

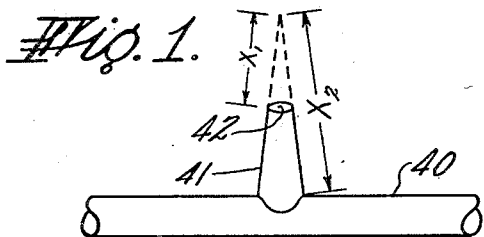
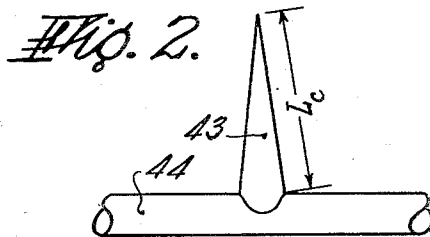
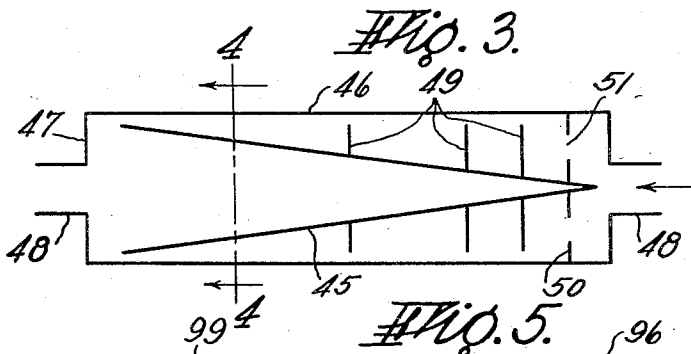
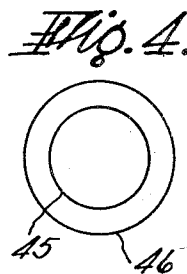
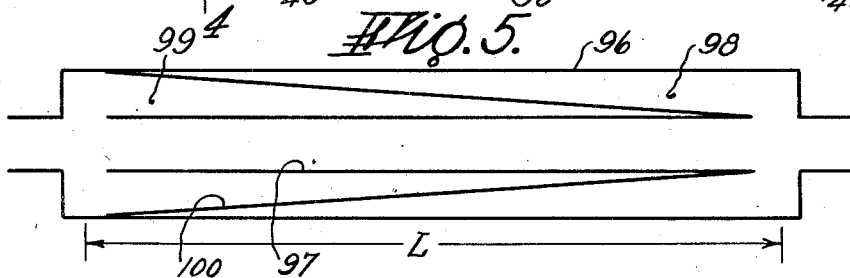
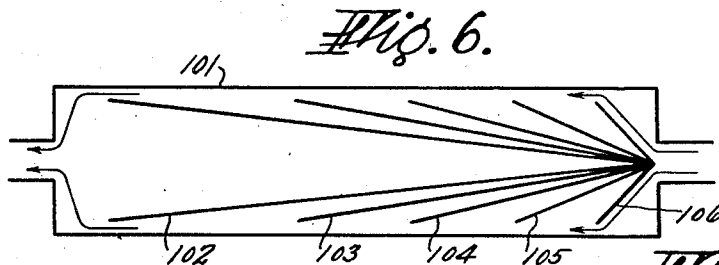
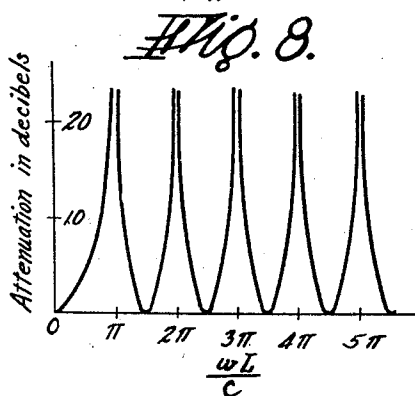
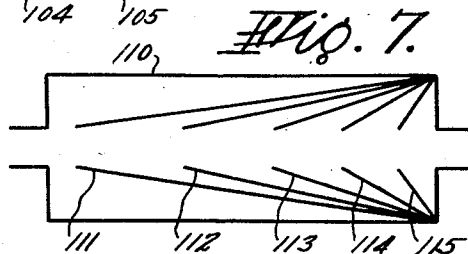
Oct. 15, 1935.

R. B. BOURNE

2,017,748

SOUND ATTENUATING DEVICE

Original Filed April 30, 1934



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UNITED STATES PATENT OFFICE

2,017,748

SOUND ATTENUATING DEVICE

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Original application April 30, 1934, Serial No.
723,085. Divided and this application Decem-
ber 14, 1934, Serial No. 757,554

8 Claims. (Cl. 181—0.5)

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

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 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.

There are in general, two types of linear sidebranches, 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 connection with silencers for internal combustion engines and the like, the use of an open sidebranch may not be feasible since both exhaust gas and sound can leave through the open end. The open type sidebranch possesses certain acoustic properties, however, that make it desirable 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 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 fundamental frequency and responds to odd harmonics thereof only.

Where reactive sidebranches are used as attenuating means for sound waves associated with exhaust and intakes of internal combustion engines and the like, it is desirable to offer attenuation not only to the fundamental frequency of

the sound, but also all its overtones. It is obvious that an acoustic sidebranch which will respond to and attenuate a full series of harmonic tones and be entirely closed except for the point at which it is coupled to the sound-bearing enclosure 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 overtones, both even and odd.

I have discovered that a sidebranch in the form of a complete cone, open to the main sound channel at its large end and of course closed off at its pointed end, will respond to and attenuate a complete series of harmonic overtones which are substantially multiples of the lowest frequency for which it resonates. In one aspect of the invention I employ such complete cones as closed linear sidebranches in an acoustic silencing 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 of the conical sidebranches and all substantially integral multiples thereof, both even and odd. In another aspect of the invention I employ as sidebranches, in an acoustic silencing device, structures having a cross sectional area decreasing with the distance from their junction point with the main channel, sufficiently slender to give substantial attenuation to at least one consecutive overtone of their fundamental frequency, and having an opening into the main channel 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 channel;

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

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

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

Figs. 5, 6 and 7 show various forms of sound wave attenuating devices employing different types of conical or conico-annular sidebranches; and

Fig. 8 shows theoretical operating characteristics of the device illustrated in Fig. 3.

This application is a division of my prior application 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 sidebranches 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

$$Z_1 = -i\sqrt{P_o\gamma\rho} \cdot \frac{\omega x_2}{C} \left[\frac{\sin \frac{\omega}{C} (x_2 - x_1) + \frac{\omega x_1}{C} \cos \frac{\omega}{C} (x_2 - x_1)}{\sin \frac{\omega}{C} (x_2 - x_1) + \frac{\omega x_1}{C} \cos \frac{\omega}{C} (x_2 - x_1) - \frac{\omega x_1}{C} (x_2 - x_1) + \frac{\omega^2}{C^2} x_1 x_2 \sin \frac{\omega}{C} (x_2 - x_1)} \right] \quad (1)$$

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 sidebranch.

f = frequency of sound wave.

$\omega = 2\pi f$

C = velocity of sound in the medium.

$i = \sqrt{-1}$

P_o = mean pressure of the sound transmitting medium.

γ = 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.

ρ = 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

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

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_s is acoustically coupled to the main conducting channel 44. In this case, $x_1 = 0$, whence, substituting for x_2 its equivalent L_s , Equation (1) reduces to

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

or

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

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

To satisfy this relationship,

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

whence

$$\frac{\omega L_s}{C} = \pi, 2\pi, 3\pi,$$

etc. = $n\pi$ where n is any positive integer, either even or odd. Therefore

$$L_s = n \frac{\lambda}{2},$$

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

I 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

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

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. 8, 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. 8 it is seen that maximum attenuation occurs at values of

$$\frac{\omega L_c}{C} = \pi, 2\pi, 3\pi, 4\pi,$$

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

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

to zero at

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

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

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

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 an extremely simple embodiment of the invention comprising a casing 96, a main

conducting channel 97 centrally disposed within said casing and of such length that openings are left whereby the two sidebranches 98, 99 are acoustically coupled to the channel 97 as shown. Said sidebranches 98, 99 are formed by a conical member 100 extending from one end of the conduit 97 to the inside of the casing 96 at a point opposite the other end of the conduit 97 and may be described as being of conico-annular form. These sidebranches, it has been found by experience, conspire to offer maximum attenuation in the main conducting channel to sound frequencies substantially the same as those frequencies which would be highly attenuated by truncated true cones, closed at the small end, open at the base, and having a ratio between the area of the base and the area of the header forming the truncated cone, of 9:1. The impedance of such a truncated cone may be written

$$Z_{\gamma C} = -i\sqrt{P_o\gamma\rho} \left[\frac{1 + \frac{\omega L}{2C} \cot \frac{\omega L}{C}}{\frac{2}{3\omega L} + \frac{\omega L}{C} - \frac{2}{3} \cot \frac{\omega L}{C}} \right] \quad (7)$$

The resonating frequencies for such a sidebranch are given by

$$-2 \tan \frac{\omega L}{C} = \frac{\omega L}{C}$$

The roots of this equation are found to be approximately $.73\pi, 1.62\pi, 2.58\pi, 3.57\pi$. For high frequencies, it is seen that these values approach the value

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

where n is odd, and therefore, for high orders of overtones, the device behaves, insofar as attenuation peaks are concerned, substantially as a closed cylindrical sidebranch. The points of zero attenuation may likewise be shown to occur at values of

$$\frac{\omega L}{C} = n\pi$$

where n is any integer. Where two such sidebranches are separated a distance L along a main conducting channel, as in Fig. 5, the device forms a wave filter, the transmission and attenuation characteristics of which are given approximately by

$$\cosh \Gamma = \cos \frac{\omega L}{C} - \frac{S_2}{2S_1} \sin \frac{\omega L}{C} \left[\frac{\frac{2}{3\omega L} + \frac{\omega L}{2C} - \frac{2}{3} \cot \frac{\omega L}{C}}{1 + \frac{\omega L}{2C} \cot \frac{\omega L}{C}} \right] \quad (9)$$

A consideration of Fig. 5 further discloses that the larger the ratio S_2/S_1 , the more nearly the operation of the sidebranch 99 approaches that of a true complete cone, while the operation of the sidebranch 98 approaches that of a cylinder. As has been shown previously, the combination of a cone and cylinder to form acoustic sidebranches results in useful frequency-attenuation characteristics.

Fig. 6 shows a sound wave attenuating device employing a number of conical members nested together at their respective apexes, within the casing 101. The cones 102, 103, 104, 105 and 106 each form a true conical sidebranch coupled to the main conducting channel which in this case is the annular space between the bases of

the various cones and the inside of the casing 101. By properly choosing the dimensions for the various components of the device it is possible to offer attenuation to a very wide band of sound frequencies.

In Fig. 7 a similar arrangement of conico-annular sidebranches is shown. The casing 110 houses truncated conical members 111, 112, 113, 114 and 115 each of which has a different degree of conicality. The small ends of the conical members are left open for the passage of gas straight through the device. The conico-annular sidebranches thus formed simulate truncated cones. Suitable choice of dimensions for the various elements of the device results in relatively high attenuation over a wide band of sound frequencies. In this device, as well as in the device of Fig. 6, considerable attenuation to sound waves of high frequency such as hisses and the like is afforded due to the large amount of surface exposed to such sound waves and to the shape of the sidebranches.

I claim:

1. A sound wave attenuating device comprising a casing and at least three chamber defining members arranged within the casing in annularly nested relation, at least one of said members being conical in form, said members being connected to the casing and to each other so as to define a main sound conducting channel and a plurality of closed acoustic sidebranches acoustically coupled thereto.

2. A sound wave attenuating device comprising a main acoustic channel and a plurality of annularly nested conico-annular sidebranches acoustically coupled thereto.

3. A sound wave attenuating device comprising a generally cylindrical casing, a centrally disposed sound conducting channel extending coaxially therethrough and a pair of closed acoustic sidebranches nested within said casing and acoustically coupled to said sound conducting channel at either end thereof, the cross sectional area of said sidebranches continuously decreasing with distance from their respective points of coupling to said channel.

4. A sound wave attenuating device comprising an outer shell, an inner coaxially disposed tube or conduit extending therethrough, end closures

extending from said outer shell to said inner conduit, an opening at each end of said inner conduit and a coaxially disposed conical shell extending from said inner conduit at a point adjacent to and inside of one of said openings to said outer shell at a point adjacent the other of said openings.

5. A sound attenuating device comprising three nested shells, the innermost of said shells forming a conduit for the passage of gas and sound, the space between said inner shell and the intermediate shell forming a closed acoustic sidebranch acoustically coupled to one end of said inner conduit, the space between the outer shell and said intermediate shell forming a closed acoustic sidebranch acoustically coupled to the other end of said inner conduit, the cross sectional area of each of said sidebranches decreasing continuously with the distance from the said points of coupling to said inner conduit.

6. A sound attenuating device comprising a cylindrical casing having an opening in each end thereof, and a plurality of inter-nested complete cones, with open bases interiorly and coaxially disposed within said casing, the respective bases of said cones being of smaller diameter than said casing whereby is formed an annular path for gas and sound adjacent said casing and a plurality of closed acoustic sidebranches acoustically coupled thereto at intervals along the length thereof.

7. A sound attenuating device in accordance with claim 6 wherein the cones are so disposed that the apex of one cone is nested within the apex of another cone.

8. A sound attenuating device comprising a cylindrical casing having an inlet opening in one end and an outlet opening in the other end, a plurality of truncated conical members nested at their respective bases at one end of the interior of said casing, said truncated conical members being of different lengths and forming a centrally disposed main conducting channel to which are acoustically coupled a plurality of closed acoustic sidebranches of different lengths and of continuously decreasing cross sectional area as a function of the distance from said main conducting channel.

ROLAND B. BOURNE.

Certificate of Correction

Patent No. 2,017,748.

October 15, 1935.

ROLAND B. BOURNE

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Page 2, first column, line 45, strike out the formula and insert instead $-i\sqrt{P_0}\gamma\rho = -i\rho C$; page 3, second column, line 23, for the first group of letters in the formula " $Z_{\gamma c}$ " read Z_{Tc} ; and line 30, after the formula insert the formula number (8); and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 19th day of November, A. D. 1935.

[SEAL]

LESLIE FRAZER,
Acting Commissioner of Patents.

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