Nov. 10, 1953 R. E. SWANSON 2,658,470

SOUND PRODUCING DEVICE

Filed Feb. 2, 1950

Fig. 1.

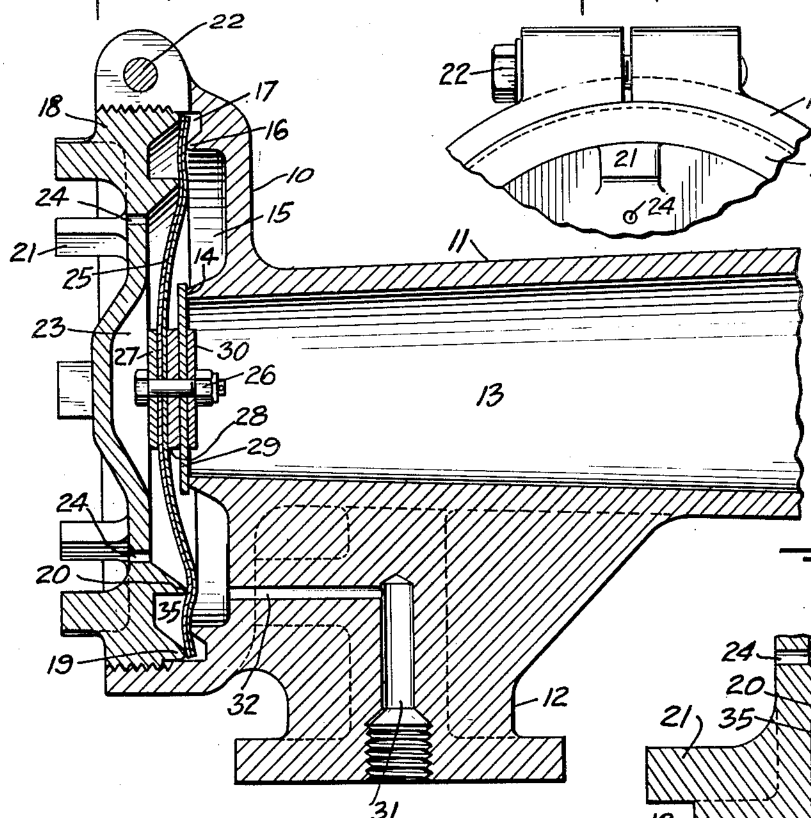


Fig. 2.

Fig. 3.

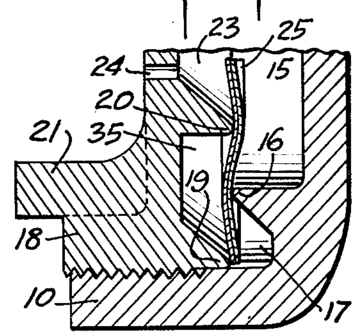


Fig. 4.

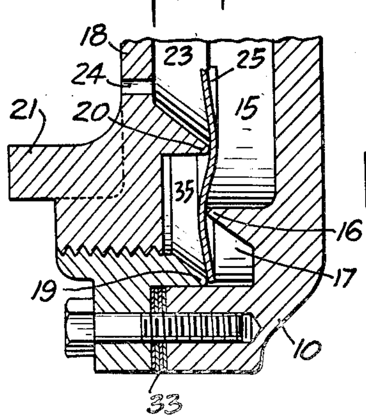


Fig. 5.

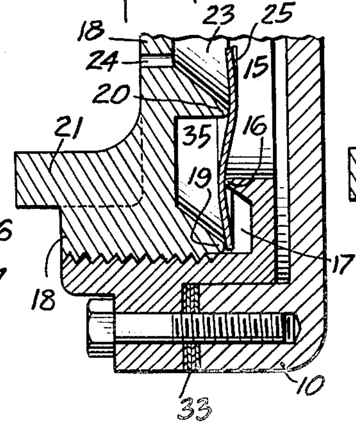
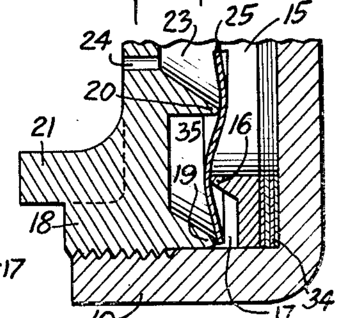


Fig. 6.



INVENTOR

ROBERT E. SWANSON.

BY Walter E. Wollheim

ATTORNEY.

Patented Nov. 10, 1953 2,658,470

UNITED STATES PATENT OFFICE

2,658,470

SOUND PRODUCING DEVICE

Robert E. Swanson, Vancouver, British Columbia, Canada, assignor, by mesne assignments, to Nathan Manufacturing Corp., a corporation of New York

Application February 2, 1950, Serial No. 141,959

11 Claims. (Cl. 116—142)

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This invention relates to sound producing devices for signalling purposes and more particularly to improvements in pneumatically operated horns.

As usually constructed, horns of the pneumatic type employ flexible diaphragms which are caused to vibrate rapidly to produce sound when compressed air or other gaseous fluid under pressure is caused to pass through the device. The continued rapid flexing and bending in opposite directions on each side of the neutral line of these diaphragms causes them to fail by fracture rendering the device inoperative. Further, the usual methods of mounting and tensioning these diaphragms in the diaphragm chambers causes them to become distorted and change their nodes of vibration on a change of operating pressure which further causes them to emit distorted notes of an unmusical character; and still further when horns as usually constructed, having mechanical means to adjust the deflection of such diaphragms for a change in operating pressure, are operated on a range of pressures other than that for which they may be adjusted, they either fail completely or emit a discordant and distorted note.

It is the purpose of this invention to provide an improved pneumatic horn which is capable of producing a musical note of powerful sound volume without distortion of the musical qualities of the note produced.

A further object of the invention is to provide a horn in which the diaphragm produces as near as possible a piston motion resulting in a true musical note.

Another object of the invention is to provide a horn in which musical harmonics can be developed to enhance the quality of the fundamental tone.

Another object of the invention is to provide a horn that will operate over a wide range of pressures without it being necessary to make adjustments for changes in operating pressure.

Another object of the invention is to provide a horn in which the volume of sound produced can be cut down at the will of the operator by cutting down the operating pressure so that with greatly reduced pressure the horn will continue to produce its true musical note but at a reduced volume of sound and will work in harmony with a plurality of other similar horns.

A further object of the invention is to provide a horn in which the diaphragm has a long life.

Other objects of the invention and features of novelty will be apparent from the following description taken in connection with the accompanying drawing in which:

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Fig. 1 is a fragmentary sectional view of a horn embodying my invention;

Fig. 2 is a fragmentary end view showing clamping means employed to hold an adjusting cap in an adjusted position;

Fig. 3 is an enlarged fragmentary sectional view of a portion of Fig. 1 showing diaphragm clamping and adjusting means; and

Figs. 4, 5 and 6 are enlarged fragmentary sectional views, similar to Fig. 3, showing modified forms of construction embodying the principles of my invention.

Like characters of reference denote similar parts throughout the several views and the following specification.

Referring to Fig. 1 the horn device shown therein has a housing consisting of a body 10 preferably made of metal and formed preferably integral with a horn bell 11 and a base 12, the latter supporting the horn.

The body 10 has a hollow resonating chamber 13 within the bell 11 shown in fragmentary view. This resonating chamber 13 terminates with its outer end into the free atmosphere in the shape of a flare (not shown) for the purpose of amplifying the sound produced and is calculated to have a cut-off length of ¼ wave length of the note to be produced by the horn, the inherent harmonics by natural laws being thirds, fifths and sevenths. It will be noted chamber 13 projects at its other end into the body of the device in the form of an annular seat 14 around the outside of which is formed an annular chamber 15 which has in turn at its outer marginal edge an annular seat ring 16 facing in the same direction as the seat 14. Another annular chamber 17 is formed around the outside of annular seat ring 16, and in line with the outer marginal edge of annular chamber 17 is a concentric bore, part of which is threaded to receive an adjusting cap 18. It will be noted adjusting cap 18 may be screwed in or out of body 10 and that it has on its outer peripheral edge an annular concentric seat ring 19 similar to seat ring 16 in the body 10 but of a larger diameter and pointing in the opposite direction. It will also be noted that adjusting cap 18 has another annular seat ring 20, also similar to annular seat ring 16 in the body but of a smaller diameter and also facing in the opposite direction.

In order to screw adjusting cap 18 in or out of body 10 lugs 21 are provided for. Cap 18 can be locked into position by tightening a cap screw

22 which clamps body 10 tightly onto threads of cap 18. Cap 18 is shaped substantially concavedly between seat ring 20 to form a chamber 23 which is in communication with the atmosphere through drilled holes 24.

The diaphragm unit as shown in Fig. 1 consists of a plurality of thin flat unstressed circular metal discs 25 of suitable spring-like material, at the diametrical center of which is clamped by a bolt 26, a washer 27, diaphragm discs 25, a washer 28, an auxiliary diaphragm plate 29 and a washer 30.

Still referring to Fig. 1 it will be noted that with diaphragm plate 29 firmly resting on seat 14 considerable pressure has been required to be exerted by movement of cap 18 to the right in order to bend and force diaphragm 25 to seat on annular seat ring 16 and that, as further pressure has been exerted by annular seat rings 19 and 20 by further adjustment of cap 18 to the right, the outer marginal boundary of diaphragm 25 has had an annular crimp pressed into it by being forced over annular seat ring 16 by pressure from seat rings 19 and 20. If cap 18 were loosened so that diaphragm plate 29 lightly rested on annular seat 14, main diaphragm discs 25 would not be touching outer annular seat ring 16 by a considerable amount and discs 25 would be perfectly flat and unstressed in this unadjusted position.

I have found that in order to cause a diaphragm to vibrate so that the central active portion of the diaphragm will oscillate on a nearly true piston motion it is first necessary to mechanically force the diaphragm into the shape of a concave with respect to that side which is to receive the application of fluid pressure, which pressure will tend to further force the diaphragm into a concave of a smaller radius. This principle is known in the art and when the above has been complied with the diaphragm will vibrate on its natural node so long as the pressure of the fluid remains within certain limits, which limits when exceeded cause the diaphragm to distort so that a distorted note is sounded by the horn.

I have discovered this difficulty can be overcome by introducing tension into the diaphragm discs in addition to the bending action obtained by forcing the diaphragm discs into a concave shape. This tension is added to the diaphragm members on the principle in which the membrane of a drum is stretched while at the same time the diaphragm discs are forced into the shape of a concave by mechanical means and forced still further into a concave by the application of the operating fluid pressure. In this state such a diaphragm will vibrate on its natural node over an external wide range of pressures when such vibration is supported and strengthened by sympathetic resonance of a suitably proportioned and connected horn bell. This is accomplished as follows:

Referring to Fig. 1, it is understood that until cap 18 is screwed into body 10 diaphragm discs 25 are substantially circular flat discs and as cap 18 is screwed into body 10 the flat discs 25 are gently moved to the right until plate 29 engages annular seat 14. In this position discs 25 are still flat and a substantial distance to the left of outer concentric seat ring 16. With a further movement of cap 18 to the right annular concentric rings 19 and 20 which form part of cap 18 force discs 25 into a concave over central seat 14 until the right side of discs 25 (as a unit) comes in contact with left side of annular ring 16. This is more clearly shown in Fig. 3. With discs 25 in this position further movement of cap 18 is obtained by application of force on a lever or bar applied to lugs 21 and a crimp is forced into the elastic material of discs 25 by continued movement to the right of rings 19 and 20 with stationary annular seat ring 16 forcing an annular reversed crimp into the outer boundary of discs 25. As the discs 25 have an annular crimp forced into them near the periphery of the spring-like material by virtue of the illustrated construction, stresses are set up which tend to draw metal from the center of the discs 25 toward the outside resulting in tension radially outward from the centers of discs 25.

As fluid pressure is applied to chamber 15 by way of passage 31 and port 32 in the body 10 and discs 25 are forced further to the left in the shape of a concave the outer boundary of discs 25, not being firmly clamped but crimped by virtue of mechanical pressure on spring-like material, sufficient flexibility and provision for radial movement exists at the outer clamping edges of discs 25 to allow the discs a greater deflection when vibrating and also allows them to return promptly to the seated position with greater force than would be the case if discs 25 were clamped in the conventional manner.

By this means extremely thin diaphragm discs 25 may be used which may or may not be laminated giving the advantage of longer life and also the added advantage of being able to utilize extremely low operating pressures and as such thin discs, when so clamped, do not distort under higher pressures until a limit of minimum thickness is reached when finally the note distorts due to excessive turbulence of air currents in chamber 15 or by the impingement effect of the incoming air on diaphragm 25.

When it becomes desirable to combine several horns to comprise a multiple horn unit my invention offers means to overcome the difficulties usually encountered when conventional horns are used. The usual difficulties encountered when horns are combined for multiple operation are that when such individual horns are separately adjusted to emit individual true tones the minimum speaking pressure of each individual horn is at variance with each other and as a result often certain horns in a group fail to work on a lowered operating pressure. When such horns are then individually adjusted so that all initial speaking pressures are the same certain horns in the group will either fail to function entirely or will emit distorted notes resulting in an overall discord.

My invention overcomes this difficulty as with the novel diaphragm clamping arrangement incorporated in all horns of a group, each of which are adjusted by tightening cap 18 so that all initial speaking pressures are approximately 18 pounds p. s. i., such horns will emit true notes of pleasing harmonics when the operating pressure is increased up to 150 p. s. i., consequently a true chord is sounded on high operating pressures as well as on lowered operating pressures and it becomes possible to vary the sound intensity by controlling the operating pressures at the horn.

Should it become necessary to raise or lower the initial speaking pressure so that horns incorporating the features of my invention will work in conjunction with other existing horns on which the initial speaking pressure cannot be adjusted without resultant distortion of tone, cap 18 may be tightened within certain limits giving the desired result by further deflecting the diaphragm 25 to the right which will raise the initial speaking pressure to say 30 p. s. i. If it becomes desirable to raise the initial speaking pressure to say 40 p. s. i., shims 33 shown in Fig. 5 may be removed which will permit outer annular seat ring 16 to be located further to the right allowing a greater initial concave to be forced into diaphragm 25 which will raise the initial speaking pressure when cap 18 is further tightened to the right. With reference to Fig. 6 this may be accomplished by removing shims 34 after which cap 18 may be adjusted to the left or the right to set the exact speaking pressure required in the higher bracket of initial speaking pressures thus obtained. Under these conditions at all times, a reverse crimp is forced into the outer boundary of diaphragm 25 by annular seat ring 16 forcing the outer bounds of diaphragm 25 into a chamber 35 between rings 19 and 20 which annular deflection results in tension being drawn into the active central portion of diaphragm 25 so that distortion is avoided and a nearly true piston motion is attained at the central portion of the diaphragm when it is vibrating at a rapid rate. Conditions conducive to rapid and undistorted vibration are further favored by the features of this invention in that diaphragm 25 is supported in body 10 entirely by virtue of the resiliency of diaphragm 25. It will be noted diaphragm 25 is clamped between annular body seat ring 16 and adjustable cap seat rings 19 and 20 which last two rings are a substantial radial distance on either side of body seat ring 16. After cap 18 is tightened and a crimp is sprung into diaphragm 25 without the metal being actually strained the diameter of diaphragm 25 is slightly reduced so that its periphery does not touch body 10. Under these conditions vibration is uninhibited in diaphragm 25 especially when it is apparent diaphragm 25 can readily adjust itself to a greater or lesser deflection when the outer boundary of diaphragm 25 is not clamped solidly but is sprung between three points at its outer boundary as shown in the various figures.

An added advantage is also obtained by annular seat rings 19 and 20 forcing diaphragm 25 over stationary annular seat ring 16 in that a very tight air seal is thus assured without the use of gaskets and the like.

In designing a horn for manufacture incorporating the features of my invention it is first necessary to calculate the resonant length of horn bell chamber 13 to resonate on the natural fundamental frequency of the note desired. It is next necessary to calculate by formula the proportions of diaphragm 25 so it will vibrate on a natural frequency to coincide with the natural frequency of horn bell chamber 13. The vibration of diaphragm 25 will then be supported and strengthened by resonance of the horn bell. Auxiliary diaphragm plate 29, which is a circular plate clamped at its radius of gyration, is calculated to vibrate at its periphery on the third, fifth or seventh harmonic of the fundamental frequency of horn bell chamber 13, consequently its vibration is strengthened and supported by the inherent harmonics of horn bell chamber 13 and the tone is made richer by the addition of desirable overtones.

In a single horn unit when undesirable distortion has been eliminated by the features of this invention, inherent overtones can be developed by adjustment of cap 18 and removal or addition of shims 33 and 34, as shown in the modifications illustrated in Figs. 4, 5 and 6.

Operation

In operation a supply of fluid under pressure through passage 31 flows at a restricted rate through port 32 to chamber 15. At this moment auxiliary diaphragm plate 29 is held firmly in contact with seat 14 by virtue of the spring-like nature of diaphragm 25 clamped between annular seat rings 16, 19 and 20 which are so disposed as to cause diaphragm 25 to be forced into a concave as clearly shown in Fig. 1. This mechanical pressure caused by the tension of diaphragm 25 upon plate 29 forms a very tight seal between chamber 15 and horn chamber 13 and causes plate 29 to bulge slightly to the right assuming the form of a concave with respect to the diaphragm 25. As the fluid pressure increases in chamber 15 a point in pressure is reached where the pressure due to the fluid overcomes the mechanical pressure due to the resilient qualities of diaphragm 25 and the radius of the concave of the auxiliary plate 29 is gradually increased until the plate becomes straight and diaphragm 25 is gradually forced further into chamber 23 which is open to the atmosphere through holes 24.

This movement allows fluid to pass the periphery of plate 29 into chamber 13 with a restricted flow causing the periphery of plate 29 to vibrate. This vibration being a third, fifth or seventh harmonic of the natural resonance of chamber 13 causes the vibration to be supported and strengthened so that the natural frequency of resonance in chamber 13 tends to set diaphragm 25 into vibration on its natural node, thus allowing diaphragm assembly 25 to move to the right and seal plate 29 again against seat 14. As fluid under pressure still continues to flow through port 32, pressure in chamber 15 is quickly restored so that diaphragm 25 is again forced to the left, opening communication between chamber 15 and resonant chamber 13. As this action continues, on the flow of fluid through port 32, rapid vibration in diaphragm 25 is set up on its natural frequency which vibration is supported and strengthened by the resonance of horn bell chamber 13, resulting in sound at the mouth of the horn.

As the flow of fluid through port 32 is increased due to an increase in the pressure of the fluid supply, diaphragm assembly 25 is forced further to the left allowing greater circular puffs of fluid to enter chamber 13 from chamber 15 at the frequency of vibration which is also the frequency of resonance of horn bell 13. A note of greater intensity is thus propagated in horn bell 13 with increased operating fluid pressure admitted through port 32 into chamber 15.

When the fluid pressure in chamber 15, due to a greatly increased pressure in the source of supply, reaches a point where horns not embodying the features of this invention would emit a distorted note due to diaphragm distortion it will be noted the features of construction embodied in this invention permit the diaphragm to vibrate undistortedly without further adjustment even though higher operating pressures are admitted through port 32. It will be noticed in Fig. 1 the diaphragm 25 is forced by mechanical means into a concave with the outside portions of the diaphragm forced into a reversed annular curve or crimp which draws the metal of the diaphragm

25 from the center toward the outside boundary of circular diaphragm 25, thus causing tension in the central active portion of diaphragm 25. With the advent of greatly increased fluid pressure the diaphragm is forced by virtue of the increased fluid pressure still further into the shape of a concave and those annular portions of diaphragm 25 bent over annular ring seats 20 and 16 yield sufficiently to allow the central portion of diaphragm 25 to assume a concave with a decreased radius, while the same annular portions of diaphragm 25, above described, increase the resiliency of the diaphragm when it is vibrating rapidly. If on the other hand the diaphragm were forced by mechanical adjustment to assume a convex with respect to the application of fluid pressure instead of concave it is understandable that such a diaphragm would distort when vibrating rapidly as any tension in the diaphragm discs would be eased allowing distortion to take place resulting in distorted notes.

Attention is particularly drawn to the same diameters of washers 28 and 30 at the sides of the auxiliary diaphragm plate 29. This is for the purpose of eliminating undesirable metallic harmonics. When unequal diameters of such washers are used and the auxiliary diaphragm plate is flexed over the edge of the smaller washer and then returns to a neutral position, the plate slaps the edges of the larger washer and causes non-musical harmonics in the notes. The same objection is present when the faces of the washers do not abut the auxiliary diaphragm plate but where space is left between the washers and the plate. This drawback is entirely avoided by using washers of the same size abutting the plate. The washers on each side of the main diaphragm 25 need not be of equal diameters because this diaphragm does not flex on both sides of a neutral position. The diameters of the washers 28 and 30 and their relation to the diameter of the unsupported portion of the diaphragm plate 29 are also important because the frequency of the overtones is influenced by the natural frequency of that unsupported portion. The weight of the complete diaphragm assembly also affects the frequencies.

While the embodiment of a laminated diaphragm 25 with central clamping washers 27, 28 and 30, together with auxiliary diaphragm plate 29 is shown as a unit in Fig. 1 and has been described as such herein it is not my intention to limit the scope of the invention to that type of diaphragm alone. Other types of diaphragms may be used as shown in Figs. 4, 5 and 6. Plain or laminated diaphragms may be used with the diaphragm clamping arrangement described and shown. When diaphragms of the type embodying an auxiliary diaphragm plate 29 and washers 27, 28 and 30 are used in combination with the functions of the invention the superimposition of harmonics on the fundamental note may be controlled, as explained herein, enabling a horn to be constructed which will have pleasing sound characteristics and may be made and adjusted within certain limits to simulate the tone of a stopped organ pipe or that of a whistle.

While the embodiments of the improved pneumatic horn provided by this invention have been illustrated and described in detail, it should be understood that the invention is not limited to those details of construction, and that numerous changes and modifications may be made without departing from the scope of the following claims.

What I claim as new, is:

1. In a horn device, a body having an annular chamber with a front wall, a diaphragm within the chamber, a member adjustably secured to the body forming a rear wall of the chamber, the member having an outer annular seat ring at its periphery and an inner annular seat ring in spaced relation radially inwardly from the outer seat ring, both seat rings extending into the chamber, a raised annular seat ring extending from the front wall toward the member concentrically with and between the outer and inner seat rings of the member, whereby adjusting the member will clamp the peripheral portion of the diaphragm between the three seat rings and tension the central portion of the diaphragm.

2. In a horn device, a body having an annular chamber with a front wall, a diaphragm within the chamber, a member secured to the body forming a rear wall of the chamber, the member having an outer annular seat ring at its periphery and an inner annular seat ring in spaced relation radially inwardly from the outer seat ring, both seat rings extending into the chamber, a raised annular seat ring extending from the front wall toward the member concentrically with and between the outer and inner seat rings of the member, and means to adjust the axial distance between the seat rings of the member and the seat ring extending from the front wall to clamp the peripheral portion of the diaphragm between the three seat rings and tension the central portion of the diaphragm.

3. In a horn device, a body having an annular chamber with a front wall, a diaphragm within the chamber, a member adjustably secured to the body forming a rear wall of the chamber, the member having an outer annular seat ring at its periphery and an inner annular seat ring in spaced relation radially inwardly from the outer seat ring, both seat rings extending into the chamber, a raised annular seat ring extending from the front wall toward the member concentrically with and between the outer and inner seat rings of the member, whereby, by adjusting the member, the peripheral portion of the diaphragm is clamped between the three seat rings and the central portion of the diaphragm caused to assume a concave with respect to the front wall.

4. In a horn device, a body having an annular chamber with a front wall, a diaphragm within the chamber, a member adjustably secured to the body forming a rear wall of the chamber, the member having an outer annular seat ring at its periphery and an inner annular seat ring in spaced relation radially inwardly from the outer seat ring, both seat rings extending into the chamber, a raised annular seat ring extending from the front wall toward the member concentrically with and between the outer and inner seat rings of the member, the front wall having a central outlet to a resonant chamber, whereby adjusting the member will clamp the peripheral portion of the diaphragm between the three seat rings and tension the central portion of the diaphragm so as to seal the outlet to the resonant chamber.

5. In a horn device, a body having an annular chamber with a front wall, a main diaphragm within the chamber, a member adjustably secured to the body forming a rear wall of the chamber, the member having an outer annular seat ring at its periphery and an inner annular seat ring in spaced relation radially inwardly from the outer seat ring, both seat rings extending into the chamber, a raised annular seat ring

extending from the front wall toward the member concentrically with and between the outer and inner seat rings of the member, the front wall having a central outlet to a resonant chamber, and an auxiliary diaphragm attached to the main diaphragm larger in diameter than the central outlet, whereby adjusting the member will clamp the peripheral portion of the main diaphragm between the three seat rings and tension the central portion of the main diaphragm so as to seal the outlet to the resonant chamber with the auxiliary diaphragm.

6. In a horn device, a body having an annular chamber with a front wall, a main diaphragm within the chamber, a member adjustably secured to the body forming a rear wall of the chamber, the member having an outer annular seat ring at its periphery and an inner annular seat ring in spaced relation radially inwardly from the outer seat ring, both seat rings extending into the chamber, a raised annular seat ring extending from the front wall toward the member concentrically with and between the outer and inner seat rings of the member, the front wall having a central outlet to a resonant chamber, an auxiliary diaphragm attached to the main diaphragm larger in diameter than the central outlet, whereby adjusting the member will clamp the peripheral portion of the main diaphragm between the three seat rings and tension the central portion of the main diaphragm so as to seal the outlet to the resonant chamber with the auxiliary diaphragm, and a rigid washer at each face of the auxiliary diaphragm, both washers being of the same diameter but appreciably smaller than the diameter of the central outlet, opposing faces of the washers abutting the auxiliary diaphragm.

7. In a horn device, a body having an annular chamber with a front wall, a diaphragm within the chamber, a member adjustably secured to the body forming a rear wall of the chamber, the member having an outer annular seat ring at its periphery and an inner annular seat ring in spaced relation radially inwardly from the outer seat ring, both seat rings extending into the chamber, a raised annular seat ring extending from the front wall toward the member concentrically with and between the outer and inner seat rings of the member, the front wall having a central outlet to a resonant chamber, and means to admit fluid pressure to that side of the diaphragm facing the front wall, whereby adjusting the member will clamp the peripheral portion of the diaphragm between the three seat rings and tension the central portion of the diaphragm toward the outlet to the resonant chamber, the pressure of the fluid causing the diaphragm to vibrate thereby opening and closing the outlet rapidly.

8. Diaphragm clamping means in a sound producing device including an annular chamber in the device having a front wall, a diaphragm within the chamber, a member adjustably secured to the chamber forming a rear wall thereof, the member having, near its periphery, an outer and an inner seat ring extending into the chamber, a raised annular seat ring extending from the front wall toward the member concentrically with and between the outer and inner seat rings of the member, whereby adjusting the member will clamp the peripheral portion of the diaphragm between the seat rings and tension the central portion of the diaphragm.

9. Diaphragm clamping means in a sound producing device including an annular chamber in the device having a front wall, a diaphragm within the chamber, a member adjustably secured to the chamber forming a rear wall of the chamber, the member having, near its periphery, an outer and an inner annular seat ring extending into the chamber, an annular plate in the chamber having a raised annular seat ring extending toward the member concentrically with and between the outer and inner seat rings of the member, and a plurality of shims interposed between the front of the plate and the front wall, whereby adjusting the member will clamp the peripheral portion of the diaphragm between the seat rings and tension the central portion of the diaphragm and varying the number of shims will serve as additional adjustment.

10. Diaphragm clamping means in a sound producing device including an annular chamber in the device having a front wall, a diaphragm within the chamber, a body ring fastened to the end of the annular side wall of the chamber, a plurality of shims interposed between the body ring and the end of the side wall, a member adjustably secured to the ring forming a rear wall of the chamber, the member having, near its periphery, an outer and an inner annular seat ring extending into the chamber, the body ring being extended into the chamber and having a raised annular seat ring facing the member concentrically with and between the outer and inner seat rings of the member, whereby adjusting the member will clamp the peripheral portion of the diaphragm between the seat rings and tension the central portion of the diaphragm and varying the number of shims will serve as additional adjustment.

11. Diaphragm clamping means in a sound producing device including an annular chamber in the device having a front wall, a diaphragm within the chamber, a member forming a rear wall of the chamber comprising a body ring fastened to the end of the annular side wall of the chamber, a plurality of shims interposed between the body ring and the end of the side wall, the body ring being extended into the chamber to form an outer annular seat ring, a plate adjustably secured to the body ring and being extended into the chamber to form an inner annular seat ring in spaced relation to the outer annular seat ring, a raised annular seat ring extending from the front wall toward the member concentrically with and between the outer and inner annular seat rings of the member, whereby adjusting the plate of the member will clamp the peripheral portion of the diaphragm between the seat rings and tension the central portion of the diaphragm and varying the number of shims will serve as additional adjustment.

ROBERT E. SWANSON.

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