May 6, 1930. H. C. HARRISON 1,757,459

SOUND TRANSLATING SYSTEM

Original Filed May 2, 1923 2 Sheets-Sheet 1

Fig. 1

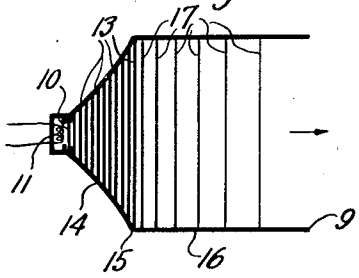

Fig. 2

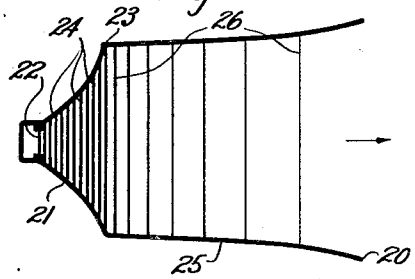

Fig. 3

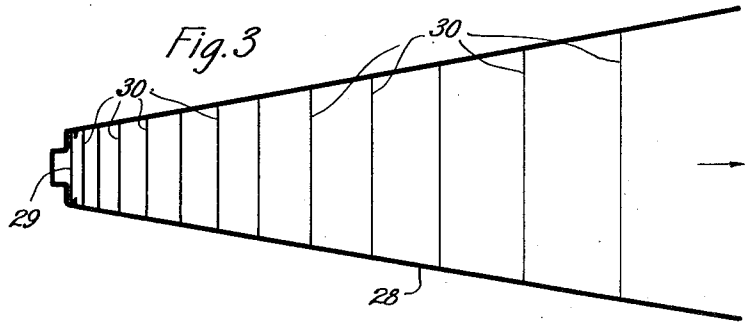

Fig. 4

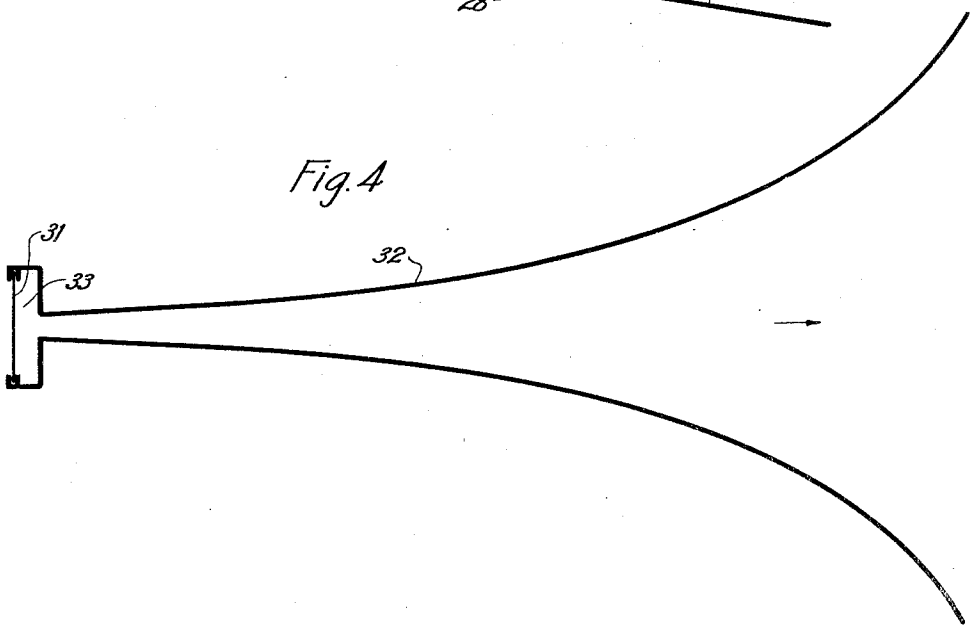

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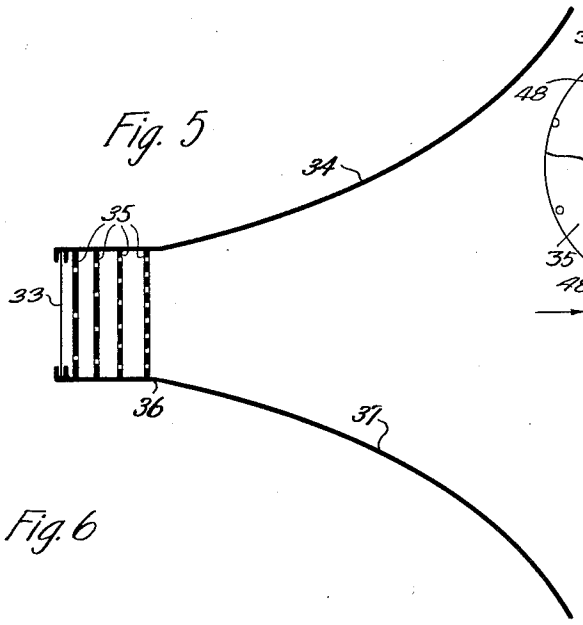
Fig. 5



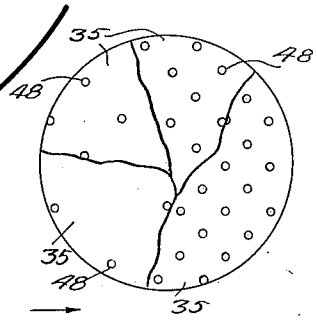


Fig. 5a.

Fig. 6

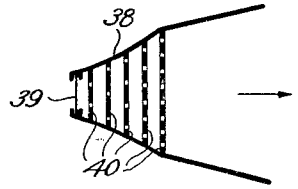


Fig. 7

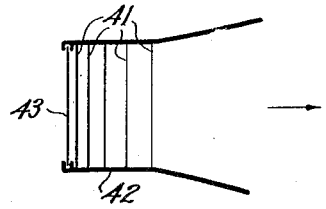
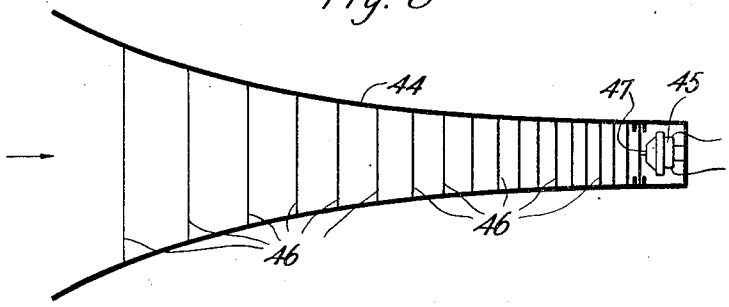


Fig. 8



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Patented May 6, 1930 1,757,459

UNITED STATES PATENT OFFICE

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SOUND-TRANSLATING SYSTEM

Application filed May 2, 1923, Serial No. 636,088. Renewed August 18, 1927.

This invention relates to sound translating systems such as tubular horns employed, for example, with phonographs and loud speaking telephone receivers.

An object of this invention is to provide a high efficiency coupling between a vibrating member of small area and a column of air of much larger area.

Another object of this invention is to reduce reflection losses in a loud speaking horn.

The problem of coupling a vibrating member, such for example, as the diaphragm of a telephone receiver to a column of air of larger area involves large reflection losses unless special precautions are taken to adapt the mechanical impedance of the vibrating member to that of the column of air desired. In employing a tubular horn for such a purpose the problem involves starting with a sound wave of high velocity and small area and ending with a sound wave of low velocity and large area. The rate of transformation of the wave in such a system depends upon the rate of change of the mechanical impedance of the channel, which depends upon the area, the elasticity and the density. It has been found that a certain change in mechanical impedance per wave length is permissible with good operation and this invention therefore proposes to provide in a relatively small space a tapered mechanical impedance arrangement which will change by small steps from the impedance of the vibrating member to the impedance at the open end of the horn. A tapered change in impedance to develop from the small area of the vibrating member to the area equal to the mouth of the horn may be made in a comparatively small distance if the average density of the translating medium is kept high, because with any maximum permissible change in mechanical impedance per wave length the rate of change per unit length is greater the greater the density of the medium in which the change in area takes place. In accordance with one form of this invention a rapid increase in the outline of the horn is made permissible by including within the horn a plurality of diaphragms of sufficient thickness and proximity to maintain substantially constant at a high value the average density of the translating medium until the desired increase in area is obtained. The horn is then extended over a small distance to support a plurality of diaphragms gradually decreasing in thickness and increasing in spacing looking in the direction of the mouth of the horn, thereby producing gradual changes in the average density of the medium until the open air is reached. The diaphragm should be of a material of low elasticity such as thin rubber or soft paper. The tapered impedance may also be secured by non-vibrating plates within the horn and perforated to allow the air to flow from one compartment to the other. The effective density of the medium will depend upon the plate spacing and the number and size of the holes so that the density may be gradually varied in the manner desired.

Referring to the drawings, Fig. 1 represents this invention employed for coupling a diaphragm of small area and high density to a column of air of larger area and smaller density; Fig. 2 is a modification of Fig. 1 in which the outline of both sections of the horn is curved; Fig. 3 is a modification of Fig. 1 in which the horn has a constant slope from end to end; Fig. 4 discloses an arrangement for providing an efficient coupling between a diaphragm of larger area and the small end of a large horn; Fig. 5 discloses how the horn of Fig. 4 may be considerably shortened by the use of perforated plates of constant area; Fig. 5^a represents a view with the plates in section looking into the mouth of the horn of Fig. 5; Fig. 6 discloses how the horn of Fig. 4 may be shortened by the use of perforated plates of varying area; Fig. 7 discloses how the horn of Fig. 4 may be shortened by the use of imperforate diaphragms; and Fig. 8 discloses this invention employed in the mouth piece of a telephone transmitter.

Referring more particularly to Fig. 1 a tubular horn 9 is disclosed having located at its small end the diaphragm 10 of a telephone receiver or a phonograph reproducer, indicated by the block 11. Such a diaphragm is usually of considerably smaller area than the mouth of the horn associated therewith

and is also of considerably higher density than air several thousand times as a rule, made usually of steel or other metal in the case of a telephone receiver and in the case of a phonograph reproducer is made of material such as wood or mica. The mechanical impedance of the diaphragm 10 is therefore quite different from the mechanical impedance of a column of air equal to its area and large reflection losses will take place when vibrating this column of air unless special precautions are taken to adapt the mechanical impedance of the vibration member to that of the column of air.

It has been found, that a certain change in mechanical impedance per unit wave length is permissible with good operation and this invention therefore proposes to provide a tapered mechanical impedance arrangement which will change by small steps from the impedance of the vibrating member to the impedance looking out into the air. This tapered impedance arrangement, to develop from the area of the vibrating member to the larger area at the mouth of the horn, may be made in a comparatively small space if the average density of the translating medium is kept high because the maximum permissible change in mechanical impedance per wave length is greater the greater the density. The change from the area at small end of the horn to the area at the open end of the horn is made rapidly in section 14 by employing therein a large number of diaphragms 13 with constant spacing but gradually increasing in area. The thickness of the diaphragms 13 should be such as to maintain substantially constant the average density of the translating medium from the diaphragm 10 until the point 15 is reached. The thickness of the diaphragms 13 will depend not only upon the material of which they are made but also upon the average density of the diaphragm 10 and the layer of air on each side. By having the diaphragms 13 gradually increase in area from adjacent the diaphragm 10 until the maximum area of the horn is reached, the tapered change in mechanical impedance due to gradual increase in area may be made rapidly because the change in impedance is being made in a medium of relatively high density compared to that of air. The change in impedance from the diaphragm 10 to the point 15 may therefore allow the area of the horn to be rapidly increased in area without danger of appreciable reflection losses or a reduction in the quality of transmission of the sound waves.

The maximum permissible change in mechanical impedance per wave length depends upon the quality desired in any particular case. It has been found for example that the impedance may be changed by a factor 2500 per wave length without impairing the transmission.

After the point 15 is reached the problem still remains to taper gradually the density of the translating medium from the high density maintained in the portion 14 until the density has been tapered to the density of air. This is taken care of in section 16 of the horn by providing a relatively large number of diaphragms 17 of gradually diminishing thickness from the point 15 until the open end of the horn is reached, and also gradually increasing in spacing looking in the direction of the mouth of the horn. This arrangement therefore enables the density of the translating medium to be rapidly tapered from the high density of the diaphragm 10 to the density of the air without impairing the high quality transmission desired.

In the above described horn with the diaphragms 13 and 17 the translating medium behaves substantially as though it were a homogeneous medium of constant density as long as there are several, preferably more than seven lumped masses per wave length.

The diaphragms 13 and 17 should preferably be made of material which does not have appreciable elasticity so that the diaphragms 13 and 17 will act as substantially pure masses for all frequencies within the speech range. For example the diaphragms 13 and 17 may be made of cloth impregnated with rubber or may be made of rubber entirely or of soft paper. In any case these diaphragms should be preferably air-tight to prevent the circulation of air between the various compartments. The periphery of each diaphragm may be attached to the inner wall of the horn in any suitable manner.

The arrangement of the diaphragms with the air compartments between also acts as a low pass filter comprising series masses (the diaphragms) and shunt elasticities (the air between the diaphragms) so as to suppress objectionable high frequencies above the cut-off frequency, such as a part of the scratching noises and the like. The spacing and the weight of the diaphragms 13 and 17 will therefore depend upon the cut-off frequency desired in any particular case.

Fig. 2 is a modification of Fig. 1 in which a horn 20 is disclosed having a section 21 rapidly increasing in area from the diaphragm 22 until the point 23 is reached. This section 21 is filled with a large number of diaphragms 24 constructed in substantially the same manner as the section 14 of the horn shown in Fig. 1. The section of the horn from the point 23 to the open end instead of being straight as in Fig. 1 is shown slightly curved to allow a gradual increase in the area of the horn even after the point 23 is reached. This section 25 is similar to the corresponding section of Fig. 1, in other respects, since it contains a plurality of diaphragms 26 gradually diminishing in thickness and increasing in spacing looking in

the direction of the mouth of the horn to produce the desired taper change in density.

Fig. 3 illustrates a tubular horn 28 which has a constant rate of increase in area from its small end to the large end. In this figure, the sound responsive diaphragm 29 is coupled to the column of air at the mouth of a horn by a plurality of diaphragms 30 of gradually increasing area and diminishing thickness looking in the direction of the large end of the horn. This arrangement is therefore a modification of that previously discussed in that the tapered change in density is made simultaneously with the tapered change in area. The maximum permissible change in mechanical impedance per unit length along the horn 28 will depend as previously discussed upon the wave lengths of the sound waves to be transmitted thereby, since for a given wave length there is a maximum permissible change in mechanical impedance per unit length beyond which serious reflection losses will occur. The thickness of the diaphragms 30 will therefore depend upon the density of the sound responsive diaphragm 29 as well as upon the maximum frequency of the sound it is desired to transmit efficiently along the horn.

It has been previously disclosed in my prior application Serial No. 610,977, filed January 6, 1923, that a satisfactory arrangement for coupling a sound responsive diaphragm to the small end of a long horn is by means of an air chamber of predetermined size which acts as an auto-transformer for stepping down the mechanical impedance of the sound responsive diaphragm to the impedance at the small end of the horn. It is disclosed for reference purposes in Fig. 4 in which the diaphragm 31 is coupled to the small end of a long horn 32 by an air chamber 33 designed so that the mechanical impedance of the diaphragm 31 as seen from the small end of the horn is substantially the same as the mechanical impedance of the column of air looking in the direction of the open end of the horn from the same point.

The length of the horn 32 may be considerably reduced and decreased to a length of 1.3 or less by employing the present invention for producing a tapered change from the density of the sound responsive diaphragm to the density of air.

In Figs. 5 and 5a, for example, the sound responsive diaphragm 33 is located at the small end of the horn 34 and matches the impedance at this point because it has been made high by the use of a plurality of plates 35 of constant area but perforated, the number of perforations 48 per unit area increasing from plate to plate looking in the direction away from the sound responsive diaphragm 33. The effective density of the wave transmitting medium depends of course upon the plate spacing and the number and size of the perforations so that by increasing the number or size of the perforations in the plates looking in the direction of the mouth of the horn the average density of the translating medium for the sound vibrations may be rapidly decreased from the high density of the diaphragm 33 to that of air.

The size of the holes will depend upon the thickness of the plates and for thin plates of the thickness of paper they may vary from $\frac{1}{3}$ in. to $\frac{1}{5}$ in. or more while for thick plates they may have a diameter two or three times the thickness of the plates. In some cases only a few holes in each plate will be necessary while at other times a larger number such as thirty or more will be needed. After the point 36 is reached the horn 34 is given a tapered outline to increase gradually the area from the point 36 until the mouth of the horn is reached. Care must be taken of course to insure that the change in mechanical impedance per unit length along the section 37 of the horn is not greater than the maximum permissible change in mechanical impedance for the desired wave lengths to be efficiently transmitted. The change in area between the point 36 and the open end of the horn may, of course, be made still more rapidly without impairing the efficiency of transmission by employing imperforate diaphragms as in Fig. 1 of gradually diminishing thickness and gradually increased spacing looking in the direction of the mouth of the horn.

Fig. 6 is a modification of Fig. 5 in which the section 38 employed for changing from the high density of the diaphragm 39 to that of the density of air is made while simultaneously increasing the area. The perforated plates 40 are similar to the plates 35 of Fig. 5 except that looking in the direction of the mouth of the horn their area is increased in addition to the increase made in the number or size of the perforations. This gradual increase in the area of the perforated plates 40 may be made safely providing the maximum permissible change in impedance per wave length is not exceeded.

The form of this invention disclosed in Fig. 7 differs from the form shown in Fig. 5 only in that a plurality of imperforate diaphragms 41 are disclosed in section 42 of the horn for tapering the density of the sound responsive diaphragm 43 to that of air so that the imperforate diaphragms act simultaneously to the perforated plates 35 of Fig. 5. The diaphragms 41 are shown to be of gradually decreased thickness and increased spacing looking in the direction of the mouth of the horn for the reasons hereinbefore given.

The forms of this invention discussed up to this point have dealt with the application of this invention to a coupling means between a sound actuated diaphragm and a column of

air of much larger area such as is of interest in connection with phonograph reproducers, loud speaking telephone receivers and the like. This invention, is applicable to other types of sound translating systems as will appear to those skilled in the art and may, for example, be employed in connection with the mouth piece for a telephone transmitter. Such a modification is disclosed in Fig. 8 in which the mouth piece 44 for a telephone transmitter 45 is provided with a plurality of spaced diaphragms 46 to enable the diaphragm 47 of the telephone transmitter to be adapted to the mechanical impedance at the open end of the horn. These diaphragms 46 looking from the open end of the horn in the direction of the transmitter diaphragm 47 are gradually decreased in spacing and increased in thickness to taper the impedance at the open end of the horn to the impedance of the transmitter diaphragm 47 or to the mechanical impedance of the associated carbon chamber without exceeding the maximum permissible change in impedance per unit length, so as to produce an efficient translating system.

Perforated plates may be used instead of the diaphragms 47. Other modifications of this invention will be apparent to those skilled in the art without departing anywise from the invention as defined in the appended claims.

What is claimed is:

1. A sound translating member comprising a horn having a plurality of diaphragms of low elasticity spaced along a portion of the length of said horn and in contact with the inner surfaces of said horn.

2. A mechanical network of tapered impedance comprising a tubular channel having a plurality of inelastic diaphragms spaced along a portion of its length and in contact with its inner surface.

3. A mechanical network of tapered impedance comprising a horn, a sound responsive diaphragm located near one end of said horn and being of high density compared to air, and a plurality of plates spaced on one side of said diaphragm within said horn of such dimensions and of such a distribution to give a tapered decrease throughout the length of the horn in the average density of the translating medium per unit length along the horn looking away from said diaphragm.

4. A sound radiating member comprising a tubular channel and a plurality of plates graduated in mass and spacing being spaced along and in contact with a portion of said channel.

5. A sound radiating member comprising a tubular channel and a plurality of plates graduated in thickness and spaced along a portion of said channel.

6. A sound radiating member comprising a horn and a plurality of plates graduated in thickness and spaced along a portion of said horn at graduated intervals.

7. A sound radiating member comprising a tubular channel, a diaphragm at one end of said channel and a plurality of plates spaced inwardly along the axis of a portion of said channel and graduated in mass to taper the density per unit length along the channel by small steps from the density of said diaphragm to that of air.

8. A sound radiating member comprising a horn, a plurality of plates spaced along a portion of said horn and having the same thickness but varying in area, and a plurality of plates spaced along and in contact with another portion of said horn with a tapered spacing.

9. In combination, a horn, a sound responsive diaphragm located near one end of said horn, and means within the horn for tapering the impedance of said diaphragm to the impedance of the air at the mouth of said horn without causing substantial reflection losses within said horn.

10. In combination, a horn, a sound responsive diaphragm located near one end of said horn, and means within the horn for compensating for difference in mechanical impedance caused by any difference in area between the area of said diaphragm and the area of the mouth of said horn without causing substantial reflection losses.

11. In combination, a horn, a sound responsive diaphragm located near one end of said horn, and means within said horn for compensating for the difference in mechanical impedance caused by said diaphragm having a greater density than that of air without causing substantial reflection losses within said horn.

12. A horn comprising a sound responsive diaphragm at one end thereof, a plurality of inelastic diaphragms adjacent said first diaphragm of constant thickness but progressively increasing in area proceeding away from the diaphragm, and a plurality of other diaphragms located in a different part of said horn of progressively diminished thickness looking away from said first diaphragm.

13. A loud speaking horn having a sound responsive diaphragm located near one end, a plurality of diaphragms of constant thickness but progressively increasing in area located within said horn and adjacent said first diaphragm, and a plurality of other diaphragms located in another portion of said horn with progressively increased spacing and progressively diminished thickness looking away from said first diaphragm, both sets of said diaphragms being composed of a material having negligible elasticity compared to the elasticity of said first diaphragm.

14. A sound radiating member in accordance with claim 4 in which said plates are

so distributed that there are at least seven per wave length.

15. An acoustic device comprising a tubular member having a sound transmitting medium therein, a plurality of diaphragms dividing said member into a plurality of separate substantially air-tight chambers, said diaphragm being adapted to vibrate solely in response to forces transmitted through said medium, and means for impressing sound waves on said medium at one end of said member.

16. An acoustic device for uniformly transmitting sound waves covering a range of frequencies, comprising a tubular member, having a sound transmitting member therein, and acoustic impedances comprising lumped masses along the length of said member dividing said member into a plurality of separate substantially air-tight chambers, said masses being adapted to vibrate solely in response to forces transmitted through said medium.

In witness whereof, I hereunto subscribe my name this 30th day of April, A. D. 1923.

HENRY C. HARRISON.