ACOUSTIC DEVICE

Filed June 28, 1927 3 Sheets-Sheet 1

Fig. 1

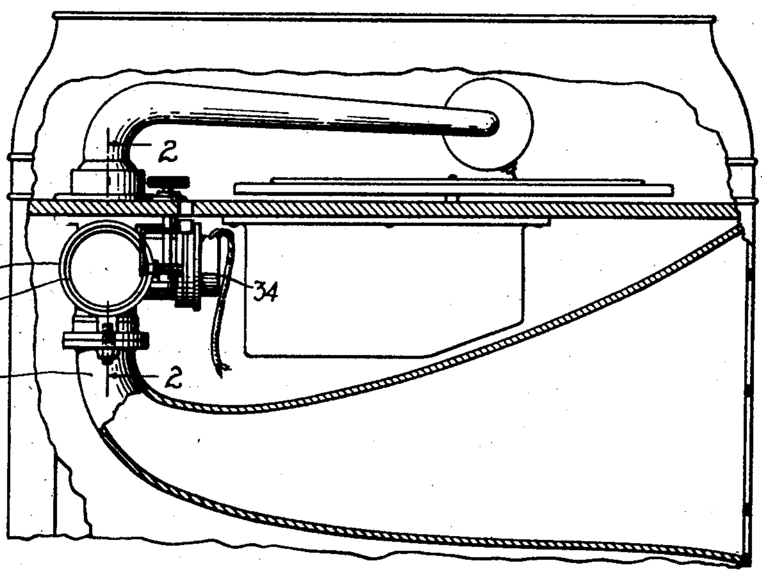


Fig. 2

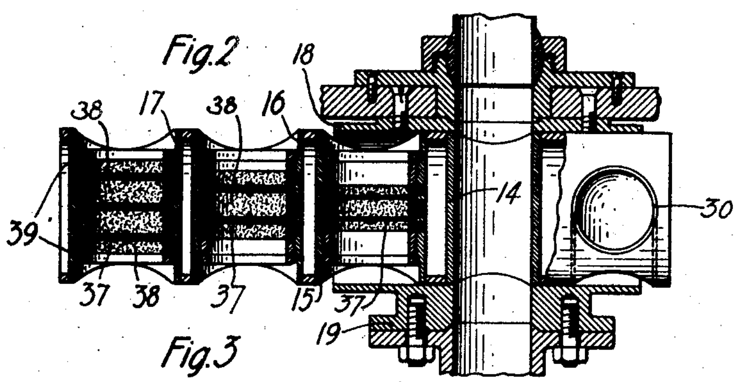


Fig. 3

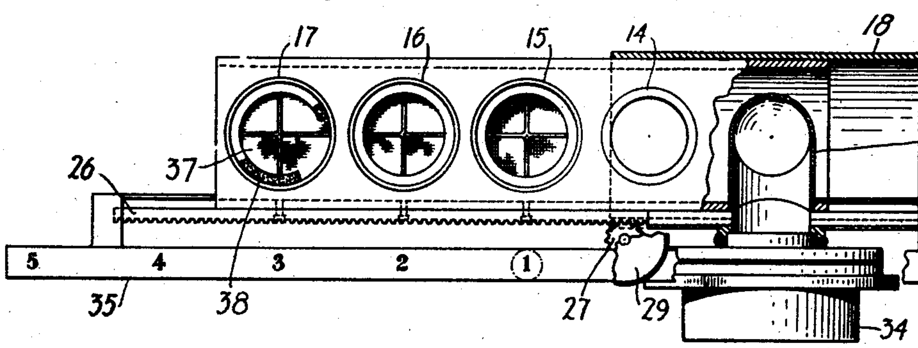


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FIG. 4.

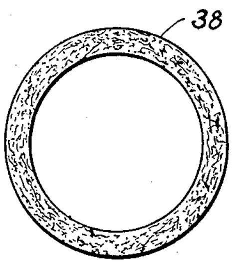


FIG. 5.

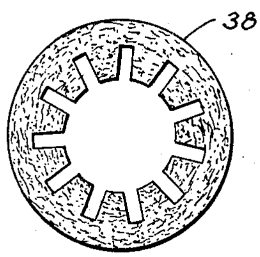


FIG. 6.

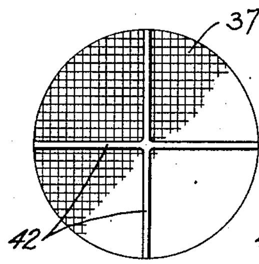


FIG. 6A

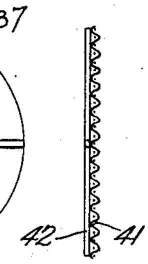


FIG. 11.

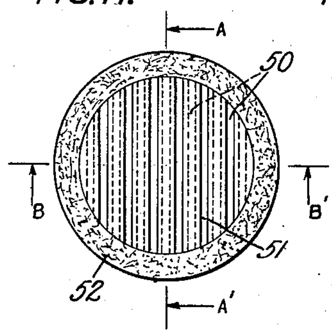


FIG. 11A.

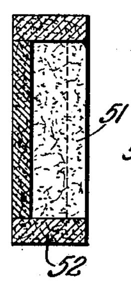


FIG. 11B.

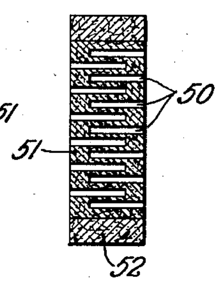


FIG. 12.

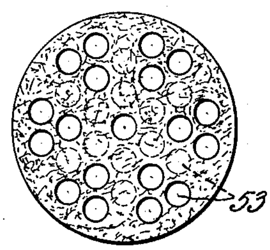


FIG. 12A.

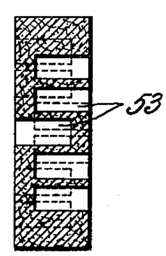


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FIG. 7.

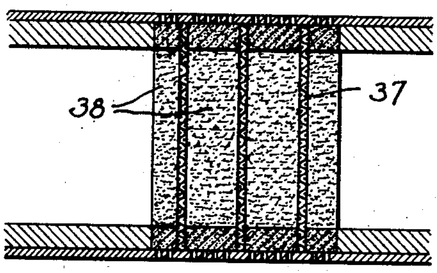



FIG. 8.

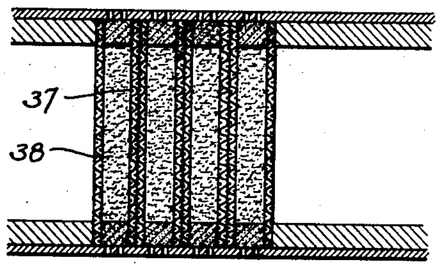



FIG. 9.

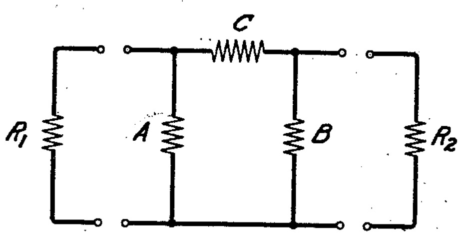
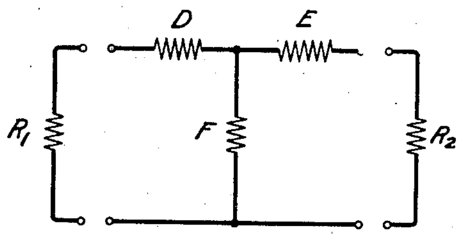



FIG. 10.

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Patented May 12, 1931 1,804,688

# UNITED STATES PATENT OFFICE

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## ACOUSTIC DEVICE

Application filed June 28, 1927. Serial No. 202,072.

This invention relates to acoustic devices, and more particularly to attenuating devices for use in connection with acoustic wave transmission systems.

An object is to attenuate sound wave energy in an acoustic system without introducing appreciable distortion.

Another object is to control the volume of the sound radiated from phonograph horns electrical loud speakers, and other acoustic devices; specifically, to control the volume selectively in steps of any desired magnitude.

In accordance with the invention there is inserted in the sound conduit of an acoustic transmission line a system of acoustic impedance elements which are alternately disposed to obstruct the vibratory flow of the air, and to divert some of the wave motion from the main transmission path. The impedance elements are, in effect, arranged alternately in series and in shunt with respect to the acoustic transmission line, forming therein an artificial line section, the wave transmission properties of which may be controlled by the design of the component impedances. By the use of energy dissipative elements constructed from sound absorbing material such as fine wire gauze or hair felt the attenuating properties of the device may be made substantially uniform at all important sound wave frequencies. In addition the combination of a plurality of elements in series and shunt connections permits of the proportioning of the elements so that the device may be inserted in a given transmission system without causing any wave reflection. By these means a uniform overall effect is secured and the result is achieved that the sound energy level is controlled in a substantially distortionless manner.

In one embodiment the attenuating device comprises series impedance elements in the form of discs or screens of very fine wire gauze placed transversely across the sound conduit of a transmission system, and shunt elements in the form of porous rings inserted between the discs to form a porous sound absorbing wall around the sound conduit. Preferably the outer surfaces of the porous rings are exposed, either wholly or in part, to the open air so that any portion of the escaping sound energy may not be reflected back into the sound conduit.

The term impedance is used herein in its broad sense to define the ratio of the effective value of a simple harmonic vibratory force of any character to the resulting velocity in the medium to which the force is applied. This is an extension of the definition of the term as ordinarily used in connection with electrical wave motion. In acoustic systems the wave motion takes the form of a vibratory flow of air under the action of a corresponding vibratory pressure superimposed upon the normal pressure of the air. The air velocity is most conveniently measured as the volumetric rate of flow past a given cross section of the air conduit, and the term "acoustic impedance" is used to define the ratio of the excess pressure intensity at a given point in the system to the volumetric velocity at that point. The acoustic impedance may be resistive or reactive or complex according as the velocity is in phase or out of phase with the driving force, and further a reactive impedance may be of the inertia or the elastic type according as the element is adapted to store energy in the kinetic form or the potential form.

Under certain conditions the acoustic impedance may be computed from the geometrical dimensions, and in other cases it may be determined by direct measuring methods. A suitable method of measurement is described by G. W. Steward in the Physical Review vol. 28, No. 5, Nov. 1926, page 1038.

The concept of acoustic impedance enables the well known wave transmission formulæ that have been developed in connection with electrical systems to be applied to the investigation of acoustical systems, and the knowledge of the impedance values permits the wave transmission properties to be determined in any particular case.

The attenuating devices of the present invention, being resistance structures, are particularly adapted for use in connection with high quality acoustic transmission systems, which in general are characterized by a substantially constant resistance characteristic impedance. An example of such a system is the exponential horn and sound box combination disclosed in the copending application of H. C. Harrison, Serial No. 33,619, filed May 29, 1925. The attenuators, however, are not restricted to use in connection with high quality transmission systems, but may be used advantageously in any acoustic system, and in certain cases may bring about an improvement in the quality of transmission.

The invention may be better understood by referring to the accompanying drawings in which:

Fig. 1 illustrates the invention as applied to a phonograph;

Fig. 2 is a detailed sectional view taken along the line 2—2 of Fig. 1;

Fig. 3 is a detailed plan view, partly in section, of the attenuator shown in Figs. 1 and 2;

Figs. 4, 5, 6 and 6A show various types of acoustic impedance elements suitable for use in acoustic attenuators of the invention;

Figs. 7 and 8 illustrate different modes of assembling the elements of an acoustic attenuator;

Figs. 9 and 10 are schematic diagrams used to illustrate the theory of the invention; and

Figs. 11, 11A, 11B, 12 and 12A illustrate additional types of acoustic impedance elements.

Referring to Figures 1 to 3, the device illustrated is a multi-unit attenuator adapted for use in connection with a phonograph. Near its throat the phonograph horn 10 is provided with a transverse tubular element 18 within which slides the carrier element 13 with the individual attenuators. The attenuators, three in number, are mounted in transverse tubes 15 to 17 so that by sliding the carrier 13 within the tube 18 any one may be inserted in the sound passage of the horn. An additional straight through tube 14 enables the horn to be used in its normal manner without the inclusion of an attenuator. The carrier 13 is adapted to be moved in the direction of its axis by means of rack 26 and pinion 27 to which is attached the operating handle 29. The position of the carrier with respect to the sound passage of the horn is shown by means of the graduated index bar 35 rigidly attached thereto.

Although not an essential part of the attenuator, a useful feature of the construction shown consists of an additional tube 30 mounted in the carrier which provides a sound passage from the horn to an alternative wave source such as the electrical receiver unit 34.

The attenuators comprise screens 37 of fine mesh wire gauze placed transversely in the mounting tubes, and rings 38 of porous sound absorbing material separating the successive screens. A suitable sound absorbing material for the rings is the pressed sugar-cane fibre board known under the trade mark "Celotex". The screens by virtue of their fine mesh act as series impedances tending to reduce the wave pressure as the air passes through them, and the porous rings act as shunt elements tending to absorb some of the wave motion velocity. The mounting tubes 15, 16 and 17 are preferably perforated so that the sound energy shunted through the porous rings can escape freely to the atmosphere. The screens and rings are held in position in the mounting tubes by clamping rings 39.

Figs. 4 and 5 are sectional views of rings of sound absorbing material suitable for use as shunt impedance elements. These rings may be made of compressed vegetable fibre, for example the trade marked product "Celotex", or of other foraminous material. The ring shown in Fig. 4 should have its inside diameter approximately equal to the diameter of the sound passage in which the attenuator is inserted. The value of the acoustic resistance is approximately proportional to the radial thickness of the ring and inversely to the area of its exposed internal surface. An increase of the shunting effect may therefore be obtained by reducing the thickness of the ring, or by increasing its exposed surface area. The ring shown in Fig. 5 illustrates one method of increasing the exposed surface area without increasing the axial length of the ring.

Figs. 6 and 6A illustrate the series impedance elements or screens. In the construction of these it has been found satisfactory to use a metallic gauze having from 200 to 250 .004″ diameter wires to the inch in one direction, and 28. 009″ diameter wires in the other. A gauze of this type provides a screen in which the air passages are so narrow that the air flow therethrough is controlled very largely by viscosity, with the result that the impedance to sound waves is almost wholly or a resistive, or dissipative character. To give the screens a sufficient amount of rigidity they may be soldered to a frame of heavy cross wires 42.

Figs. 7 and 8 illustrate two typical methods of assembling the resistance elements. Both figures show recurrent uniform structures of three complete sections. In Fig. 7 the end elements are shunt impedances, the value of the end impedances being twice that of the intermediate shunt impedances. To this type of termination of term "mid-shunt" is applied. Fig. 8 illustrates the converse, or mid-series, termination, the end impedance consisting of a single screen series element and the intermediate impedances comprising a pair of screens placed back to back. One screen of each pair may be disposed with its wires rotated angularly with respect to the wires of the other thereby ensuring the most effective cooperation of the two screens in retarding the air flow. The line in Fig. 7 may be regarded as being made up of a series of sections each comprising a pair of shunt impedances separated by a series impedance, the sections being of the general type shown, according to the familiar electrical conventions, in Fig. 9. In the general case the component impedances of the section may all have different values but in the uniform type of line illustrated the sections are symmetrical. Fig. 10 shows the schematic form of the general type of section corresponding to Fig. 8.

The design problem is to proportion the impedances of one or more three element sections, such as in Figs. 9 and 10, so that the device may be inserted between portions of a system having preassigned impedances without causing wave reflection, and at the same time bringing about a desired reduction in the wave pressure as the wave traverses the system. Design formulæ from which the values of the impedances for a single section of either type may be computed are given below. The more general case is assumed in which the section is required to be connected between unequal impedances $R_1$ and $R_2$; the formulæ for the case in which the connected impedances are equal readily follow.

Let it be assumed that the attenuator is connected to a system of impedance $R_1$ at its input end and to an impedance $R_2$ at its output end, and let $p_1$ and $p_2$ be the wave pressures at the two ends respectively. The pressure diminution ratio $p_1/p_2$ may be assigned a definite value and this value together with $R_1$ and $R_2$ may be used as parameters for the computation of the component impedances. For the two types of section shown in Figures 9 and 10 the values of the component impedances are given by the following equations:

Fig. 9,

$$C=\sqrt{R_1R_2}\sinh T;$$

$$A=\frac{C}{\sqrt{\frac{R_2}{R_1}}\cosh T-1};$$

$$B=\frac{C}{\sqrt{\frac{R_1}{R_2}}\cosh T-1}$$

Fig. 10,

$$F=\frac{\sqrt{R_1R_2}}{\sinh T},$$

$$D=F\left(\sqrt{\frac{R_1}{R_2}}\cosh T-1\right)$$

$$E=F\left(\sqrt{\frac{R_2}{R_1}}\cosh T-1\right).$$

In these equations the quantity T is in the nature of a propagation constant and is defined by

$$T=\log_e\frac{p_1}{p_2}\sqrt{\frac{R_2}{R_1}}$$

The quantity T has been termed the image transfer constant to distinguish it from the the propagation constant of a uniform line section. It differs from the propagation constant in that it takes account of the inequality of the terminal impedances, when these are equal it is equal to the propagation constant. For a general discussion of the principles on which the foregoing formulæ are based reference is made to the text book "Transmission Circuits for Telephone Communication" by K. S. Johnson, and particularly to Chapter XI.

It is evident that any desired degree of attenuation may be obtained by means of a single three element network, but it is generally more convenient from a manufacturing standpoint to obtain large attenuations by combining several similar sections each designed for a smaller attenuation.

The foregoing design method is applicable when means is available for the measurement of the impedance of the elements or when data are available for the computation of the impedance from the geometrical dimensions. In the absence of such facilities the series-shunt type of structure lends itself to empirical design; the overall transmission characteristic, or response characteristic, of the system being used as a criterion of the performance, and the values of the elements being modified in accordance with a few simple rules.

As a rule a trial design will show a certain average attenuation throughout the desired frequency range, but due to the improper matching of impedances the attenuation characteristic will undulate above and below the average value at different frequencies.

The average attenuation may be increased by increasing the values of the series impedances with respect to the shunt impedances, and vice versa, and the impedance of the system as a whole may be raised or lowered by increasing or decreasing the series and shunt impedances in the same ratio. In this way an attenuator may be constructed as the result of a small number of trials to give approximately a desired attenuation or volume diminution and to do so without introducing distortion. The impedances of the elements, using a given material, are easily varied by changing the exposed surface and the thickness of the elements.

Figs. 11, 11A, 11B, 12 and 12A illustrate composite types of elements which are adapted to combine series and shunt acoustic resistances in a single structure. These are particularly useful for obtaining a high degree of attenuation.

In Figs. 11, 11A, and 11B the acoustic impedance element comprises a disc of finely porous material which extends across the sound passage. A plurality of parallel slots 50 are cut into the opposite faces of the central portion 51 of the disc in such a way that the slots in one face are in staggered relation with respect to slots in the other face. These slots are deeper than one-half the thickness of the porous material so that the slots in the opposite faces overlap. An annular peripheral portion 52 is provided to give rigidity to the structure and to close the ends of the slots 50 so that they do not extend to the walls of the sound passage in which the impedance element is positioned. Figs. 11A and 11B show respectively cross sections of the element at the mutually perpendicular diameters AA′ and BB′. The series component of the resistance offered by an element of this type of a given size is dependent on the amount of overlap of the slots and upon the distance between the slots, that is, the series resistance decreases as the amount of overlap is increased and increases as the distance between the slots is increased. The shunt resistance component depends on cross-sectional area of the slots and the radial thickness of the annular portion 52.

The disc shown in Figs. 12 and 12A is similar to that shown in the preceding figures except that it has holes 53 drilled in the opposite faces thereof instead of having slots as shown in the preceding figures. These holes overlap and function in the same way as the slots.

It is to be understood that this invention is not limited to the specific type of acoustic attenuator described above or to one employing the specific sound absorbing elements described. Other combinations of series and shunt resistance elements readily suggest themselves and also other means for mechanically varying the degree of attenuation, for example, by covering the surface of the series elements and simultaneously uncovering the surface of the shunt elements by mechanically operated shutters.

In addition to being used as attenuating devices the attenuators may also be usefully employed as resistive line "pads" for preventing the interaction of wave reflections between two positions of an acoustic system. In this case the attenuators operate as distortion corrective means, since the interaction of reflected waves or the repeated reflection of waves between two points in a system is generally productive of distortion of the transmission characteristic. The distortion correction is, of course, accompanied by some attenuation. A useful application of the attenuators as distortion eliminating devices is in connection with sound reproducer horns which on account of their irregular contours or of improper terminal conditions at their mouths or throats exhibit peaks in the response characteristics due to reflection effects. The insertion of an attenuator of the type described in the throat of the horn is effective to a large extent in removing the reflection peaks.

What is claimed is:

1. In an acoustic transmission line, an attenuating network of acoustic resistances comprising a section having both series and shunt resistance components.

2. An acoustic attenuator comprising a combination of a series and a shunt impedance element, said series impedance element comprising a plurality of gauze members having a finer mesh in one direction than in the other, said gauze members being so positioned that the direction of the finer mesh of one bears an angular relation to the direction of the finer mesh in an adjacent gauze member.

3. An attenuator for an acoustic transmission line comprising an acoustic system having series and shunt impedance elements, said shunt elements comprising sound absorbing materials, a portion of which is in contact with the transmitted sound waves and another portion of which is in contact with the free atmosphere.

4. In an acoustic transmission line, an element of finely porous material extending across the transmission line and having surfaces exposed longitudinally of said line whereby it offers both series and shunt impedance to acoustic waves transmitted through said line.

5. In an acoustic transmission line, an element of finely porous material extending across the transmission line, said element having openings in opposite faces extending part way through the material.

6. A volume control for an acoustic device including a sound passage, comprising a movable structure having a plurality of sound passages, means for selectively positioning the sound passages of said movable structure in alignment with the sound passage of said acoustic device, and means included in a plurality of the sound passages of said movable structure for providing progressively varying degrees of attenuation, said attenuating means each comprising a system of acoustic resistances, having such values that its characteristic impedance is equal to that of the sound passage of the acoustic device.

7. An acoustic attenuator comprising a sound conduit, a gauze member therein through which the sound waves pass and a porous sound absorbing member adjacent said gauze member and having a large opening therein through which the sound waves pass, said attenuator giving substantially constant attenuation over a wide range of frequencies.

8. An acoustic attenuator comprising a

sound conduit, a gauze member of finely woven wires across said conduit, and a porous member adjacent said gauze member and having a large opening therein through which the sound waves pass.

9. In a device for transmitting acoustic energy of a wide range of frequencies, an attenuating acoustic network comprising series and shunt resistance elements so proportioned and arranged with respect to the acoustic impedance of the transmitting device that said network substantially uniformly attenuates waves of all frequencies within said range.

10. A sound wave attenuator for an acoustic transmission line comprising a plurality of acoustic resistance elements disposed alternately in series and in shunt with respect to the direction of wave transmission.

11. In an acoustic transmission line, a sound wave attenuator comprising a plurality of acoustic resistances certain of which are disposed in series with respect to the direction of wave transmission, and others of which are disposed in shunt with respect to the direction of wave transmission.

12. A sound wave conduit, and an acoustic attenuator included therein, said attenuator comprising a plurality of acoustic resistance elements, certain of which are disposed to impede the wave movement of air in said conduit, and others of which are disposed to provide acoustic leakage paths in shunt to the wave path in said conduit.

13. An acoustic attenuator comprising means defining a sound wave channel, a porous screen forming a sound impeding barrier across said channel, and a tubular element of porous material disposed to form a sound absorbing wall for a portion of said channel.

14. An acoustic attenuator for a sound wave transmission line, comprising series means for impeding the sound wave motion, and shunt means for absorbing the sound wave motion, said series and shunt means comprising acoustic resistances which are substantially free from reactance.

15. In combination with a sound wave transmission line, an acoustic attenuator comprising a plurality of acoustic resistance elements disposed alternately in series and in shunt with respect to the transmission line, the values of said resistance elements being such that the attenuator has a characteristic impedance substantially equal to that of the transmission line.

16. A volume control for an acoustic device including a sound passage, comprising a plurality of acoustic attenuators, adapted to provide different degrees of attenuation, and means for inserting said attenuators selectively in the sound passage of the acoustic device, said attenuators comprising systems of acoustic resistance elements having values such that the characteristic impedance of each attenuator is equal to that of the sound passage of the acoustic device.

In witness whereof, I hereunto subscribe my name this 27 day of June, A. D. 1927.

HENRY C. HARRISON.