Aug. 30, 1932.

W. P. MASON

1,874,326

SOUND MUFFLER

Filed June 14, 1929

2 Sheets-Sheet 1

FIG. 1

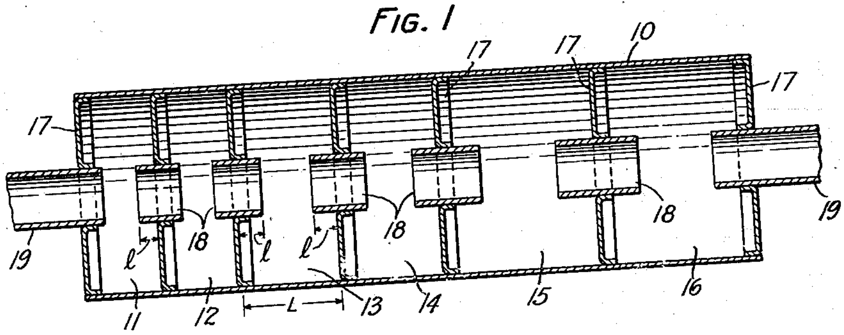

FIG. 2

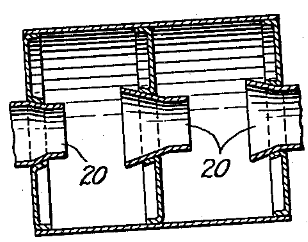

FIG. 3

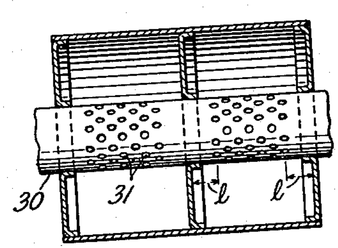

FIG. 4

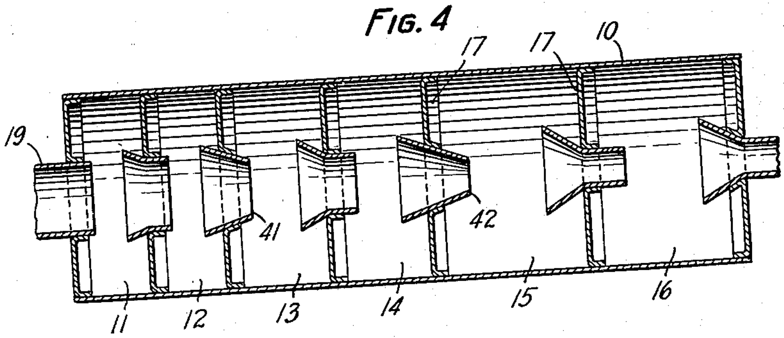

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FIG. 5

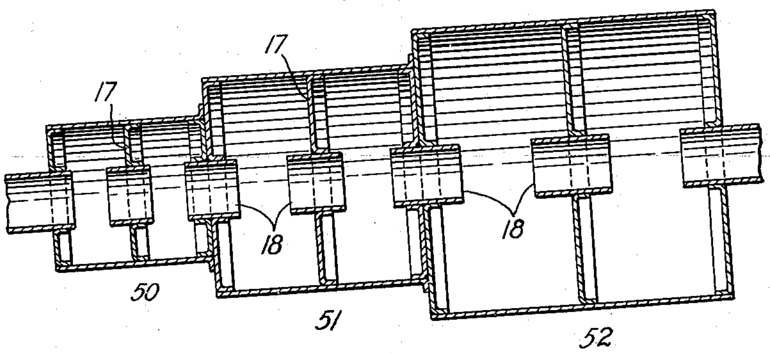


FIG. 6

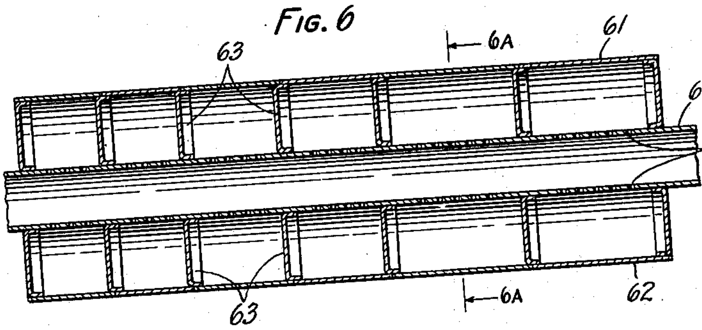
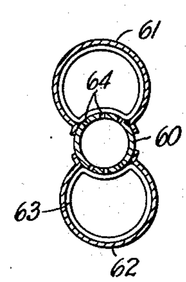


FIG. 6A



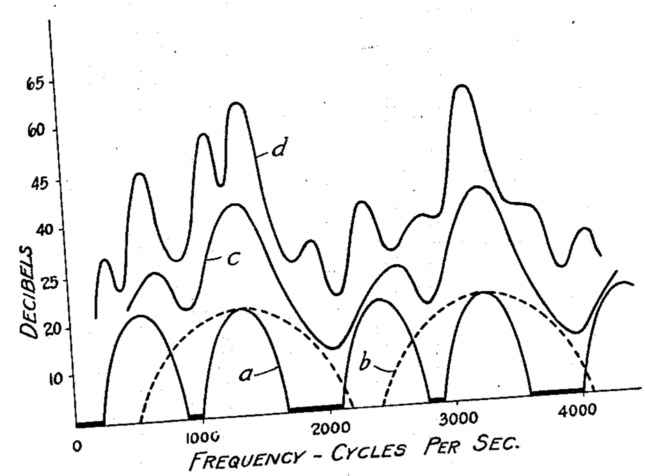


FIG. 7

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UNITED STATES PATENT OFFICE

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SOUND MUFFLER

Application filed June 14, 1929. Serial No. 370,816.

This invention relates to noise suppressing devices and more particularly to exhaust mufflers for internal combustion engines. It has for its principal objects increasing the degree of noise suppression and diminishing the effective back pressure against the flow of the exhaust gases. Another object is to diminish the weight of exhaust mufflers for a prescribed degree of noise suppression and back pressure.

These objects are accomplished by making use of the principle of wave interference as in acoustic wave filters. The component gas vibrations which make up the periodic train of exhaust impulses are operated on in such manner that all of the high frequency vibrations, which give the exhaust noise its sharp quality, are strongly attenuated in the muffler, while the low frequency components pass through the exhaust passage without obstruction. Free passage of the low frequency components is essential to the prevention of back pressure, but, by limiting the low frequency components that can be passed freely to the range below about 200 cycles per second, back pressure is prevented and the exhaust noise is reduced to a soft pulse of slight audibility.

In its general form, the invention comprises a main gas conducting channel having apertures disposed at intervals along its length, opening into enclosed chambers. An important feature of the invention is that the side chambers are of graded sizes, this graduation being essential for the satisfactory suppression of all of the higher frequency, or noise creating, vibrations. Another feature of the invention is that the exhaust passage contains no baffles, which if present, would tend to impede the free passage of the low frequency vibrations and thereby create objectionable back pressure. Due to the absence of baffles, it is possible to construct a muffler which, in respect to the degree of its noise suppressing properties, is extremely light in weight.

In the drawings, Fig. 1 illustrates in section one form of the invention;

Fig. 2 illustrates in section a modified construction which may be used in the muffler shown in Fig. 1;

Fig. 3 shows a side view, in section, of another modified construction;

Fig. 4 illustrates in section a variation of the muffler shown in Fig. 1;

Fig. 5 shows another variation;

Fig. 6 shows a side sectional view of a form of muffler in which heat from hot gases can be more readily radiated; and

Fig. 7 illustrates typical sound attenuation characteristics of mufflers embodying the invention.

In the case of a sound muffler applied to a gas engine the exhaust gases from the engine are discharged into the muffler in a series of sharp puffs or explosions which follow each other in a regular succession. The noise that would be produced by the explosions is not of a recognizably tonal character, but nevertheless it may be regarded as being the resultant of a multiplicity of pure tones having certain definite phase and amplitude relationships. Moreover, so long as the engine is running at an approximately steady speed, the explosions follow each other at regular intervals which results in a harmonic relation being established between the frequencies of the component tones, and in a relatively simple tone composition of the exhaust noise. If the high frequency components are removed the noise loses its sharp quality, and if all of the component tones down to about 200 c. p. s. or lower, are removed, only a rather soft pulsing noise remains. If the pulses of frequencies up to about 200 c. p. s. are permitted to pass freely, practically no back pressure is set up, which might interfere with the operation of the engine.

The muffler in Fig. 1 comprises a cylinder 10 divided into chambers 11, 12, 13, 14, 15 and 16 by means of transverse partitions 17. Communicating passages are provided between the chambers by tubular elements 18 which pass through the centers of the partitions and provide a path for the gas flow. Similar tubular elements 19, extending through the end partition provide means for introducing and ejecting the exhaust gas. The muffler in the drawings is composed of three stages, chambers 11 and 12 constituting one stage, 13 and 14 a second stage, and 15 and 16 a third stage. The chambers and tubular gas conducting elements constituting a stage are of uniform size, but the dimensions vary in the different stages. Referring to the first stage on the left, for example, chambers 11 and 12 are of equal size and so also are the lengths l that the tubular elements extend into each of the chambers. Similarly, in the next stage, chambers 13 and 14 are equal, and likewise the associated pipe lengths; but the component parts in this stage are larger than in the first stage. In the drawings, each of the stages is shown divided into two chambers, although a greater number of chambers may be provided if desired, and in certain cases it may be found sufficient to have a single chamber in each stage. The muffling properties, however, are improved by increasing the number of chambers per stage, and also by increasing the number of stages.

The construction may be of any material capable of withstanding heat and vibration. The parts may be made of sheet steel welded together. The pipe extending from one end of the muffler may be attached to the exhaust pipe of the engine by any suitable means, such as threads or a flange.

The muffler operates as follows: Each of the stages acts as a sound wave filter which permits the passage of low tones but suppresses tones of a frequency higher than a certain value determined by its dimensions. The suppression of the higher pitched tones in each stage, however, is not complete. There are certain regions in the higher frequency range in which the tones are transmitted almost as freely as the low pitched tones. These ranges have been found to occur at regular harmonic intervals, and their occurrence can be predicted from the dimensions of the air chambers and passages. By varying the dimensions of the air chambers in the successive stages the transmission ranges of one stage can be made to fall within the suppression ranges of the other stages, with the result that all of the high frequency noise components are suppressed, and only the nearly inaudible frequencies are transmitted. By the combination of properly proportional stages the noise suppression can be effected with a muffler of minimum size and at a substantial saving of weight.

The propagation of sound waves through one of the stages is expressed by the formula:

$$\operatorname{Cosh} P = \cos\frac{2\omega l}{v}\cos\frac{\omega L}{v} - \frac{1}{2}\left[\frac{S_2}{S_1}+\frac{S_1}{S_2}\right]\sin\frac{2\omega l}{v}\sin\frac{\omega L}{v} \quad (1)$$

where

P = the propagation constant per chamber of the stage;

$2l$ = the length of the central conduit in the chamber;

L = length of the chamber in the direction of gas conduction;

S_1 = cross-sectional area of the central conduit;

S_2 = cross-sectional area of the chamber;

v = velocity of sound propagation;

$\varpi = 2\pi$ times the frequency of sound waves.

The propagation constant P is, in general, a complex quantity and can be expressed as:

$$P = A + jB \quad (2)$$

where A, the real component, is called the attenuation constant; and B, the imaginary component, is called the phase constant. So long as the energy dissipation in the chambers is relatively small, it may be shown that for certain ranges of frequencies A is substantially negligible as compared with B, and in other frequency ranges A is the most important term. Under the first mentioned condition, which is also defined by the relation

$$\operatorname{Cosh} P < \pm 1,$$

the vibrations are transmitted without substantial attenuation, but are changed in phase as they traverse the section. The second condition, which corresponds to

$$\operatorname{Cosh} P > \pm 1,$$

represents the frequency ranges in which the vibrations are strongly attenuated, that is, the noise suppression range. An examination of Equation (1) shows that there is a band of free transmission beginning at zero frequency, and also an infinite number of transmission bands centered about frequencies occurring in harmonic order. In general, the attenuation bands are considerably wider than the transmission bands which separate them, and their widths are dependent upon the areas S_1 and S_2; the larger the quantity

$$\left[\frac{S_2}{S_1}+\frac{S_1}{S_2}\right],$$

the narrower become the harmonically related transmission bands. The location of the transmission bands is dependent upon the pipe and chamber dimensions, l and L; the greater these lengths the closer is the spacing of the bands.

To operate effectively a muffler should have an initial transmitting range from zero to about 100 or 200 cycles per second, followed by an attenuation range embracing all of the higher audible frequencies. In a stage comprising a group of uniform chambers and connecting passages there will generally occur one or more transmitting regions well within the audible range of frequencies and the noise suppression will not be complete. To overcome this difficulty is the purpose of using a plurality of stages, each stage having expansion chambers of a different size from the other stages. The lengths of the connecting passages may also be varied from stage to stage for the same purpose. The sizes of these chambers are preferably so proportioned with respect to each other that the central frequencies of the transmitting ranges of the one stage bear incommensurate ratios to those of the other stages, thereby causing the higher frequency transmission bands to be eliminated.

Computed attenuation characteristics of a typical muffler in accordance with the invention are shown in Fig. 7. Curve "*a*" shows the theoretical attenuation of one stage comprising a single chamber whose dimensions are:

$$l=1.8'', L=7.2'' \text{ and } \frac{1}{2}\left[\frac{S_2}{S_1}+\frac{S_1}{S_2}\right]=7.$$

The regions of free transmission are indicated by the heavy lines on the axis of abscissæ. It is seen that this stage, or section, has several transmitting bands in the audible frequency range. To eliminate these transmission bands, a stage having the chamber dimensions,

$$l=\frac{3''}{4}, L=3'' \text{ and } \frac{1}{2}\left[\frac{S_2}{S_1}+\frac{S_1}{S_2}\right]=7,$$

may be added. The theoretical attenuation of one such chamber is shown by the dotted curve "*b*". Curve "*c*" represents a typical attenuation characteristic such as would actually be obtained in a muffler comprising a chamber corresponding to curve "*a*" and a chamber corresponding to curve "*b*". This muffler transmits frequencies from zero to about 220 c. p. s. Curve "*d*" represents a typical attenuation characteristic of the muffler corresponding to curve "*c*" to which a chamber with dimensions,

$$l=4'', L=16'' \text{ and } \frac{1}{2}\left[\frac{S_2}{S_1}+\frac{S_1}{S_2}\right]=7,$$

has been added. This muffler begins to attenuate at 100 c. p. s. The attenuation can be increased by using more than one chamber per stage. The unit used to measure the transmission is the decibel, which is a logarithmic measure of the wave power attenuation. A treatment of the decibel is given by W. H. Martin in the Journal of the American Institute of Electrical Engineers, page 223, March 1929.

Fig. 2 illustrates a modified construction of a muffler stage in which back pressure arising from the expansion of the exhaust gases is more completely eliminated. Back pressure from this cause is due mainly to the creation of eddies at the openings into the expansion chambers and the modification illustrated reduces this back pressure by preventing the creation of such eddies. The construction in Fig. 2 obviates the formation of eddies by the use of a series of tapered tubes 20 for the central circuit, the convergence being in the direction of the gas flow. This construction produces a contraction in the diameter of the jet as it passes from one chamber to the next, the subsequent expansion of the jet not being great enough to make its diameter greater than the mouth of the next tube.

Fig. 3 is another modification of a muffler stage in which the effect of eddies is similarly reduced. In this construction the gas channel, instead of comprising short lengths of pipe through the partitions separating the chambers comprises a single pipe 30 extending entirely through the chambers. The portions of the pipe in the centers of the chambers are drilled with numerous holes 31 which serve for communication with the chambers. The ratio of undrilled pipe surface to the area of the holes in the drilled portion of the pipe may conveniently be made unity. It is desirable that the ratio of diameter of holes to the thickness of the pipe should not be greater than 5, to prevent a whistling which might otherwise occur. In the design of stages of this type, the length $2l$ is taken as the length of the gas pipe in each chamber which is left undrilled.

Fig. 4 shows a muffler in which the ratio

$$\frac{S_2}{S_1}$$

as well as the axial lengths of the chambers is varied from stage to stage. The muffler comprises a cylinder 10 partioned into three stages of two chambers each, by means of partitions 17 through which extend gas conducting elements of the tapered type shown in Fig. 2. The particular feature of this muffler is that the cross-section of the gas jet is reduced in passing from one stage to the next. In the first stage, comprising chambers 11 and 12, the cross-section of the jet is approximately that of the end pipe 19. But the jet passing through chambers 13 and 14, which constitute the second stage, has the cross-section of the small end of the tapered gas conducting element 41, which tapers to a smaller cross-section than that of pipe 19. In a similar manner the tapered element 42 reduces the jet in the third stage to a still smaller cross-section.

The reduction in the size of the gas channel increases the quantity

$$\left[\frac{S_2}{S_1}+\frac{S_1}{S_2}\right],$$

which has the effect of widening the attenuation bands. Since, in passing through the muffler, the gas cools and contracts, it is generally feasible to reduce, somewhat the size of the gas pipes in succeeding stages and thus obtain the advantage of narrower transmitting bands.

Fig. 5 illustrates a muffler in which the ratio

$$\frac{S_2}{S_1}$$

is adjusted by an alternative method. In this construction the cross-section of the gas channel is kept constant, while that of the outer shell is increased from stage to stage. The muffler comprises three closed-ended cylindrical stages 50, 51 and 52, of progressively increasing axial length and cross-section, coaxially aligned. Each stage is shown divided into two chambers by means of partitions 17. The gas conducting elements 18 extending through the centers of the partitions are uniform in cross-section.

Figs. 6 and 6A illustrate, respectively, side and end views in section of a muffler in accordance with the invention, in which the central gas passage is exposed to the surrounding air so that heat will be more readily radiated. The muffler comprises a gas pipe 60, on opposite sides of which are located shells 61 and 62, of equal size, in which the expansion chambers are formed. Each shell may conveniently be a length of pipe having a segment cut out longitudinally. The edges left by the removal of the segment are then bent back and welded to the circumference of the central pipe 60. Each shell is partitioned into the chambers by the partitions 63, and the chambers in the two shells which are oppositely located are made equal in size, that is, the expansion chambers are arranged in pairs. Numerous small holes 64, communicating with the expansion chambers, are provided in the pipe 60, similar to those shown in Fig. 3.

In designing a muffler of this type, the quantity S_2 is taken as the total cross-sectional area of a pair of expansion chambers. The length $2l$ as in Fig. 3, is the length of the central pipe in each chamber which is free from holes.

It can be seen from the figure that a large part of the gas conducting pipe is exposed to the air whereby heat can be readily radiated.

Mufflers of the type described can be used for a variety of purposes besides the suppression of exhaust noises from internal combustion engines, for example, they may be used to silence the hissing noise from the blowing off of air or steam or the exhaust noise from steam engines. They may also be used as ventilators where it is desired to admit a free flow of air into a room, and at the same time prevent outside noise from entering.

What is claimed is:

1. A sound muffler comprising an exhaust pipe forming a continuous exhaust passage, a tubular member disposed parallel to said pipe and attached thereto along its length, and a plurality of transverse partitions subdividing said tubular member into a plurality of chambers equal in pairs, the axial length of the chambers of the several pairs increasing progressively from one end of the tubular member to the other, the exhaust pipe having lateral apertures communicating with each of said chambers, and the said tubular member comprising a tube segment enclosing a fractional portion of the periphery of the exhaust pipe.

2. A sound muffler comprising an exhaust pipe forming a continuous exhaust passage, tubular members disposed parallel to said pipe on opposite sides thereof and attached thereto along its length, and a plurality of transverse partitions subdividing said tubular members into chambers equal in pairs, the axial length of the chambers of the several pairs progressively increasing from one end of the tubular member to the other and corresponding to the lengths of the chambers on the opposite side of said exhaust pipe, and said exhaust pipe having apertures at points along its length to provide gas communication with each of said chambers.

In witness whereof, I hereunto subscribe my name this 13th day of June, 1929.

WARREN P. MASON.