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SOUND ATTENUATING GAS CONDUIT AND RESONATORS THEREFOR

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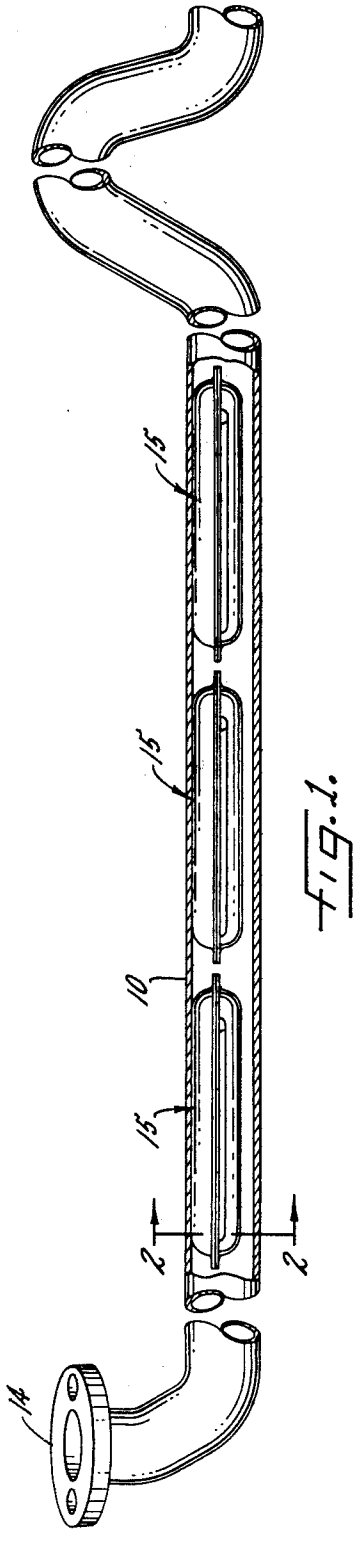


FIG. 1.

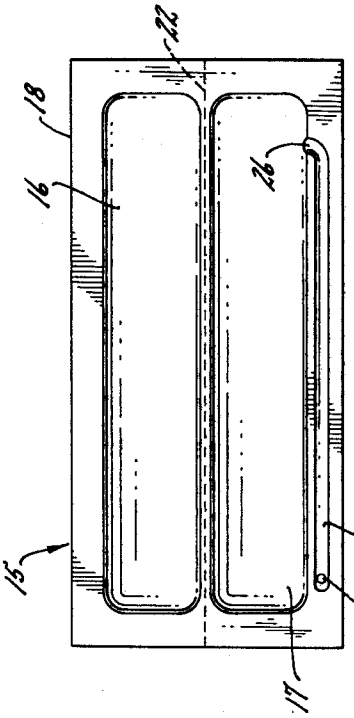


FIG. 3.

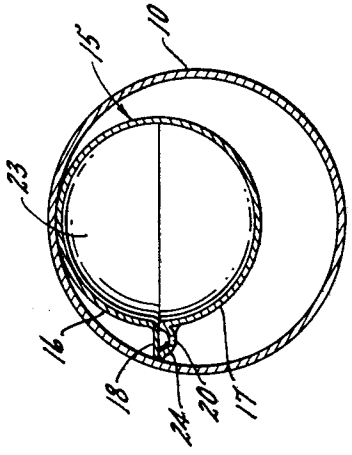


FIG. 2.

INVENTORS.
EDMUND LUDLOW
BENJAMIN H. IRWIN
BY
Trask, Jenkins & Hanley
ATTORNEYS.

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SOUND ATTENUATING GAS CONDUIT AND RESONATORS THEREFOR

Edmund Ludlow and Benjamin H. Irwin, Columbus, Ind., assignors to Arvin Industries, Inc., Columbus, Ind., a corporation of Indiana

Original application Aug. 17, 1961, Ser. No. 132,117, now Patent No. 3,128,841, dated Apr. 14, 1964. Divided and this application Jan. 16, 1964, Ser. No. 338,129

4 Claims. (Cl. 181—48)

This invention relates to a sound attenuating gas conduit for conveying and attenuating the noise level of, a moving gas stream, and to a sound attenuating resonator for use with such a conduit. This application is a division of our copending application Serial No. 132,117, filed August 17, 1961, now Patent Number 3,128,841, issued April 14, 1964.

It is an object of this invention to provide such a sound attenuating gas conduit which will meet limited space requirements, and which can be of a light weight construction with its weight substantially uniformly distributed along its length. It is a further object of the invention to provide such a sound attenuating gas conduit which will be less susceptible to certain types of corrosion than conventional gas-silencing systems, and which may employ replaceable sound attenuating resonators. It is a further object of the invention to provide a sound attenuating resonator which can be used in association with such a conduit having the configuration of a simple pipe, which resonators can be formed from inexpensive sheet-metal stampings, which can be made to effect sound attenuation over a wide range of frequencies, which may be tuned to attenuate undesired frequencies, and which will remain substantially in tune with said frequencies irrespective of temperature changes of the gas stream in which the sound waves are carried.

It is a special object of the invention to provide a sound attenuating conduit for the exhaust gas stream of an automotive vehicle and employing sound attenuating resonators which will eliminate the need for the bulky, expensive, and troublesome mufflers which are required in conventional automotive exhaust-silencing systems.

The present invention is concerned with the construction of sound attenuating resonators mounted in a conduit for conveying the exhaust gases away from an automotive engine. Such resonators may be constructed from inexpensive sheet-metal stampings and may be constructed such that they are tuned to attenuate different and overlapping bands of sound wave frequencies. Prior resonator constructions of this general type for use in association with a sound attenuating conduit have used auxiliary components, such as the adjacent conduit walls, to help form the resonators, or have employed more expensive constructions utilizing interconnected lengths of tubing of different diameters and lengths. However, the instant invention overcomes these problems by the employment of resonators which may be wholly and completely formed from sheet-metal stampings.

In the employment of the invention as an exhaust system for an automotive vehicle, the exhaust manifold of the engine is connecetd to a pipe to convey the exhaust gases emanating from said engine to the desired discharge point, as at the rear of the vehicle. Such a pipe, usually with at least part of the manifold, forms a conduit in which the exhaust sound produces standing wave pressure patterns wherein each of the several harmonic components of the standing waves have one or more distinct pressure points, that is, points of maximum sound pressure, at particular locations along the conduit. Our present invention is concerned with the construction of sound attenuating resonators mounted in the conduit at or adjacent these pressure points and tuned to attenuate the noise level of the frequencies producing such pressure points.

In accordance with one form of construction of said resonators, there is provided a sheet-metal member which is contoured to provide first wall areas in spaced relation to each other to form a resonator volume. Second wall areas are provided on the shell which borders the first wall areas and serve to enclose the periphery thereof. Formed within the extent of said second wall areas are third wall areas in spaced relation to each other and forming a resonator throat opening within the extent of said volume and outside the extent of said second wall areas. Thus, with the resonators mounted in the conduit, the resonator throats will operatively interconnect the resonator volumes with the gas-flow passage formed by the conduit whereby said resonators will attenuate the noise level of the exhaust gases moving through said conduit.

Other objects and features of the invention will become apparent from the more detailed description which follows and from the accompanying drawings, in which:

FIG. 1 is a fragmentary isometric view partially broken away and showing a sound attenuating conduit embodying our invention;

FIG. 2 is an enlarged transverse section taken on the line 2—2 of FIG. 1; and

FIG. 3 is a plan view of a sheet-metal stamping forming the resonator shown in FIG. 2.

This invention is particularly well adapted for use with an internal combustion engine in an automotive vehicle to silence the exhaust gases emanating from said engine and to convey them to a suitable discharge point. The essential features characterizing this invention are the construction of our resonators and their combination with a pipe for conveying the exhaust gas from an engine to a suitable discharge point, said resonators attenuating the noise level of the gases passing through said pipe. These resonators are formed from sheet-metal stampings which are constructed so as to form resonator volumes and throats tuned to the desired sound wave frequencies and mountable within said pipe in the desired locations.

Our resonators comprise a plurality of sheet-metal stampings which are rigidly secured to the inner wall of the gas-carrying pipe. Because the resonators are formed from relatively small sheet-metal stampings, the overall weight of the silencing system will be minimized, as will the cost of such system. Further, because of their relatively small size, the resonators can be mounted in the pipe in any desired circumferential position to thus obviate mounting them on the bottom of the pipe in a position in which they would trap condensed corrosive materials. Furthermore, our resonators, being mounted within the pipe, are in direct thermal-coupling relationship with the exhaust gases passing through said pipe. The frequencies of the sound waves in the exhaust gases will vary with temperature changes in said gas stream, but with the resonators mounted internally of the pipe, they will assume the temperature changes of the gas stream and will substantially remain in tune with the sound wave frequencies which they are tuned to attenuate irrespective of the temperature of the gas stream.

In the operation of a conventional internal combustion engine in an automobile, the combustion of fuel within the cylinders produces a substantial volume of hot exhaust gases which are exhausted with substantial noise into the exhaust manifolds mounted on the engine in communication with the cylinder exhaust ports. The frequencies of the sound waves in such exhaust gases extend over a wide range, such as from about 30 cycles per second to about 5,000 cycles per second, with the lower frequencies largely representing the fundamental and lower harmonics determined by the length of the exhaust con-

duit. In many exhaust systems it is the lower range of frequencies, i.e., frequencies below 200 cycles per second, that are the most difficult to attenuate and produce the most objectionable noises, especially since it is in this low frequency range that the firing frequencies of the engine coincide with and augment the natural resonant frequencies of the exhaust system itself.

The lower frequencies are particularly difficult to silence when the engine is propelling the vehicle at a rate of speed of from about 20 miles per hour to about 50 miles per hour. At these speeds most engines fire at frequencies below 200 cycles per second, the range in which the fundamental and first overtone of substantially all silencing systems fall. Generally, if the engine is propelling the automobile at a speed slower than about 20 miles per hour, its firing frequencies will be well below the fundamental frequency of the silencing system and thus will not coincide with nor augment the natural resonant frequency of the exhaust system itself to any appreciable extent. And if the engine is propelling the automobile faster than about 50 miles per hour, its firing frequencies will generally be higher than the first overtone of the exhaust system. Also, the natural road noises at these higher speeds are more predominant than the exhaust gas noises.

In many conventional mufflers these lower frequencies are quite difficult to attenuate because the large size of the mufflers prevents them from being positioned in the exhaust system on the underside of the vehicle to act upon and attenuate these low frequencies.

Our invention is adapted to attenuate the exhaust noises incident to the operation of an internal combustion engine over a wide range of sound wave frequencies, including the troublesome frequencies below 200 cycles per second, by passing the exhaust gases of said engine through an exhaust conduit having a plurality of resonators mounted within it along its length. The resonators may be tuned to attenuate different and overlapping bands of frequencies. While resonators in accordance with our invention may be used alone to effect attenuation of the exhaust gas noises, they may be used in combination with conventional mufflers, or may be incorporated within otherwise conventional mufflers as acoustical muffler components, or used in combination with acoustical liners employed in the manifold or in the exhaust conduit itself.

The embodiment shown in FIG. 1 comprises a pipe 10 adapted to be connected at one end to an exhaust manifold by a conventional mounting flange 14, with its opposite end open to the atmosphere. Conveniently, the pipe 10 may have the same outer diameter as the exhaust and tail pipes used in conventional exhaust systems. For example, it may have a diameter of about one and three-quarters to two and one-half inches, the diameters normally used in conventional exhaust pipes and tail pipes on automobiles; but it may have a larger diameter, say as large as four inches, the diameter of conventional exhaust and tail pipes in trucks, buses, and other large vehicles. While the pipe 10 is shown as having a unitary length, it may be formed from a plurality of short interconnected lengths of pipe to facilitate the installation and replacement of the resonators.

As shown, our resonators are rigidly secured to the inner face of the pipe 10 defining a gas-flow passage for attenuating the noise level of the exhaust gases moving therethrough. As shown, each of said resonators is formed from a sheet-metal blank 15 having a pair of abutting elongated concavities 16 and 17 formed therein and bordered by a coplanar peripheral wall area 18. An elongated bead 19 is also formed in the blank 15 within the extent of the wall area 18, said bead having one of its ends open, as at 20, and its opposite end terminating within the extent of the concavity 17.

As shown in FIG. 3, the blank 15 is bendable along an imaginary line 22 into the position shown in FIG. 2 in

which the opposed concavities 16 and 17 define a resonator volume 23, sealed along its border by the wall area 18 adjacent the concavity 16 which abuts, and is rigidly secured to, the portion of the wall area 18 adjacent the concavity 17. In this assembled position, a portion of the wall area 18 adjacent the concavity 16 overlies the bead 19 to form therewith a resonator throat 24 which is in open communication with the gas-flow passage, as at 20, and the resonator volume 23, as at 26, so that the resonator will attenuate the noise level of the gases moving through the pipe 10.

In order that the system of resonators will attenuate a substantial range of sound wave frequencies in the exhaust gases, it is necessary that the individual resonator volumes and throats be tuned with respect to the harmonic characteristics of the exhaust conduit and/or the firing frequencies of the engine. The latter, at least in the troublesome range below 200 cycles per second, normally are correlated with the former so that in most instances the resonators are tuned to frequencies which constitute multiples of the fundamental resonant frequency of the conduit. Such multiples may constitute whole number multiples (for example, 1, 2, 3, etc.) in which case the resonators will be tuned to the various harmonics of the conduit, and such multiples may also constitute mixed number multiples (for example, 1½, 2½, etc.) in which case the resonators will be tuned to fractional components of the conduit harmonics. Desirably, the resonators are tuned to both the whole number multiples and mixed number multiples of the fundamental resonant frequency of the conduit, and are thus correlated with, and responsive to, both the harmonic conduit frequencies and the firing frequencies of the engine when said engine is propelling a vehicle at speeds in the range of from about 20 m.p.h. to about 50 m.p.h.

Tuning of the resonators may be effected by adjusting the conductivity of the resonator throat with respect to the size or capacity of the resonator volume. The formula for calculating such tuning may be represented by the formula:

$$f=\frac{C}{2\pi}\sqrt{\frac{C_0}{V_c}}$$

where f is the frequency to which the resonator is to be tuned, C is the speed of sound in inches per second at the temperature of the medium, V_c is the capacity of the resonator volume, and C_0 is the conductivity of the resonator throat calculated from the formula:

$$C_0=\frac{2\pi r^2}{2h+\pi r}$$

where r is the radius of the throat and h is the length of the throat. Where the throats are non-circular in cross-section, their conductivity may be calculated by the above formula using their cross-sectional areas instead of quantity πr^2, and the mean radii of their cross-sections instead of the quantity πr. While each resonator attenuates to a maximum degree the particular frequency to which it is tuned, it will of course, attenuate to a lesser extent a limited band of frequencies on either side of that particular frequency, and will effect some attenuation of substantially all frequencies. It is apparent that this tuning of the throats may be easily accomplished by merely controlling the depth and/or longitudinal and lateral extents of the concavities 16 and 17 and the throat-forming bead 19.

The fundamental resonant frequency of the exhaust conduit with which the frequency of the resonators are to be coordinated depends upon the speed of sound, and as shown by the first formula set forth above, the frequency of a resonator likewise depends upon the speed of sound. Since the speed of sound varies with temperature, a temperature gradient between the resonator throats and exhaust gases will interfere with the co-ordination necessary for the resonators to achieve their maximum

attenuation. These changes in the speed of sound resulting from changes in temperature of the medium in which the sound waves are carried will also cause the frequencies of the sound waves to change, the degree of frequency change depending upon the temperatures and frequencies involved. In our exhaust conduit, the temperature of the exhaust gases in the engine to which the conduit is connected will vary over a wide temperature range of from about 200° F., when the engine is cold, to a temperature of about 1,700° F., when the engine is hot.

In a typical example of our invention using an exhaust conduit having a first overtone (second harmonic) of 80 cycles per second, we have found that that first overtone shifted to 106 cycles per second when the engine was propelling the vehicle 25 miles per hour, and that it was shifted to 121 cycles per second when the engine was propelling the vehicle 50 miles per hour. This frequency shifting resulted from the increased temperatures of the exhaust gases. Furthermore, at 25 miles per hour the engine had a firing frequency of about 80 cycles per second, and a firing frequency of 120 cycles per second at 50 miles per hour. As will be apparent, in the lower frequency range, i.e., below 200 cycles per second, the firing frequencies of the engine coincide with and augment the natural resonant frequencies of the exhaust conduit making these lower frequency ranges extremely difficult to attenuate.

Our resonator construction, however, permits the resonators to be mounted within the conduit in the gas stream so that said resonators are thermally coupled thereto. Thus, they are subjected to the same temperature changes as the gas stream to maintain a minimal temperature gradient between said resonators and the gas stream irrespective of gas stream temperature changes and thus cause said resonators to be co-ordinated with the resonant harmonic pipe frequencies which they are to attenuate.

Preferably, the resonators formed by the members 15 are tuned to attenuate the objectionable harmonics, or fractional components of said harmonics, in the gases in the conduit. Each of these harmonic components will have specifically located maximum sound-pressure points along the length of the conduit, the number of such pressure points and their location being a function of the particular harmonic component involved. For example, the second overtone (third harmonic) will have three maximum pressure points along the conduit which will occur at points spaced from either end of the conduit by distances of one-sixth, one-half, and five-sixths of the conduit-length. Each of the resonators will attenuate to the maximum degree the particular harmonic, or fraction of a harmonic, to which it is tuned, if its throat opening is coupled to the gas stream at one of the points of maximum pressure of the harmonic or harmonic fraction for which it is tuned. While the resonators will effect maximum attenuation while their throats are located precisely at their maximum pressure points, they will, of course, still operate at high attenuation efficiencies if their throats are located adjacent such pressure points. For example, we have found that a resonator will operate at not less than 90% efficiency if its throat opening is placed at any point within a distance from the true maximum pressure point equal to one-twentieth of the length of the sound wave producing the pressure point.

In general, such maximum pressure points are spaced from an end of the conduit by fractions L of the conduit-length according to the formula:

$$L=\frac{2_m-1}{2_n}$$

where n is the harmonic number for which the resonator is tuned, and m is every integer between and including 1 and n.

The above formula is used for calculating the locations of the various sound pressure points when the conduit and the exhaust gases moving therethrough are at ambient

temperatures. However, when the engine connected to the conduit is in operation under normal conditions of use, it will discharge gases into the conduit at elevated temperatures thereby increasing the temperature of the conduit and increasing the velocity of the sound waves carried in said gases to shift the locations of the pressure points as calculated from the above formula. When the engine is operating under normal conditions, the locations of the pressure points shift downstream a distance equal to from about 2% to about 4% of the wave length of the frequencies producing the various pressure points. The temperature gradient along the conduit from the exhaust manifold on the engine to the discharge end of said conduit is not uniform, and the locations of the pressure points toward the upstream end of the conduit will be shifted downstream to a greater degree than the locations of the pressure points toward the discharge end of the conduit. Thus, the resonators are tuned to attenuate the desired sound wave frequencies in the gases in the conduit and the above formula is employed to determine the positions that the resonator throats should open into the conduit. However, for the resonators to achieve maximum effectiveness, the resonators are mounted on the conduit with their throats opening into the conduit at points spaced downstream from the locations calculated by said formula by distances equal to about 2% to about 4% of the wave length of the frequencies to which the resonators are tuned.

Although our resonators are shown as being formed in single units, it is to be understood that the members 15 may have pluralities of longitudinally spaced volume-forming concavities 16 and 17 and throat-forming beads 19 formed therein so that a single member 15 will form a plurality of resonators.

While our resonators have been shown as being mounted within a gas-carrying pipe having a circular cross-section, it is to be understood that said pipe may have any desired cross-sectional configuration. Indeed, in certain applications it may be desirable for purposes of vertical clearance to flatten such gas-carrying pipe into a generally elliptical cross-section.

For purposes of simplicity of description, the invention has only been described for use in an exhaust system for an engine. However, it may, of course, also be used on the intake side of an internal combustion engine for transporting and silencing the gas intake flow to the engine, or many other silencing applications.

We claim:

1. A sheet-metal sound attenuating resonator, comprising a sheet-metal member formed from a unitary piece of sheet-metal having first wall areas disposed in spaced relationship to each other to form a resonator volume, second wall areas bordering said first wall areas and enclosing said volume, elongated third wall areas extending within the extent of said second wall areas and disposed in spaced relationship to each other to form an elongated resonator throat, said throat being open within and without the extent of said volume for operatively interconnecting said volume to a sound energy source for attenuating the noise level thereof, said volume being completely enclosed except for its communication with said throat.

2. A sheet-metal sound attenuating resonator, comprising a unitary sheet-metal member having at least one concavity formed therein inwardly from the edges thereof, a bead formed in said member having one of its ends terminating in said concavity and having an opening formed therein adjacent its opposite end, said member being folded back upon itself whereby said concavity and the portion of said member overlying said concavity forms a resonator volume and said bead and the portion of said member overlying said bead form a resonator throat for operatively interconnecting said volume to a sound energy source for attenuating the noise level thereof, the portions of said member extending around said

volume being interconnected whereby said volume is completely enclosed except for its communication with said throat.

3. In a sound attenuating gas conduit for conveying, and attenuating the noise level of a moving gas stream, a pipe forming a main gas-flow passage, at least one resonator carried within said pipe comprising a unitary sheet-metal member having first wall areas disposed in spaced relationship to each other to form a resonator volume, second wall areas bordering said first wall areas and enclosing said volume, third wall areas extending within the extent of said second wall areas and disposed in spaced relationship to each other to form a resonator throat, said throat being open within and without the extent of said volume for operatively interconnecting said volume and passage whereby said resonator will attenuate the noise level of the gas stream moving through said pipe, said member being rigidly secured to the inwardly presented face of said pipe for mounting said resonator in said gas-flow passage.

4. An exhaust silencing system for an internal combustion engine, comprising a pipe for connection to the engine to receive the exhaust gases thereof and to convey such gases to a discharge point, said pipe forming a gas conduit wherein the exhaust gas sound produces one or more distinct pressure points at particular locations along the conduit, and a resonator disposed adjacent one or more of said points, said resonator comprising a unitary sheet-metal member having first wall areas disposed in spaced relationship to each other to form a resonator volume, second wall areas bordering said first wall areas and enclosing said volume, third wall areas extending within the extent of said second wall areas and disposed in spaced relationship to each other to form a resonator throat, said throat being in open communication with said volume and with the interior of said pipe adjacent the pressure point of the frequency to which it and its associated volume are tuned whereby said resonator will preferentially attenuate the noise level of said frequency, said sheet-metal member being rigidly secured to the inwardly presented pipe face.

References Cited by the Examiner

UNITED STATES PATENTS

Re. 21,324	1/40	MacKenzie et al.	181—48
2,056,608	10/36	Jack	181—48
2,297,046	9/42	Bourne	181—48
3,031,026	4/62	Price	181—54

LEO SMILOW, *Primary Examiner.*