July 21, 1964 G. KURTZE 3,141,520

SOUND ABSORBER FOR GAS CONDUITS

Filed Feb. 11, 1964

FIG.1

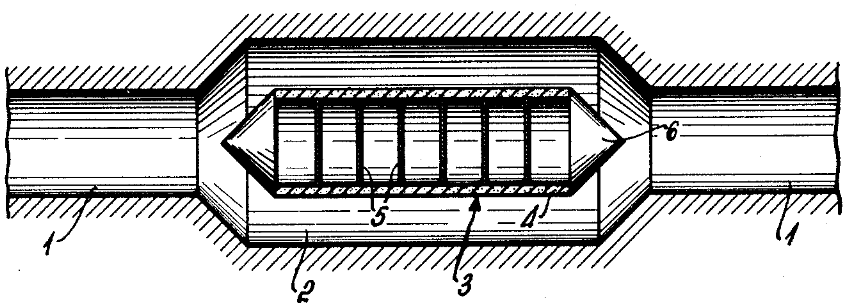


FIG.2

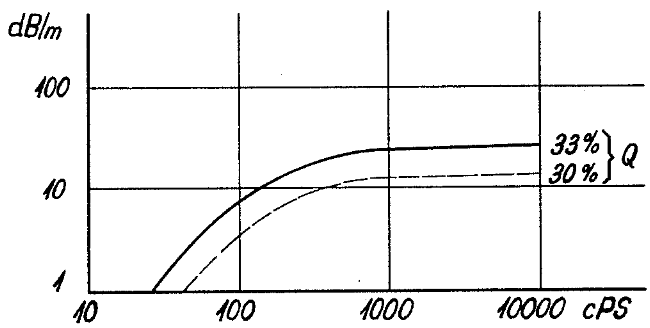
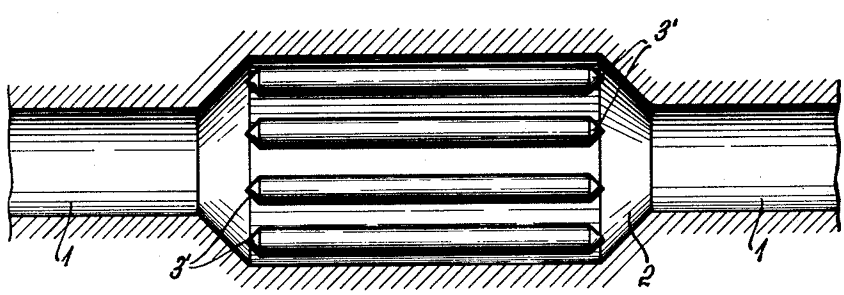


FIG.3



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3,141,520

Patented July 21, 1964

3,141,520
SOUND ABSORBER FOR GAS CONDUITS

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Filed Feb. 11, 1964, Ser. No. 344,054
Claims priority, application Germany Jan. 14, 1960
5 Claims. (Cl. 181—59)

This invention relates to sound attenuators, and more particularly to sound absorbers adapted to reduce or to prevent the propagation of sound in gas conduits, such as air conditioning and ventilating ducts, the distribution channels of a hot air heating system, exhaust lines of internal combustion engines and the like.

Sound attenuators heretofore used for such purposes may be grouped in two classes. In the first group the flow section of a gas conduit is varied to provide alternate portions of increased and decreased section which are intended to reflect sound along the conduit to its source. In the second class, the sound is absorbed in suitable materials and its energy is transformed into heat.

Effective sound absorbing materials permit passage of a stream of gas through a multiplicity of narrow channels in frictional contact with a large surface area whereby the sound energy is attenuated. Gas conveying conduits may be lined with such sound absorbing materials but it has previously been found more effective to provide empty, that is, gas-filled spaces on the side of the absorbing material away from the main stream in the conduit to permit passage of gas through the channels at relatively high speed for effective energy transfer. The depth of the empty space in the known device should be of the order of one quarter of the wave length of the sound to be absorbed to enhance the attenuation by a resonance effect. Such attenuators are more effective than those in which all available space is filled with sound absorbing material.

When a sound attenuator of the afore-described known type is to be employed for preventing propagation of low-frequency sound, the bulk of the sound absorbing material and of the empty resonance spaces become excessive for many purposes. To reduce the dimensions of sound attenuating installations, it has been proposed to connect the gas conduits with Helmholtz resonators. Empty chambers communicate with the main gas conduit by relatively small apertures which are partly obstructed by a plug of porous material, or the apertures are selected very small so as to offer appreciable resistance to the flow of gas, and insertion of a porous plug in the aperture then becomes unnecessary. Sound attenuators of the Helmholtz resonator type can be installed in a relatively small space but they are limited in their effectiveness to a rather narrow frequency range centered on the resonant frequency of the chamber.

This invention aims generally at improving sound attenuators for gas conduits.

One of the important objects of the invention is the provision of sound attenuators which combine a relatively small bulk with effective attenuation of sound over a wide range of frequencies.

Other objects and many attendant advantages of this invention will become apparent as the disclosure proceeds.

In its basic aspects, the invention relies for the effectiveness of sound attenuators for gas conduit on the known relaxation effect. A plurality of auxiliary chambers communicate with the gas conduit by duct means, preferably a porous wall common to the conduit and the chambers. The chambers each have a length in the direction of the conduit axis which is smaller than one half of the shortest wavelength of the range of wavelengths to be absorbed or attenuated, and the flow resistance R of the duct means

between the conduit and the auxiliary chambers must satisfy the relationship

$$\frac{1}{2\pi RF} \leq f_0 \qquad (1)$$

wherein F is the elastic compliance of the auxiliary chamber, and f_0 is the lowest frequency of the range of sound frequencies to be attenuated, corresponding to the highest wavelength.

Relaxation in the context of the instant problem may be defined as a delayed establishment of a state of equilibrium. When an auxiliary chamber is connected to a gas conduit by the pores of a wall or other suitable duct means of high flow resistance, a sudden pressure increase in the conduit will be followed by a corresponding adjustment of the pressure in the auxiliary chamber after a certain delay since the gas flow necessary for equalizing the pressures in the conduit and the chamber is impeded by the flow resistance of the duct means.

When pressure changes occur periodically in the conduit, as is inherent in the propagation of sound, cyclic pressure changes occur in the chamber with a phase shift reflecting the lag of pressure increases and decreases in the auxiliary chamber. A pressure differential exists at all times between the conduit and the chamber. When the pressure is higher in the conduit than in the chamber, gas flows inward of the chamber. It flows back into the conduit when the pressure there is lower. The amplitude of the pressure changes in the conduit is thereby reduced.

According to the established theory of attenuation by relaxation, the pressure differential between the chamber and the conduit reaches a maximum when the time constant τ of the attenuator equals the reciprocal of the cyclic frequency ω of the sound to be attenuated. In the present instance, the time constant τ equals the product of the flow resistance R of the porous wall and the compliance F of the auxiliary chamber, and at maximum pressure differential

$$\frac{1}{\omega} = RF = \tau \qquad (2)$$

At very low frequencies, ω is much smaller than $1/\tau$. The pressures in the conduit and the auxiliary chamber are practically in phase, and the attenuation effect is small. At high frequencies, ω is much greater than $1/\tau$ and attenuation is also weak since the pressure changes in the conduit are not accompanied by significant pressure changes in the auxiliary chamber. It can readily be demonstrated that attenuation as a function of the wavelength increases initially with increasing frequency, reaches a maximum at the frequency of $\omega = 1/\tau$, and decreases again in a linear manner as the frequency further increases.

For practical purposes, the magnitude of attenuation as a function of the wavelength is less important than the change of attenuation per unit length of a sound absorber in the direction of gas flow. Since the wavelength decreases with an increase in frequency, it follows that the attenuating effect of an attenuator of unit length relying on the relaxation effect will initially increase quadratically with increasing frequency and will then reach a constant value independent of further frequency increases as long as the width of the conduit and the length of the auxiliary chamber in the direction of the conduit axis are small compared to the wavelength of the sound to be attenuated.

Attenuators of the invention can readily be designed by those skilled in the art to satisfy even severe requirements. There are no critical minimum dimensions affecting the size, and particularly the width of the auxiliary chambers transverse to the direction of gas flow. The only important parameter is the product RF. In other words, the same effect may be achieved with an auxiliary chamber of smaller transverse width, and thus smaller compliance F, by corresponding selection of a higher flow resistance R.

The exact nature of this invention as well as other objects and advantages thereof will be readily apparent from consideration of the following specification relating to the annexed drawing in which:

FIG. 1 is an axially sectional view of a gas conduit of circular internal cross section equipped with a first embodiment of a sound attenuator of the invention;

FIG. 2 is a chart of the characteristic curve of the sound attenuator of FIG. 1; and

FIG. 3 shows a conduit equipped with several attenuators of the type illustrated in FIG. 1 in a corresponding view.

Referring now to the drawing in detail, and initially to FIG. 1, there is shown an elongated conduit **1** for the flow of a gas such as air. The conduit has a radially enlarged portion **2** in which a torpedo-shaped hollow attenuator body **3** is mounted by means not shown. The body **3** has a cylindrical wall **4** which is spaced from the axially aligned inner wall portion of the conduit portion **2** so as to form an annular flow channel of uniform cross section. The identical hollow front and rear end portions **6** of the attenuator body **3** conically taper in agreement with the corresponding wall portions of the conduit **1**.

The cylindrical wall **4** is a porous tube which may consist of burnt clay or porous concrete, or of any other material the selection of which is dictated by the operating conditions. The internal space in the tube **4** is divided into a plurality of identical cells by impervious transverse partitions **5** of sheet material. The conical front and rear end portions **6** may consist of the same material.

The spacing of the partitions **5** in the direction of air flow through the apparatus is much smaller than the diameter or transverse depth of each cell defined between axially consecutive partitions **5**, and smaller than the width of the flow channel between the wall **4** and the conduit portion **2**. The axial length of each cell must be small compared to the wavelength of the sound to be attenuated, and should preferably not exceed one half of the shortest wavelength in the sound spectrum to be absorbed. For air and an upper limit of audible sound at 20,000 c.p.s. the cell length should not exceed 1.6 centimeters.

The necessary pore size and distribution of pores in the tube **4** will be selected according to the equation

$$R'=\frac{2c_0}{d\omega_0} \qquad (3)$$

wherein c_0 is the speed of sound in the gas which fills the conduit **1** and the cells or chambers in the tube **4**, d is the radial depth of the auxiliary chamber cavity, and ω_0 is the 2π multiple of the lowest frequency yet to be attenuated.

The necessary flow resistance R is obtained by multiplying R′ with the characteristic impedance of the gas which is ρc_0, wherein ρ is the density of the gas. For a chamber depth of 4 cm. and a frequency of 160 c.p.s. ($\omega_0=1000$ sec.$^{-1}$), R′ is 17, and the flow resistance R is found to be $17\rho c_0$, a value very substantially higher than the flow resistance values employed in conventional sound attenuators.

The attenuating effect of the device of FIG. 1 depends further on the available flow section, that is, on the ratio Q of the cross sections of the attenuator body **3** and the conduit portion **2**.

FIG. 2 is a chart showing the relationship between attenuation and frequency for attenuator arrangements in which Q has values of 33% and 30% respectively. Attenuation in decibels per meter axial attenuator length is plotted against frequency in cycles per second. It is seen that for both values of Q, the attenuating effect remains practically constant over a major portion of the audible frequency range.

A modification of the apparatus of FIG. 1 is shown in FIG. 3 in a similar view. Instead of a single tubular attenuator body, there are provided several identical bodies **3′** of which four are visible in the drawing. Each of the attenuator bodies **3′** is identical in detail structure with the body **3** in FIG. 1 and operates in the same manner. Considerations of desired dimensional characteristics will partly decide the choice between the devices of FIGS. 1 and 3.

It should be understood, of course, that the foregoing disclosure relates to only a preferred embodiment of the invention and it is intended to cover all changes and modifications of the examples of the invention herein chosen for the purpose of the disclosure which do not constitute departures from the spirit and scope of the invention set forth in the appended claims.

This application is a continuation-in-part of my copending application Serial No. 81,296, now abandoned, filed on January 9, 1961.

What is claimed is:

1. A sound attenuator arrangement comprising in combination:
   - (*a*) a conduit defining a cavity for flow of gas therethrough in a predetermined direction, said conduit having an internal wall extending in said direction;
   - (*b*) a hollow attenuator body arranged in said cavity, said body having a porous wall extending in said direction and being spacedly opposite said internal wall, said porous wall and said internal wall defining a flow channel therebetween, and said porous wall separating an inner space in said body from said flow channel;
   - (*c*) a plurality of impervious partitions in said inner space, said partitions extending transversely of said direction and being substantially uniformly spaced in said direction so as to divide said inner space into a plurality of cells of substantially uniform length in said direction,
     - (1) each cell communicating with said flow channel through said porous wall,
     - (2) the length of each cell between two adjacent partitions being substantially smaller than the width of said cell transversely of said direction, and smaller than the width of said flow channel between said walls, and
   - (*d*) a gas filling said flow channel, said cells, and the pores in said wall.

2. An arrangement as set forth in claim 1, wherein the flow resistance of said porous wall to said gas satisfies the equation

$$\frac{1}{2\pi RF} \leqq 160 \text{ cycles per second}$$

wherein R is said flow resistance, and F is the elastic compliance of each cell when filled with said gas.

3. An arrangement as set forth in claim 2, wherein said length of each of said cells is not substantially greater than 1.6 centimeters.

4. An arrangement as set forth in claim 1, wherein said flow channel is of substantially uniform cross section transverse of said predetermined direction.

5. An arrangement as set forth in claim 1, wherein said flow channel is of annular cross section transverse of said predetermined direction.

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