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(54) MUFFLER WITH HELMHOLTZ RESONATOR HAVING MULTIPLE DEGREES OF FREEDOM

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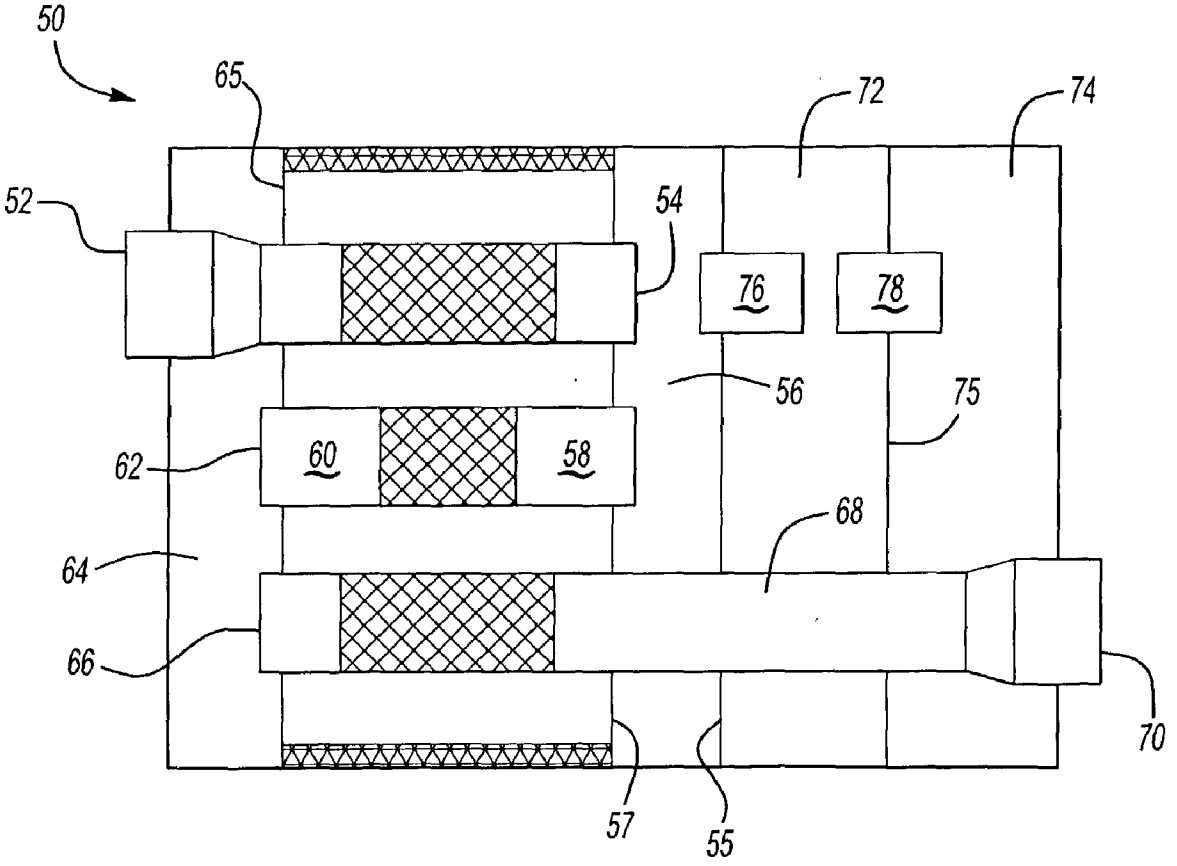
(57) **ABSTRACT**

A discharge muffler is provided with a torturous flow path for the exhaust gas. A Helmholtz resonator communicating with the torturous path has two distinct Helmholtz throats and Helmholtz resonator volumes in series with each other. The use of the two distinct Helmholtz resonator volumes and throats provides a combined Helmholtz resonator system that will dampen two distinct frequencies.



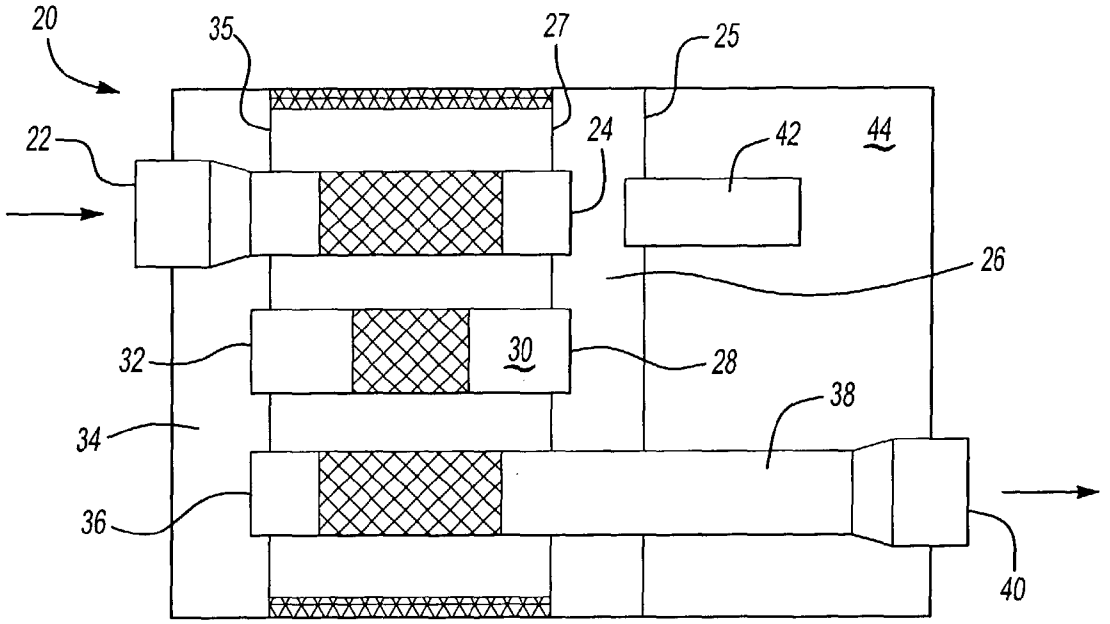


Fig-1
PRIOR ART

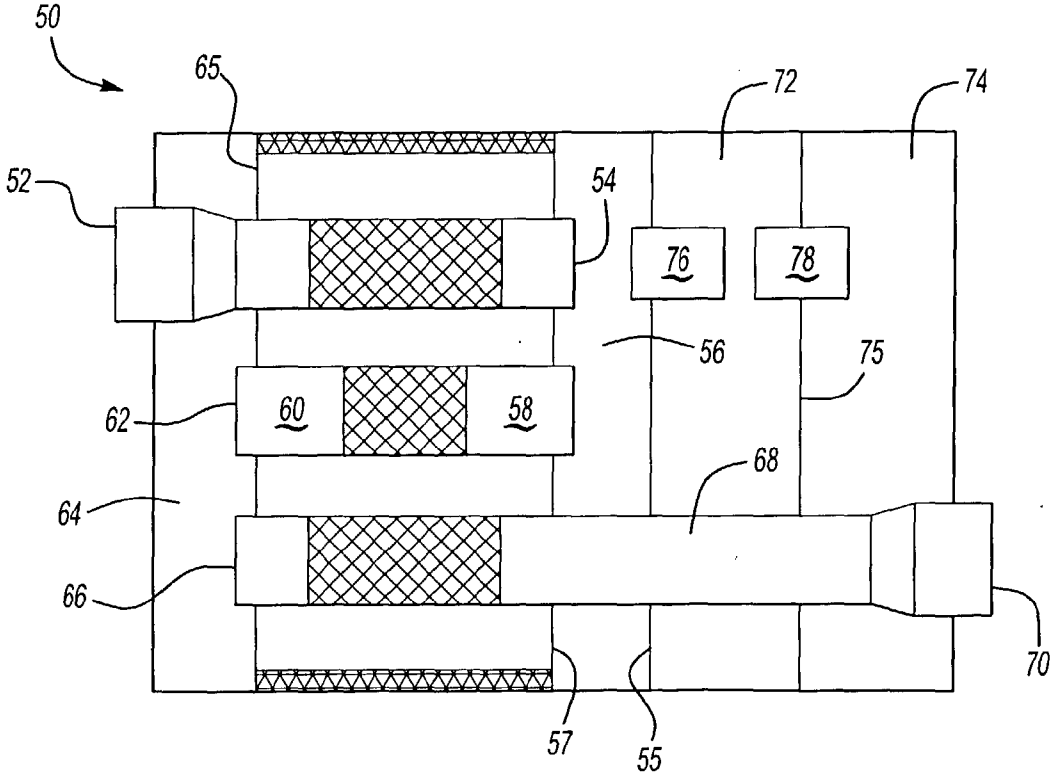


Fig-2

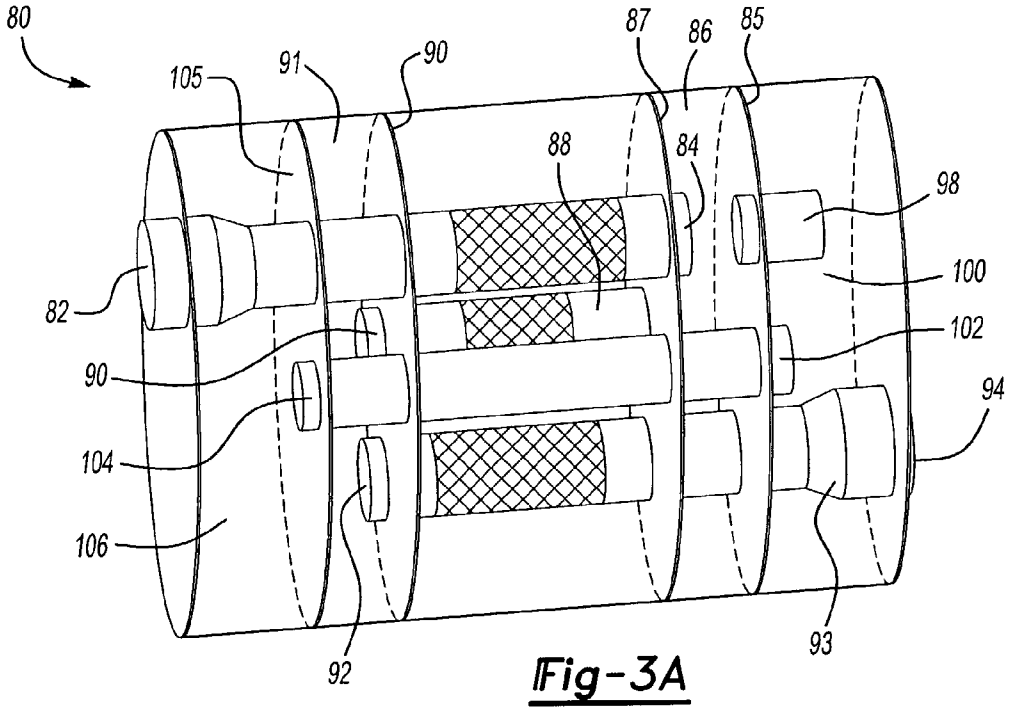


Fig-3A

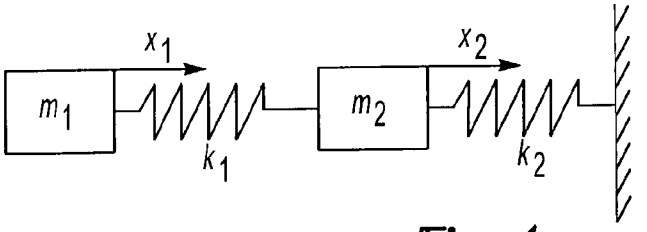


Fig-4

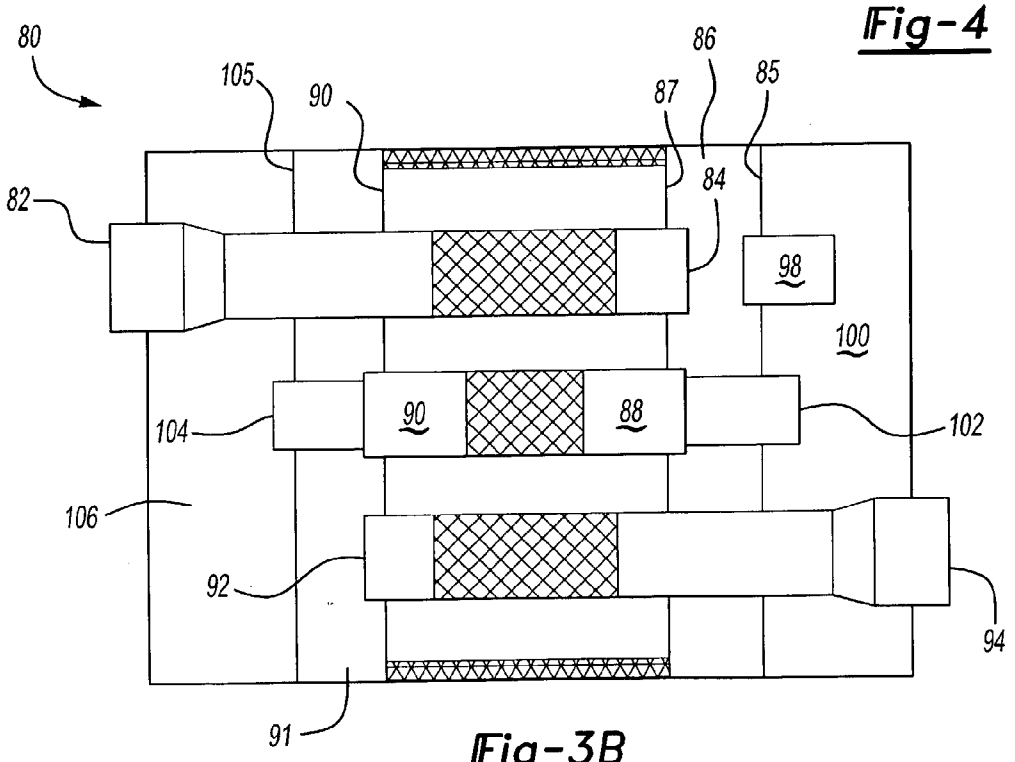


Fig-3B

MUFFLER WITH HELMHOLTZ RESONATOR HAVING MULTIPLE DEGREES OF FREEDOM

BACKGROUND OF THE INVENTION

[0001] This invention relates to a discharge muffler incorporating a Helmholtz resonator that has at least two degrees of freedom, such that it can dampen at least two distinct frequencies.

[0002] Discharge mufflers typically include an inlet pipe and an outlet pipe entering and leaving a muffler body, respectively. Exhaust gases flow through a torturous flow pass within the muffler to reduce noise. In addition, it is known to employ a Helmholtz resonator along the flow path. Typically, in a Helmholtz resonator, the flow path passes over a throat or tube leading into an enclosed Helmholtz resonator volume. That is, a throat will extend into the path of the exhaust gas flow, and lead to a sealed Helmholtz resonator volume. Effectively, this sealed Helmholtz resonator volume provides a dampening function that can be tuned to a particular frequency of noise.

[0003] A worker in this art would recognize how to design an appropriate Helmholtz resonator to greatly reduce the noise at a particular frequency. Typically, the designer of a muffler will select a particular frequency that is most problematic and design a Helmholtz resonator tuned to diminish the amount of sound in that frequency.

[0004] Helmholtz resonators are very successfully. However, in some applications it would be desirable to be able to dampen more than one frequency. Often, it is not practical to apply several Helmholtz resonators within the Helmholtz resonator volume available for the muffler. As with all aspects of modem vehicle design, there is a premium on space, and the envelope size of the muffler housing is limited.

SUMMARY OF THE INVENTION

[0005] In a disclosed embodiment of this invention, a muffler is provided that has two Helmholtz resonators mounted in series. In this way, two distinct frequencies can be addressed. The total volume is not increased over the prior art in that the Helmholtz resonators are in series, and utilize effectively the same total volume as the prior art single Helmholtz resonator.

[0006] In one disclosed embodiment of this invention, the inlet pipe brings exhaust gas into a first chamber. From the first chamber, the exhaust gas flows through an intermediate pipe back to a second chamber. From the second chamber the exhaust gas moves into an outlet pipe and passes outwardly from the muffler housing. The flow through these three pipes is reversed and torturous. In this way, a good deal of sound is muffled.

[0007] In a preferred embodiment, a Helmholtz resonator with two degrees of freedom is provided on the first chamber, and between the outlet of the inlet pipe and the inlet of the intermediate pipe.

[0008] Two Helmholtz resonators are provided with a throat leading from the first chamber into a first Helmholtz resonator volume. A second throat extends from the first Helmholtz resonator volume into a second Helmholtz resonator volume. Other than the throats, both the first and second Helmholtz resonator volumes are sealed. Thus, these Helmholtz resonators each provide a spring effect selectively dampening particular frequencies of noise. As will be shown below, there are predictable frequencies that will be dampened based upon the geometric characteristics of the throat and Helmholtz resonator volumes.

[0009] In a first preferred embodiment, both of the Helmholtz resonator volumes are on the same side of the first chamber. In a second embodiment, a first Helmholtz resonator volume communicates with a second Helmholtz resonator volume through a very long second throat. The second throat effectively extends the entire axial length of the muffler housing. As will be appreciated, and upon a consideration of the relative formulas, the choice of the second or first embodiment may well hinge on what frequencies are to be damped. The length of the throat is one of the factors that contributes to the frequencies which are to be damped.

[0010] While only two Helmholtz resonators are shown in the illustrated embodiments, it should be understood that three or more would also come within the scope of this invention.

[0011] These and other features of the present invention can be best understood from the following specifications and drawings, the following of which is a brief description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] **FIG. 1** is a prior art muffler employing a Helmholtz resonator.

[0013] **FIG. 2** shows a first embodiment of the invention.

[0014] **FIG. 3A** shows a perspective view of a second embodiment.

[0015] **FIG. 3B** is a schematic view of the second embodiment

[0016] **FIG. 4** is a schematic representation.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0017] As shown in **FIG. 1**, a prior art muffler **20** incorporates an inlet pipe **22** leading to a downstream end **24**. An exhaust gas passes into the inlet pipe **22** and through the downstream end **24** into a chamber **26** defined between walls **25** and **27**. An intermediate pipe **30** has its inlet **28** communicating with the chamber **26**, and leading to its own downstream end **32**. Thus, exhaust gas to be muffled passes from inlet pipe **22**, into chamber **26**, into intermediate pipe **30**, and into a chamber **34** defined in part by wall **35**. From chamber **34**, the exhaust gas passes into the inlet **36** of the outlet pipe **38**, and eventually outwardly of the outlet end **40** of the muffler **20**. Thus, the nominal flow of the exhaust gas is torturous and serially through pipes **22**, **30** and **38**.

[0018] As also shown, a Helmholtz resonator throat **42** communicates between chamber **26** and a Helmholtz resonator volume **44**. There is only the throat **42** leading to the Helmholtz resonator volume **44**, and thus there is not free flow of the exhaust gas between the chamber **26** and Helmholtz resonator volume **44**. Instead, gases within the Helmholtz resonator volume **44** work in cooperation with the throat **42** to provide a spring effect that dampens the particular frequency of noise passing through chamber **26**.

The description above is as known in the prior art. A worker of ordinary skill in the art would recognize that a Helmholtz resonator is a very effective way of eliminating noises at a particular frequency in a muffler.

[0019] The present invention, and the first embodiment shown in **FIG. 2**, provide the designer with a second degree of freedom such that a second frequency can also be addressed within the same approximate muffler size.

[0020] **FIG. 2** shows a muffler **50** including an inlet pipe **52** leading to a downstream end **54**. The downstream end **54** empties into a chamber **56** defined between walls **55** and **57**. An inlet **58** of an intermediate pipe **60** reverses the flow of exhaust gas back to a downstream end **62** and empties into a chamber **64**. Chamber **64** is defined in part by an internal wall **65**. From chamber **64** the exhaust gas passes into an inlet **66** of an outlet pipe **68**, and eventually to the outlet **70** of the muffler **50**. Thus, the exhaust gas experiences a torturous flow as in the prior art. The two degrees of freedom Helmholtz resonator is defined by two separate Helmholtz resonator volumes **72** and **74**. A first throat **76** communicates chamber **56** into first Helmholtz resonator volume **72**. A second throat **78** communicates first Helmholtz resonator volume **72** into second Helmholtz resonator volume **74**. An intermediate wall **75** separates the Helmholtz resonator volumes **72** and **74**. As will be shown below, this serial Helmholtz resonator dampens two separate frequencies by the combination of the two throats and two Helmholtz resonator volumes.

[0021] The designer of the muffler **50** can select two distinct frequencies to be addressed by the muffler.

[0022] A second embodiment muffler **80** is shown in **FIGS. 3A and 3B**. In this embodiment, the second throat is longer than is the case in the **FIG. 2** embodiment.

[0023] As shown in **FIGS. 3A and 3B**, the inlet pipe **82** again empties to a downstream end **84** communicating with a chamber **86** defined between walls **85** and **87**. An intermediate pipe **88** communicates from chamber **86** back to a downstream end **90** and into a chamber **91** defined between walls **90** and **105**. From chamber **91** the exhaust gas passes into an inlet end **92** of outlet pipe **93** and eventually to an outlet **94**. Again, a throat **98** communicates with a first Helmholtz resonator volume **100**. From Helmholtz resonator volume **100**, a second throat **102** communicates to a downstream end **104** associated with a second Helmholtz resonator volume **106**. The Helmholtz resonator volumes **100** and **106** are sealed other than the communication between the throats **98** and **102**. Again, the use of this embodiment will allow the muffler designer to successfully dampen two distinct frequencies. The second throat extends through the remote side of chamber **86**. In these embodiments, the two Helmholtz resonator volumes are spaced at the two ends of muffler **80**.

[0024] The formulas which are relevant to the design of the two degree of freedom Helmholtz resonator will be described, with particular reference to the disclosed embodiments.

[0025] As known, the prior art **FIG. 1** Helmholtz resonator can be described by an equivalent vibration system. This allows the development of a formula to calculate its natural frequency.

[0026] Equation 1 is the classic equation for a Helmholtz resonator natural frequency calculation.

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{m}{k}} = \frac{c}{2\pi}\sqrt{\frac{A}{LV}} \tag{1}$$

[0027] m=ρAL with L being the length of the throat, ρ the density of air and A the cross-sectional area of the throat. The k quantity can be determined from the following equation:

$$k = \frac{\rho c^2 A^2}{V} \tag{2}$$

[0028] The c quantity is the speed of sound and the V quantity is the volume of the Helmholtz resonator volume.

[0029] Again, the above formula is known in the design of Helmholtz resonators.

[0030] **FIG. 4** is a schematic of an equivalent vibration system for the inventive serially mounted Helmholtz resonators. By modeling the Helmholtz resonator on an equivalent vibration system, a new formula, similar to the formula 1 can be developed.

[0031] Applying Newton's second law to this system, the equation of motion of this system can be written as:

$$m_1x_1+k_1(x_1-x_2)=0 \tag{3}$$

$$m_2x_2+k_2x_2+k_1(x_2-x_1)=0 \tag{4}$$

[0032] Since equations 3 and 4 are both harmonic equations, they can be solved by substituting $x_1=X_1 \sin \omega t$ and $x_2=X_2 \sin \omega t$. Equations 3 and 4 can be rewritten as

$$-m_1X_1\omega^2 \sin \omega t+k_1X_1 \sin \omega t-k_1X_2 \sin \omega t=0 \tag{5}$$

$$-m_2X_2\omega^2 \sin \omega t+k_2X_2 \sin \omega t+k_1(X_2 \sin \omega t-X_1 \sin \omega t)=0 \tag{6}$$

[0033] Simplifying equations 5 and 6, equations 7 and 8 are obtained.

$$(-m_1\omega^2+k_1)X_1=k_2X_2 \tag{7}$$

$$(-m_2\omega^2+k_1+k_2)X_2=k_1X_1 \tag{8}$$

[0034] Rearrange both equations 7 and 8,

$$\frac{X_2}{X_1} = \frac{k_1 - m_1\omega^2}{k_1} \tag{9}$$

$$\frac{X_2}{X_1} = \frac{k_1}{k_1 + k_2 - m_2\omega^2} \tag{10}$$

[0035] Equation 11 is obtained by substituting Equation 9 into Equation 10 and rearranging.

$$m_1m_2\omega^4-[k_1m_2+m_1(k_1+k_2)]\omega^2+k_1k_2=0 \tag{11}$$

[0036] The frequency, ω, is obtained by solving Equation 11.

$$\omega_{1,2} = \sqrt{\frac{1}{2}\left(\frac{k_1+k_2}{m_2}+\frac{k_1}{m_1}\right) \pm \sqrt{\frac{1}{4}\left(\frac{k_1+k_2}{m_2}+\frac{k_1}{m_1}\right)^2 - \frac{k_1 k_2}{m_1 m_2}}} \quad (12)$$

[0037] As at equation 2, the k quantity includes physical variables such as ρ and c, and also relates to the area of the throat and the Helmholtz resonator volume. The m quantity again relates to a physical variable, namely the density of air, and generally the volume of the throat that is defined by its area multiplied by its length.

[0038] Equation 12 gives the frequency of the lump mass system. Since it is a 2 DOF system, two frequencies are obtained. Both of them are the resonance frequencies of the 2 DOF Helmholtz resonator.

[0039] As can be appreciated, the size of the throat factors into the m quantities. Generally, a worker in this art would select the two frequencies that are to be addressed and work backward to design an appropriate throat and volume for the two Helmholtz resonators. There will generally be restrictions on the total envelope size, and thus the total volumes available. However, the L quantity does allow the designer some freedom, particularly given the two distinct embodiments shown in **FIG. 2** and **FIGS. 3A and 3B**. That is, a designer who is faced with a desire to have a greater m_2 might consider using the embodiments of **FIGS. 3A and 3B** as it has a greater L than the earlier embodiment.

[0040] While preferred embodiments have been disclosed, a worker of ordinary skill in the art would recognize that certain modifications would come within the scope of this invention. In particular, three or even more Helmholtz resonators could be incorporated into the inventive mufflers. For that reason, the following claims should be studied to determine the true scope and content of this invention.

1. A muffler comprising:

a muffler housing having an inlet pipe and an outlet pipe with a gas flow path between said inlet and outlet pipes, and at least one chamber in said gas flow path; and

a Helmholtz resonator communicating with said at least one chamber, said Helmholtz resonator having a first throat providing a communication port between said at least one chamber and a first Helmholtz resonator volume, and a second throat communicating between said first Helmholtz resonator volume and a second Helmholtz resonator volume such there are two Helmholtz resonators mounted in series within said muffler housing.

2. A muffler set forth in claim 1, wherein said at least one chamber receives an exhaust gas from a downstream end of said inlet pipe, and passes said exhaust gas into an intermediate tube extending in a distinct direction from a flow path of said inlet pipe.

3. A muffler as set forth in claim 2, wherein said first Helmholtz resonator volume is on a first side of said at least one chamber, and said second Helmholtz resonator volume is also on said first side of said at least one chamber such that both said first and second Helmholtz resonator volumes are adjacent one end of said muffler housing.

4. A muffler as set forth in claim 2, wherein said first Helmholtz resonator volume is mounted on one side of said at least one chamber, and said second throat communicating with said first Helmholtz resonator volume and along an axial length of said muffler housing and to said second Helmholtz resonator volume such that said second Helmholtz resonator volume is on an opposed side of said at least one chamber from said first Helmholtz resonator volume.

5. A muffler as set forth in claim 1, such that said second Helmholtz resonator volume is sealed other than being open at said second throat, and such that there are only two Helmholtz resonator volumes in said muffler.

6. A muffler comprising:

a muffler housing having an inlet pipe and an outlet pipe with a gas flow path between said inlet and outlet pipes, and a first chamber for receiving exhaust gas to be muffled from said inlet pipe and passing said exhaust gas to an intermediate pipe, said intermediate pipe passing said exhaust gas to a second chamber, and said outlet pipe receiving said exhaust gas and passing said exhaust gas outwardly of said muffler housing; and

a sealed Helmholtz resonator communicating with said chamber, said sealed Helmholtz resonator having a first throat providing one communication port between said first chamber and a first Helmholtz resonator volume, and a second throat communicating between said first Helmholtz resonator volume and a second Helmholtz resonator volume such there are two Helmholtz resonators mounted in series within said muffler housing.

7. A muffler as set forth in claim 6, wherein said first Helmholtz resonator volume is on a first side of said first chamber, and said second Helmholtz resonator volume is also on said first side of said first chamber such that both said first and second Helmholtz resonator volumes are adjacent one end of said muffler housing.

8. A muffler as set forth in claim 6, wherein said first Helmholtz resonator volume is mounted on one side of said at least one chamber, and said second throat communicating with said first Helmholtz resonator volume and along an axial length of said muffler housing and to said second Helmholtz volume such that said second Helmholtz resonator volume is on an opposed side of said at least one chamber from said first Helmholtz resonator volume.

9. A muffler as set forth in claim 6, such that said second Helmholtz resonator volume is sealed other than being open at said second throat, and such that there are only two Helmholtz resonator volumes in said muffler.

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