

Oct. 15, 1935.

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2,017,745

SOUND ATTENUATING DEVICE

Original Filed April 30, 1934

*Fig. 1.*

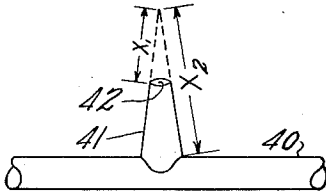


*Fig. 2.*

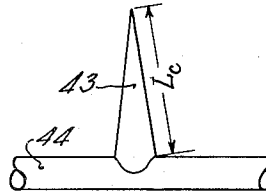


*Fig. 3.*

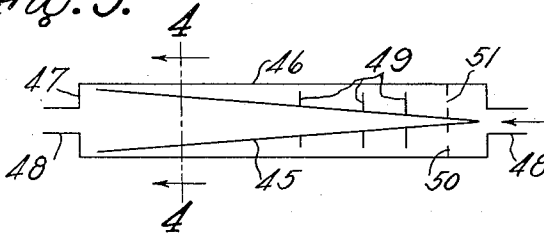


*Fig. 4.*



*Fig. 5.*

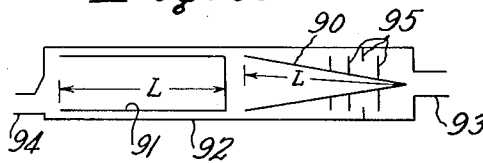
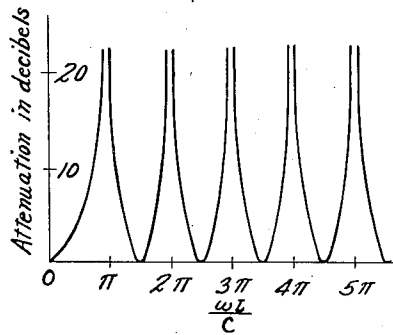


*Fig. 6.*



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## UNITED STATES PATENT OFFICE

2,017,745

## SOUND ATTENUATING DEVICE

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a corporation of Connecticut

Original application April 30, 1934, Serial No.  
723,085. Divided and this application Decem-  
ber 14, 1934, Serial No. 757,551

10 Claims. (Cl. 181—0.5)

The present invention relates to sound attenu-  
ating devices of the reactive type wherein one or  
more acoustic sidebranches capable of showing  
resonance phenomena are coupled acoustically  
5 to a main conducting channel or other enclosure  
wherein may occur sound waves which are to be  
attenuated. A primary purpose of the inven-  
tion is to provide acoustic sidebranches having  
novel characteristics, and to show how the acous-  
tic characteristics of these sidebranches may be  
10 used in connection with the design of sound  
wave attenuating apparatus. A further purpose  
of the invention is to show how these character-  
istics may be applied to the design of silencers  
15 for use in connection with the exhausts or in-  
takes of internal combustion engines, air com-  
pressors, blowers and the like. Further purposes  
and objects of the invention will be disclosed as  
the specification proceeds.

20 The acoustic sidebranches which are the main  
subject of this invention are designed and used  
on the basis that progressive change of phase as  
a function of distance occurs therein. For the  
purposes of the invention they will be referred to  
25 as "linear sidebranches". As an example of a  
sound wave attenuating device employing linear  
sidebranches having progressive change of phase  
therein, reference is made to Bourne, United  
States Patent No. 1,910,672, May 23, 1933.

30 There are in general, two types of linear side-  
branches, i. e., those open at both ends, called  
"open" linear sidebranches and those closed at  
one end, called "closed" linear sidebranches.  
When acoustic sidebranches are used in connec-  
35 tion with silencers for internal combustion en-  
gines and the like, the use of an open side-  
branch may not be feasible since both exhaust  
gas and sound can leave through the open end.  
The open type sidebranch possesses certain  
40 acoustic properties, however, that make it desir-  
able from an acoustic point of view. It is well  
known that a cylindrical tube of uniform cross  
sectional area, open at both ends, is substantially  
one-half wave length long for its fundamental  
45 natural period or frequency and also resonates to  
all substantially harmonic overtones thereof,  
both even and odd, whereas the closed tube of  
uniform cross sectional area is approximately  
one-quarter wave length long for its fundamen-  
50 tal frequency and responds to odd harmonics  
thereof only.

Where reactive sidebranches are used as atten-  
uating means for sound waves associated with  
exhaust and intakes of internal combustion en-  
55 gines and the like, it is desirable to offer attenu-

ation not only to the fundamental frequency of  
the sound, but also all its overtones. It is ob-  
vious that an acoustic sidebranch which will re-  
spond to and attenuate a full series of harmonic  
tones and be entirely closed except for the point  
5 at which it is coupled to the sound-bearing en-  
closure or conduit is very desirable. Heretofore,  
it has been impossible to combine the advantages  
of a closed linear sidebranch with one showing  
a response to a full series of harmonic over-  
10 tones, both even and odd.

I have discovered that a sidebranch in the form  
of a complete cone, open to the main sound chan-  
nel at its large end and of course closed off at  
its pointed end, will respond to and attenuate  
15 a complete series of harmonic overtones which  
are substantially multiples of the lowest fre-  
quency for which it resonates. In one aspect of  
the invention I employ such complete cones as  
closed linear sidebranches in an acoustic silenc-  
20 ing device, these sidebranches responding to and  
attenuating in the main channel or enclosure to  
which they are acoustically coupled, bands of  
frequencies, more or less wide, corresponding to  
and dependent upon the fundamental frequency  
25 of the conical sidebranches and all substantially  
integral multiples thereof, both even and odd. In  
another aspect of the invention I employ as side-  
branches, in an acoustic silencing device, struc-  
tures having a cross sectional area decreasing  
30 with the distance from their junction point with  
the main channel, sufficiently slender to give  
substantial attenuation to at least one consecu-  
tive overtone of their fundamental frequency,  
and having an opening into the main channel  
35 large enough to make the sidebranch operate  
mainly as a linear acoustic element.

Referring to the drawing,

Fig. 1 shows a truncated cone with open base,  
acoustically coupled to a main conducting chan-  
40 nel;

Fig. 2 shows a complete circular cone, con-  
tinued to the apex, acoustically coupled at its  
base to a main conducting channel;

Fig. 3 shows in diagrammatic form a sound  
45 attenuating device embodying a single complete  
cone open at its base;

Fig. 4 is a section on line 4—4 of Fig. 3;

Fig. 5 shows a sound wave attenuating device  
embodying a conical and a closed cylindrical side-  
50 branch; and

Fig. 6 shows theoretical operating character-  
istics of the device illustrated in Fig. 3.

This application is a division of my prior appli-  
cation Serial No. 723,085, filed April 30, 1934.

In order to understand the operation of the devices of the invention it is useful to make use of impedance relations, since the operation of side-branches in general can be completely expressed in terms of the acoustic impedance "looking into" the branch.

For a truncated cone such as is shown in Fig. 1, the impedance per unit area at the base, or point of coupling to the main channel 40, in terms of the dimensions of the cone 41 having a partition or header 42 a distance  $x_1$  from the apex and a slant length of  $x_2 - x_1$  may be mathematically shown to be

$$Z_s = -i\sqrt{P_s \gamma \rho} \frac{\omega X_2}{C} \left[ \frac{\sin \frac{\omega}{C}(X_2 - X_1) + \frac{\omega X_1}{C} \cos \frac{\omega}{C}(X_2 - X_1)}{\sin \frac{\omega}{C}(X_2 - X_1) + \frac{\omega X_1}{C} \cos \frac{\omega}{C}(X_2 - X_1) - \frac{\omega X_2}{C} \cos \frac{\omega}{C}(X_2 - X_1) + \frac{\omega^2}{C^2} X_1 X_2 \sin \frac{\omega}{C}(X_2 - X_1)} \right] \quad (1)$$

In the above equation the symbols have the following significances, which hold true also for the further equations below with the changes and additions there noted:

$Z_s$ =acoustic impedance looking into the side-branch.

$f$ =frequency of sound wave.

$\omega = 2\pi f$ .

$C$ =velocity of sound in the medium.

$i = \sqrt{-1}$

$P_s$ =mean pressure of the sound transmitting medium.

$\gamma$ =ratio of the specific heat of the medium at constant pressure to that at constant volume or, for waves of large amplitude, a function of this ratio.

$\rho$ =density of the medium.

$x_1$ =slant distance from the apex of the cone to its closed end (see Fig. 1).

$x_2$ =slant distance from the apex of the cone to its junction with the main conducting channel, allowing for any necessary end correction.

It may be noted, in order to permit comparison with formulas for other types of silencing units given by different authors, that

$$-i\sqrt{P_s \gamma \rho} = -i\rho C$$

In Fig. 1 the conical sidebranch is connected to the main channel at its larger end, and diminishes in cross sectional area in a direction away from the main channel. In the case of a true cone this change in cross sectional area is a simple function of the distance, while for certain sidebranches to be described below, the area depends upon the distance from the channel in a somewhat more complex manner. It should be noted particularly that the sidebranch decreases in area in a direction away from the main channel, as the performance is entirely different if the cone is turned with its small end toward the channel. As will now be shown Equation (1) may be used as the basis for determining many of the acoustical characteristics of either truncated or complete cones connected to the channel at their large ends.

In Fig. 2, the truncated cone of Fig. 1 is continued to the apex. In this figure, the cone 43 of length  $L_c$  is acoustically coupled to the main conducting channel 44. In this case,  $x_1 = 0$ , whence, substituting for  $x_2$  its equivalent  $L_c$ , Equation (1) reduces to

$$Z_s = i\sqrt{P_s \gamma \rho} \left( \frac{1}{\cot \frac{\omega L_c}{C} - \frac{1}{\omega L_c}} \right) \quad (2)$$

or

$$Z_s = i\sqrt{P_s \gamma \rho} \left( \frac{\tan \frac{\omega L_c}{C}}{1 - \frac{\omega L_c}{C} \tan \frac{\omega L_c}{C}} \right) \quad (3)$$

To find the natural frequencies of such a cone, we place  $Z_s = 0$ .

To satisfy this relationship,

$$\tan \frac{\omega L_c}{C} = 0$$

whence

$$\frac{\omega L_c}{C} = \pi, 2\pi, 3\pi \text{ etc.} = n\pi$$

where  $n$  is any positive integer, either even or odd. Therefore

$$L_c = n \frac{\lambda}{2}$$

a result identical to that applying to a cylindrical tube open at both ends commonly called an "open" tube.

We now have an acoustical resonating device, completely closed except for an opening whereby it may be acoustically coupled to a main conducting channel and capable of being used to attenuate certain groups of sound frequencies comprising a fundamental group and all multiples thereof, both even and odd. The use of the term group rather than frequency is justified by the fact that resonating devices of the acoustic type exert their influence not only upon the theoretical single frequencies of resonance but also upon neighboring frequencies. The exact nature of the behavior of this type of resonating device under various conditions will be disclosed as the specification proceeds, and the advantages of certain specific arrangements will be shown.

In order to show the attenuating effect of a complete cone acoustically coupled to a main conducting channel upon sound waves therein, it is proper to first investigate the performance of a single such sidebranch, coupled to a relatively long main conducting channel. The attenuation in decibels may be shown to be

$$Ndb = 10 \log_{10} \left[ 1 + \left( \frac{S_2}{2S_1} \right)^2 \left( \cot \frac{\omega L_c}{C} - \frac{1}{\omega L_c} \right)^2 \right] \quad (4)$$

where  $S_2$  is the area of the base of the cone.

$S_1$  is the area of the main conducting channel.

A plot of Equation (4) is shown in Fig. 6, for the condition that  $S_2/S_1 = 4$ .

In order to obtain a larger area for the base of the cone than exists in the main conducting channel, the cone may be disposed within a casing after the manner shown in Fig. 3. In this embodiment, the cone 45 is supported within the casing 46 in any convenient manner making due allowance for the passage of gas between the base of the cone and the casing and between the end of the cone and the header 47. The specific supporting construction is not shown in detail as it is not necessary for a complete understanding of the invention. It is seen that the open base of the cone is located directly opposite

to and closely adjacent the opening in the header 47 leading into the channel 48 which forms part of the main conducting channel through the device. In this particular embodiment of the invention, the space between the outside of the cone and the inside of the shell or casing is utilized to the purpose of attenuating sounds of relatively high frequency, such as bang and hiss noises usually associated with internal combustion engine exhausts. I have shown a simple baffle plate system 49 to represent such a high frequency attenuating means. Many arrangements of passageways, partitions, etc. may be used to advantage in this regard. The apex of the cone may be supported either by brackets or by a partition 50 extending from the casing to the cone and having therein holes 51 for the passage of the gas therethrough. It is theoretically preferable, in this and other embodiments, that the sidebranch retain its conical shape up to the point of coupling to the main channel. In some cases, however, it may be desirable for constructional reasons to depart from the normal conical shape adjacent the zone of coupling. The departure from the theoretical response occasioned by this slight change in shape will in most cases be of no practical consequence.

Referring again to Fig. 6 it is seen that maximum attenuation occurs at values of

$$\frac{\omega Lc}{C} = \pi, 2\pi, 3\pi, 4\pi, \text{ etc.}$$

which is the same as would be obtained for an "open" cylindrical tube of the same length. Such a tube would have an attenuation peak at zero frequency. It is to be noted that the conical sidebranch does not offer attenuation to zero frequency, the attenuation decreasing continuously from a high value at

$$\frac{\omega Lc}{C} = \pi$$

to zero at

$$\frac{\omega Lc}{C} = 0$$

as shown. The points of zero attenuation are not midway between the points of maximum attenuation, as they are in the case of the "open" cylindrical sidebranch, but are displaced slightly therefrom, the displacement becoming less as the frequency increases. It can be shown, by a consideration of Equation (4) that the condition for zero attenuation is given by the relation

$$\tan \frac{\omega Lc}{C} = \frac{\omega Lc}{C}$$

The first few roots of this equation are known to be

$$0, 1.4303\pi, 2.459\pi, 3.471\pi$$

It is seen that these successive values show a decreasing difference from the midway points, namely  $1.5\pi, 3.5\pi$ , etc. approaching

$$\frac{n\pi}{2}$$

as a limit, where  $n$  is any odd integer. It is to be noted at this time that the area under the curve is larger as the ratio  $S_2/S_1$  is made greater; and, since this area represents a measure of the usefulness, in attenuating sounds of many frequencies, of the device for which the curve shows operating characteristics, it is frequently desirable to make  $S_2$  as large compared with  $S_1$  as is commercially feasible with proper regard for the limitations imposed by acoustic theory.

Fig. 5 shows a special embodiment of the invention wherein use is made of one conical sidebranch 90 of length  $L$ , in conjunction with one cylindrical closed sidebranch 91 of length  $L$ , both suitably mounted and disposed within a casing 92 having a centrally disposed inlet connection 93 and an eccentrically disposed outlet connection 94. The cone 90 has a simple baffle system 95 attached thereto after the manner of the device shown in Fig. 3. This arrangement of the interior of the device permits the use of water admixed with the exhaust gas and the automatic draining thereof when the silencer is suitably installed. It provides a continuous band of attenuation over the frequency spectrum with peaks of attenuation in harmonic relation whereby proper design causes known frequencies in the exhaust to suffer maximum attenuation.

I claim:

1. A silencing device comprising a main sound conducting channel, and a closed cylindrical sidebranch and a closed conical sidebranch acoustically coupled to said channel at points spaced along its length.

2. A silencing device comprising a closed cylindrical sidebranch and a closed conical sidebranch open at its base, both of said sidebranches being acoustically coupled to a main sound conducting channel exteriorly disposed with respect to said sidebranches.

3. A silencing device comprising a cylindrical casing having a centrally disposed inlet opening, an eccentrically disposed outlet opening, a gas and sound conducting channel adjacent said casing, an interiorly and coaxially disposed cylindrical casing, open at one end and closed at the other, an interiorly and coaxially disposed conical casing with open base, whereby are formed two closed acoustic sidebranches each of which is acoustically coupled to said sound conducting channel at substantially different points along the length thereof.

4. A silencing device in accordance with claim 3 wherein the closed cylindrical sidebranch and the closed conical sidebranch are of substantially equal length.

5. A silencing device according to claim 3 wherein the closed cylindrical sidebranch is coupled to said sound conducting channel at a point adjacent the eccentrically disposed outlet opening and wherein the closed conical sidebranch is coupled to said channel at a point intermediate the length thereof.

6. A silencing device comprising a conduit, a cylindrical sidebranch open at one end and located within the conduit so as to form an annular conducting channel between it and the conduit, said cylindrical sidebranch being open at one end and closed at the other and having its open end opening towards one end of the conduit, and a closed conical sidebranch located within the conduit so as to form an annular conducting channel between it and the conduit, said conical sidebranch being spaced along the axis of the conduit with respect to the cylindrical sidebranch, and having an open base opening towards but spaced from the closed end of the cylindrical sidebranch.

7. A silencing device comprising a main sound conducting channel, a closed cylindrical sidebranch, and a closed conical sidebranch, said sidebranches being acoustically coupled to said channel at points spaced along its length, and having substantially equal acoustic lengths.

8. A silencing device comprising a conduit, a

closed cylindrical sidebranch having one open end, and a closed conical sidebranch having its base open, said sidebranches being arranged coaxially within the conduit so as to form an annular acoustic channel between them and the conduit.

9. A silencing device comprising a conduit, a closed cylindrical sidebranch having one open end, and a closed conical sidebranch having its base open, said sidebranches being of substantially equal acoustic length and being arranged coaxially within the conduit so as to form an annular acoustic channel between them and the conduit.

10. A silencing device comprising a conduit, a closed cylindrical sidebranch having one open end, and a closed conical sidebranch having its base open, said sidebranches being of substantially equal acoustic length and being arranged coaxially within the conduit so as to form an annular acoustic channel between them and the conduit with the open ends of the sidebranches coupled to the acoustic channel at points spaced apart along its length.

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