

Feb. 14, 1939.

A. NAGELVOORT

2,146,975

ACOUSTIC DIAPHRAGM

Filed Nov. 6, 1936

3 Sheets-Sheet 1

Fig. 1.

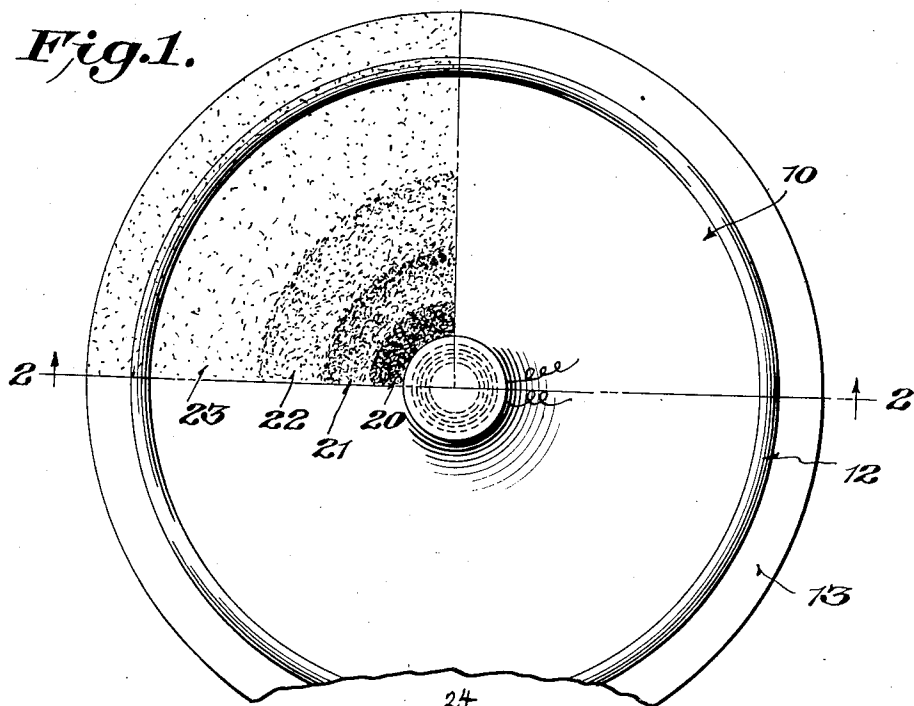


Fig. 2.

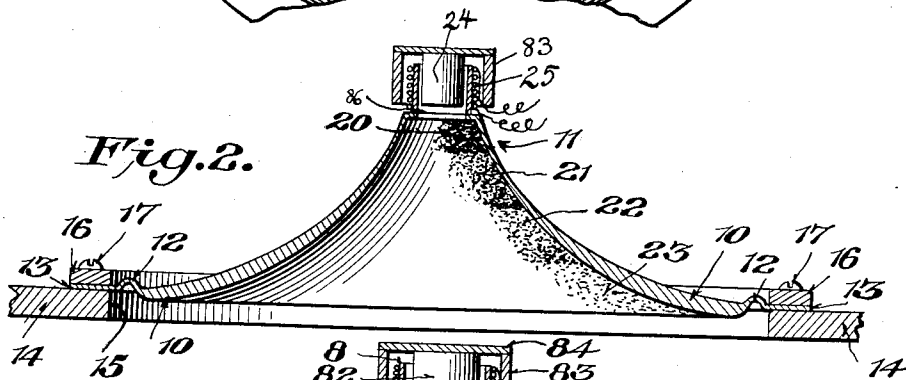


Fig. 3.

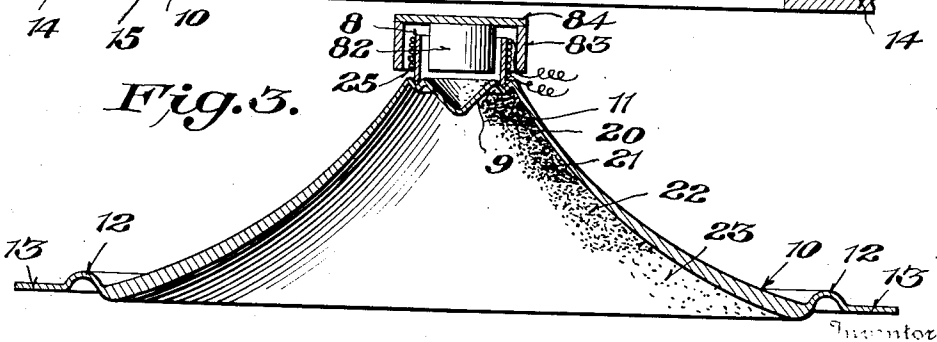
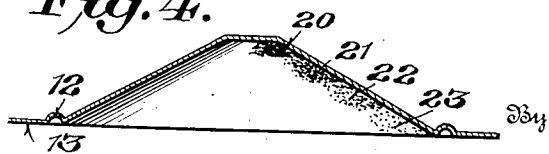


Fig. 4.



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Fig. 5.

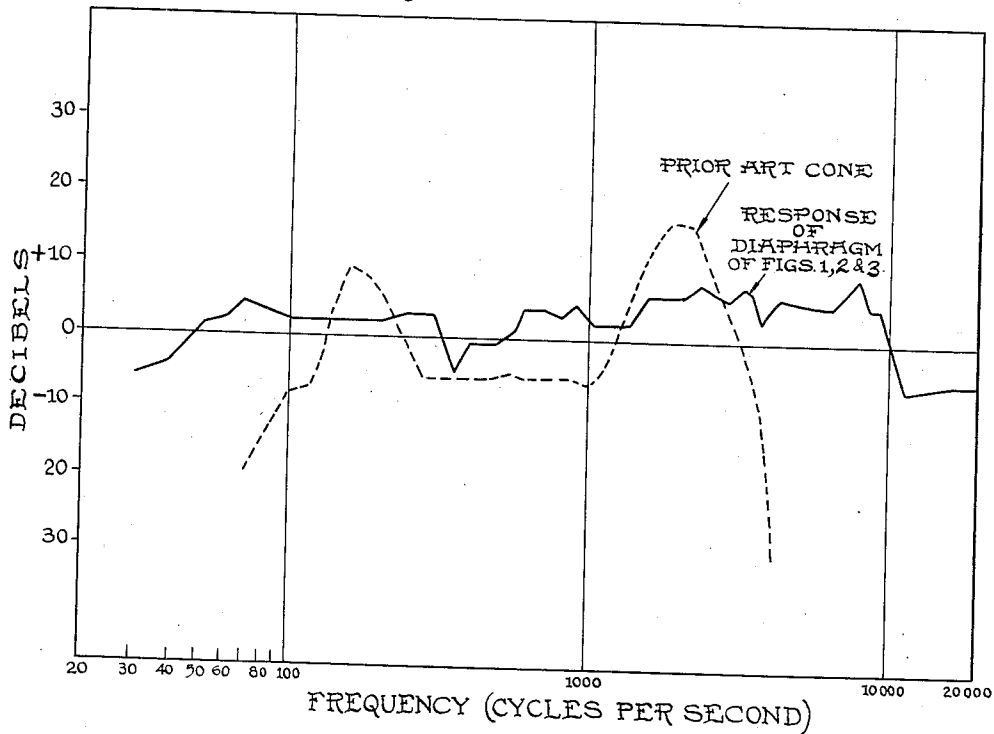
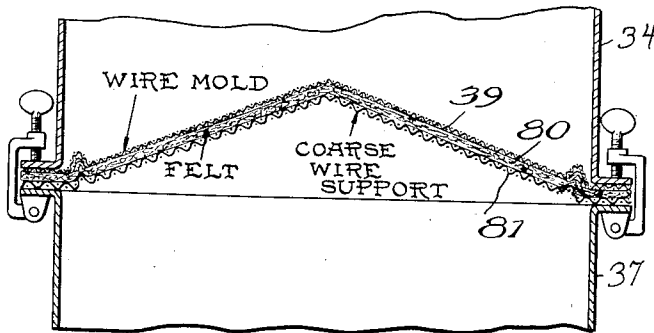


Fig. 8.

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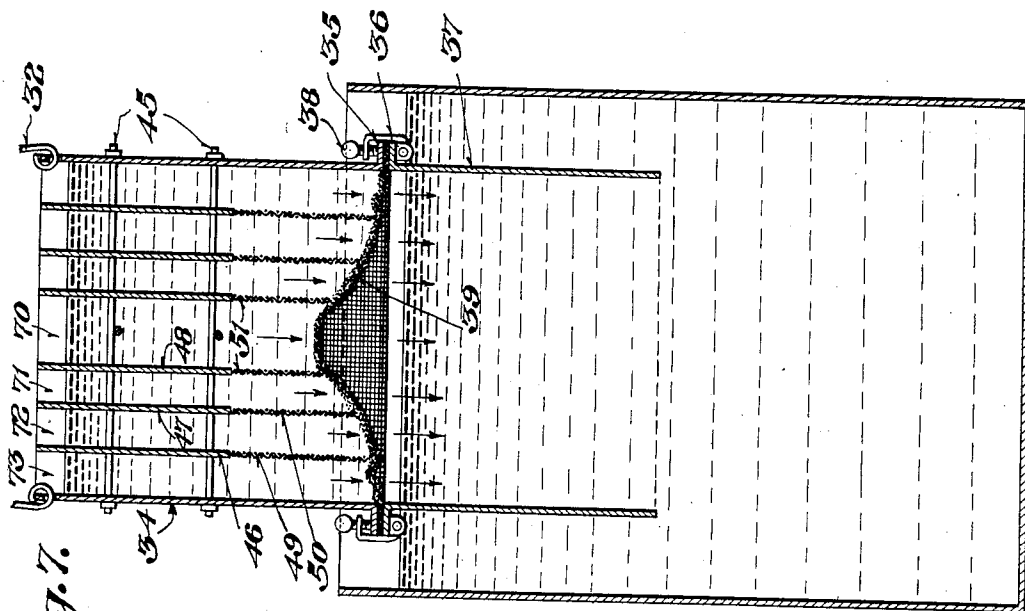


Fig. 7.

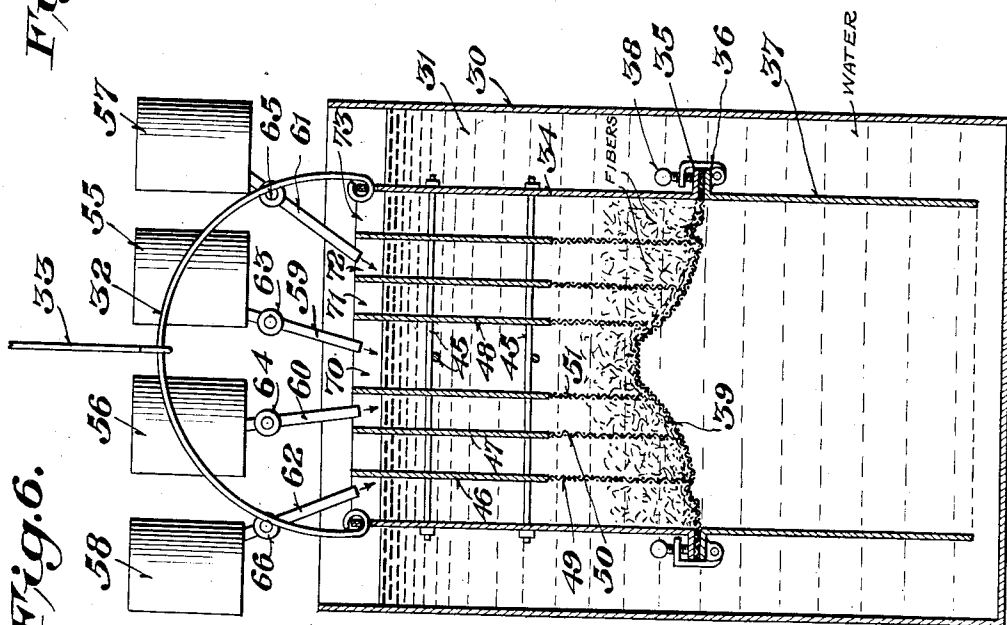


Fig. 6.

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UNITED STATES PATENT OFFICE

2,146,975

ACOUSTIC DIAPHRAGM

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Application November 6, 1936, Serial No. 109,579

4 Claims. (Cl. 181—32)

This invention relates to acoustic diaphragms; and it comprises a diaphragm of convex, non-planar shape, different annular regions of which are made of different kinds of fibrous material marginally merged and so arranged that the density, compactness and resiliency of the diaphragm are greatest adjacent the center and diminish towards the rim to a low value, the diaphragm also increasing in thickness from the center towards the rim, the diaphragm having substantially regular output for all frequencies in the range of audible sound and being free from distortion and rattling due to reflection waves in the diaphragm; all as more fully hereinafter set forth and as claimed.

Acoustic diaphragms for loud speakers are members of substantial area adapted to be vibrated by a modulated source of power (speaker unit) and thus to serve as a source of sound waves in air. The simplest arrangement, still used in telephones, is a marginally clamped disk of metal, paper, mica, etc., actuated by a power unit applied to the center. This arrangement, however, has the inherent disadvantage that it amplifies high pitches (high frequency vibrations) to a greater degree than low pitches and thus gives unfaithful reproduction of music and speech. The conventional cone diaphragm, usually a shallow paper cone marginally mounted and centrally actuated, is an improvement on the disk type.

In a prior Patent No. 1,832,832, issued Nov. 17, 1931, I have disclosed and claimed an improved acoustic diaphragm, made substantially in the shape of a semi-cubical paraboloid of revolution (the figure of rotation formed by rotating a semi-cubical parabola—equation $X^2=KY^3$ —about the axis of symmetry) and varying in thickness as the square of the radius; the variation usually being direct, that is, the thickness increasing as the square of the radial distance. The diaphragm of this prior patent is a considerable improvement over conventional diaphragms of flat or conical form. It gives a much more nearly uniform output for notes of various pitches (frequencies). The improvement is due to the bell or trumpet shape in combination with the thickness variation. However, in all homogeneous diaphragms there is a tendency for elastic compressional or longitudinal sound waves produced at the center to travel outward in the solid material and be reflected from the border of the diaphragm. This effect, which gives rise to rattling, buzzing and distortion, is inherent in any ordinary diaphragm no matter how it is mounted.

A web of fibers of cellulose or other paper making material, presents advantages for loud speak-

er diaphragms, over other materials such as wood, Bakelite or metal. The simplest way to make a paper cone is by folding a flat sheet of paper into a cone and fastening along the seam, but this does not give very good results. It has been proposed to make fiber cones directly, by depositing cellulose fibers from a water suspension upon a conical screen mold. It has also been proposed to make cones comprising two different kinds of fibers, by depositing different kinds of fibers alternately on different annular portions of a conical screen mold, in two operations, with the aid of annular masks. These proposals have not met with practical success, because they did not give anything like satisfactory knitting or merging of the two different kinds of fibers; the adjacent zones of fibers did not bond together. When each zone of fibers is allowed to mat by itself, the edges are smooth and the two zones cannot be made to knit together.

One object of the present invention is to produce a diaphragm free from distortion effects due to marginal reflections.

Another object is to produce a diaphragm which has a substantially uniform frequency response over the audible range (30 to 15,000 vibrations per second).

Another object is to produce a diaphragm including different kinds of fibers arranged in annular zones, the fibers in the different zones being thoroughly knitted together so that the diaphragm is structurally strong and acoustically efficient.

These objects are achieved by providing a diaphragm which has a shape and thickness variation generally similar to those specified in the prior patent, but instead of being homogeneous, is made of fibrous materials of different characters so that the diaphragm has a variable elasticity, density and degree of compactness from center to rim. In the best embodiment the diaphragm is made of a plurality of annular bands of different kinds of fibers or mixtures of fibers merging smoothly (without sharp discontinuities) from hard, dense fibers in the central region to soft, flexible fibers adjacent the rim. Thus the elasticity varies without discontinuities from a maximum in the central portion to a very low value adjacent the rim. With this structure, distortion due to reflections is eliminated, whatever the manner in which the diaphragm is mounted. This is because there are no interfaces which make possible reflection.

Thus the shape, the thickness variation and the variation in character of the different parts of the new diaphragm cooperate to produce a diaphragm which is free from all the defects of

conventional apparatus and which has remarkable properties.

I secure thorough knitting or interpenetration of the fibers of adjacent zones by simultaneously depositing the fibers from suspensions on a screen, from compartments separate from each other but in liquid communication near their bottoms and in communication for both liquid and fibers in the region adjacent the screen mold. By this expedient, some of the fibers from each of the two adjacent zones filter out in the rim of the other zone and produce a smoothly merging unitary structure of excellent acoustic and structural properties in one operation of molding. By depositing the annular zones simultaneously, the fibers at adjacent edges of each pair of zones interlace together and provide a strong bond.

In the accompanying drawings I have illustrated more or less diagrammatically three examples of specific embodiments of the new diaphragm, and also an example of the machine for making diaphragms, to illustrate the method.

In the drawings,

Fig. 1 is a plan view of a diaphragm;

Fig. 2 is a vertical section taken along line 2-2 of Fig. 1;

Figs. 3 and 4 are sectional views of modifications;

Fig. 5 is a chart showing the frequency-output characteristics of the new diaphragm;

Figs. 6 and 7 are diagrammatic sectional views of the machine for making diaphragms; and

Fig. 8 is a view of a modified mold arrangement.

The diaphragm

In the showings, in which like parts are denoted by the same reference characters throughout, Figs. 1 to 4 show the new diaphragm in detail. As shown (Figs. 1 and 2) the diaphragm proper is of a shallow trumpet or bell-like form, the shape being determined substantially as described in my prior patent, and has an annular rim portion 10 of gentle slope, merging gradually into a steep, almost cylindrical apex portion 11. Beyond rim 10 is a flexible, bellows-like folded annulus 12 and a supporting ring 13. The diaphragm is mounted (Fig. 2) on a mount 14 having an opening 15, being clamped thereto as by ring 16 and screws 17. The mount may be part of a radio cabinet. If the diaphragm be mounted in a box the interior of the box should be lined with sound-absorbing material.

The diaphragm is made of several different kinds of fibrous pulp in merging interlacing annuli. The portion adjacent the center is made of fibrous pulp which forms a thin, stiff hard web; e. g. sulfate (kraft) pulp. Outer portions of the diaphragm are made of progressively softer pulp mixtures; the intermediate zones usually being made of sulfate, wool and rope fibers in varying proportions and the outermost zones of wool or wool and hemp fibers. Sulfite pulp fibers can be used in the various zones. Wool fibers give a soft web or mat, almost like a felt.

In Fig. 1 there are shown four annular zones of fibers. The portion adjacent the center, denoted by 20, is made of sulfate (kraft) pulp. Annuli 21, 22 and 23 are made of fibers progressively decreasing in stiffness and resiliency. The diaphragm also increases in thickness outwardly, as shown; the actual thickness being exaggerated in the showing (Fig. 2) for the sake of clarity of illustration. In a typical embodiment

the annuli are formed of pulp and pulp mixtures as follows:

Annulus No.	Type of fiber	Average thickness	
		Percent	Inches
20.....	Sulfate.....	100	0.006
21.....	Sulfate.....	50	0.009
	Wool.....	35	
22.....	Rope.....	15	0.018
	Sulfate.....	25	
23.....	Wool.....	45	0.030
	Rope.....	30	
Fold (12).....	Hemp.....	25	0.010
Supporting rim (13).....	do.....		0.010

The width of the annular zones is regulated by the character of fibers used. Ordinarily the annuli are narrow adjacent the apex and broader near the rim. In the example given ante, annuli 20, 21 and 22 are of about the same width and annulus 23 is a little broader. There is considerable latitude in the width used.

The thickness variation described makes for the elimination of "sub-harmonics".

The rim portion 10 is thus made of soft and flexible material. In Fig. 1 the fold 12 and the supporting rim 13 are shown as made of the same wool-hemp fiber mixture. Sometimes I make rim 13 of somewhat stronger material, for the sake of mere mechanical strength. The rim 13 plays no part in the acoustics of the diaphragm, being insulated from the strongly vibrating portion by fold 12 and annulus 23.

A voice coil 25 is mounted on a cylindrical form 26 which is cemented to the diaphragm as shown, and cooperates with a stationary magnetized pole piece 24.

In operation, the coil and pole piece serve as an actuating power unit for the diaphragm. Most of the vibration takes place adjacent the apex, especially with high pitches. The rim portion 10 is, by reason of the radially decreasing resilience of the diaphragm, substantially dead even with a large volume of sound. Thus there is no chance for vibrational waves in the diaphragm to travel to the supporting rim and mount and be reflected, causing distortion or rattling. This result is secured by the continuous unbroken merging or interlacing of the different fiber annuli. A discontinuous or sharp joint between the pulp zones would defeat the object; since reflection takes place at any sharp boundary, such as the boundary between two unmerged kinds of pulp.

While Fig. 1 shows a diaphragm using four different kinds of fibers, a greater or a less number can be employed. The fold 12 is not essential, though it is desirable.

In another typical embodiment, using the same four kinds of pulp mixtures as in the first embodiment, a diaphragm 13 inches in diameter was made, in which the fibers were disposed as follows:

Annulus No.	Out-side diameter	Average thickness	Type of fiber	Weight of annulus
			Percent	Grams
20.....	5	0.010	Sulfate.....	100
21.....	7.5	0.015	Sulfate.....	50
			Wool.....	35
22.....	10.5	0.030	Rope.....	15
			Sulfate.....	25
23.....	13	0.010	Wool.....	45
			Rope.....	30
			Wool.....	75
			Hemp.....	25

The total weight of the diaphragm was only 12.5 grams or less than one-half ounce. The very light weight of my diaphragms is one of their advantages.

In this example the required weight of pulp for each annular zone was regulated directly by weighing the equivalent amount of pulp suspension into the receptacles therefor in the forming apparatus (see post).

Fig. 3 shows a slightly modified form of diaphragm, which has a reversed conical apical portion 9 of hard fibers. In this modification the voice coil 25 is mounted on a cylinder 8 of stiff fiber or paper which is annularly cemented to the diaphragm in the position shown. The pole piece comprises an inner magnetic cylindrical portion 82, projecting inside cylinder 8 as shown, and an outer annular magnetic portion 83, both carried on a backing member 84 as shown. This diaphragm functions similarly to the others.

The new diaphragm is, for purposes of reproducing speech and sound, almost perfect. The volume output is substantially constant over the audible frequency range; and there is no rattling or buzzing due to reflections in the diaphragm itself.

Fig. 5 shows in full lines the frequency-output characteristic of the diaphragm, the ordinates being relative output in decibels (unit of loudness), and the abscissae being frequencies (corresponding to pitches) on a logarithmic scale. The output of the new diaphragm is substantially constant over the entire audible range. For the sake of comparison there is also shown in dotted lines the characteristic of a good prior art diaphragm of cone type. The output varies markedly with frequency.

Absolute dimensions are important in acoustical diaphragms. In my diaphragm the diameter determines the low frequency cut-off; that is, the minimum frequency which is correctly reproduced. The greater the diameter, the lower the frequency that can be reproduced.

It is sometimes desirable to increase the gradient of density and resilience beyond that obtainable by merely using different kinds of pulp. Accordingly, I sometimes provide sizing materials in the different pulps used, the materials being present in greatest proportion in the apical region and diminishing to a small proportion or zero adjacent the rim. I usually incorporate a hard sizing material such as rosin in the kraft pulp for the apex. In addition, I can provide annular coatings or impregnations of varnish or lacquer adjacent the apex. It is often desirable to varnish the extreme apical region.

The diaphragms sometimes show slight peaks or depressions in the output curve (Fig. 5). These are insignificant for all ordinary purposes but to meet the most exacting requirements of reproduction I can iron these out, as it were, by providing annuli of greater or less flexibility at appropriate radial distances on the diaphragm. As stated, in operation the higher sound frequencies are related primarily to vibration in the central regions. The lower frequencies relate to vibration in the outlying regions. If a diaphragm exhibits an abnormally high response to a certain frequency, e. g. 500 vibrations a second, a narrow annular zone of less flexibility can be provided in the portion of the diaphragm corresponding to that frequency.

Fig. 4 shows a conical diaphragm made according to the method of the invention, having

annular fiber zones 20, 21, etc., with their edges merging and interlaced as described.

Method

Figs. 6 and 7 show apparatus useful in performing my method. The method is illustrated in connection with forming a diaphragm of the belled shape as described, but is equally well applicable to forming diaphragms of other non-planar shapes in which it is desired to provide annular zones of different types of fiber, merging to form a strong structure, unitary in both the mechanical and the acoustical sense. Fig. 6 shows the arrangement of the parts in getting the fibers in place, and Fig. 7 illustrates the actual forming operation. A liquid container 30 is provided, substantially filled with a body of water 31, and in it is suspended by bail 32 and hook 33 a cylindrical tank 34 having a flange 35 at its lower end cooperating with a similar flange 36 on a lower cylinder 37. Cylinder 37 is spaced from the bottom of tank 30 to provide free liquid passage. Between the flanges is clamped by clamps 38 a foraminous mold 39 of the desired shape; being shown as a trumpet- or bell-shaped mold. The mold is conveniently made of perforated sheet metal. I have found a mold having 625 perforations per square inch (25 per linear inch) to be very satisfactory. The mold can be made of woven wire cloth (advantageously brass) of an equivalent mesh. The mold is inherently so shaped and so supported as to have high structural strength; even with thin perforated metal or wire cloth there is no danger of buckling or bending.

In tank 34 are mounted as by tie-rods 45 three concentric cylindrical partitions 46, 47 and 48, the upper portions of which are impervious and the lower portions of which are pervious, the openings being formed either by perforating the solid metal or by providing cylindrical screen extensions 49, 50 and 51 as shown. These screen portions allow equalization of pressure between the several compartments. The screen extensions extend close to, but not touching mold 39.

Above the tanks are positioned four receptacles, 55, 56, 57 and 58, having conduits 59, 60, 61 and 62 controlled by valves 63, 64, 65 and 66 and adapted to deliver into cylindrical and annular compartments 70, 71, 72 and 73 formed by cylinder 48 and cylinders 48 and 47, 47 and 46, and 46 and 34 respectively. Receptacle 55 is for holding a liquid suspension of hard or dense pulp (kraft) and receptacles 56, 57 and 58 for suspensions of progressively softer fiber pulps.

In forming a diaphragm, the apparatus is initially disposed in the position shown in Fig. 6. Pulp is introduced into the annular compartments from the receptacles, the contents of the receptacles being kept agitated by any suitable means (not shown). A predetermined quantity of each kind of pulp is thus introduced, the respective quantities being gaged as by observation of the fall in level in the receptacles, or by initially putting in each receptacle the exact weight of pulp required.

There is thus deposited on the form (39) a bulky mat or layer of fibers, as shown (Fig. 6). Since some clearance is provided between cylindrical elements 49, 50 and 51 and the form, fibers from adjacent annular compartments are caused to intermingle to a certain extent. However, elements 49, 50 and 51 and their corresponding elements 46, 47 and 48 prevent undesirable intermixture. The clearance between the

bottom of members 49, 50 and 51 is important, as it ensures the right amount of interpenetration between fibers from the adjacent compartments. Ordinarily I make the clearance about one-half inch.

The function of the reticulated elements 49, 50 and 51 is to keep a constant liquid level in all the compartments and thus to prevent pulp from getting on the wrong part of the diaphragm. They are necessary because of the fact that the different kinds of pulp filter (i. e., form a web or felted mat) at different rates. If one were allowed to deposit slower than another, as by using impervious separating cylinders, there would be a flow from one compartment to the other under the bottom edge of the separators. This would wash the pulp from the form and make impossible a smooth, merging knitted union of the two kinds of fiber.

When the required quantity of pulp has been introduced into each compartment, valves 62, 63, 64 and 65 are closed, and the tank assembly is raised to the position indicated in Fig. 7, which shows the situation just after the assembly has been raised. The water in tank 34 now flows out through the fibers and the form, causing the fibers to deposit on the form as a compact felted mat. When all the water has drained out of tank 34, tank 37 is detached and the form is removed with the diaphragm thereon. The diaphragm is dried on the form, as by exposure to hot air. When dry, the diaphragm is taken off the form. The wire side is smooth, but the felt side is rather rough, so I usually subject the diaphragm to hot pressing in an appropriately shaped mold to smooth the surface. The voice coil is now mounted on the apex, and the diaphragm proper is finished. If desired, it can be given a thin protective layer of lacquer, etc., but coatings, of any but negligible stiffness or thickness are usually undesirable except in the central regions. The object of the invention as regards minimizing marginal reflections is achieved only by having the fibers grade in flexibility to a low value adjacent the rim. Heavy lacquering would introduce stiffness and elasticity which are not desired.

Fig. 7 shows the mold assembly raised just above the surface of the water in tank 30. Thus the pressure tending to force the water in cylinder 34 through the mold and the fiber layer thereon is determined only by the height of water in cylinder 34. However, if desired, the mold assembly can be lifted higher, for instance until the lower edge of cylinder 37 is just below the surface of the water in tank 30. Then there will be developed suction below the mold tending to draw water from the cylinder 34 through the mold and the fiber layer. When the mold is raised, the suction drains water out and some is retained on the mold in the form of small drops. Then upon removing the mold assembly from the tank, that is breaking the suction, the water drops tend to be sucked back into the matted fibers. Accordingly, I find it advantageous to provide a felt blotting element below the wire mold and in contact therewith, so that the sucked-out water drops will be held in the felt and not rewet the diaphragm. This saves drying costs. This arrangement is shown in a separate figure, Fig. 8, for the sake of clarity. As shown, a felt member 80 is provided, pressed against the

wire mold by a coarse wire screen or similar retaining element, 81. The wire mold is shown in Fig. 8 as of conical shape.

While, as stated, the method is applicable to making diaphragms of conical and other non-planar contours, it is particularly well suited for meeting the exigencies of the present invention.

The rate of filtering or deposition of the fibers depends on the kind of fiber, and is thus different for each annular zone. My method has the advantage that by keeping the several batches of fiber separate during the simultaneous deposition, the fibers deposit regularly and without undesirable intermingling, even though the filtering rates of the various fibers are widely different. Thus the weights of the various fiber zones in the finished diaphragm are accurately predetermined, and rejects due to faulty weight distribution are minimized.

What I claim is:—

1. A diaphragm of shallow, outwardly concave bell shape, different annular regions of which are made of different kinds of fibrous material so arranged that the density, compactness and resiliency of the diaphragm are greatest adjacent the center and diminish without discontinuities toward the rim, the diaphragm thickness increasing from the center toward the rim, the diaphragm having substantially uniform output for all frequencies in the range of audible sound and being free from distortion due to marginal reflections.

2. A diaphragm substantially in the shape of a semi-cubical paraboloid of revolution and made of different kinds of fibrous materials in merging annularly disposed zones, the axial region being of stiff fibers, the intermediate annular regions being of moderately flexible fibers and the marginal region being of soft inelastic fibers, the diaphragm being further characterized in that the thickness increases from the center toward the rim, the diaphragm having substantially uniform output for frequencies in the range of audible sound and being free from distortion due to marginal reflections.

3. A diaphragm of shallow concave bell shape made of different kinds of fibrous material disposed in annular zones of thickness increasing with distance from the center, the fibrous material adjacent the center being of a dense, resilient and compact character, the fibrous material adjacent the rim being of a soft light non-resilient character and the fibrous material of intermediate regions being of intermediate character, the diaphragm having a folded portion beyond the rim, and beyond the folded portion a fibrous annulus for supporting purposes, all the fibers in the diaphragm being merged into each other without sharp boundaries so that the diaphragm has substantially uniform output-frequency response in the range of audible sound and is free from distortion due to marginal reflections.

4. An acoustic diaphragm of round convex shape formed of fibers arranged in a plurality of annular zones, the fibers near the center being of relatively hard, dense character and the fibers near the rim being of softer character, the fibers of adjacent zones interlacing and merging to form a strong unitary structure free from discontinuities.

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