogg Patent No. 1,707,617, for working into a horn or a baffle. The coil 3 is adapted to be flexibly supported by field structure, not shown, in a manner that is well known, as by means of a centering disc 7, preferably of flexible material with damping properties. The outer edge or base of the diaphragm is adapted to be supported from a frame structure, usually known as a cone housing, attached to said field structure by means of flexible damping material, or compliant coupling, shown in the form of a ring 9 secured to the peripheral edge of the cone diaphragm. For convenience in assembly an annular ring, as of cardboard, 10 is cemented around the edge of the ring 9, and in turn, rings 9 and 10 are adapted to be clamped to the cone housing, a portion of which is shown in dotted lines at 12.

For the purpose of performing the functions set forth in the above mentioned objects of invention I have provided a compliance 11, preferably in the form of a logarithmic spiral, in the diaphragm, the compliance being positioned at a continuously varying distance from the voice coil to the periphery throughout the circumferential expanse of the diaphragm. It is preferred that this compliance be in the form of a single corrugation and of such nature that mechanical wave reflections in the cone surface, that take

place in the higher audio frequency range, will occur at different high frequencies thereby resulting in a smooth overall response characteristic.

In the process of manufacture the cone is formed from a blank or flat sheet of fibrous material such as parchment paper. The sheet is cut into a circle with a concentric small opening for attachment to the voice coil, and a sector is removed. While I have shown a radial sector as removed, a spiral form may be removed. Modification shown in Fig. 5 will serve to illustrate these steps without additional illustration. The paper is embossed with the corrugation 11, preferably prior to securing the radial edges together in a seam, the ends of the corrugation preferably terminating short of the edges of the cut-out sector. When the cone is formed by securing radial edges shown at 13 and 14, it will be noted that the ends of the corrugation terminate adjacent the seam at 13 and 14, but do not extend across the seam, which may be other than radical, e. g., slightly spiral, a well-known form of seam.

In manufacturing processes it is advantageous to form the corrugations while the diaphragm is in the blank form, and prior to the coning operation. While it is easier to emboss the corrugation in the blank while flat, it is more desirable to emboss the blank on a conical die having an angle slightly more obtuse than the cone when finished. This avoids the possibility of breakage of the corrugation on forming the cone. Structurally, it is a further advantage in not having the corrugation cross the seam as in most of the present day constructions using the multiple concentric corrugations in seamed type cones. An advantage of a single compliant path over the multiple arrangement is that there is ample diaphragm area to draw from and no adjacent corrugations to disturb during the embossing.

In a diaphragm that I have designed and built in accordance with my invention, by way of example, the base diameter of the finished cone was six inches, the cone angle 105 degrees and the radial length of one side 2.81 inches. The parchment paper employed was about 5 mills thick and was finally sprayed with a cellulose base lacquer for protection against weather. The corrugation depth was .050 inch and the radius, in cross section, of the corrugation was 0.060 inch. I have made cone diaphragms employing the logarithmic spiral curve of other sizes, as large as 12 inches in diameter, but do not wish to be restricted by the above figures which are given only by way of example.

Referring to Fig. 1*a*, more in detail, the centering disc 7 is preferably made of damping material having a substantial degree of flexibility, such as rubberized fabric. This material in sheet form is rather tightly stretched over a flanged frusto-conical ring 8 and cemented thereto as a sub-assembly prior to attachment to the small end of the cone adjacent the driving coil.

Referring to Fig. 2*a*, and to certain explanations given above, in place of the single corrugation shown in Fig. 1 or 6, it may be desirable to divide the corrugation into a plurality of shallower corrugations 11*a* of which I have illustrated a family of two corrugations in the compliant path.

Referring to Fig. 4 of the drawings, I have shown a characteristic curve of a plain cone diaphragm in a dynamic speaker working into a baffle, the curve being plotted between sound pressure, in any arbitrary units, and frequency in cycles per second. Because of the fact that the base of the cone is supported by compliant material which does not have the fully desired mechanical characteristic, there being no commercially practical material available, there are reflections from the base edge which cause in-phase and out-of-phase disturbance at the higher frequencies, resulting in peaks *p1*, *p2*, etc. and dips *d1*, *d2*, etc. It is noted that dip *d1* occurs at about double the frequency of peak *p1*. The basis for my improved diaphragm with the single corrugation was founded upon the fact that with different size cones the peaks and dips were found to vary in frequency position inversely as the size of the cone. In other words, I found, for instance, that with a 12 inch cone the first dip in the acoustic curve occurred at about 1250 cycles. This established the relation that the dip and peak spectrum depends on the physical distance from the voice coil to the edge of the cone. Therefore, it was felt that if means could be provided by which this distance could be made variable about the cone in a circumferential direction, the dips and the peaks could be smoothed out. After considerable development work I found that a spiral-shape corrugation or compliance in the cone, as shown in Fig. 1, produced the desired results.

Referring to the curves shown in Fig. 3, curves A to X, in dot-dash lines, certain of which have been omitted to avoid unnecessary complication, correspond respectively with imaginary radial sectors A to X of the diaphragm in Fig. 1. Curves A to X are similar in nature to the curve in Fig. 4, above described, except that each curve represents the performance of each radial sector.

For the purpose of further simplifying the explanation I have plotted the curves for only the higher audio range of 1000 to 6250 cycles, the range in which the peaks and dips occur in practice. The analysis of the characteristics of acoustic diaphragms is extremely complicated and it will be understood that my explanation is not to be taken as completely comprehensive nor as a limitation upon the scope of my invention.

The corrugation (in the case of a 6 inch cone) is placed at a varying radial distance *r'* from the voice coil, for twenty-four positions or equally divided sectors about the circumferential expanse of a cone diaphragm. The effective response from each section is calculated, for the frequencies 1000 to 6250, shaping the peaks and dips in accordance with the *r* ratio which is *r'* (average) divided by 2.81 (where 2.81 represents in inches the radial distance from the voice coil to the base edge of the diaphragm). A correction should be made in each section for the area, since a larger area contributes more to the final response than a smaller area. To tabulate the entire calculation for deriving the curves would appear to be unnecessarily complicated, so the following figures are given for certain of the sectors, such as A and X.

Section	r'	r Ratio	Sound units	
			1000 Cycles	6250 Cycles
A	1.007	.358	56.6	54.8
X	2.301	.818	212.5	330.5

Curve Y of Fig. 3, shown in full lines, is derived from the summation of the component curves A to X and illustrates the manner in which

the dips and peaks of the components add to produce an overall characteristic that is substantially uniform. It should be noted that the dip *d1* of curve X is quite pronounced.

The corrugation acts very much like the edge of a cone diaphragm, in producing reflections at different frequencies, which reflections cause the peaks and dips as measured in the response curves. According to one way of viewing the matter, the compliant coupling, formed by the corrugation, is of such nature that for low frequencies the diaphragm sections on both sides of the corrugation vibrate as a whole but as the frequencies become higher the compliant coupling transmits less and less of the higher frequency vibratory energy, which travels by wave action, to the outer portion.

It will be noted that the compliant spiral path, starting from the point nearest the voice coil progresses very gradually in a radial direction around the circumferential expanse of the diaphragm for a considerable distance but toward the other end of the path the advance becomes very rapid. This is essential in order to give more effect to the summation of the sectors having the smaller high frequency areas.

Referring to the curves of Fig. 3, it will be noted that the first peak for each section occurs at a higher frequency as the radial distance from the voice coil to the corrugation decreases. In other words, the corresponding peaks and dips vary inversely with the radial distance to the corrugation. It will be seen that the resultant effect is comparable to the effect produced by 24 diaphragms of different size and characteristics, used in combination for the production of uniform output.

Referrring to Fig. 5, I have shown a simplified way in which a cone diaphragm may be corrugated. Although the results are not so favorable as with my preferred modification, they are a considerable improvement over the type now in general use. A single corrugation 21 is embossed in the paper in the blank form. For simplifying operations it has been found that quite satisfactory results may be obtained with a circular corrugation, the center of which is at 23, eccentric with respect to the center 25 of the cone blank. It is preferred that the center 23 be on the side of center 25, opposite the removed sector, rather than diametrically opposite since the ends of the corrugation meet at a more practical angle. Making the corrugation circular in this manner greatly simplifies the tools and expense of production, principally because it is easier to cut a circular groove in a die than a helical one, and will give sufficiently good results for many purposes.

Referring to Fig. 6, it will be seen that the corrugation 21 departs from a circle when the diaphragm is coned up. The corrugation lies substantially in a plane that cuts the dynamic axis of the diaphragm at an acute angle. The disadvantage of this arrangement is that there is not as great control over the progressive variation in the above mentioned "*r* ratio" around the circumferential expanse since the variation is limited by the choice and positioning of a circular corrugation in the blank.

Referring to Figs. 7 and 8, the portion of the diaphragm, corresponding to the corrugation of Figs. 1 and 6, has been cut away at 26 and replaced by a compliant coupling strip 27 of damping or high loss compliant material, one species of which is illustrated in Bedford 1,846,937, namely a flexible succinate resin, of high viscosity yet elastic. Another material that is very good is known as "viscoloid", a form of celluloid with a plasticizer. Such a structure is not so desirable from the point of view of durability, production difficulties, cost, etc. There would be little or no advantage in using such an arrangement in connection with diaphragms of fibrous material such as paper which has quite desirable damping characteristics, but it may be desirable to employ such a nonintegral compliance in the case of hard material such as metal where the diaphragm material itself is inherently not damped.

While I have illustrated my invention in connection with conical diaphragms of the seamed type made from the flat sheet material, it will be understood among those skilled in the art that the invention also has as much utility in the case of cone diaphragms of the seamless type. It will also be understood that the same invention will have utility when applied to diaphragms of other than conical configuration, such as the trumpet type or the dish type, that is, where the cone departs from a straight line in its transverse section into a bowed-in or a bowed-out construction, the latter of which has substantial acoustic and mechanical advantages. I desire it to be understood that the term piston diaphragm or diaphragm of the conical type will also include these forms of diaphragms. I have disclosed my invention in connection with cone type diaphragms mainly because they are in more general use and are easily formed of flat material. This type of diaphragm may be further considered as being of the substantially free or unrestrained class, wherein the diaphragm vibrates as a whole, or piston fashion, for the lower audio frequencies because of the rigidity of the diaphragm and the flexibility of the supports, as distinguished from the flexing disc type diaphragms used in telephone receivers and sound boxes which are rigidly supported at the peripheral edge and, therefore, incapable of vibration as a whole at any frequency.

It will be understood that other modifications may be made within the spirit of my invention without departing from the scope thereof and I do not wish to be restricted to the modifications that I have disclosed.

I claim as my invention:

1. In an acoustical device, a diaphragm of the conical type, translating means attached thereto, means for flexibly supporting the periphery of said diaphragm, compliant means for radially subdividing the diaphragm non-symmetrically into inner and outer sections, characterized by successive sectors varying in mechanical and acoustic characteristics continuously around the circumferential expanse of the diaphragm, said translating means being attached to one of said sections.

2. In an acoustical device, a diaphragm of the conical type, translating means carried thereby, means for supporting said diaphragm for vibration as a whole at lower audio frequencies, compliant coupling means for subdividing said diaphragm, said means being disposed eccentrically with respect to the axis of said diaphragm whereby successive sectors of said diaphragm vary in mechanical and acoustic characteristics around the circumferential expanse of the diaphragm.

3. In an acoustic diaphragm, a frusto-conical diaphragm of fibrous material formed with a seam, a single helically arranged compliant coupling path embossed in the surface of the dia-

phragm and characterized by the ends of the coupling path terminating on opposite sides respectively of said seam.

4. The method of forming a conical diaphragm from a flat sheet of fibrous material which comprises forming a circular sheet, removing a circular central and concentric section, removing a sector of said sheet, embossing in the sheet a single corrugated path extending around said sheet eccentrically with respect to the center thereof and securing the radial edges of said sheet together to form a frusto-cone.

5. In an acoustical device, a diaphragm of the conical type, means for flexibly supporting the periphery thereof, an eccentrically arranged compliant coupling path radially subdividing said diaphragm into inner and outer substantially plain non-symmetrical conical surfaces, and translating means attached to one of said surfaces.

6. In an acoustic diaphragm of the conical type, an eccentrically arranged compliant coupling path formed in the surface thereof, said path lying substantially in a plane that cuts the axis of the diaphragm at an acute angle.

7. In an acoustic diaphragm of the direct acting conical type, a plurality of substantially non-symmetrical outer and inner sections of non-circular contour and having different mechanical and acoustical characteristics, compliant coupling means connecting adjacent sections, and driving means for actuating said diaphragm connected to said inner section.

8. In an acoustic diaphragm of the conical type, a compliant path dividing said diaphragm mechanically and acoustically into outer and inner sections, said path being helically arranged with respect to the axis of revolution of the diaphragm and extending substantially throughout one angle of revolution of the cone.

9. The invention as set forth in claim 8 characterized in that said compliant path comprises a plurality of closely spaced corrugations.

10. The invention as set forth in claim 8 characterized in that said path comprises damping material having high loss characteristics.

11. In a conical type acoustic diaphragm of fibrous material, means for rendering said diaphragm non-symmetrical acoustically and mechanically comprising a single compliant path, said path including a corrugation embossed in said diaphragm and arranged substantially helically with respect to the diaphragm axis.

12. In an acoustical device, a diaphragm of the conical type, means for flexibly supporting the base of said diaphragm for vibration as a whole for lower audio frequencies, said diaphragm being of fibrous material and provided with a single corrugation of logarithmic derivation and arranged helically with respect to the axis of said diaphragm around the circumferential expanse thereof, and driving means carried by the small end of said diaphragm whereby said corrugation functions at higher audio frequencies as a flexible support for the portion of the diaphragm adjacent said translating means.

13. The invention as set forth in claim 1 characterized in that said compliant means comprises a corrugation embossed in the surface of said diaphragm and arranged helically with respect to the moving axis of said diaphragm.

14. In an acoustical translating device, a diaphragm of the conical type, means for supporting said diaphragm for vibration as a piston at lower audio frequencies, compliant means eccentrically disposed with respect to the axis of said diaphragm and around the circumferential expanse thereof for radially sub-dividing said diaphragm non-symmetrically into inner and outer sections, translating means attached to said inner section for driving both of said sections piston fashion at lower audio frequencies and substantially only the inner section at certain higher audio frequencies.

15. In an acoustic translating device, a diaphragm of the conical type, means for so flexibly supporting the diaphragm that it is adapted to vibrate as a whole at lower audio frequencies, a compliant path eccentrically disposed in the surface of said diaphragm with respect to the moving axis thereof for radially sub-dividing said diaphragm into outer and inner non-symmetrical portions, driving means directly attached to said inner portion for driving same at higher audio frequencies, and through said compliant path, driving the diaphragm as a whole at lower audio frequencies, said compliant path being characterized in that it transmits less high frequency wave energy to the outer section as the frequency increases.

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