

Oct. 7, 1958

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2,854,944

FOG HORN

Filed Sept. 29, 1955

3 Sheets-Sheet 1

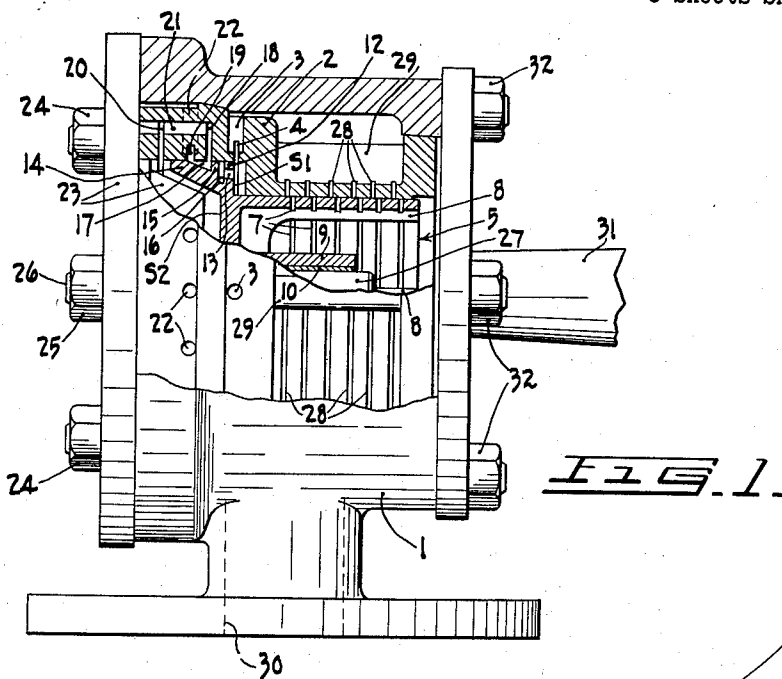


FIG. 1.

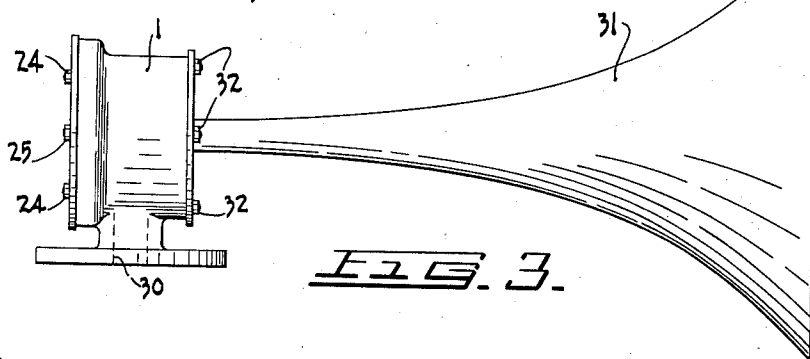


FIG. 3.

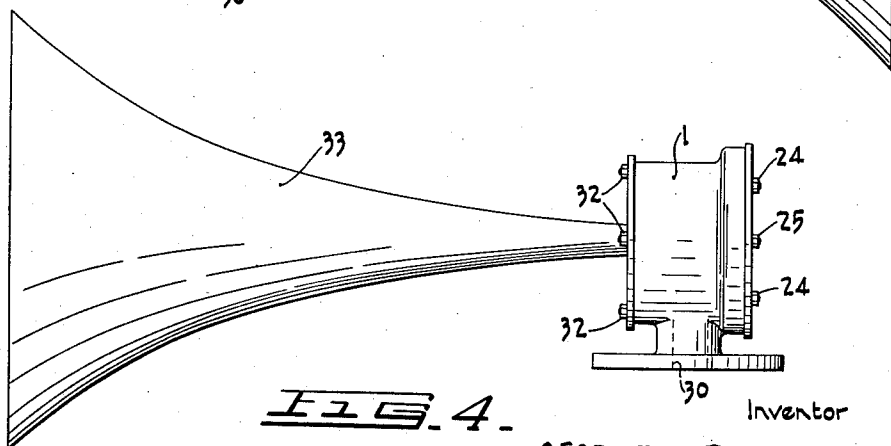


FIG. 4.

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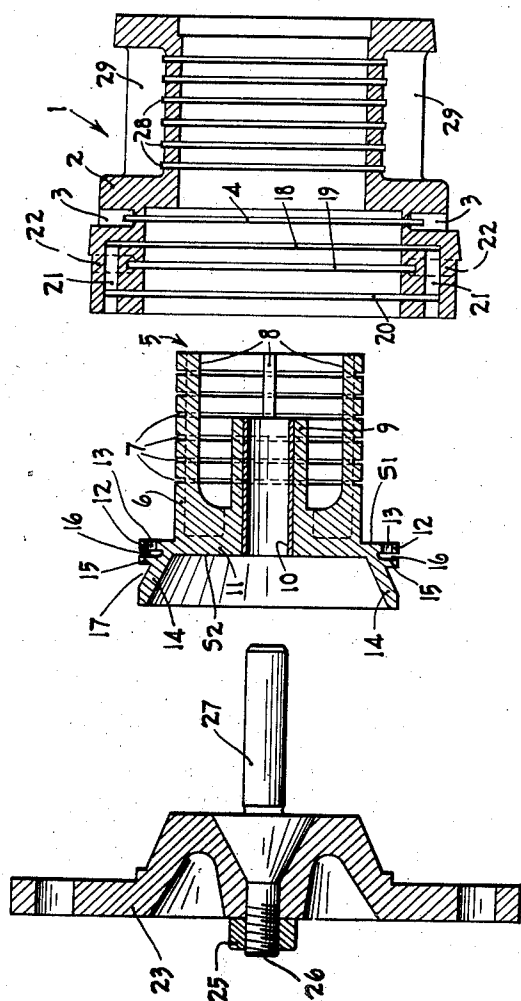


Fig. 2.

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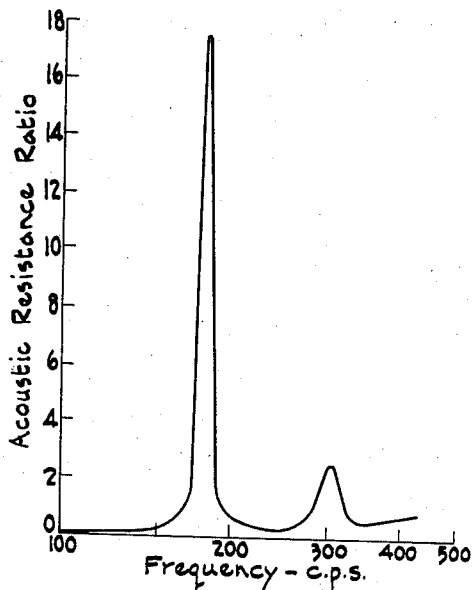


FIG. 5.

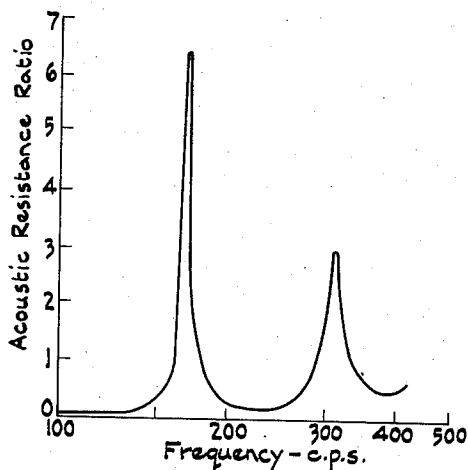


FIG. 6.

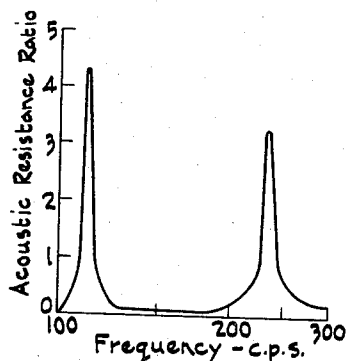


FIG. 7.

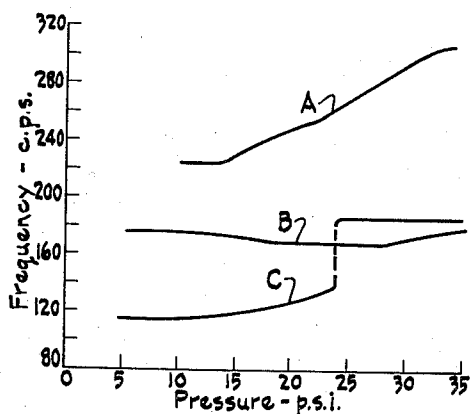


FIG. 8.

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8 Claims. (Cl. 116—147)

This invention relates to improvements in the diaphone type of sound-producing device, the primary application of which is as a fog horn.

It should perhaps first be explained that the diaphone fog horn consists essentially of an acoustic generator, i. e. the diaphone mechanism itself, feeding into an acoustic load, i. e. the horn.

A diaphone mechanism as used at the present time consists of a cylindrical cast iron or steel casing into which is fitted a brass liner, and a hollow brass piston closed at one end which is slidably mounted within this liner. At its closed end the piston has an enlarged portion which slides in a correspondingly enlarged part of the liner. This rear end of the piston includes faces which are acted upon by the pressure of driving air that is admitted through ports disposed around the outer casing. The enlarged portion of the piston includes peripheral recesses disposed in relation to fixed ports in the liner so that this portion of the piston acts also as a valve whereby it alternates the surfaces against which the air pressure is effective. As a result the piston oscillates back and forth in the casing. A second supply of air, the "speaking" air, which is normally taken from the same source as the driving air, is fed to an axial series of circumferential slots in the main part of the liner. The piston carries a corresponding series of circumferential slots extending through the piston from its outer face to its interior, these slots being disposed so as to be continuously moved into and out of alignment with the slots in the liner as the piston oscillates back and forth. This alignment of the slots occurs twice for each cycle of the piston and on each occasion a puff of air is allowed to escape into the interior of the piston. Thus a direct current air stream is chopped to provide an alternating component. The frequency of the piston is usually chosen as a nominal 90 cycles per second which will produce a note with a fundamental frequency of 180 C. P. S., assuming the vibrations to be sufficiently symmetrical. The pressure of air commonly used is 30 to 35 pounds per square inch gauge, this pressure having been selected because it was found the most satisfactory compromise between the greater theoretical energy output of a high pressure and the lower efficiencies obtained with higher pressures.

The front end of the diaphone at which the open end of the piston is situated is connected to a cast iron horn (sometimes called a "resonator") acting as the acoustic load. In conventional fog horns, this horn is conical in shape.

The diaphone fog horn was widely adopted as the standard fog horn signalling device about forty years ago and has been little modified in that period. It is a sturdy and reliable instrument, but its practical operating efficiency is extremely low. Occasionally in isolated instances, fog horns may be found to operate with efficiencies as high as 5%, but operating conditions are so unstable that one can only rely on a value of efficiency of the order of one-half of one percent.

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Clearly, the most desirable fog horn is one that can operate with relatively high efficiency. To provide such a fog horn is the principal object of the present invention.

Another object of the present invention is to provide a fog horn that can operate with relative high efficiency over a wide range of air pressure. In practice there will normally be experienced a pressure drop of the order of 5 p. s. i. from beginning to end of a single blast of say 5 seconds duration. Thus a horn operating with a nominal 30 p. s. i. will in fact only be receiving 25 p. s. i. towards the end of the blast. Another factor in practice is the need to provide a high energy output as soon as the equipment is turned on. It is not the usual practice in fog horn installations to maintain a supply of pressure air at all times, and thus there may be an appreciable delay before the nominal 30 to 35 p. s. i. pressure is built up by the pumps. Since a need to operate the horn may arise suddenly, efficiency at low pressure, say 5 p. s. i., and over the intermediate range, is important.

In the development of the present invention, it has been found that to attain reasonable efficiencies from a chopper type of transducer supplied from a high pressure air source, it is first necessary to load the source with a high acoustic impedance.

It can be shown that a much greater acoustic impedance than is obtained with a conventional conical horn can be obtained by the use of a short catenoidal horn of comparable size or smaller. The impedance characteristics of an infinite catenoidal horn (one in which the mouth diameter is very large compared to the wavelength) have been discussed by Salmon (U. S. Patent No. 2,338,262, issued January 4, 1944). He shows that such a horn provides a comparatively flat frequency characteristic. The higher impedance obtainable with a short catenoidal horn (one in which the mouth diameter is small compared to the wavelength) shows very sharp resonance characteristics. In other words the high impedance is only obtained over a very narrow range of frequencies. Some increase of acoustic impedance can be obtained by the use of a short exponential horn, a short hyper-exponential horn or a short hyperbolic horn, all of which also have similar resonance characteristics, but the greatest impedance at resonance is yielded by the short catenoidal horn, which is thus the preferred form of horn to be employed with a diaphone according to the present invention.

It follows from this sharp resonant characteristic of short horns, that high frequency stability is essential if any benefit is to be obtained from the high impedance.

Existing diaphone type fog horns have unsatisfactory frequency stability. Measurements taken on five different horns in service, each having a nominal frequency of 180 cycles per second, gave frequencies of 206, 196, 192, 243 and 184 C. P. S. respectively when blown at 30 p. s. i. air pressure. When the piston of the last fog horn was removed, oiled and then replaced, it gave a frequency of 199 C. P. S. initially, but gradually drifted back to 187 C. P. S. after 50 seconds of actual blowing.

Moreover, the frequency of all these fog horns was found to vary with the air pressure. A variation of 5 p. s. i. in the air pressure resulted in frequency changes in most cases at least as great as 20 C. P. S. Since in the diaphone type of fog horn efficiency is closely related to frequency, the maintenance of the desired frequency within comparatively close limits independent of the fluctuations in air pressure which must be expected in practice, is most important.

According to the present invention, the frequency stability of the fog horn is improved by reducing the mechanical impedance of the piston in the diaphone as an oscillating mass, while maintaining as high as possible

the mechanical impedance of the throat of the horn. When the piston impedance is low enough in relation to the throat impedance, the horn will dominate the system and it will then tend to take charge of the piston and control the oscillation thereof.

The increase in mechanical throat impedance is automatically achieved by the selection of a horn having a high acoustic impedance, since these two are linearly proportional to each other.

To reduce the mechanical impedance of the piston in the diaphone, there are three factors to be considered.

These are: (a) the oscillating mass; (b) the friction; and (c) the "spring force," which is related to the air pressures acting on each occasion against the piston driving surfaces.

Thus to decrease the mechanical impedance, firstly the piston can be made of low mass. Apart from reducing the thickness of the metal as far as possible commensurate with adequate strength, this requirement for low mass will necessitate the use of a light metal for the material of the piston. In practice it will be preferred to use aluminum or an aluminum alloy. The only other practical light metal, magnesium, is severely attacked by the salty atmosphere that is encountered in sites where fog horns are normally mounted and thus could only be used if appropriately surface treated.

The second factor the reduction of which will decrease the mechanical impedance of the piston is the friction between the piston and its casing. It is proposed according to the present invention to reduce this friction by mounting the piston centrally on a piston guide pin fixed to the diaphone housing. This guide pin supports the piston and holds it just slightly clear of the inner surface of the liner.

In the conventional form of fog horn the amount of sliding friction between the exterior of the piston and the inner surface of the liner has been very considerable. Moreover, it has not been uniform or capable of accurate assessment. The arrangement of the piston on a central guide pin in accordance with the present invention has the effect of greatly reducing and stabilizing the frictional forces. A much smaller area of contact exists between the relatively movable parts, and the ratio between the length of the surfaces in contact and their circumference is increased so that any tendency for the piston to twist and jam is eliminated. This arrangement also makes it practicable to provide a low friction bushing as a lining for the passage in the piston that fits over the guide pin and thus still further to reduce the friction and to reduce wear.

A central guide pin is preferred, but it may of course be replaced by two or more parallel pins if desired.

The third factor which has a bearing on the mechanical impedance of the piston is the "spring force," that is to say the force resulting from the driving air. Except by increasing the length of the air cavities in the direction of the longitudinal axis of the piston, which would involve fundamental redesign of the diaphone and would increase the air consumption, this spring force can only be reduced by lowering the air pressure. It is possible to reduce the pressure of the driving air by means of constrictions arranged between the air reservoir and the ports into the enlarged part of the liner or by using fewer ports, without necessarily reducing the pressure of the "speaking" air fed to the slots in the liner.

At this point attention is directed to the accompanying drawings which illustrate a manner of carrying the invention into practice.

Figure 1 shows partly cut away the inner structure of an assembled diaphone mechanism constructed in accordance with the invention;

Figure 2 is an exploded view of the parts seen in Figure 1 omitting the casing;

Figure 3 shows a complete assembled diaphone on a reduced scale, connected to a catenoidal horn;

Figure 4 shows a complete assembled diaphone on a reduced scale, connected to an exponential horn;

Figures 5 and 6 are each diagrams illustrating respectively the acoustic resistances of short catenoidal and exponential horns;

Figure 7 is a similar diagram illustrating the acoustic resistance of a short conical horn; and

Figure 8 is a diagram containing a number of curves demonstrating the frequency characteristics of a diaphone when loaded with short conical, catenoidal and exponential horns as a function of air pressure variation.

The diaphone mechanism seen in Figures 1 and 2 consists of a brass cylindrical liner 2 having, at its rear enlarged end, eight circumferentially disposed radially extending inlet ports 3 that serve to feed air from the interior of the casing 1 which is connected to a pressure reservoir (not shown), to a circumferential slot 4 communicating with the interior of the liner 2. It is really not essential for the liner to be cylindrical, but this is the convenient practical shape commonly adopted.

The enlarged end of the liner 2 also includes three additional circumferential slots 18, 19 and 20 communicating with the interior of the liner. The slots 18 and 20 both connect with a number of intermediate ports 21 which exist for the purpose of interconnecting these slots, and the slot 19 connects with a number of outlet ports 22 arranged in staggered relationship to the intermediate ports 21 so as not to be in communication therewith.

The piston 5 which is made of aluminum or an aluminum alloy comprises a hollow cylindrical main portion 6 formed with a series of circumferential slots 7 and supported by four ribs 8 which extend radially outwardly to the periphery from a central cylindrical bearing tube 9 coaxial with the cylindrical body 6 and fitted with a bronze bushing 10. One end of the cylindrical body 6 of the piston is open, but the other end is closed by a partition 11 which extends radially beyond the outer periphery of the cylindrical portion 6 to form a flange 12 through which a number of ports 13 is formed. The piston 5 also includes an outwardly flaring skirt portion 14 extending from the partition 11 in a direction away from the main body 6 of the piston. The outer surface of the skirt portion 14 includes a radially projecting flange 15. The flanges 12 and 15 and the outer end of the skirt portion 14 all project to the same radial extent so as to lie closely within the cylindrical enlarged end of the liner 2. The flanges 12 and 15 serve to define between them an annular cavity 16, and the flange 15 and the outer end of the skirt portion 14 serve to define between them an annular cavity 17.

The rear end of the liner 2 is closed off by means of a back plate 23 that is secured to the casing 1 by means of a number of bolts 24. This back plate 23 has secured to it by a nut 25 the threaded shank 26 of a hardened steel shaft 27 that serves to engage the bronze bushing 10 of the piston 5 and thus slidably to support the piston 5 within the liner 2. A clearance of the order of 0.001" between the piston and liner will be found satisfactory.

The liner 2 also includes a series of six slots 28 that extend between the interior of the liner 2 and a number of cavities in its exterior defined between ribs 29, each slot 28 being disposed for co-operation with one of the six slots 7 of the piston 5, as such piston is reciprocated.

The method of achieving reciprocation of the piston 5 is identical with that adopted in prior forms of diaphone fog horn. When air pressure is applied at the inlet ports 3, this acts on the annular surface S1 on the right hand side of the flange 12 and urges the piston 5 to the left, from the position seen in Figure 1. As soon as the flange 15 passes the slot 18, this air pressure is connected through ports 13, cavity 16 and slot 18 to the intermediate ports 21 and thus to the slot 20 and to the annular surface S2 on the left hand side of the partition 11. The area of the surface S2 is greater than the area of the surface S1 and thus the piston is moved back towards the right until the

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flange 15 again passes the slot 18 whereupon the air acting on the surface S2 is allowed to pass to atmosphere via the slot 20, intermediate ports 21, slot 18, cavity 17, slot 19 and outlet ports 22. The pressure on the surface S1 will then again exceed that on the surface S2 and the cycle of operations will be repeated.

Figure 3 illustrates a complete fog horn according to the invention, the diaphone mechanism being mounted in the casing 1 which has an air pressure inlet 30 and which is bolted to a short catenoidal horn 31 by bolts 32. A catenoidal horn is one in which the area A at any point is given by the expression

$$A = A_0 \cosh^2 mx$$

where x is the distance along the axis of the horn at which the area A is taken, A_0 is the area at the throat and m is a constant determining the rate of flare. In practice m will have a small positive value.

Figure 4 shows an alternative form of complete fog horn according to the invention in which the casing 1 housing the diaphone mechanism is similarly secured to a short exponential horn 33, the area A of which is determined by the expression

$$A = A_0 e^{2mx}$$

These two expressions are particular cases of the general expression developed by Salmon:

$$A = A_0 (\cosh mx + T \sinh mx)^2$$

and occur when T is made equal to 0 and 1 respectively. It will be evident that any one of the whole family of curves obtained by assigning different finite positive values to T could be chosen for use in the present invention. The catenoidal horn ($T=0$) yields the highest resonant peak, for comparable size horns (i. e. with given throat diameter, mouth diameter and length—factors determined by practical considerations). If

$$T = \frac{k}{m}$$

k being a constant, and m is made equal to zero so that T is infinity, the shape of the horn becomes conical with $A = A_0(1+k)^2$.

Figure 5 illustrates the frequency characteristics of a short catenoidal horn. The ordinate of this graph represents the acoustic resistance ratio of the horn, i. e. the ratio between the acoustic resistance of the horn at the throat at the selected frequency and the acoustic resistance of the horn at the throat at very high frequencies. At resonance, the acoustic impedance is high, and substantially wholly resistive (analogously with an electric parallel resonant circuit), and thus the acoustic resistance ratio can be taken as a practical measure of the acoustic impedance. A short catenoidal horn will be seen to have a high, very sharp resonant peak. The horn shown in Figure 5 was designed to resonate at 180 C. P. S. and deviations of a few cycles can very appreciably affect the acoustic resistance ratio. The importance of frequency stability in the diaphone mechanism is thus strikingly evident.

Figure 6 shows a corresponding curve for a short exponential horn of the same length and mouth and throat diameters as the catenoidal horn of Figure 5. A similar sharp peak appears at the fundamental frequency, but the maximum value of the acoustic resistance ratio achieved is only about a third of that obtained with the short catenoidal horn.

Figure 7 shows values for a short conical horn as hitherto employed in fog horns. This horn was considerably bigger than the horns of Figures 5 and 6. The fundamental peak is lower, although just as sharp. With a conical horn of size equivalent to the horns of Figures 5 and 6, the peaks would have been still lower. It is clear that frequency stability is just as important with a conical

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horn as with the other types of horn, but that even with a stable frequency the efficiency will be lower.

In practice, frequency variation with air pressure is important, and again the catenoidal horn is found most satisfactory, with the exponential type the next best. These characteristics are illustrated in Figure 8 which shows three curves, plotting the diaphone frequency (twice the piston frequency) against the applied air pressure. Curve A shows the behaviour of a diaphone as modified by the present invention when loaded with the presently used short conical horn; curve B shows this behaviour when the load is the catenoidal horn of Figure 5; and curve C shows this behaviour when the load is the exponential horn of Figure 6.

The catenoidal horn will be seen to give rise to the greatest frequency uniformity in that the diaphone is locked to the horn frequency over the widest pressure range. The exponential horn results in extremely high frequency control over a limited pressure range. Above a pressure of about 24 p. s. i. the frequency jumps to a much higher value, but is very stable over the range of 25 to 35 p. s. i. air pressure. Although the diaphone modifications have improved the stability of the conical horn to some extent, this still leaves much to be desired.

I claim:

1. A diaphone mechanism comprising a tubular housing having orifices extending through its wall, means for connecting said orifices to a source of pressure air, a pin extending in an axial direction in said housing, means for fixing said pin stationarily in relation to said housing, a tubular piston with an outer shape complementary to said housing, said piston being slidably mounted on said pin, and fluid-pressure actuated means for effecting cyclic reciprocation of said piston to cause sound-producing orifices extending through the wall of said piston to pass successively into and out of register with said orifices in said housing.

2. A diaphone mechanism comprising a tubular housing having orifices extending through its wall, means for connecting said orifices to a source of pressure air, a pin extending in an axial direction in said housing, means for fixing said pin stationarily in relation to said housing, a tubular piston constructed from light metal with an outer shape complementary to said housing, said piston being slidably mounted on said pin, and fluid-pressure actuated means for effecting cyclic reciprocation of said piston to cause sound-producing orifices extending through the wall of said piston to pass successively into and out of register with said orifices in said housing.

3. A diaphone mechanism comprising a tubular housing having orifices extending through its wall, means for connecting said orifices to a source of pressure air, a tubular piston constructed from light metal with an outer shape complementary to said housing, said piston being slidably mounted in said housing, and fluid-pressure actuated means for effecting cyclic reciprocation of said piston to cause sound-producing orifices extending through the wall of said piston to pass successively into and out of register with said orifices in said housing.

4. A sound producing device comprising a diaphone mechanism and a horn physically secured thereto and in acoustic co-operation therewith, said diaphone mechanism comprising a tubular housing having orifices extending through its wall, means for connecting said orifices to a source of pressure air, a tubular piston with an outer shape complementary to said housing, said piston being slidably mounted in said housing, and fluid-pressure actuated means for effecting cyclic reciprocation of said piston to cause sound-producing orifices extending through the wall of said piston to pass successively into and out of register with said orifices in said housing whereby to produce a sound of frequency determined by the frequency of oscillation of said piston, and wherein said horn is a short horn of the formula

$$A = A_0 (\cosh mx + T \sinh mx)^2$$

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where x is the distance along the axis of the horn at which the area A is taken;

A_0 is the area at the throat of the horn;

m has a positive value greater than 0; and

T has a positive finite value;

the mechanical impedance of said piston being of such low value in relation to the throat impedance of the horn at the principal resonant frequency of said horn that said horn dominates the oscillating system and controls the frequency of oscillation of said piston.

5. A sound producing device as claimed in claim 4, wherein said horn is a short catenoidal horn.

6. A sound producing device as claimed in claim 4, wherein said horn is a short exponential horn.

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7. A sound producing device comprising the combination of a diaphone mechanism as claimed in claim 1 and a short catenoidal horn physically secured to and in acoustic co-operation with said diaphone mechanism.

8. A sound producing device comprising the combination of a diaphone mechanism as claimed in claim 1 and a short exponential horn physically secured to and in acoustic co-operation with said diaphone mechanism.

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