



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
01.12.2004 Bulletin 2004/49

(51) Int Cl.7: **F01N 1/02, F01N 1/08**

(21) Application number: **04253097.2**

(22) Date of filing: **26.05.2004**

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HU IE IT LI LU MC NL PL PT RO SE SI SK TR**
Designated Extension States:
AL HR LT LV MK

(72) Inventors:
• **Wan, Deming**
Colombus, IN 47201 (US)
• **Soedel, Dirk**
Columbus, Indiana 47203 (US)

(30) Priority: **30.05.2003 US 449406**

(74) Representative: **Croston, David et al**
Withers & Rogers,
Goldings House,
2 Hays Lane
London SE1 2HW (GB)

(71) Applicant: **Arvin Technologies, Inc.**
Troy, MI 48084 (US)

(54) **Muffler with helmholtz resonator having multiple degrees of freedom**

(57) A discharge muffler (50,80) is provided with a torturous flow path for the exhaust gas. A Helmholtz resonator communicating with the torturous path has two distinct Helmholtz throats (76,78,98,102) and Helmholtz

resonator volumes (72,74,100,106) in series with each other. The use of the two distinct Helmholtz resonator volumes (72,74,100,106) and throats (76,78,98,102) provides a combined Helmholtz resonator system that will dampen two distinct frequencies.

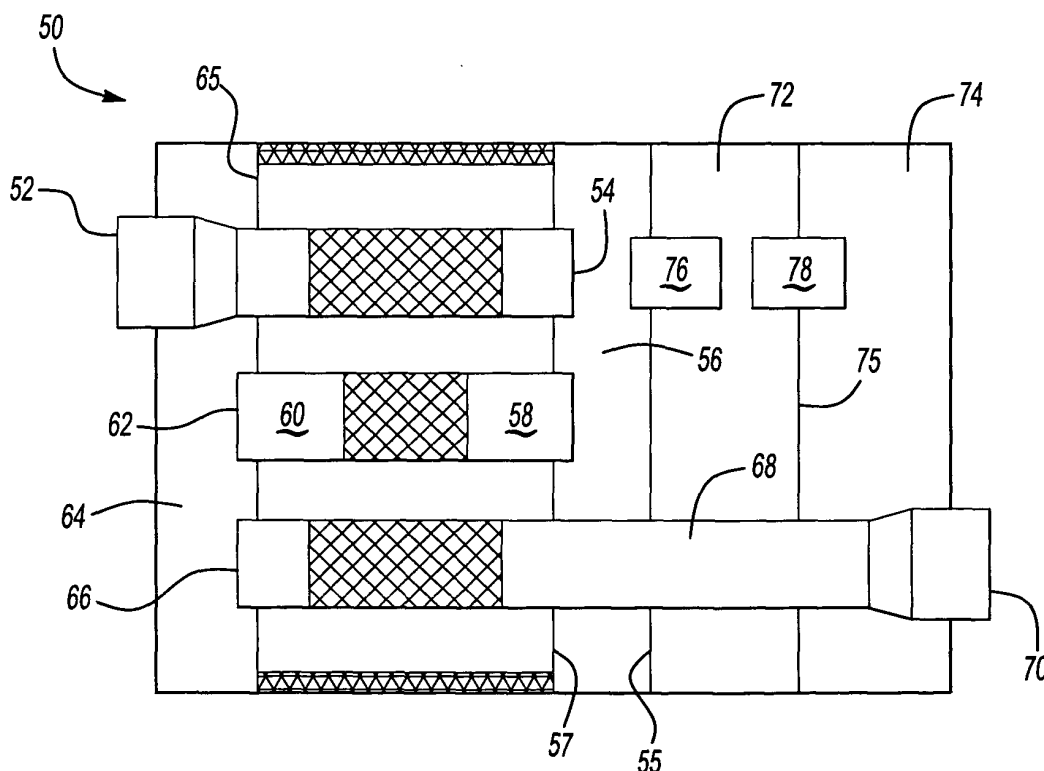


Fig-2

Description**BACKGROUND OF THE INVENTION**

5 [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.

10 [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.

15 [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 modern vehicle design, there is a premium on space, and the envelope size of the muffler housing is limited.

SUMMARY OF THE INVENTION

20 [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.

25 [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.

30 [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.

35 [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.

40 [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.

45 [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]**

50 Figure 1 is a prior art muffler employing a Helmholtz resonator.

Figure 2 shows a first embodiment of the invention.

Figure 3A shows a perspective view of a second embodiment.

Figure 3B is a schematic view of the second embodiment

Figure 4 is a schematic representation.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0013] As shown in Figure 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 tortuous and serially through pipes 22, 30 and 38.

[0014] 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.

[0015] The present invention, and the first embodiment shown in Figure 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.

[0016] Figure 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 tortuous 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.

[0017] The designer of the muffler 50 can select two distinct frequencies to be addressed by the muffler.

[0018] A second embodiment muffler 80 is shown in Figures 3A and 3B. In this embodiment, the second throat is longer than is the case in the Figure 2 embodiment.

[0019] As shown in Figures 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 190 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.

[0020] 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.

[0021] As known, the prior art Figure 1 Helmholtz resonator can be described by an equivalent vibration system. This allows the development of a formula to calculate its natural frequency.

[0022] Equation 1 is the classic equation for a Helmholtz resonator natural frequency calculation.

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

$m = \rho AL$ 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:

$$k = \frac{\rho c^2 A^2}{V} \quad (2)$$

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

[0023] Again, the above formula is known in the design of Helmholtz resonators.

[0024] Figure 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.

[0025] Applying Newton's second law to this system, the equation of motion of this system can be written as:

$$m_1 \ddot{x}_1 + k_1 (x_1 - x_2) = 0 \quad (3)$$

$$m_2 \ddot{x}_2 + k_2 x_2 + k_1 (x_2 - x_1) = 0 \quad (4)$$

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

$$-m_1 X_1 \omega^2 \sin \omega t + k_1 X_1 \sin \omega t - k_1 X_2 \sin \omega t = 0 \quad (5)$$

$$-m_2 X_2 \omega^2 \sin \omega t + k_2 X_2 \sin \omega t + k_1 (X_2 \sin \omega t - X_1 \sin \omega t) = 0 \quad (6)$$

[0026] Simplifying equations 5 and 6, equations 7 and 8 are obtained.

$$(-m_1 \omega^2 + k_1) X_1 = k_1 X_2 \quad (7)$$

$$(-m_2 \omega^2 + k_1 + k_2) X_2 = k_1 X_1 \quad (8)$$

[0027] Rearrange both equations 7 and 8,

$$\frac{X_2}{X_1} = \frac{k_1 - m_1 \omega^2}{k_1} \quad (9)$$

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

[0028] Equation 11 is obtained by substituting Equation 9 into Equation 10 and rearranging.

$$m_1 m_2 \omega^4 - [k_1 m_2 + m_1 (k_1 + k_2)] \omega^2 + k_1 k_2 = 0 \quad (11)$$

[0029] The frequency, ω , is obtained by solving Equation 11.

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

[0030] As at equation 2, the k quantity includes physical variables such as p 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.

[0031] 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.

[0032] 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 Figure 2 and Figures 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 Figures 3A and 3B as it has a greater L than the earlier embodiment.

[0033] 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.

Claims

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 that there are two Helmholtz resonators mounted in series within said muffler housing.

2. A muffler as 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 1 or 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 1 or 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 any preceding claim, 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 as set forth in any of claims 1 to 5 wherein said at least one chamber is 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

the Helmholtz resonator communicating with said first chamber and being sealed save for being open at the first and second throats.

7. A muffler as set forth in any preceding claim wherein the first throat has a first throat diameter and the second throat has a second diameter and the second diameter is different to the first diameter.

8. A muffler as set forth in any of claims 1 to 6 wherein the first throat has a first throat length and the second throat has a second throat length and the first throat length is different to the second throat length.

9. A muffler according to any of claims 1 to 6 wherein the first and second Helmholtz resonator volumes are different in volume.

5 10. A method of treating an exhaust gas flow of an internal combustion engine exhaust comprising providing a muffler having a housing with an inlet pipe, an outlet pipe with a gas flow path between said 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 defining two communicating Helmholtz resonator volumes, passing exhaust gas through the inlet pipe into the chamber, passing the exhaust gas serially through the two Helmholtz resonator volumes, and passing the exhaust gas to the outlet.

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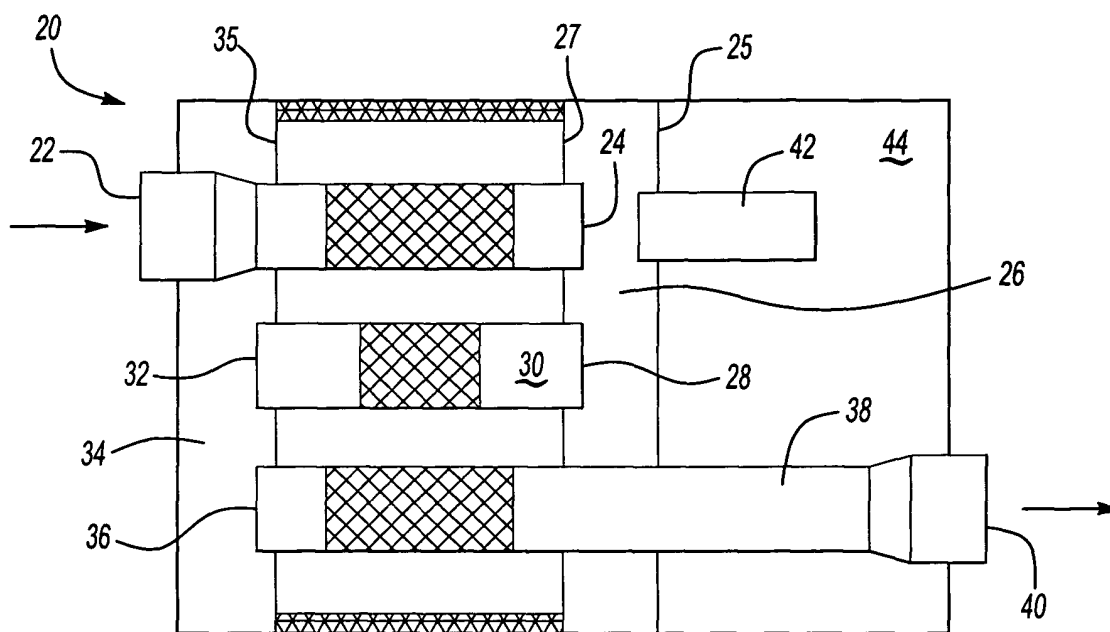


Fig-1
PRIOR ART

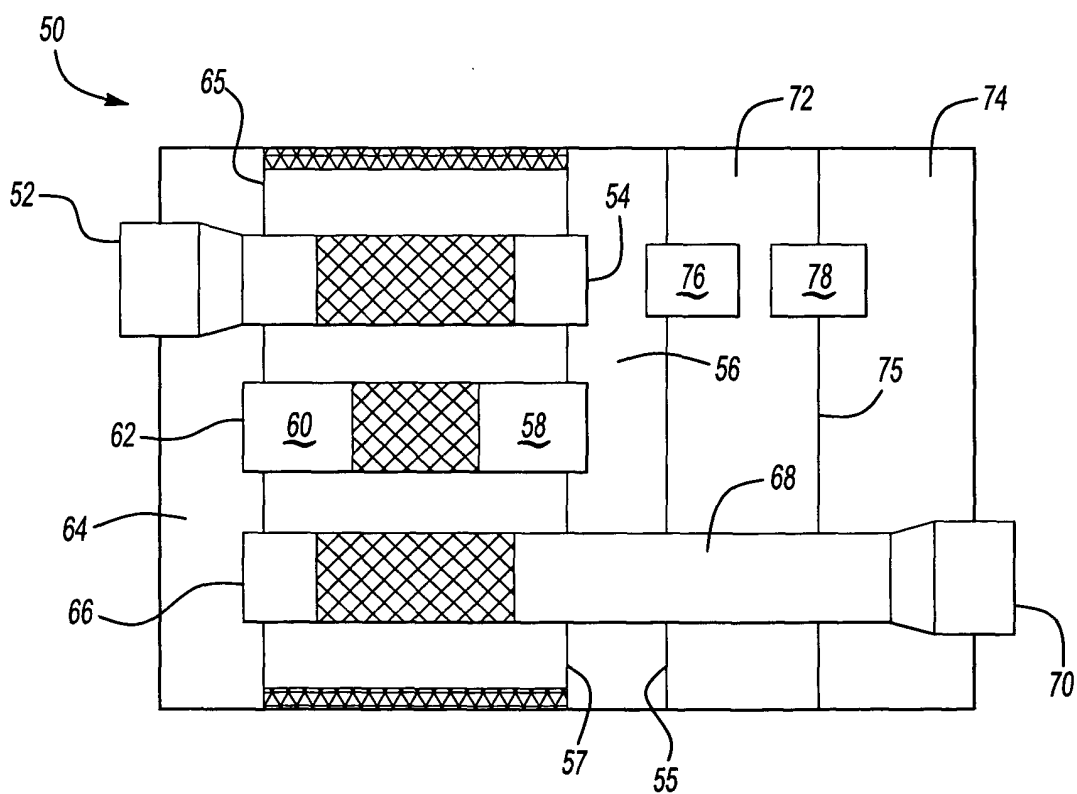
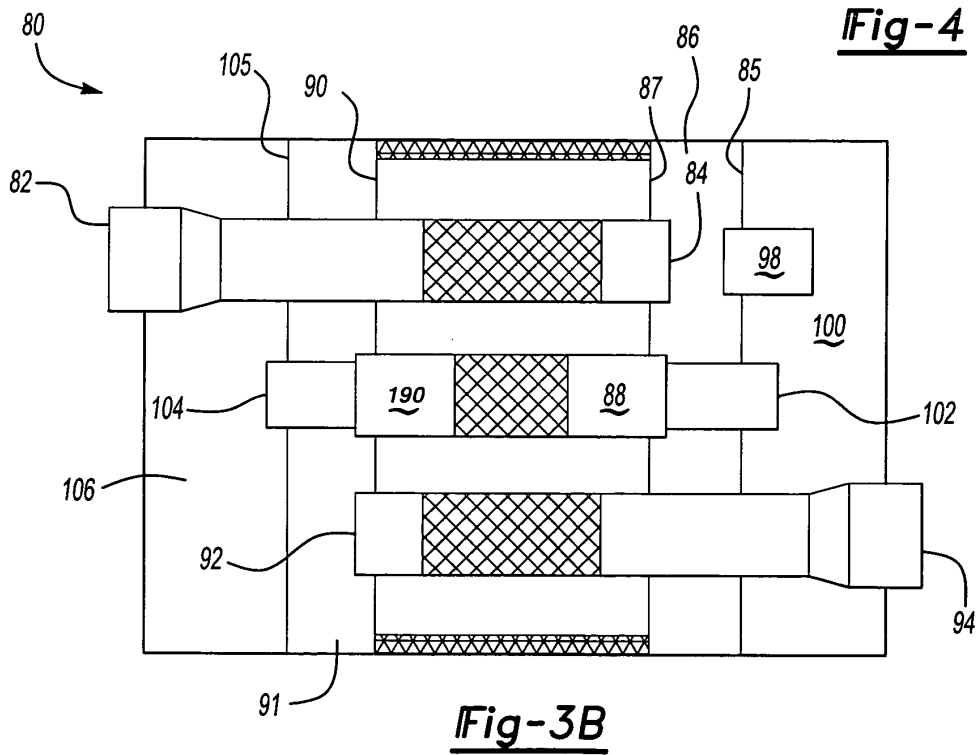
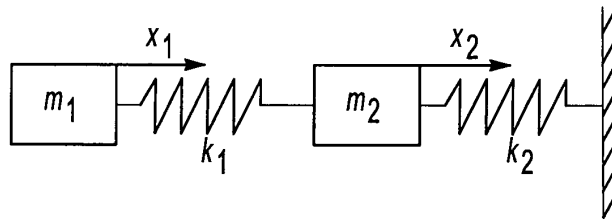
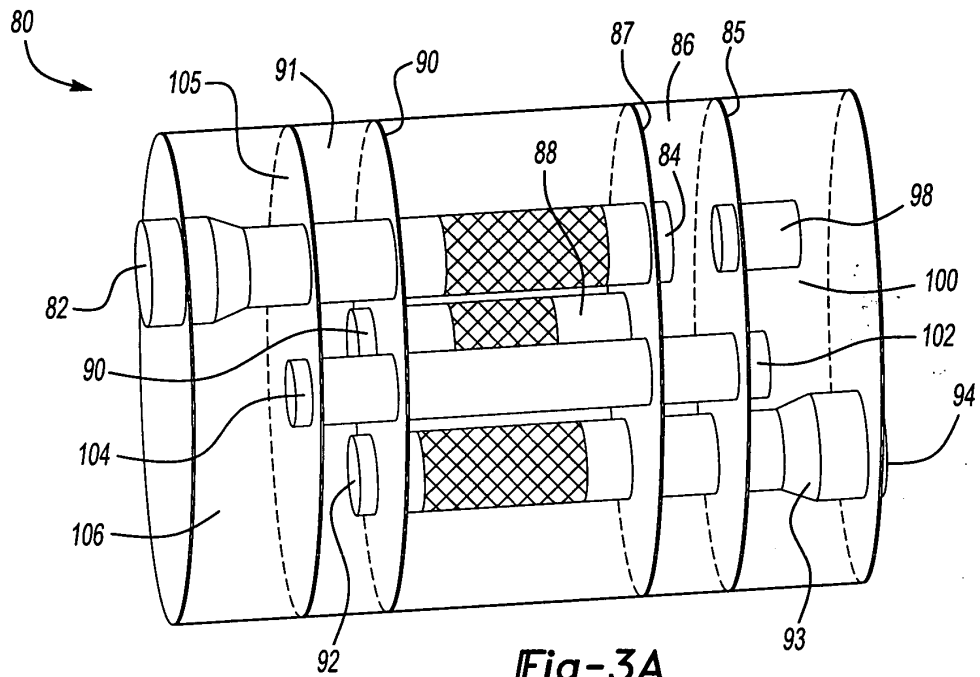


Fig-2





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 04 25 3097

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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 2 September 2004	Examiner Nobre, S
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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