Feb. 5, 1935. G. F. DUTTON 1,990,066

DIAPHRAGM FOR ACOUSTIC DEVICES

Filed Nov. 15, 1933 2 Sheets-Sheet 1

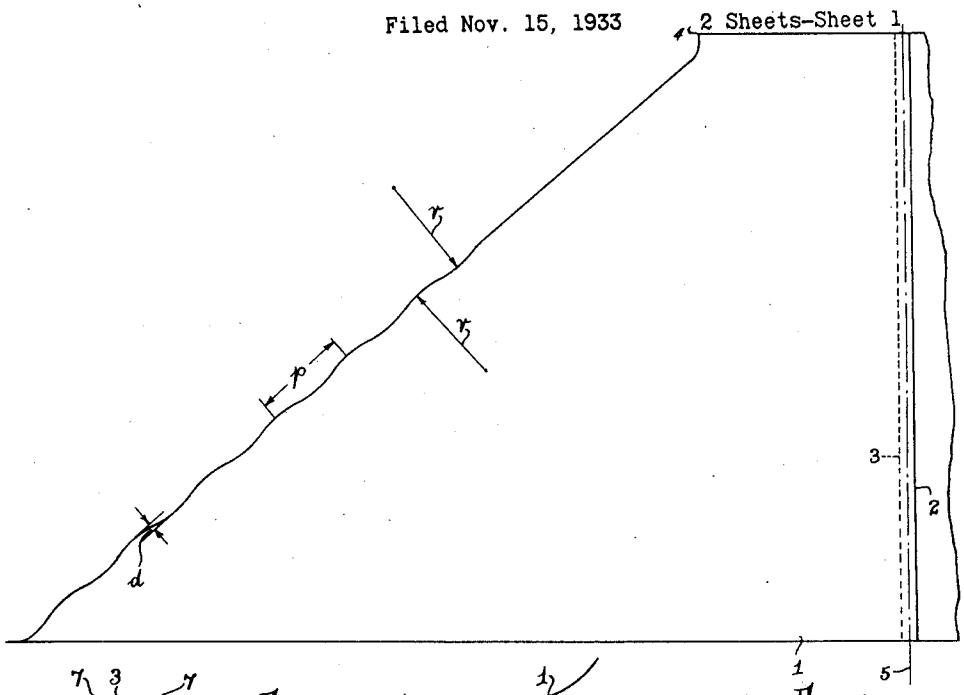


Fig. 1.

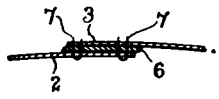


Fig. 2.

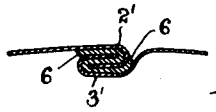


Fig. 3.

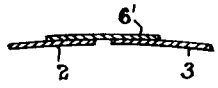


Fig. 4.

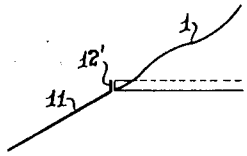


Fig. 8.

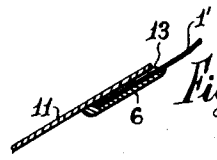


Fig. 9.

Fig. 7.

INVENTOR
GILBERT FARADAY DUTTON
BY H. S. Sweet
ATTORNEY

Feb. 5, 1935. G. F. DUTTON 1,990,066

DIAPHRAGM FOR ACOUSTIC DEVICES

Filed Nov. 15, 1933 2 Sheets-Sheet 2

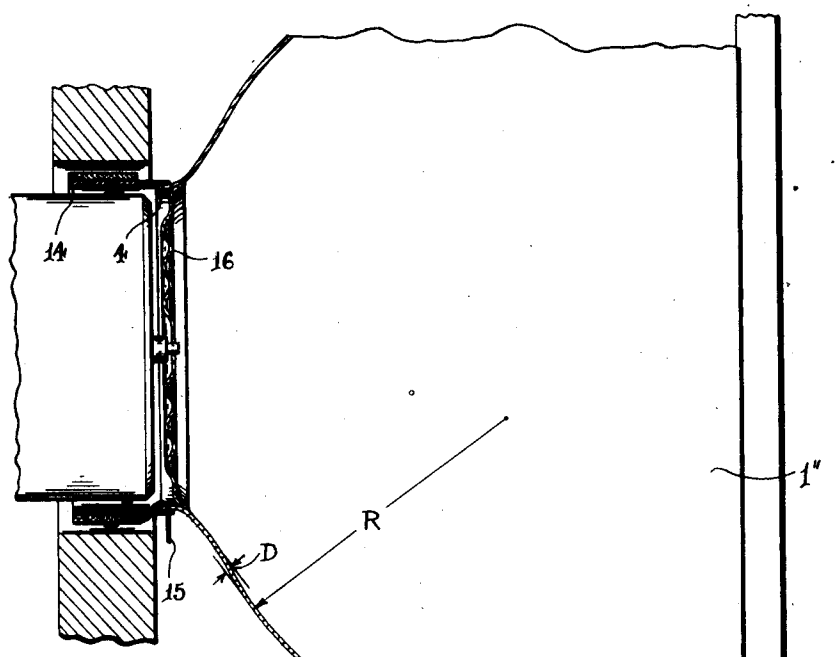


Fig. 5.

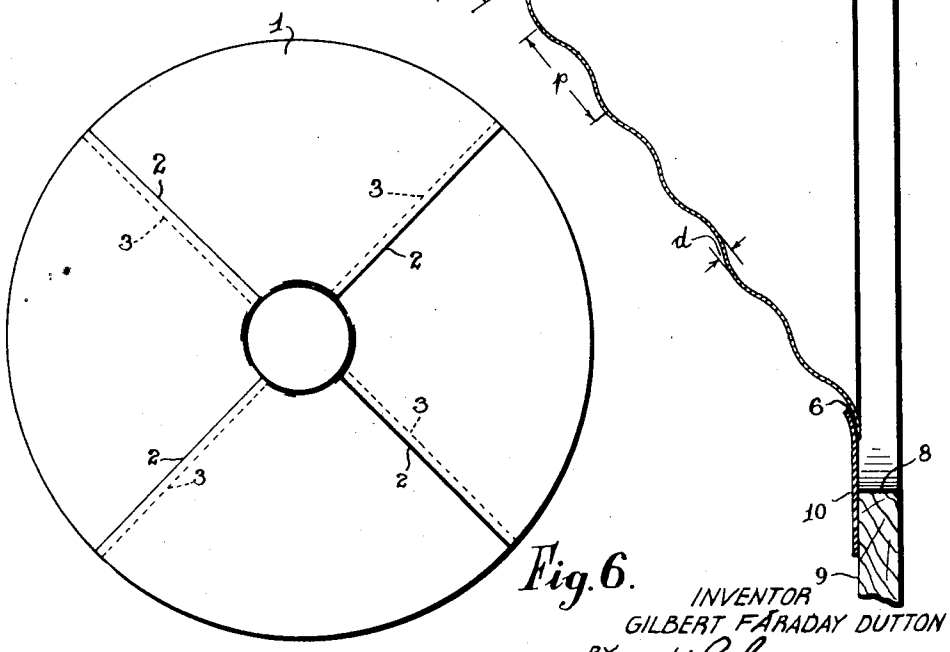


Fig. 6.

INVENTOR
GILBERT FARADAY DUTTON
BY H. S. Brown
ATTORNEY

Patented Feb. 5, 1935 1,990,066

UNITED STATES PATENT OFFICE

1,990,066

DIAPHRAGM FOR ACOUSTIC DEVICES

Gilbert Faraday Dutton, South Kensington, London, England, assignor to Electric and Musical Industries Limited, Hayes, England, a company of Great Britain

Application November 15, 1933, Serial No. 698,052
In Great Britain November 15, 1932

20 Claims. (Cl. 181—32)

The present invention relates to acoustic devices and more particularly to large diaphragms, that is to say diaphragms of a size adapted to radiate sound effectively without the aid of a horn, and to arrangements for supporting such diaphragms.

Hitherto large conical diaphragms have usually been made of paper, and in some cases these have been corrugated. It has usually been found that such a paper diaphragm can be made thick enough to prevent undue trouble due to the formation of radial modes at low frequencies. A diaphragm is said to vibrate in a radial mode when one part thereof vibrates relatively to another part thereof in such a manner that nodes and antinodes lie along a radial line on the diaphragm. These radial modes do not assist radiation, since simple air-flow takes place from one moving surface to the adjacent oppositely moving surface. There is, however, a reaction on the actuating means which tends to increase the effective mass of the diaphragm, and hence the final response characteristic curve of the diaphragm will show a depression at the frequency at which a radial mode occurs.

Variation in radial modes produces bending stresses in the diaphragm; hence increasing the thickness of the diaphragm raises the frequency at which the radial mode occurs; and the introduction of internal friction damps the vibrations. A diaphragm of paper having a density of 0.7 gram per cubic centimetre can be made 0.02 inch thick without being unduly heavy. Such a diaphragm is very stiff as regards bending, and this property, together with internal friction, is sufficient to suppress the radial modes in the lower frequency range, that is below 2,000 cycles per second. If the paper is thinner, for example 0.01 in. thick, radial modes in the lower frequency range tend to become troublesome.

Paper, whether plain or impregnated with hardening resins, does not have a very high wave transmission velocity. The value of this velocity is given by the square root of the ratio of the Young's modulus to the density. In the best kraft paper the velocity is 1.7×10^5 cm. per second, and impregnating this paper with a hard resin may increase this value to 2.5×10^5 cm. per second. The high-frequency response of a conical diaphragm depends on this value of wave velocity, a low value giving a low cut-off frequency and vice versa. At frequencies exceeding 2,000 cycles per second, wave transmission begins to become apparent in a large conical diaphragm. It is necessary that this type of transmission should occur, since it reduces the effective mass of the diaphragm. In an ideal diaphragm wave transmission would take place without wave reflection, all the energy being radiated before the wave reached the boundary of the diaphragm.

Hitherto attempts have been made to use aluminium, which has a higher ratio of Young's modulus to density than paper (its wave transmission velocity being about 5.1×10^5 cm. per second), for conical diaphragms, but such diaphragms have proved unsatisfactory on account of radial modes and strong reflections. These defects are due to the high density of aluminium, compared with paper, which necessitates the use of thin material about 0.0025 in. thick, and to the small internal friction of such a diaphragm. The radial modes therefore appear at low frequencies and tend to cause the diaphragm to rattle.

A known conical aluminium diaphragm has a small number of widely spaced concentric depressions, or half corrugations with uncorrugated portions between them. This arrangement is not satisfactory, since reflection occurs at the corrugations and the metal between the corrugations buckles under the stresses imposed by normal operation and emits rattling sounds similar to the noise made by shaking a thin sheet of metal.

It has been proposed to use a conical diaphragm of aluminium or aluminium alloy having continuous corrugations in its surface. The corrugations were, however, of such a shape and depth that portions thereof lay substantially in planes normal to the direction of vibration of the diaphragm.

An object of the present invention is to provide a diaphragm which has a good response to the higher as well as to the lower acoustic frequencies.

A further object is to provide a metal diaphragm in which the defects hereinbefore referred to are obviated.

According to the present invention a large acoustic diaphragm comprises (that is to say is formed substantially wholly or partly of) a material having a higher ratio of Young's modulus to density than paper and is provided with corrugations merging into one another over at least a part of the surface of this material, the ratio of the pitch of the corrugations to the depth thereof (measured from trough to crest) being greater than 5 to 1.

According to the invention in a further aspect, a large acoustic diaphragm is formed substantially wholly of a material having a higher

ratio of Young's modulus to density than paper and provided with corrugations merging into each other over at least the radially outer portion of its surface, the ratio of the pitch of the corrugations to the depth thereof being not less than 8 to 1.

According to the invention in yet another aspect, a large acoustic diaphragm comprises a radially inner portion formed of a material having a higher ratio of Young's modulus to density than paper, this portion being provided with corrugations merging into one another over at least a part of its surface, the ratio of the pitch of the corrugations to the depth thereof being greater than 5 to 1. The radially outer portion of this diaphragm is preferably of paper and of frusto-conical form.

The functions of the corrugations are to remove irregularities from the surface of the diaphragm, to increase the lowest frequency at which radial modes of vibration take place and to give the diaphragm the stiffness necessary for safe handling. It is therefore important that, at least in the outer region of the material having a high ratio of Young's modulus to density, the corrugations should merge into one another and not be spaced widely apart by uncorrugated portions.

It is preferred to make the improved diaphragms of dished form, such as of conical form (which term in the appendant claims is to be read as including a frusto-conical form), and where a dished form is employed, it is advantageous to make the shape of the corrugations such that all parts thereof lie at a considerable angle to planes normal to the direction of vibration of the diaphragm.

The region round the driving point of a conical diaphragm or driving zone of a frusto-conical diaphragm may be uncorrugated or provided with corrugations of smaller depth, or longer pitch, or both, than those on a region farther from the driving point or zone. Where the region round the driving point or zone is uncorrugated the material may be thicker there than elsewhere. Alteratively in a frusto-conical diaphragm the smaller diameter end may have the form of a cylindrical metal spigot flared out of the frustum so as to provide the necessary rigidity.

When vibrated at high frequencies, say from about 1,500 cycles per second upwards, a cone of, for example, 7 in. diameter acts in the manner of a mechanical transmission line, the impedance of which increases from the centre outwards. In order to avoid the formation of pronounced standing waves in the diaphragm, the latter must represent a smooth mechanical transmission line. It is therefore necessary to avoid a sudden change of mechanical impedance along the cone radius, such as would occur if the corrugations were deep. The corrugations should consequently be made as shallow as possible, consistent with freedom from rattle. It is also necessary to terminate the mechanical line with a suitable resistive element of approximately the same impedance as the cone. In this way the formation of pronounced standing waves due to reflection from the periphery of the diaphragm is prevented.

A preferred arrangement to prevent appreciable reflection from the periphery is to mount the edge of the diaphragm within a circular aperture in a box or baffle with the aid of an annulus of velvet or the like, there being interposed between the annulus and the diaphragm a layer of a substance which offers high internal friction to distortion due to vibrations and which is capable of withstanding considerable distortion within the elastic limit. A suitable substance is a highly-plasticized vinyl acetate polymer, a suitable plasticizer being tricresyl phosphate.

In order to damp vibrations within the diaphragm, it may be formed with one or more joints incorporating a damping substance such as the above mentioned polymer.

The invention will be further described with reference to the examples shown in the accompanying drawings, in which

Fig. 1 is a section of part of a metal frusto-conical diaphragm,

Figs. 2, 3 and 4 are diagrammatic sections of alternative forms of radial joint in the diaphragm shown in Fig. 1,

Fig. 5 is a section of part of a moving-coil loud speaker comprising an alternative form of metal frusto-conical diaphragm,

Fig. 6 is a front elevation of a modification of the diaphragms shown in Figs. 1 and 5,

Fig. 7 is a section of part of a metal and paper frusto-conical diaphragm,

Figs. 8 and 9 are diagrammatic sections of alternative forms of circumferential joint in the diaphragm shown in Fig. 7.

Referring to Fig. 1, the diaphragm 1 is formed from a circular sheet of aluminium about 8 in. in diameter. After a central disc and a sector have been cut from it, the sheet is formed in known manner into a conical frustum by joining the two radial edges 2 and 3, the apex angle of the frustum being about 105 deg. The joint is made by applying the vinyl acetate polymer softened by heat and lapping the edges. The frustum is then placed in a press and corrugated. While the diaphragm is in the press, the smaller diameter end is drawn into a cylindrical spigot 4 adapted to receive a driving coil. The corrugations are concentric with the cone and extend from the periphery inwards for about two-thirds of the distance from the periphery to the spigot, the radially inner portion being uncorrugated. The corrugations are formed by merging arcs of which the radius r is 0.4 in. and the depth d is 0.015 in. The pitch p is thus about 0.3 in., and the ratio of pitch to depth is about 20 to 1. Further, the corrugations are all of such shape and depth that no parts thereof approach parallelism to planes normal to the direction of vibration of the diaphragm as a whole, that is normal to the axis 5 of the frustum.

Owing to the reaction following the stretching process of drawing the spigot, the metal of the spigot is put into circumferential compression and the metal in the zone immediately adjoining the spigot is put into circumferential tension. This prevents the occurrence of slackness over any small area of the radially inner part of the diaphragm and obviates crackling noises during operation.

The aluminium has the following properties: Breaking stress, 9 to 10 tons per square inch; Young's modulus, 7.3×10^{11} dynes per sq. cm. For this aluminium cone of about 7 in. in diameter the preferred thickness is 0.0025 in. Radial modes have been found to become prominent in diaphragms of this kind if the thickness exceeds 0.004 in. and the diaphragm becomes too fragile if the thickness is below 0.0015 in.

The value of the square root of the ratio of

Young's modulus to density for this quality of aluminium is about 5.1 x 10^5 cm./sec. whereas the corresponding value for paper is between about 1.7 x 10^5 and 2.5 x 10^5 cm./sec., as hereinbefore mentioned.

The aluminium used in constructing the above diaphragm is known as semi-hard. If harder material is used it will be found to have become too hard (and therefore liable to fracture in use) after the corrugations have been formed if these are formed in the cold. A softer material has not sufficient strength to withstand sudden low frequency impulses such as may be met with in practice. If the material is annealed during the corrugating process it may be possible to use a harder material. In any case endeavour should be made to arrange that when the corrugating process has been finished the material of the diaphragm has the highest possible degree of hardness consistent with capacity to resist alternating stress without fracture.

In order to damp circumferential vibrations, the diaphragm shown in Fig. 1 may be modified by the provision of a plurality of radial joints, for example four, spaced at equal intervals, and incorporating a damping substance. These joints may be plain lapped joints, as previously described and as shown in Fig. 6. Alternative forms of joints are shown in Figs. 2, 3 and 4. In Fig. 2, the lapped edges 2 and 3 are united by a layer 6 of plasticized vinyl acetate polymer reinforced by thread stitches 7. Fig. 3 shows a folded joint, with the vinyl acetate polymer 6 lying between the folded edges 2' and 3'. In Fig. 4 the edges 2 and 3 are substantially butted and joined by a butt strap 6' of resistance material, which may be the vinyl acetate polymer. The diaphragm provided with such joints consists, nevertheless, substantially wholly of metal.

The above-described diaphragms may be mounted in a manner similar to that hereinafter described with reference to Fig. 5.

An alternative form of diaphragm is generally similar to that described with reference to Fig. 1, except that it has no radial joints. Furthermore, the spigot may be shorter, the necessary stiffness being provided by making the metal of the radially inner zone thicker than elsewhere. Thus the conical blank may be spun from a sheet of a thickness equal to the maximum thickness of the finished diaphragm, the radially outer portion being drawn thinner by the spinning operation. Alternatively the conical blank may be formed from a flat sheet by a series of drawing operations interspersed with annealing operations, by which the thickness can be graduated as desired.

In the modified diaphragm shown in Fig. 5, which however has not been found quite so satisfactory as that shown in Fig. 1, such a jointless construction is adopted. The size and material are substantially the same, but the corrugations over the outer two-thirds of the diaphragm surface are formed by merging arcs of which the radius r is 0.21 in. and the depth d 0.04 in. In this case the pitch p is about 0.36 in., and the pitch-to-depth ratio is therefore about 9 to 1. The inner one-third of the cone-surface is provided with a little more than one shallow corrugation of which the dpth D is 0.03 in., formed by merging arcs of 1.25 in. radius R. The pitch is then about 0.95 in. and the pitch-to-depth ratio is 32 to 1. The thickness of the diaphragm is preferably graded from 0.004 in. at the spigot to 0.002 in. at the periphery.

The driving coil former 14 is attached to the spigot 4 by cellulose cement, and the leads to the driving coil (one of which is shown and denoted by 15) are secured to the former 14 and not to the cone, to avoid rattling. The diaphragm 1'' is supported at its centre in known manner by means of a corrugated buckram spider 16 (see Fig. 1) secured by an adhesive such as cellulose cement to the cone, and it is mounted within an aperture 8 in a box or baffle 9 with the aid of a ring 10 of velvet attached by means of plasticized vinyl acetate polymer 6 to the periphery of the diaphragm 1''. The velvet ring 10 may be impregnated with this polymer which may be dissolved in methylated spirit or benzol and applied cold.

Fig. 7 shows a further form of diaphragm having a radially inner portion 1' of aluminium and a radially outer portion 11 of paper. The maximum diamter is about 7 in. and the frustum of paper 11 extends from the periphery to the mid point between the periphery and the spigot 4, being joined at 12 to the aluminium portion which is 0.0025 in. thick and provided with corrugations of the same section as those shown in Fig. 1 and extending from the joint 12 to about the mid point between the joint and the spigot. The joint 12' shown in Fig. 8 is lapped, a resistance material, for example plasticized vinyl acetate polymer, being used as the adhesive. The joint may, if desired, be reinforced, for example by sewing with thread, similarly to the radial joint shown in Fig. 2. Alternative forms of resistance joints between the aluminium and the paper are shown in Figs. 8 and 9. In Fig. 8 the paper and the aluminium cones are flanged, the resistance material 6 being employed to couple the flanges together. In Fig. 9 the two portions are lap jointed and secured by a relatively rigid adhesive 13, such as cellulose cement, the joint being coated with a damping layer of the resistance material 6.

I claim:

1. A large acoustic diaphragm comprising a material having a higher ratio of Young's modulus to density than paper, and provided with corrugations merging into one another over at least a part of the surface of said material, the ratio of the pitch of said corrugations to the depth thereof being greater than 5 to 1.

2. A large acoustic diaphragm formed substantially wholly of a material having a higher ratio of Young's modulus to density than paper and provided with corrugations merging into one another over at least the radially outer portion of its surface, the ratio of the pitch of said corrugations to the depth thereof being not less than 8 to 1.

3. A large acoustic diaphragm the radially inner portion of which is formed of a material having a higher ratio of Young's modulus to density than paper, said portion being provided with corrugations merging into one another over at least a part of its surface, the ratio of the pitch of said corrugations to the depth thereof being greater than 5 to 1.

4. A large acoustic diaphragm of conical form, comprising a material having a higher ratio of Young's modulus to density than paper, and provided with corrugations merging into each other over at least a part of the surface of said material, the ratio of the pitch of said corrugations to the depth thereof being greater than 5 to 1.

5. A large acoustic diaphragm comprising a radially inner portion of conical form and of

a material having a higher ratio of Young's modulus to density than paper, and a radially outer portion of frusto-conical form and of paper.

6. A large acoustic diaphragm comprising a radially inner portion formed of a material having a higher ratio of Young's modulus to density than paper and provided with corrugations merging into one another over at least a part of its surface, and a radially outer portion of frusto-conical form and of paper.

7. A large acoustic diaphragm of dished form and provided with corrugations merging into one another over at least a part of its surface, the shape of said corrugations being such that all parts thereof lie at a considerable angle to planes normal to the direction of vibration of the diaphragm.

8. A large acoustic diaphragm of conical form, comprising a material having a higher ratio of Young's modulus to density than paper, and provided with corrugations merging into one another over at least a part of the surface of said material, the shape of said corrugations being such that all parts thereof lie at a considerable angle to planes normal to the direction of vibration of the diaphragm.

9. A large acoustic diaphragm of conical form, comprising a material having a higher ratio of Young's modulus to density than paper, the part of said material in the region round the driving point or zone being uncorrugated, and the part of said material in a region farther from said point or zone being provided with corrugations merging into one another, the ratio of the pitch of said corrugations to the depth thereof being greater than 5 to 1.

10. A large acoustic diaphragm of conical form, comprising a material having a higher ratio of Young's modulus to density than paper, said material being provided with corrugations merging into one another over its surface, and said corrugations being of smaller depth in the region round the driving point or zone than in the region farther from said point or zone.

11. A large acoustic diaphragm of conical form consisting substantially wholly of a material having a higher ratio of Young's modulus to density than paper, the region round the driving point or zone being uncorrugated, and the radially outer region being provided with corrugations merging into one another and having a pitch-to-depth ratio of between 15 to 1 and 25 to 1.

12. A large acoustic diaphragm of frusto-conical form of which at least the radially inner portion is of metal uncorrugated in the region round the driving zone and provided with corrugations merging into one another over a region farther from said zone, the smaller diameter end of the diaphragm having the form of a cylindrical spigot flared out of the frustum in such a manner as to put the spigot into circumferential compression and the metal in the zone immediately adjoining the spigot into circumferential tension.

13. A large acoustic diaphragm of conical form comprising light metal having corrugations merging into one another over at least a part of said metal, the ratio of the pitch of said corrugations to the depth thereof being between 15 to 1 and 25 to 1.

14. A conical acoustic diaphragm of aluminium between 0.0015 and 0.004 in. thick, between 6 and 10 in. in diameter, having an apex angle of between 90 and 120 deg., and provided with corrugations merging into one another over at least the radially outer portion of its surface, the ratio of the pitch to the depth of the corrugations on said radially outer portion being between 8 to 1 and 30 to 1.

15. A conical acoustic diaphragm of which at least the radially inner portion is of aluminium between 0.0015 and 0.004 in. thick and has an apex angle of between 90 and 120 deg., the region of said portion more remote from the driving point or zone being provided with corrugations merging into one another and having a pitch-to-depth ratio of between 8 to 1 and 20 to 1.

16. A large acoustic diaphragm comprising a material having a higher ratio of Young's modulus to density than paper, and a joint incorporating a substance which offers high internal friction to distortion and which is capable of withstanding considerable distortion within the elastic limit, said diaphragm material being provided with corrugations merging into one another over at least a part of its surface, the ratio of pitch to depth of said corrugations being greater than 5 to 1.

17. A large acoustic diaphragm formed at least in part of a material having a higher ratio of Young's modulus to density than paper, and comprising a joint incorporating a highly plasticized vinyl acetate polymer which serves as a damping substance.

18. A large acoustic diaphragm of conical form comprising a material having a higher ratio of Young's modulus to density than paper and a joint incorporating a highly plasticized vinyl acetate polymer, said diaphragm material being provided with corrugations merging into one another over at least a part of its surface.

19. A large acoustic diaphragm comprising a material having a higher ratio of Young's modulus to density than paper, and a plurality of radial joints incorporating a material which offers high internal friction to distortion and which is capable of withstanding considerable distortion within the elastic limit.

20. In combination, a large acoustic diaphragm comprising a material having a higher ratio of Young's modulus to density than paper, and a mounting ring of flexible material attached to the periphery thereof by means of a highly plasticized vinyl acetate polymer.

GILBERT FARADAY DUTTON.