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P. B. FLANDERS

1,854,830

ACOUSTIC DEVICE

Filed April 28, 1928

FIG. 1

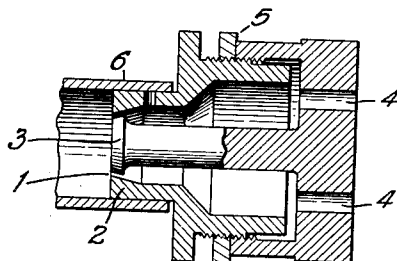


FIG. 2

FIG. 2a

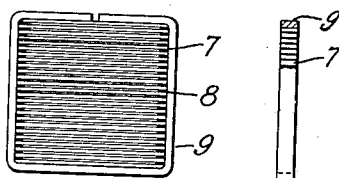


FIG. 3

FIG. 3a

FIG. 4

FIG. 4a

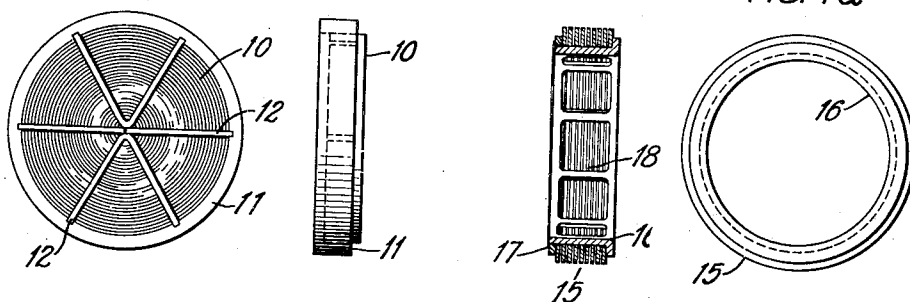
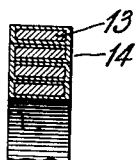


FIG. 5



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ACOUSTIC DEVICE

Application filed April 28, 1928. Serial No. 273,523.

This invention relates to acoustic devices, and more particularly to acoustic impedance elements of resistive, or energy dissipative character, suitable for damping of acoustic vibrations. The principal object of the invention is to secure a high degree of constancy, with respect to wave frequency, of the resistance value, and a high degree of purity of the resistive character of acoustic resistance elements. Other objects relate to the reduction in size of resistance elements, and to the simplification of their manufacture.

In accordance with the invention use is made of the acoustic properties of narrow slots or crevices, between parallel walls to provide the desired resistance characteristics. It has been discovered that when the width of a crevice between the walls is reduced below a certain value the flow of air, or other gaseous medium, is governed almost entirely by its viscosity, and the opposition to the flow developed by the crevice is almost wholly of a dissipative or resistive character. The impedance is readily calculable from the dimensions of the slot, and is substantially constant over a very wide range of frequencies.

In the preferred forms, the resistance elements of the invention consist essentially of flat plates, or of short cylindrical tubes, perforated by a multiplicity of fine slots of predetermined size. Other forms may, however, be used, and in certain instances it has been found advantageous to employ a single slot of adjustable width to provide a resistance of adjustable value.

The impedance of an acoustic device is defined as the steady state value of the ratio of an impressed force to the resulting velocity in the acoustic medium at the point of application of the force. The impressed force may be measured as the excess over the normal pressure intensity of the medium, (usually air), and the velocity may be taken as the rate of volumetric displacement of the medium over the cross-section of the acoustic channel of the device. The ratio of these quantities gives the value regularly defined as the acoustic impedance. Alternatively the impressed force may be taken as the total excess pressure over the cross-sectional area of the acoustic channel, and the velocity as the linear, or particle, velocity of the medium. The ratio of these quantities gives a different value, which, to distinguish from the acoustic impedance defined above, will be termed the mechanical impedance. The mechanical impedance of an acoustic device is equal to its acoustic impedance multiplied by the square of the cross-sectional area of the acoustic passage at the point for which the impedance is considered.

When the impressed force is of a periodic character, the resulting velocity may or may not be in phase with the force. The impedance is thus a vector, and is most conveniently expressed by a complex quantity, the real part of which represents the resistance, and the imaginary part the reactance.

The particular features of the invention, the manner of its construction, and the principles involved in the design and operation will be more fully understood from the following detailed description and from the accompanying drawings of which

Fig. 1 represents one form of adjustable resistance element in accordance with the invention;

Figs. 2 and 2a represent a simple form of fixed resistance;

Figs. 3, 3a, 4 and 4a represent preferred forms of the invention; and

Fig. 5 is a sectional drawing to illustrate a method of manufacture.

In the device of Fig. 1 the resistive impedance is provided by the annular slot 1 between the tapered wall of a fixed hollow bushing 2 and the correspondingly tapered surface of an adjustable plug 3, the head of which is recessed and threaded internally to engage with a corresponding thread on the outside of

bushing 2. A lock nut 5 serves to hold the parts firmly in their adjusted position. A number of holes 4 in the head of the screwed plug permit free communication between the outer air and the enclosed space inside the hollow bushing. A device of this type is well adapted for use as a test load on acoustic devices such as telephone receivers or phonograph sound boxes, to which it may be applied by means of a connecting tube 6. Preferably the unit is made to correspond to the size of the sound wave aperture of the device to be tested, but it may be adapted to apertures of different size by the use of a tapered connecting tube.

The principles underlying the design of this type of acoustic resistance will appear from the following consideration of the acoustic properties of a slot aperture.

The acoustic impedance of a parallel sided slot having a length l in the direction of wave propagation, a transverse breadth b , and a separation d between its walls, is given by the equation

$$Z_a = \left(\frac{12\mu}{d^2} + j\frac{6}{5}\omega\rho \right) \frac{l}{bd} \quad (1)$$

in which Z_a denotes the acoustic impedance as already defined, and,

μ = the coefficient of viscosity of the medium (air)

ρ = the density

ω = 2π times the wave frequency.

This formula holds for slots that are narrow enough to make the viscosity the most important factor in the determination of the motion. The width should be less than the length λ of the so-called "diffusion wave" given by the equation

$$\lambda = 2\pi\sqrt{\frac{2\mu}{\omega\rho}} \quad (2)$$

The length l of the slot should also be short in comparison with the wave length of sound at any frequency within the desired range of operation, but preferably should not be shorter than ten times the separation d .

The resistive component of the impedance is independent of the frequency, while the reactive component is directly proportional thereto. At high frequencies the impedance tends to become more and more reactive, but by making the separation d small enough the reactance may be made negligibly small with respect to the resistance throughout any pre-assigned frequency range. The ratio of resistance to reactance is equal to

$$\frac{10\mu}{d^2\omega\rho}$$

and if this be given a preassigned value at the highest frequency to be considered, the value of the slot separation readily follows:

For example, if it is desired that the resist-

ance should be 10 times the reactance at a frequency of 5000 c. p. s., then

$$d = \sqrt{\frac{\mu}{2\pi \cdot 5000 \cdot \rho}} \quad 70$$

For air the ratio

$$\frac{\mu}{\rho}$$

may be taken as 0.154 c. g. s., in which case

$$d = 2.22 \times 10^{-3} \text{ cm.}, \text{ or } .875 \times 10^{-3} \text{ inches.} \quad 75$$

Separations of the order of one thousandth of an inch thus give rise to an impedance that is substantially free from reactance over the whole range of speech frequencies; wider separations may, however, be used, and for many purposes separations as great as 2 mils are satisfactory.

Equation 1 gives the acoustic impedance of the slot itself, but in many cases the impedance it is desired to know will be that of the conduit in which the device is inserted. Thus in the device of Fig. 1 the desired value may be the impedance as measured in the conduit 6 at a cross-section close to the slot. By definition the acoustic impedance is the ratio of the pressure intensity to the volumetric rate of displacement, and since the displacement in the slot is the same as that over the cross-section of the conduit it follows that the acoustic impedance measured in the conduit is the same as that of the slot itself.

In many cases it is more convenient to make use of the mechanical impedance, as previously defined, instead of the acoustic impedance. For example, if the device is used as a load for a telephone receiver or a phonograph sound box the mechanical impedance of the acoustical system can be compared directly with the impedance of the mechanical driving system. From the definitions already given it follows that the mechanical impedance of an acoustic path is equal to the acoustic impedance multiplied by the square of the cross-sectional area of the path. The mechanical impedance of a slot denoted by Z_m is therefore given by the equation

$$Z_m = Z_a (bd)^2, \quad (3) \quad 115$$

where Z_a , b and d have the same meanings as in Equation 1. Referred to the conduit in which the resistance device is inserted, the mechanical impedance is increased in proportion to the square of the ratio of the cross-sectional areas of the respective paths. Thus, for Fig. 1,

$$Z'_m = Z_m \left(\frac{A}{bd} \right)^2, \quad (4) \quad 125$$

$$= Z_a \cdot A^2$$

where Z'_m is the impedance as measured in the conduit 6, and A is the area of the conduit.

To provide a resistance of relatively low

value, the separation d may be increased or the length l reduced. The values of d and l , however, are dependent upon other considerations. The preferred method of reducing the resistance value is to increase the breadth b of the slot. This leads directly to a reduction of the acoustic resistance, but as will be seen from Equation 3, to an increase in the mechanical impedance. The increase, however, is in the mechanical impedance of the slot itself, whereas the value referred to the conduit in which the device is inserted is actually diminished. This follows from Equation 4.

Various constructions that enable low resistance values to be obtained are illustrated in Figs. 2, 3 and 4. In the device of Figs. 2 and 2a, flat rectangular rods 7 are piled up to form a flat rectangular plate, the individual rods being separated from each other by small pieces of foil 8 inserted between the ends of the rods. The array is held rigid by a suitable clamping frame 9. The thickness of the rods and of the separation may be proportioned in accordance with the foregoing formulæ to give the desired resistance value.

Figs. 3 and 3a illustrate a preferred form of resistance device. In this form a very large slot area is obtained by winding a thin metallic ribbon into a closely spaced spiral, forming in effect a flat disc of porous structure. The spiral element, designated 10 in the drawings is mounted on a metallic supporting frame comprising a circular ring 11, and a number of radial arms 12, to which the ribbon is securely attached by soldering or by other suitable means.

It is desirable in a construction of this type that the slot width should be uniform, and to this end the following methods of construction have been found satisfactory.

A ribbon of copper is first coated with zinc to a thickness equal to half the desired slot width, and is then wound into a closely packed spiral of whatever diameter is desired. It is convenient to wind the spiral around a small copper rod about 0.1 inch diameter, the inner end of the ribbon being soldered or welded to the rod for security. A cross-section of a part of the spiral so formed is shown in Fig. 5, in which 13 denotes the copper core of the ribbon and 14 the zinc coating. The close packed spiral element thus formed is next soldered to its supporting frame, the surfaces of which should be well tinned to make sure that all of the turns will be properly attached to each of the arms. It is also necessary that the outer edge of the spiral element should make a tight connection with the outer ring 11 so that there will be no leakage path for the air at this point. The next step is to remove the zinc coating from the ribbon, which may be done by dissolving it in a solution of hydrochloric acid. This leaves the copper spiral with its convolutions uniformly spaced

at the desired separation, and rigidly attached to the mounting frame. As a final step the structure should be washed to remove any traces of the acid that might cause further corrosion of the parts. The method described above may obviously be varied by using other metals in the bi-metallic ribbon and by using other solvents depending on the nature of the chosen metals.

Another method of construction is to wind a pair of ribbons of different metals side by side into a solid double spiral, and thereafter to dissolve out one of the ribbons by the use of a suitable solvent. In this method the ribbons may be of copper and aluminum, and the aluminum may be dissolved out by a solution of caustic potash.

Figs. 4 and 4a represent a form of the invention suited for providing a resistive leak in a sound conduit. In effect, this form of device consists of a porous cylindrical ring adapted to be included as part of the wall of a circular sound conduit. The resistive leak is provided by narrow slots between thin flat rings 15, which are mounted upon a skeleton cylindrical frame 16, and are held in place, slightly separated from each other by being soldered to the ribs 18 of the skeleton frame. A flange on one end of the ring 16 and a clamping ring 17 on the other end also serve to hold the rings in place.

To secure the proper spacing of the rings temporary spacers of another metal having the desired thickness may be inserted during the assembly process, and after the rings have been soldered to the frame the spacers may be removed by the use of a suitable solvent as already described. Alternatively, the slotted structure may be achieved by winding a coated ribbon edgewise in a close helix on the cylindrical frame, and after soldering to the ribs, dissolving away the coating of the ribbon.

It is sometimes desirable to provide a sound wave conduit with a terminating device which will prevent wave reflection at the end of the conduit. In accordance with the principles of wave transmission the terminating device must have an impedance equal in value to the characteristic impedance of the conduit. If the conduit is of uniform cross-section its characteristic impedance is resistive and has the value

$$K = \frac{c\rho}{A} \quad (5)$$

where K = the characteristic impedance,
 c = velocity of sound
 ρ = density of the medium
 A = cross-sectional area of the conduit.

For air at ordinary pressures and temperatures the product $c\rho$ has the value 41.3.

A resistance of this value can be obtained readily in a device of the form shown in Fig. 130

3. The design requirements are expressed in the equation

$$\frac{12\mu}{d^2} \cdot \frac{l}{bd} = \frac{41.3}{A} \quad (6)$$

or

$$\frac{l}{d^2} = \frac{41.3}{12\mu} \cdot \frac{bd}{A}$$

which follows readily from Equations 1 and

5. The factor

$$\frac{bd}{A}$$

is a space factor, namely the ratio of the total slot area to the area of the conduit. If the space taken up by the radial arms is neglected, the space factor may be expressed in terms of the thickness of the ribbon, denoted by t and the slot width d , and Equation 6 may be rewritten as

$$\frac{l}{d^2} = \frac{41.3}{12\mu} \cdot \frac{d}{d+t}$$

Finally, taking $\mu = 1.86 \times 10^{-4}$ c. g. s. as the value of the viscosity coefficient for air,

$$\frac{l}{d^2} = 1.85 \times 10^4 \cdot \frac{d}{d+t} \quad (7)$$

This equation involves the three mechanical dimensions, l , d and t , and it is necessary that two of these be fixed before the third can be determined. The slot width d is roughly determined by the condition that the reactance should be negligible at all frequencies to be considered, and the length l is preferably at least 10 times the slot width. These conditions do not, however, fix the values rigidly, and a considerable latitude is thus permissible in the choice of values to suit other conditions that may be imposed by the nature of the materials available and the method of construction chosen.

What is claimed is:

1. An acoustic resistance device comprising means defining a sound wave passage in the form of an open slot having substantially parallel sides, having a length in the direction of wave motion that is small in comparison with the wave lengths of the highest speech frequencies, and having a width between the parallel sides that is small in comparison with the lengths of the diffusion waves corresponding to the highest speech frequencies.

2. An acoustic resistance device comprising means defining a sound wave passage in the form of an open slot having substantially parallel sides, the width between the parallel sides of the slot being so small with respect to the diffusion wave lengths in the sound transmitting medium that the reactance of the passage is substantially negligible in comparison with its resistance throughout the range of speech and musical frequencies.

3. An acoustic resistance device comprising means defining a sound wave passage in the form of a parallel sided open slot, the width between the sides of the slot being so small with respect to the diffusion wave lengths in the sound transmitting medium that the reactance of the passage does not exceed 20 percent of the resistance value at a wave frequency of 5000 cycles per second.

4. An acoustic resistance device comprising a member adapted to be inserted in a sound conduit and having an open slot defining a sound wave passage therethrough, said slot having substantially parallel sides separated not more than .003 inch, and a length in the direction of wave motion that is small in comparison with the wave lengths of the highest frequencies of speech.

5. An acoustic resistance device comprising a member adapted to be inserted in a sound conduit and having an open slot defining a sound wave passage therethrough, said slot having substantially parallel sides separated not more than .0015 inch, and a length in the direction of wave motion that is small in comparison with the wave lengths of the highest frequencies of speech.

6. An acoustic resistance device comprising means defining a plurality of wave passages in the form of parallel sided open slots, the widths between the sides of the slots being less than .003 inch.

7. An acoustic resistance device comprising means defining a plurality of wave passages in the form of parallel sided open slots, the widths between the sides of the slots being less than .003 inch, and the lengths of the slots in the direction of wave motion being greater than 10 times the width, but small in comparison with the wave length in air of sound waves of any frequency in the range of speech.

8. An acoustic resistance device comprising a substantially flat spiral coil of ribbon-like material in which the spacing between the successive layers of the spiral is so small that the impedance to sound waves passing therethrough is substantially free from reactance at the frequencies of speech.

9. An acoustic resistance device comprising a closely wound spiral coil of ribbon-like material, the pitch of the spiral being such as to provide a space between the successive layers not greater than .003 inch.

10. An acoustic resistance device comprising a closely wound spiral of metallic ribbon, and means for maintaining the successive layers of the spiral at a preassigned spacing.

11. An acoustic resistance device comprising a plate member having a plurality of parallel sided open slots therein, the total area and the width of the slots being proportioned with respect to the area of the plate

member to provide an acoustic resistance value equal to the characteristic impedance of a uniform sound conduit having a cross-sectional area equal to that of the plate.

3 In witness whereof, I hereunto subscribe my name this 27th day of April, 1928.

PAUL B. FLANDERS.

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