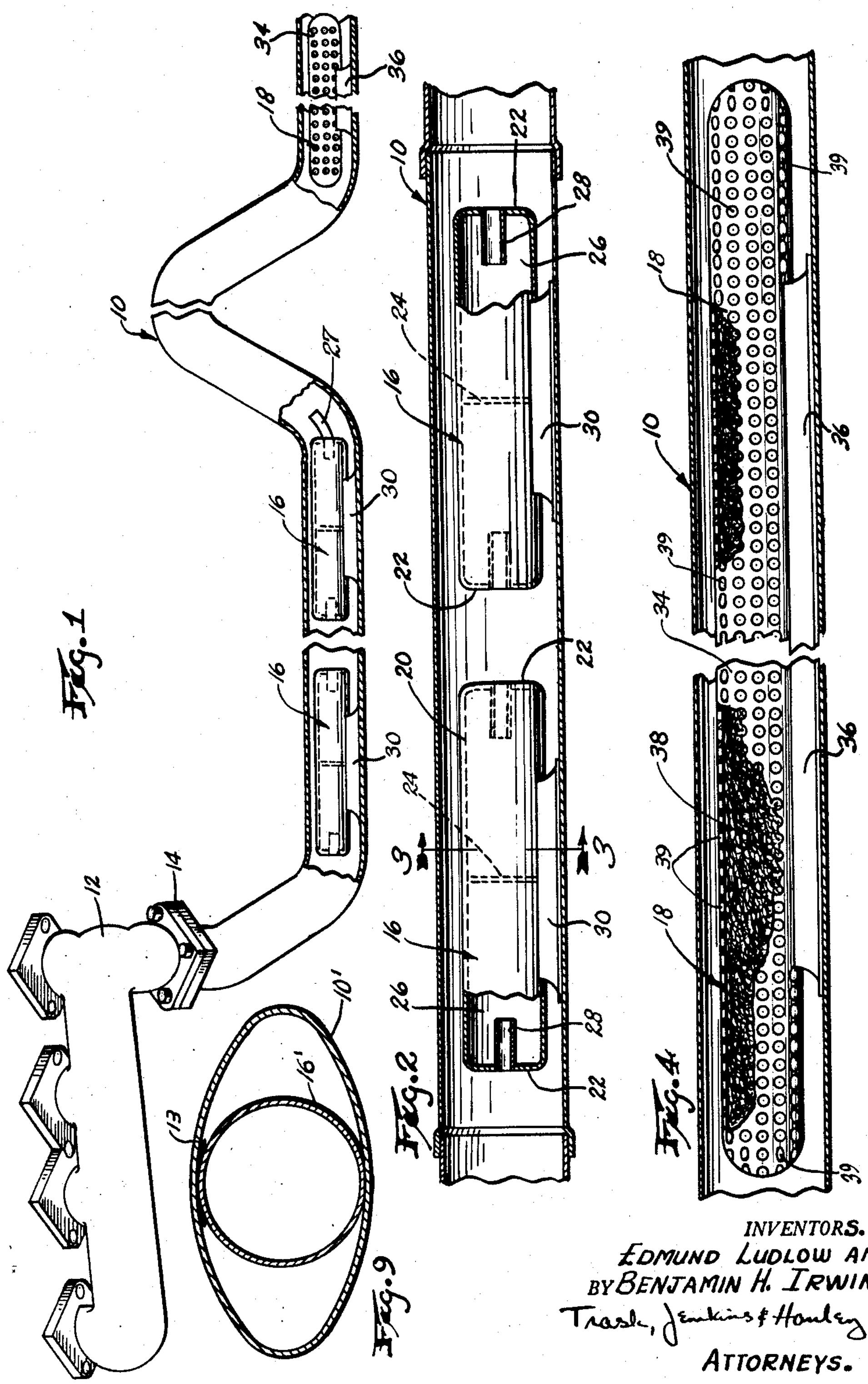
Jan. 28, 1964 E. LUDLOW ETAL 3,119,459

SOUND ATTENUATING GAS CONDUIT

Filed Feb. 13, 1961 2 Sheets-Sheet 1



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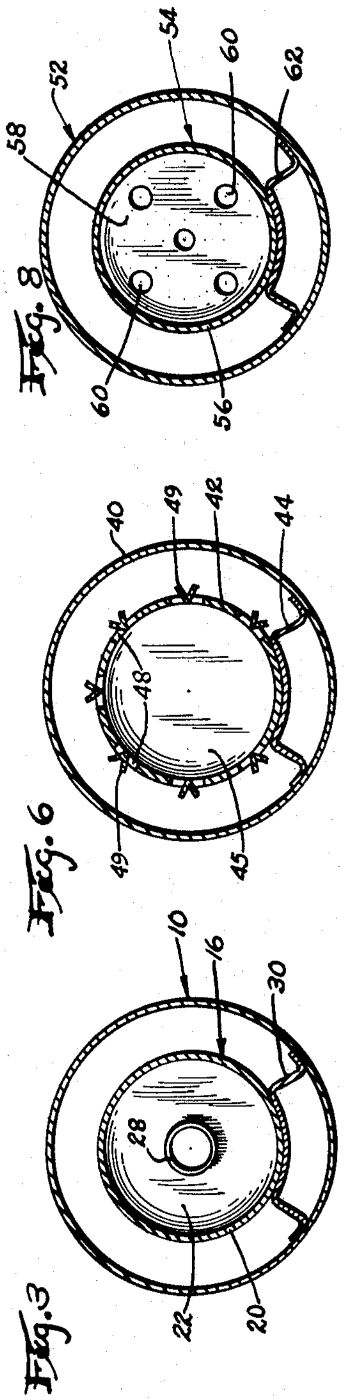

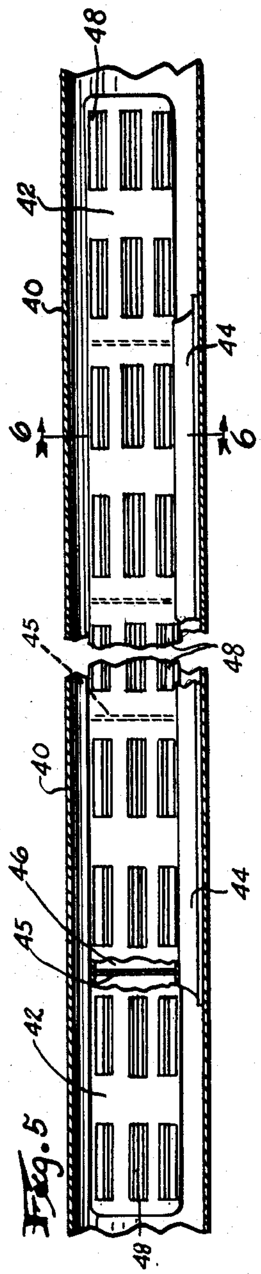

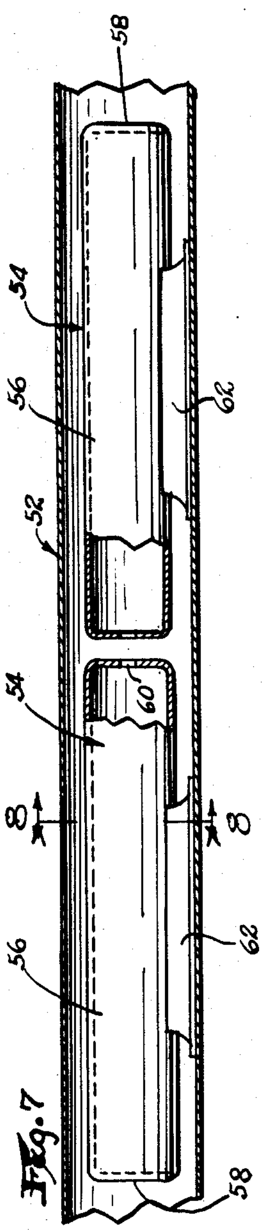

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SOUND ATTENUATING GAS CONDUIT

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15 Claims. (Cl. 181—59)

This invention relates to a sound attenuating gas conduit for conveying, and attenuating the noise level of, a moving gas stream, and which is well adapted for use with an internal combustion engine for conveying the exhaust gases therefrom and silencing the noise level of said exhaust gases.

It is an object of our invention to provide such a sound attenuating gas conduit which will meet limited space requirements, which can be easily manufactured largely from inexpensive metal-tubing, and which can be of lightweight construction with its weight substantially uniformly distributed along its length. It is a further object of our invention to provide such a sound attenuating gas conduit 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 still a further object of our 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 units.

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

We have discovered that it is possible to attenuate the noise level of individual sound frequencies by suitably located tuned elements of much smaller physical size than the structures required in prior muffler-type systems, and that by the use of a combination of such elements we can provide a complete and practical automotive exhaust silencing system within the configuration of a simple pipe extending from the usual automotive engine to the usual point of discharge of the exhaust gases.

Our silencing elements may be used individually or in combination with other silencing means, and, in such applications as automotive exhaust silencing, our invention contemplates a system embodying a number of silencing elements in interrelated arrangement.

In accordance with our invention as applied to an automotive exhaust system, the exhaust manifold is connected to a pipe to convey the exhaust gases to the desired discharge point, as at the rear of the vehicle. Acoustically, such pipe, usually with at least part of the exhaust 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 has one or more distinct pressure points, that is, points of maximum sound pressure, at particular locations along the conduit. In accordance with our invention, sound attenuating elements are placed at or adjacent to these pressure points, and are respectively made to attenuate the particular harmonic frequencies or bands of frequencies having pressure points at or adjacent such locations.

In order to maintain effective attenuation under the varying temperature conditions and gradients which will occur, the silencing elements are arranged in direct and close thermal coupling relation with the gas stream, as

within and surrounded by the gas stream. The silencing elements may include resonance cavities or volumes and one or more throats for acoustically coupling the volumes with the gas stream. These thermal and acoustical coupling relationships with the gas stream are desirably made maximal as by disposing the volumes and throats within, and axially symmetrical with, the gas stream.

Other forms and locations of silencing elements may also be used. For example, units for suppressing relatively wide bands of high sound wave frequencies may be placed at points not occupied by specifically tuned elements.

Other objects and features of our 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 in section showing a sound attenuating exhaust system embodying our invention;

FIG. 2 is an enlarged fragmentary longitudinal section of the exhaust system shown in FIG. 1, but with the outer pipe shown as interfitting pipe sections;

FIG. 3 is an enlarged vertical section taken on the line 3—3 of FIG. 2;

FIG. 4 is an enlarged fragmentary longitudinal section of another portion of the exhaust system shown in FIG. 1;

FIG. 5 is a fragmentary longitudinal section showing a different form of silencing element;

FIG. 6 is an enlarged vertical section taken on the line 6—6 of FIG. 5;

FIG. 7 is a fragmentary longitudinal section showing another form of silencing element;

FIG. 8 is an enlarged vertical section taken on the line 8—8 of FIG. 7; and

FIG. 9 is a vertical section of a modified embodiment of our invention.

Our invention is particularly well adapted for use with an internal combustion engine in an automobile to silence the exhaust gases emanating from said engine and to convey them to a suitable discharge point. In such usage, it completely replaces a conventional exhaust system in which all of the silencing effect is lumped in specific locations determined by the structural requirements of the vehicle, as in a muffler connected between an exhaust pipe joined to the exhaust manifold of the engine and a tail pipe leading from the muffler to a gas discharge point. Such a muffler conventionally comprises an outer shell having an elliptically or circularly shaped cross-section many times larger than the cross-sections of the exhaust and tail pipes, and has a relatively small number of large resonators, each adapted to attenuate a wide band of sound frequencies in the exhaust gases passing through the system. In such mufflers, there are normally provided two large resonator chambers respectively tuned to attenuate the harmonic frequencies of the exhaust and tail pipes. All of the resonator chambers are baffled one from another, and are arranged within the muffler shell in staggered patterns which, combined with the large size of the resonator chambers for the exhaust and tail pipes, result in the muffler being large and difficult to mount in the limited space available on the underside of an automotive vehicle.

Our invention, however, avoids the need for such large mufflers in specific locations by the employment of a series of small silencing elements in in-line relationship within the gas stream in a pipe extending from the manifold to the gas discharge point. The different silencing elements may be designed to attenuate different and/or overlapping bands of wave frequencies, and may be located in the pipe with respect to the harmonic characteristics of the pipe so that they will effect sound attenuation without the use of any large bulky resonator chambers, as are required in a conventional muffler-type system. Our invention thus provides an exhaust system which has a substantially smaller size and a lighter weight than a conventional muffler-type system, while still effecting at least the same degree of attenuation as a conventional muffler-type system.

In muffler-type silencing systems, the muffler silencers used provide in the flow passage of the system a substantial, abrupt enlargement of the cross-sectional area of the passage, with an abrupt increase in area at the upstream end of the silencing structure and an abrupt decrease in area at the downstream end. Among other things, this produces a velocity decrease and an abrupt gas expansion which reduces the temperature of the gas and tends to condense exhaust vapors in position to be trapped and corrode the muffler structure. In contrast to this, our invention avoids such enlargement of the gas-flow passage, and desirably uses an outer pipe of substantially uniform cross-section with the silencing elements disposed wholly within such cross-section, which produces a reduction instead of an enlargement of the flow passage area at the location of a silencing element. While we avoid the abrupt enlargement of prior systems, and conveniently have reductions instead, we may form the structure to give a flow passage of generally uniform area.

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/sec. to about 5,000 cycles/sec., with the lower frequencies largely representing the fundamental and lower harmonics determined by the length of the exhaust conduit. In many exhaust systems it is the lower range of frequencies, i.e., frequencies below 200 cycles/sec., 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. In many conventional mufflers these low frequencies are not adequately attenuated because the large size of the mufflers prevents them from being positioned on the underside of a vehicle in the proper positions with respect to the exhaust system to act upon and attenuate these low frequencies.

Our invention is adapted to attenuate the noise level of the exhaust gases over a wide range of frequencies, including the troublesome frequencies below 200 cycles/sec., by passing said gases through an exhaust conduit having a series of silencing elements mounted within it along its length. The silencing elements may take several forms. For example, one form may be used to attenuate frequencies up to 300 cycles/sec., another form to attenuate frequencies in the range of 100 cycles/sec., to 700 cycles/sec., another form to attenuate frequencies in the range of 300 cycles/sec. to 1,500 cycles/sec., and still another form to attenuate those frequencies above 1,500 cycles/sec.

While silencing elements 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 lining axial sections of the conduit.

The embodiment shown in FIG. 1 comprises a pipe **10** adapted to be connected at one end to an exhaust manifold **12** 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** may be a unitary length, it may be formed from a plurality of short interconnected lengths of pipe, as indicated in FIG. 2, to facilitate the installation and replacement of the silencing elements.

In the exhaust system illustrated in FIG. 1, a plurality of low frequency silencing elements **16** and high frequency silencing elements **18** are mounted in the pipe **10** in the path of the gas stream moving through said pipe. As shown in FIG. 2, each of the elements **16** comprises an elongated wall, conveniently in the form of a length of metal-tubing **20**, closed at its opposite ends as by inturned flanges forming end walls **22**. A baffle plate **24** is mounted within the tubing **20** intermediate its ends to divide the tubing **20** into a pair of elongated cavities or resonator volumes **26**. Each of the volumes **26** has associated with it a resonator throat-forming tube **28** having one of its ends open to its respective volume **26** and its opposite end open to the gas-flow passage formed by the pipe **10**. In this manner, each of the volumes **26** is directly coupled by means of its throat **28** with the gas stream moving through the pipe **10** so that the resonators formed by said throats and volumes will attenuate the noise level of sound waves in the exhaust gases.

In the embodiment of FIGS. 1 and 2, the elements **16** are supported in the pipe **10** by brackets **30**, conveniently in the form of sheet-metal stampings. The brackets **30** are rigidly secured to each of the sound attenuating elements **16** and to the wall of the pipe **10**, and support the element **16** in spaced relation to the wall of the pipe **10**. Thus, the elements **16** are maintained out of contact with the wall of the pipe **10** and out of contact with any corrosive liquids condensed out of the exhaust gases onto the pipe wall, said liquids thus being free to drain out of the pipe. Further, the brackets **30** support the elements directly in the gas stream so that said elements are thermally coupled to the gas stream and will assume the temperature changes of said gas stream.

In order that the system of resonators formed by the volumes **26** and throats **28** will attenuate a substantial range of sound wave frequencies in the exhaust gases, it is necessary that individual resonators be tuned to given frequencies or frequency ranges at least approximately coordinated with the fundamental resonant frequency of the exhaust conduit. Such tuning may be effected by adjusting the conductivity of the resonator throat with respect to the size or capacity of the resonator volume. For resonators with tubular throats, the formula for calculating the 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. In calculating the C_0 for a nontubular throat, the cross-sectional area of the throat is substituted for the quantity πr^2, and the mean radius of the cross-section of the throat is substituted for the quantity πr. Thus, the length and area of the resonator throats and the capacity of the resonator volumes may be adjusted with respect to each other to tune the resonators to attenuate the desired sound wave frequencies.

While each resonator attenuates to the 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.

As will be understood from well known principles of acoustics, the fundamental resonant frequency of the exhaust conduit, with which the frequncies of the resonators are to be coordinated, depends upon the speed of sound. 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, differences between the temperatures of the resonators and the exhaust gases will interfere with the coordination necessary for the resonators to achieve their maximum attenuation.

These changes in the speed of sound resulting from changes in the 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. For example, we have found that in the temperature range of 72° F. to 500° F., each 100° F. change in temperature will produce the following frequency changes in a conduit whose fundamental wave frequency is 37.7 cycles/sec.: its fundamental wave frequency of 37.7 cycles/sec. will change 3 cycles/sec.; its second harmonic of 75.4 cycles/sec. will change 6 cycles/sec.; its third harmonic of 113.1 cycles/sec. will change 9 cycles/sec.; etc. Thus, in the normal operation of an automobile where the exhaust gases may range from a temperature of about 200° F. when the engine is cold to a temperature of about 1,700° F. when the engine is hot, the harmonic frequencies of the pipe **10** are subject to wide changes in the lower frequency ranges. In our system, we place the silencing elements directly in the gas stream so that the resonators are subjected to the same temperature changes as the gas stream at the points where the resonators are located in said gas stream. This maintains the temperature difference between the resonators and the gas stream at a minimum, irrespective of gas stream temperature changes, and the resonators will thus remain coordinated with the resonant harmonic pipe frequencies which they are to attenuate.

Preferably, the resonators in the silencing elements **16** are respectively tuned to attenuate the objectionable harmonics in the gases in the conduit. Each harmonic 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 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 for which it is tuned if its throat opening is coupled into the gas stream at any one of the points of maximum pressure of the harmonic for which it is tuned. While the resonators will effect maximum attenuation if their throats are located precisely at their maximum pressure points, they will, of course, still operate at high attenuating 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:

$$L=\frac{2m-1}{2n}$$

where n is the harmonic number for which the resonator is tuned, and m is every integer between and including 1 and n. Thus, if a particular resonator is tuned to attenuate the second harmonic frequency of the gases in the conduit, the above formula may be employed to determine that the throat opening for the resonator should be spaced from one end of the conduit by a distance equal to one-fourth or three-fourths of the length of the conduit.

It is to be understood that instead of a single resonator, two or more resonators may be employed to attenuate a particular harmonic; indeed, in certain cases, substantially improved results may be obtained by using the same total resonator capacity in two or more resonators rather than in a single resonator. If two resonators are employed to attenuate a particular harmonic, they should be spaced along the conduit either so that their throats open to the conduit adjacent to the appropriate pressure points, or mounted in the conduit so that the throats of both open to the gas stream adjacent one of such pressure points.

For ease of construction, each of the silencing elements **16** is mounted only in a straight section of the outer pipe **10**, but the maximum pressure point of a harmonic frequency for which its resonator is tuned may be in a curved section of the pipe. To overcome this difficulty and to permit the resonator to operate at its maximum efficiency, the silencing element may be constructed with the resonator throat projecting outwardly therefrom so that with the element mounted adjacent the curved section, the throat will project into said curved section to dispose its open end at the desired maximum pressure point location, as indicated at **27** in FIG. 1.

The relative positioning of the elements **16** with respect to each other also influences the action of the resonators with respect to the frequencies which they attenuate. We have found that by positioning a pair of elements **16** closely adjacent each other as in the relationship shown in FIG. 7, the space between the opposed end walls **22** forms a common annular extension of the throats **28**. This increases the effective length of the throats **28** with the result that the opposed resonators attenuate lower frequencies than they would attenuate if their walls **22** are spaced relatively farther apart. Of course, if the resonators are spaced too close together, the space between their opposed end walls will be insufficient for the necessary acoustic coupling and will substantially reduce the attenuation efficiencies of the resonators. Conversely, if the opposed end walls are spaced substantially apart, there will be no mutual throat action between the resonators and they will act independently of each other.

The silencing element **16** shown in FIG. 2 with the elongated tubular throats **28** is particularly well adapted for attenuating the troublesome sound wave frequencies below 300 cycles/sec. To attenuate those frequencies occurring above 1,500 cycles/sec., the silencing element **18** is employed. As shown in FIG. 4, the element **18** comprises an elongated tube **34**, conveniently a length of metal-tubing, closed at each of its ends, and supported on a bracket **36** mounted in the pipe **10** to thus dispose the element **18** directly in the path of the gas stream moving through the conduit. The cavity within the tube **34** contains a porous fibrous material **38**, such as asbestos fibers, stainless steel wool, or the like. This material may be in the form of a porous wadding filling the cavity, a hollow sleeve lining the cavity walls, or any other suitable configuration.

A plurality of perforations **39** are formed in the tube **34** to render it at least 30% open, and thus dispose the cavity containing the porous material **38** in operative acoustical communication with the sound waves in the gas stream. The perforations **39** correspond to the throats **28** shown in FIG. 2 in that they operatively interconnect the cavity of the tube **34** with the gas stream. However, because of their negligible length, the conductivity of the perforations 39 is extremely high to thus cause the element 18 to preferentially attenuate the extremely high frequency sound waves above 1,500 cycles/sec.

The type of silencing element shown in FIG. 4 will attenuate broad bands of high frequency sound waves having large numbers of relatively closely spaced maximum pressure points. Therefore, the axial positioning of these elements along the conduit is less critical than the placement of silencing elements for attenuating the lower frequency sound waves, and the type of element shown in FIG. 4 may thus be disposed immediately adjacent the discharge end of the conduit downstream from the silencing elements for the lower frequency sound waves. This leaves the other parts of the conduit free for mounting the lower frequency silencing elements at the maximum pressure points of the frequencies for which they are tuned.

Another form of silencing element in accordance with our invention is shown in FIGS. 5 and 6, and comprises an outer pipe 40 having suspended within it one or more silencing elements, each comprising an elongated tube 42 closed at its ends and mounted on a channeled bracket 44 mounted in the pipe 40 to thus suspend the tube 42 in the gas stream in spaced relation to the pipe 40. Conveniently, a plurality of baffle plates 45 are mounted within the tube 42 to divide it in a plurality of axially spaced resonator volumes 46.

To operatively interconnect each of the volumes 46 with the gas stream, a plurality of throat-forming openings 48 are formed in the tube 42 around its circumference within the axial extent of each of said volumes. Desirably, the openings are formed by shearing the tube 42 to provide tongues 49 bent to project from the tube wall. In this manner, the openings 48 with their adjacent tongues 49 constitute resonator throats which, because of their sheared construction, have a conductivity such that the silencing element will attenuate sound wave frequencies in the range of 300 cycles/sec. to 1,500 cycles/sec.

Still another form of silencing element in accordance with our invention is shown in FIGS. 7 and 8, in which there is an outer pipe 52 forming the gas-flow passage and having suspended within it pairs of silencing elements 54. As shown, each of the elements 54 comprises an elongated tube 56 having one of its ends closed as at 58, and its opposite end provided with one or more perforations 60 which constitute throat-forming means for the resonator volume formed by the tube 56. Each of the elements 54 is mounted on a bracket 62 mounted in the pipe 52 to thus dispose said elements in spaced relation to the pipe 52.

As previously described in connection with the silencing elements 16, the elements 54 may be arranged in opposed pairs with their perforated end faces immediately adjacent each other. In such a closely spaced relationship, the space between the opposed end faces forms a common extension of the throat-forming means in the two resonators to increase the effective length of said means and cause the elements 54 to act upon a lower range of sound wave frequencies than the frequencies for which they are individually tuned. When the elements 54 are disposed in their opposed relationship, they will attenuate sound wave frequencies in the range of 100 cycles/sec. to 700 cycles/sec., with their preferential frequency response in said range depending upon the size of the volumes of the tubes 56, the size and number of their perforations 60, and the spacing between their opposed end faces. If it is desired to modify the effective throat length of only one of the silencing elements, the pair of elements are mounted in alignment with the perforated end face of one of said elements being disposed adjacent the nonperforated end face of the other.

It is to be understood, of course, that either of the elements 54 may be employed without the use of the other and/or the throat-forming perforations in said elements may be disposed around the side walls of said elements instead of in their end faces. However, the degree to

which the elements 54 are perforated will normally be very small in comparison with the large degree of perforation present in the silencing element 18 shown in FIGS. 1 and 4.

In all of the modifications shown, our silencing elements are carried within an outer pipe forming the gas-flow passage whereby the gases moving through said pipe will have to pass through the space between said pipe and the silencing elements. The pipe forming said passage has a generally uniform cross-section with no substantial, abrupt changes in its diameter adjacent said silencing elements, and the average cross-sectional area of the gas-flow passage between said elements and the pipe within the axial extents of said elements is smaller than the average cross-sectional area of the gas-flow passage in the open portions of the pipe outside the extent of the silencing elements. However, the cross-sectional area of the silencing elements is in the range of from about 25% to about 75% of the cross-sectional area of the pipe within the axial extent of said elements so that said elements will effect the necessary degree of attenuation but will not unduly obstruct gas flow through the pipe and create excessive back pressures.

As will be apparent, by employing several of the illustrated types of silencing elements in combination, a wide range of sound wave frequencies may be attenuated. For example, elements of the type shown in FIGS. 2 and 4 may be employed to attenuate extremely low and high ranges of frequencies, respectively, and elements of the type shown in FIGS. 5 and 7 may be used in combination therewith to attenuate the intermediate range frequencies. It is also possible to combine several types of elements in a single combination structure carried within the outer pipe. For example, elements of the type shown in FIGS. 2, 4, and 5 may be incorporated in an axially spaced relationship in the same length of tubing, and that length of tubing mounted in an outer pipe.

As shown in the drawings, the silencing elements are located in the path of the gas stream movement. This permits our silencing elements to be intimately acoustically and thermally coupled to said gas stream so that said elements will not only achieve their maximum acoustic efficiencies through such direct coupling, but in addition, their resonant frequencies will adjust directly with the frequency changes in the gas stream due to temperature changes. Further, such suspension positions the silencing elements out of contact with the outer pipe to reduce their susceptibility to corrosion. However, should such corrosion occur, the silencing elements may be easily replaced by simply removing the corroded element and replacing it with a new element. As previously described, such replacement may be facilitated by forming the outer pipe from a plurality of short interfitting sections of pipe so that the defective silencing element and its respective pipe section may be replaced as a unit.

While we have shown our silencing elements as disposed concentrically within an outer pipe on brackets, it is to be understood that such brackets may be omitted and the elements may contact the outer pipe along one or more lines of contact. To this end, the elements may be suspended from one line of contact along the wall of the outer pipe, or the pipe and elements may have different cross-sectional configurations which permit the elements to contact, and be supported from, the pipe along two or more lines of contact. An example of the latter situation is shown in FIG. 9, in which the outer pipe indicated at 10′ is flattened into an eliptical cross-section, and the silencing element indicated at 16′ abuts it along two lines of contact and is secured thereto by welds 13. However, as in the embodiments of our invention, there are no substantial, abrupt changes made in the general cross-section of the pipe. Where the silencing elements are in line contact with the pipe, the means supporting the elements therein may comprise welded interconnections between the pipe and silencing elements along their lines of contact. However, even where the silencing elements contact the pipe, the major portions of the walls of said elements are disposed wholly out of contact with the outer pipe to provide a high degree of coupling between the elements and the gas stream, and to cause the gases to move through the space between the elements and the pipe.

For purposes of simplicity of description, we have only described our invention 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 for many other silencing applications.

We claim as our invention:

1. In a sound attenuating gas conduit for conveying, and attenuating the noise level of, a moving gas stream, an open-ended pipe free from substantial abrupt changes in its diameter forming a gas-flow passage having unrestricted flow at its ends, at least one silencing element mounted within said pipe inwardly from the ends thereof and comprising an elongated enclosed wall forming a sound attenuating cavity, and throat-forming means in direct communication with the interior of said pipe operatively interconnecting said cavity and gas-flow passage whereby said element will silence the gases moving through said passage, the cross-sectional area of the gas passage within the axial extent of said element being smaller than the average cross-sectional area of the gas passage outside the axial extent of said element, said silencing element being mounted within said pipe in said gas-flow passage on a bracket secured to said pipe to support said silencing element wholly out of contact with said pipe whereby said gas stream must pass through the space between said element and pipe during its movement through the conduit.

2. In a sound attenuating gas conduit for conveying, and attenuating the noise level of, a moving gas stream, an open-ended pipe free from substantial abrupt changes in its diameter forming a gas-flow passage having unrestricted flow at its ends, at least one silencing element mounted within said pipe inwardly from the ends thereof and comprising an elongated enclosed wall forming a sound attenuating cavity, and throat-forming means in direct communication with the interior of said pipe operatively interconnecting said cavity and gas-flow passage whereby said element will silence the gases moving through said passage, said element having a cross-sectional area in a range of from about 25% to about 75% of the cross-sectional area of the pipe within the axial extent of said silencing element with at least substantially all of said wall in spaced relation to said pipe whereby said gas stream must pass through the space between said element and pipe during its movement through the conduit.

3. The invention as set forth in claim 2 in which said wall comprises a first length of tubing having enclosed ends, and said throat-forming means comprises a second length of tubing mounted on said first length of tubing, said second length of tubing having a smaller cross-sectional area than said first length of tubing and having one of its ends open to said gas-flow passage and its opposite end open to the cavity formed by said first length of tubing.

4. The invention as set forth in claim 2 in which said wall comprises a length of tubing having enclosed ends, and said throat-forming means comprises a plurality of axially and circumferentially spaced openings formed in said tubing, the portions of the tubing defining the edges of said openings being deformed out of the general plane of said tubing.

5. The invention as set forth in claim 2 in which said wall comprises a length of tubing having enclosed ends, and said tubing is provided with one or more perforations comprising said throat-forming means.

6. The invention as set forth in claim 2 in which said wall comprises a length of tubing having enclosed ends and containing a porous, fibrous sound-absorbing material, and said throat-forming means comprises a plurality of perforations formed in said tubing to render the same at least 30% open.

7. The invention as set forth in claim 6 in which said sound-absorbing material is in the form of a porous wadding filling said tubing.

8. The invention as set forth in claim 2 in which said wall comprises an elongated length of tubing having enclosed ends and provided with a plurality of axially spaced baffle plates mounted on its interior to divide said cavity into a plurality of cavities, and said throat-forming means forms a plurality of passages each of which is open to said gas-flow passage and one of said plurality of cavities.

9. The invention as set forth in claim 2 in which said wall abuts the inner face of said pipe along one or more lines of contact, and said element and pipe are rigidly secured together along at least one of said lines of contact.

10. In a sound attenuating gas conduit for conveying, and attenuating the noise level of, a moving gas stream, a pipe forming a gas-flow passage for said gas stream, a plurality of silencing elements mounted within said gas stream, each of said silencing elements comprising an elongated wall closed at its ends and forming a sound attenuating cavity, and throat-forming means operatively interconnecting said cavity and gas-flow passage whereby each of said elements will attenuate the noise level of the gases moving through said passage, at least one pair of said elements being mounted in the gas stream in opposed relationship with the throat-forming means of each of said pair of elements being disposed in their opposed end faces and said opposed end faces being disposed closely adjacent each other to define a common extension for the throat-forming means of said pair of elements, and means supporting each of said elements in said gas-flow passage with at least substantially all its wall in spaced relation to said pipe whereby said gas stream will have to pass between said silencing elements and the pipe during its movement through the conduit.

11. In a sound attenuating gas conduit for conveying, and attenuating the noise level of, a moving gas stream, an open-ended elongated pipe forming a gas-flow passage wherein a sound source will produce standing waves having pluralities of harmonic frequencies, and a plurality of silencing elements mounted within said pipe along the length thereof with their adjacent ends in axially spaced relationship, said pipe being free from substantial, abrupt changes in its diameter adjacent said silencing elements, each of said silencing elements comprising means disposed in said gas-flow passage forming a closed resonator volume, said means being positioned in said gas-flow passage with at least a major portion of said volume spaced from said pipe whereby said gas stream must pass between said means and the pipe during its movement through the gas-flow passage, and means on said first mentioned means forming a resonator volume throat operatively interconnecting said volume and gas-flow passage whereby said plurality of silencing elements will be acoustically coupled to said gas stream at points along the length of said conduit to attenuate the noise level of the gas stream moving through the conduit, one or more of said silencing elements having a volume and throat construction to cause said silencing element to have a frequency response according to the formula

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

where C is the speed of sound at the temperature of the gas stream, V_c is the capacity of the resonator volume, and C_0 is the conductivity of the resonator throat equal to

$$\frac{2(\text{cross sectional area of the throat})}{2h+(\text{mean radius of the throat cross section})}$$

and h is the length of the throat.

12. The invention as set forth in claim 11 in which each of said one or more silencing elements has a throat formed from an elongated tubular element, and each of said one or more silencing elements is responsive to a predetermined sound wave frequency constituting one of the standing harmonic frequencies of the conduit with its associated throat operatively connected to said gas-flow passage adjacent a position along the length of the conduit where the harmonic frequency for which the silencing element is responsive reaches its maximum pressure.

13. An exhaust silencing system for an internal combustion engine, comprising an open-ended 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 sound produces one or more distinct harmonic sound-pressure points at particular locations along the length of the conduit equal to fractional lengths thereof according to the formula

$$L=\frac{2m-1}{2n}$$

where n is a harmonic number and m is every integer between and including 1 and n, and a plurality of silencing elements mounted in said conduit along the length thereof with their adjacent ends in axially spaced relationship and in close thermal coupling relationship with the gas stream, one or more of said silencing elements comprising a resonator volume formed from a closed end pipe and an elongated tubular throat operatively associated with said volume, each of said one or more silencing elements having volume and throat construction to cause said silencing element to have a frequency response according to the formula

$$f=\frac{C}{2\pi}\sqrt{\frac{C_0}{V_0}}$$

where C is the speed of sound at the temperature of the gas stream, V_c is the capacity of the resonator volume, and C_0 is the conductivity of the resonator throat equal to

$$\frac{2(\text{cross sectional area of the throat})}{2h+(\text{means radius of the throat cross section})}$$

and h is the length of the throat, the frequency responses of said one or more silencing elements corresponding to the sound frequencies producing said pressure points, and each of said throats is acoustically coupled to the gas stream adjacent the pressure point of the frequency to which it and its associated volume are responsive.

14. In an exhaust silencing system for an internal com-

bustion engine, an elongated open-ended pipe constituting a main gas-flow passage and formed from a plurality of axially extending interconnected shorter lengths of pipe, said pipe being free from substantial abrupt changes in its diameter and being adapted to be connected to said engine for transferring the exhaust gases therefrom, and a plurality of axially spaced siliencing elements mounted within said elongated pipe along the length thereof and having at least the major portion of their outwardly presented surfaces in spaced relation to said elongated pipe whereby gases moving through said conduit must pass through the spaces between said silencing elements and said elongated pipe, each of said silencing elements comprising a length of tubing forming a sound attenuating cavity, and throat-forming means in direct communication with said gas-flow passage operatively interconnecting each cavity to the gas-flow passage, a first set of said silencing elements having hollow sound attenuating cavities and a second set of said silencing elements having a porous fibrous sound attenuating material carried in their sound attenuating cavities.

15. The invention as set forth in claim 14 in which the throat-forming means in each of the silencing elements in said second set comprises a plurality of perforations formed in said tubing to render the same at least 30% open, and all of said second set of silencing elements are mounted in said pipe downstream of said first set of silencing elements.

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