



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
23.08.2023 Bulletin 2023/34

(51) International Patent Classification (IPC):
F04D 29/66 ^(2006.01) **F04D 25/08** ^(2006.01)

(21) Application number: **22158036.8**

(52) Cooperative Patent Classification (CPC):
F04D 29/665; F04D 25/08

(22) Date of filing: **22.02.2022**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

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(54) **NOISE REDUCED BLOWER MEANS AND THEIR USE IN ELECTRIC POWER TOOLS AND DEVICES**

(57) The invention relates to noise reduced blower means and their use in electric power tools and devices. The blower means comprise a housing (1), one or more air intake openings, a plurality of air exhaust openings (2), a fan disposed in the housing (1) and drivingly coupled to an electric motor for generating an air flow through said one or more air intake openings into the housing (1) and through said air exhaust openings out of the housing

(1), and a plurality of spaced resonators (3) each having a wall which defines a resonator cavity and a resonator opening (4) which is in fluid communication with said resonator cavity and said air flow and points either in an upstream direction or a downstream direction of the air flow. As a result direct air borne sound transmission via the air exhaust openings (2) is reduced.

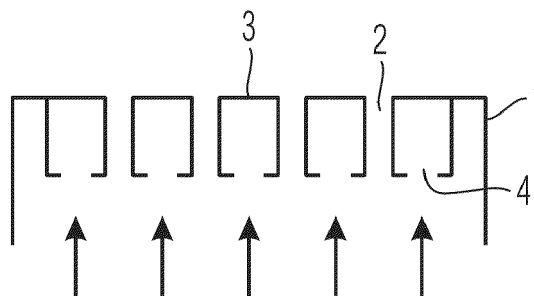


Fig. 1 (a)

Description

[0001] This disclosure relates to noise reduced blower means comprising a housing, at least one air intake opening, at least one air exhaust opening, a fan disposed in the housing and drivingly coupled to an electric motor for generating a flow of air through said at least one air intake opening into the housing and through said at least one air exhaust opening out of the housing, noise reduction means including at least one acoustic resonator which has a wall defining a resonator cavity and a resonator opening, said resonator opening being in fluid communication with said resonator cavity and said flow of air. This disclosure also relates to the use of noise reduced blower means in electric power tools and devices.

[0002] Most electric power tools and devices include a ventilation device such as a fan to draw cooling air into the housing through the air intake opening, and exhaust the cooling air having absorbed heat in the housing out of the housing through the air exhaust opening. In some cases a ventilation opening may be an air intake and an air exhaust opening at the same time. Currently, the area of the ventilation openings is determined by the requirement from the cooling system and the geometry is controlled in terms of the safety issue and structural strength. But the sound emission through the ventilation is not considered.

[0003] The total noise emission of such an electric power tool or device, which is usually generated by the motor, gear, fan etc. inside the tool or device, may be transmitted from the inside to the outside of the housing of the tool or device via three different paths:

- (i) Structure borne sound transmission and radiation via the housing walls; structure-borne noise sources excite the housing which vibrates and radiates sound to the outside (structure borne sound radiation)
- (ii) Air borne sound transmission via the housing walls; airborne noise sources, including sound radiation from the housing to the inside, excite the sound field inside the housing, which excites the housing to vibrate and radiates sound to the outside.
- (iii) Direct air borne sound transmission via the ventilation openings; airborne noise sources, including sound radiation from the housing to the inside, excite the sound field inside the housing; this sound is transmitted from the inside of the housing to the outside via the ventilation openings.

[0004] An additional noise source is flow noise; i.e. aerodynamics noise, which is generated due to the air flow through the ventilation openings. In many cases the direct airborne sound transmission via the ventilation openings dominates the overall sound emissions for the electric power tools and devices.

[0005] Noise reduced blower means of the kind defined in the pre-characterizing part of claim 1 are disclosed in JP5029593B2. Such blower means include a funnel-

shaped Helmholtz resonator which is positioned in a duct which extends between an air intake opening and a fan. In operation the fan sucks air into the duct via the air intake opening. The air sucked into the duct via the air intake opening flows past the resonator and its opening before it reaches the fan. The resonator is arranged adjacent to the air intake opening and is closed except for its opening that faces the fan. As a result the sound emission from the air intake opening is reduced.

[0006] An object of the invention is to provide noise reduced blower means of the kind defined in the pre-characterizing part of claim 1 which noise reduced blower means reduce the noise emission through the air exhaust opening especially in cases where airborne sound transmission through the air exhaust opening dominates the overall sound emission from the housing.

[0007] The above-mentioned object of the invention is achieved by incorporating the features of the characterizing part of claim 1 into the blower means of the kind defined in the pre-characterizing part of claim 1. According to the invention noise reduced blower means are characterized in that there is a plurality of air exhaust openings and a plurality of resonators each of which is disposed adjacent to a respective one of said air exhaust openings.

[0008] Preferably the resonators are spaced from each other and the air exhaust openings are defined by the resonators.

[0009] Conveniently the resonator openings each point in an upstream direction of the air flow in the vicinity of the resonators. Alternatively, the resonator openings each point in a downstream direction of the air flow in the vicinity of the resonators.

[0010] The resonators each may be of the Helmholtz resonator type or the Lambda quarter resonator type, or the resonators may consist of a combination of the aforementioned types of resonators.

[0011] The air exhaust openings each may be covered partially by a portion of the wall of the respective resonator. Conveniently two or more resonators of the plurality of resonators may be tuned to different frequencies.

[0012] Acoustically absorptive material may be placed in the cavity and/or the neck of the resonators. Acoustically absorptive material may also be placed around the neck of the resonators. The acoustically absorptive material may be in the form of one or more surface layers.

[0013] Noise reduced blower means according to the invention reduce the direct sound transmission via the ventilation openings by a composition of a purposely designed air path, opening geometries and acoustic resonators in the vicinity of ventilation openings. The acoustic resonator dissipates the sound energy into heat, and the noise emission from the power tool or device via the opening is reduced. This is particularly effective in cases where airborne sound transmission via the ventilation openings dominates the overall sound emissions of the electric tools and devices. When the resonators are placed inside the housing the sound pressure levels in-

side the housing are reduced, and hence less sound is transmitted through the housing wall and less sound is transmitted through the ventilation openings. This is the conventional method. However, when the resonators are placed in the vicinity of the ventilation openings as taught by the invention the sound transmission loss of the opening is improved, which significantly reduces the sound transmission through the ventilation openings. At the same time the air path, openings and acoustic resonators in the vicinity of ventilation openings should be designed so that they do not produce excessive flow noise (aer-oacoustics noise).

[0014] This invention is applicable to electric power tool and devices producing a tonal noise at the fixed frequency, which is transmitted to the outside by means of air-borne sound transmission via the ventilation openings. An example is a motor driven by PWM (Pulse-Width Modulation signal). The motor during each active PWM cycle causes the impulse torque, which generates the noise at PWM driven frequency. The conventional methods of solving the noise generation due to the PWM problem are:

(i) Shifting the PWM cycle frequency toward further higher frequency above the audible range of a human ear, or

(ii) Oscillating, i.e. randomizing the PWM cycle frequency, such that the sound power is distributed into the wide frequency range.

[0015] However, the PWM cycle frequency is limited due to the power loss of the electronic components. The oscillation of the PWM signal frequency is effective to reduce the peak amplitude of the tonal components, which is closely related to the annoyance due to sound. The above mentioned methods reduce the generation of tonal noise components. The invention disclosed herein does not reduce noise generation but reduces the sound transmission of tonal noise components via the ventilation openings.

[0016] An acoustic resonator is a particularly useful measure to suppress pure tones at a constant frequency. The maximum sound mitigation by a resonator is achieved at the resonator resonance frequency which is determined by its geometry and the characteristics of the surrounding fluid. The larger the resonator is the lower the resonance frequency is. As the dominating tonal noise emissions of electric power tools are often in the single digit kHz range. Hence the required dimensions of the acoustic resonators is in the range of a few centimeters, which is small enough to be installed, even in handheld electric power tools and devices.

[0017] When placing a resonator into an air flow, care must be taken, not to excite flow induced self-noise. When air flow is laterally passing the opening of the cavity of an acoustic resonator the air flow may excite a cavity tone. In the worst case, the flow generates howling tones

(whistling). Some musical instruments like the pan flute are based on this excitation principle. To avoid this form of flow induced noise, in this invention, the orientation of the resonator with reference to the flow is modified such that these "whistling" conditions, in terms of Reynolds and Strouhal numbers, are limited and are not encountered under normal operations.

[0018] The invention will now be explained in more detail by way of example and with reference to the accompanying drawings in which:

Fig. 1(a) shows a schematic view of a housing, a plurality of spaced Helmholtz resonators and a plurality of air exhaust openings defined between the Helmholtz resonators, the Helmholtz resonators having openings pointing in an upstream direction of a flow of air which, as indicated by an array of parallel arrows, is directed towards the resonators and the air exhaust openings defined between the resonators;

Fig. 1(b) shows a schematic view similar to that of Fig. 1(a). However, in contrast to the resonators shown in Fig. 1(a), the Helmholtz resonators shown in Fig. 1(b) are oriented so that their openings point in a downstream direction of the flow of air indicated by the arrows, the flow of air passing through the air exhaust openings defined between the Helmholtz resonators;

Fig. 2(a) shows a schematic view similar to that of Fig. 1(a). However, in contrast to the relative position of the Helmholtz resonators shown in Fig. 1(a), the relative position of the Helmholtz resonators shown in Fig. 2(a) is such that the resonators are shifted outwardly relative to the housing so that they project partially outwardly from the housing, while their openings still point in the upstream direction of the air flow indicated by the arrows;

Fig. 2(b) shows a schematic view similar to that of Fig. 2 (8b). However, in contrast to the orientation of the resonators shown in Fig. 2(a), the orientation of the Helmholtz resonators shown in Fig. 2 (b) is such that the resonator openings point in the downstream direction of the flow of air indicated by the arrows, while the resonators still project partially outwardly from the housing;

Figures 3(a), 3(b) and 3(c), respectively, show a schematic view of a plurality of acoustic resonators arranged on the side of a plurality of air exhaust openings as seen in a plane extending along a z-axis and along an x-axis and a plane extending along a z-axis and along a y-axis, with Fig. 3(a) showing a simple model of resonators, Fig. 3(b) showing resonators with an adapted length, and Fig. 3(c) showing resonators with an adapted cavity volume;

Fig. 4(a) shows a schematic view of a Lambda quarter resonator;

Fig. 4 (b) shows a schematic view of a Helmholtz resonator;

Fig. 5 shows a photo of an acoustic demonstrator test rig with a duct;

Fig. 6 shows a photo of a dummy head with a binaural recording system, together with a schematic view of the ear of the dummy head, the demonstrator and the distances between them;

Fig. 7 shows a schematic sectional view of the ventilation slits with Helmholtz resonators;

Fig. 8 shows a graph showing the effect of the resonator on air-borne noise;

Fig. 9 shows a graph showing the effect of the resonator on fluid-born noise; and

Fig. 10 shows a graph showing the effect of the resonator on the flow rate.

[0019] With reference to the drawings, blower means of a power tool or device comprise a housing 1 which includes a plurality of air exhaust openings 2 having the shape of slits and being referred to hereinafter also as ventilation openings or ventilation slits. A fan which is not shown in the drawings is disposed in the housing and drivingly coupled to an electric motor for generating a flow of cooling air through an air intake opening (not shown) into the housing 1 and through the air exhaust openings 2 out of the housing 1. The flow of cooling air serves to absorb heat inside the housing and transfer the heat out of the housing via the air exhaust openings 2. The blower means further include noise reduction means which include a plurality of acoustic resonators 3 each of which is disposed adjacent to a respective one of the air exhaust openings 2.

[0020] In Figures 1(a), 1(b), 2(a), and 2(b) the resonators 3 are arranged along the direction of the air flow such that the resonators 3 do not disturb the flow. The air flow is indicated by an array of parallel arrows. The resonators 3 are spaced from each other so that the walls of the resonators 3 form a short duct which contributes to the sound reduction over a wide frequency range. Furthermore, the opening 4 of each acoustic resonator 3 is placed in the direction of the flow, i.e. normal incidence flow, and thus the resonators whistle under more limited conditions compared to the situation with a grazing flow. The opening 4 of the resonators 3 points either in the upstream direction of the air flow as shown in Figures 1(a) and 2(a) or in the downstream direction of the air flow as shown in Figures 1(b) and 2(b). A resonator 3 can be installed inside or outside of the housing between

adjacent ventilation openings 2 which may have the shape of slits.

[0021] As shown in Fig.3 (a) an acoustic resonator 3 can be rotated 90 degrees and lie on the outer surface of the housing 1 next to every opening 2. The resonant frequency of a resonator 3 can be adjusted by modifying the length of the resonator (Fig.3 (b)), or the volume of the resonator cavity (Fig. 3(c)). The resonator structure is extended to the openings to form a cover over the ventilation openings 4 such that (i) the sound is not directly transmitted from the noise source through the ventilation openings 2, and (ii) the air flow is not along the opening sideways. It is important to assure that the opening area of the resonator neck is at least as big as the ventilation opening 2 in order to keep the flow rate (pressure loss) similar to that of a prior art device having no resonators at the ventilation openings of the housing.

[0022] An advantage of the invention is that it is not only applicable to large installments but also to small handheld electrical power tools and devices with limited space due to compact house dimensions.

[0023] The resonators 3 shown in Fig. 1 to Fig. 3 are composed with a narrow neck. This kind of resonators is referred to as a Helmholtz resonator. The basic parameters of a Helmholtz resonator are the mass of air enclosed in the neck, and the volume of the attached cavity. The shape of the cavity is of lesser importance. Therefore, the shape of a resonator is not confined to be cuboidal. The resonators 3 can also be designed as quarter wavelength resonators which have a simple tube like geometry and no dedicated neck (see Fig. 4 (a)). The resonant frequency of the quarter wavelength resonator is determined by the length of the cavity.

[0024] As a resonator is designed to tackle a single frequency, sound mitigation will occur only in a narrow frequency range. The bandwidth over which a resonator is effective is determined by the internal loss of the resonator system. This issue of limited bandwidth could be partly overcome by using two or more resonators 3 tuned to slightly different frequencies. Alternatively, the placement of acoustically absorptive material in the resonator cavity or, especially, in the neck can broaden the bandwidth at the expense of peak performance at the resonance frequency. Furthermore, the placement of the absorptive material around the neck further reduces the risk of aero-acoustic self-noise, i.e. whistling.

[0025] Experimental set-up:

As shown in Fig. 5, an experimental demonstrator test rig has been designed in order to perform acoustic tests on small sample plates. The floor and walls of the test rig casing are made from 30 mm thick acrylic glass. The inner dimensions of casing are 297 mm × 210 mm × 252 mm, which gives an inner volume of about 0.016 m³. A duct of 100 mm outer diameter is connected to conduct air flow into the demonstrator with the flow rate between 3L/s and 35L/s. The primary sound source inside the casing is an in-house design miniature hexahedron loudspeaker with monopole like radiation characteristics. For

the experiments, a white noise signal with controlled amplitude is used as input to the loudspeaker. A dummy head with a binaural recording system is used for measuring the sound pressure levels (SPLs). As shown in Fig. 6, a dummy head is placed next to the demonstrator with 300 mm distance from the side and the top face of the demonstrator in order to avoid the interaction with the flow from the demonstrator. The top of the demonstrator casing is covered by a 15 mm thick aluminum mounting plate, in which a sample plate with the grid of 10x1 rectangular apertures with dimensions of 3 mm × 30 mm, which gives the total ventilation opening area of 900 mm². As shown in Fig. 7, the ventilation slit geometries are modified by attaching Helmholtz resonators 3 whose resonant frequency is tuned to 6.8 kHz.

[0026] Experimental Results:

Figure 8 shows the measured air-borne noise emission of the test set-up with a primary loudspeaker without air flow. The results show that the Helmholtz resonator arrangement can reduce the radiated sound through the ventilation opening by more than 10dB in 1/3rd octave band around the resonant frequency of the resonators at 6.8 kHz (Fig. 8) It was found that the orientation of the resonators (upstream or downstream) has no significant effect on the performance. The modest broad band frequency reduction is achieved due to the higher impedance of a duct, formed by the wall pair of acoustic resonators.

[0027] Figure 9 shows the measured flow noise for a flow rate of 8 L/s without a primary loudspeaker. The results show that the installation of the resonators considerably increases the aero-acoustic self-noise in the entire frequency range up to 7 kHz. This is because the resonators distort the flow. The results show that for the acoustic self-noise the direction of the acoustic resonator does make a difference. For low flow noise the resonators should be arranged with the openings in downstream direction.

[0028] It is important to note that the spectrum of the flow noise is broadband without dominating tonal components (no whistling). It is also important to note that the sound pressure levels of flow noise are significantly lower than the sound pressure levels measured for the excitation via the primary loudspeaker inside the test rig. Hence for practical applications the observed increase in flow noise may be tolerable if

1) the primary broad band noise emitted by the electric power/tool device is higher than the levels of the flow noise.

2) The resonator arrangement significantly mitigates sound emission around frequencies at which the electric power tool/device produces a dominating tonal noise which is transmitted via the ventilation openings.

[0029] The main function of the ventilation openings 2

is to allow for the exchange of air between the inside of the housing 1 and the surrounding. Hence it has also been experimentally investigated how the proposed modifications affect the pressure loss, i.e. volume flow, across the ventilation openings 2. Fig. 10 shows the reduction of the volume flow rate for constant fan RPM of a blower. The results show that the flow resistance of the ventilation opening increases due to the resonator arrangement. This is because the resonator walls form a short duct, which compared to the prior art configuration in which no resonators are arranged at the air exhaust openings, increases the friction losses. However, the maximum reduction of the flow rate is about 2.5% which are tolerable in most applications. It is interesting to note that, as for the aero acoustic self-noise, the resonator arrangement with the opening facing in the downstream direction also shows lower reductions in the flow rate, with a maximum reduction of 1.5 %.

[0030] The invention has positive effects on the air-borne noise. The modified opening with resonators 3 reduces the total noise significantly around the tuned resonance frequency of the acoustic resonators and also provides modest reduction over a wide frequency range (Fig. 8)

[0031] Due to more complex geometries higher levels of aero acoustic self-noise are generated (Fig. 9). However, if designed properly, the spectrum of the flow noise has a broadband characteristic without dominant tonal components. The absolute levels of flow noise observed are still relatively low, such that an increase is tolerable for most applications of the invention.

[0032] Another adverse effect is the possibility of an increased pressure loss across the ventilation openings 2 and hence a reduction in the flowrate compared to the prior art configuration in which no resonators are placed adjacent to the air exhaust openings. However, for the design tested in the experimental studies a maximum reduction in the flow rate of about 2.5% is observed, which is tolerable for most applications of the invention

[0033] The invention can be used for the ventilation of any product, provided (1) air-borne noise transmission through ventilation openings is the dominant contributor to the noise emissions, and (2) the noise emissions include a tonal component at the fixed frequency.

[0034] For example, this invention can be applied to the following power tools:

- Power tools: e.g. electric drill, milling cutter

[0035] The following devices can also be an application, provided a fan rotates at the constant r.p.m., and generates a tonal fan noise.

- Fan, compressor, blower, leaf blower, vacuum cleaner
- Air purifier, heat pump
- Beamer, PC.

Claims

tools.

1. Noise reduced blower means comprising a housing (1), at least one air intake opening and at least one air exhaust opening (2), a fan disposed in the housing (1) and drivingly coupled to an electric motor for generating an air flow through said at least one air intake opening into the housing (1) and through said at least one air exhaust opening out of the housing (1), noise reduction means including at least one resonator (3) having a wall which defines a resonator cavity and a resonator opening (4), said resonator opening (4) being in fluid communication with said resonator cavity and said air flow, **characterized in that** there is a plurality of air exhaust openings (2) and a plurality of resonators (3) each of which is adjacent to a respective one of said air exhaust openings (2). 5 10 15
2. Noise reduced blower means as claimed in claim 1, **characterized in that** the resonators (3) are spaced from each other and the air exhaust openings (2) are defined by the resonators (3). 20
3. Noise reduced blower means as claimed in claim 1 or 2, **characterized in that** the resonator openings (4) each point in an upstream direction of the air flow in the vicinity of the resonators (3). 25
4. Noise reduced blower means as claimed in claim 1 or 2, **characterized in that** the resonator openings (4) each point in a downstream direction of the air flow in the vicinity of the resonators (3). 30
5. Noise reduced blower means as claimed in any one of the preceding claims, **characterized in that** the resonators (3) are either of the Helmholtz resonator type or the Lambda quarter resonator type, or the resonators (3) consist of a combination of the aforementioned types of resonators (3). 35 40
6. Noise reduced blower means as claimed in any one of claims 1 to 3, **characterized in that** the air exhaust openings (2) each are covered partially by a portion of the wall of the respective resonator (3). 45
7. Noise reduced blower means as claimed in any one of the preceding claims, **characterized in that** two or more resonators (3) of the plurality of resonators (3) are tuned to different frequencies. 50
8. Noise reduced blower means as claimed in any one of the preceding claims, **characterized in that** the resonators (3) each include a surface layer of acoustically absorptive material disposed on the inside of the respective resonator (3). 55
9. Use of noise reduced blower means as claimed in any one of the preceding claims in electric power
10. Use of noise reduced blower means as claimed in any one of claims 1 to 8 in electric devices such as fans, compressors, blowers, leaf blowers, vacuum cleaners, air purifiers, heat pumps, beamers or computers.

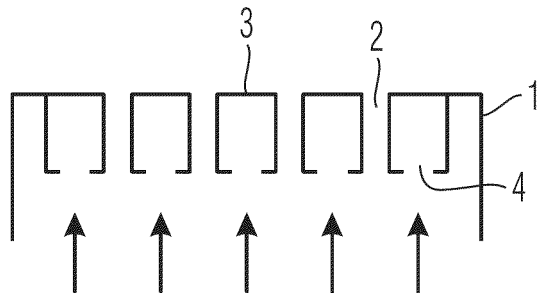


Fig. 1(a)

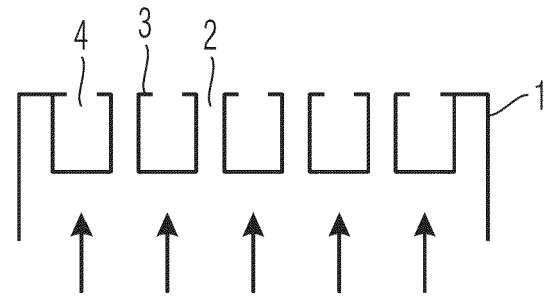


Fig. 1(b)

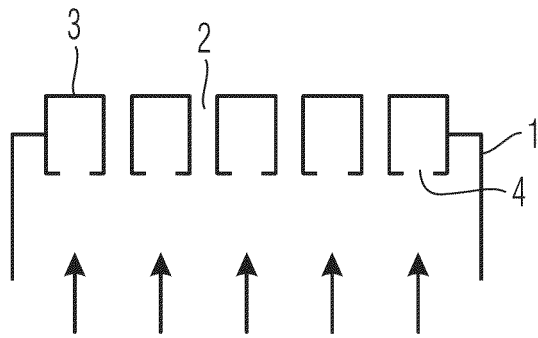


Fig. 2(a)

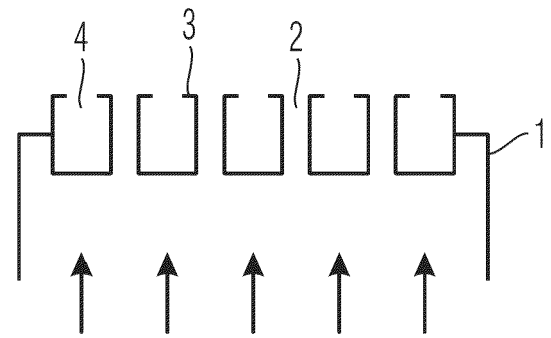


Fig. 2(b)

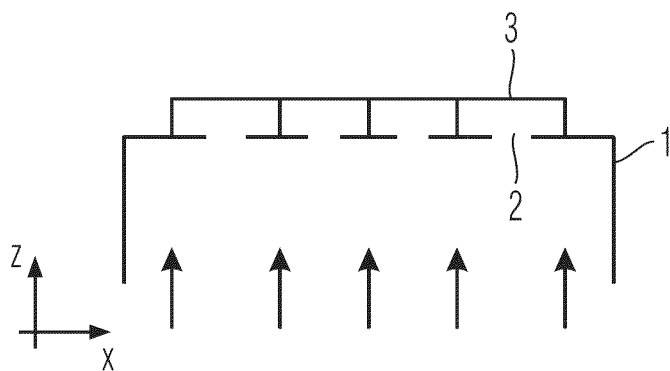
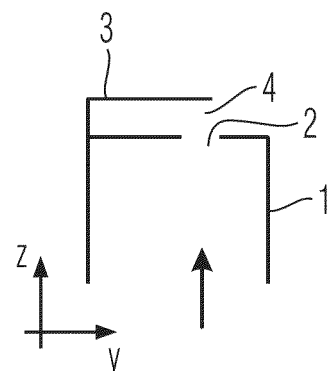


Fig. 3(a)



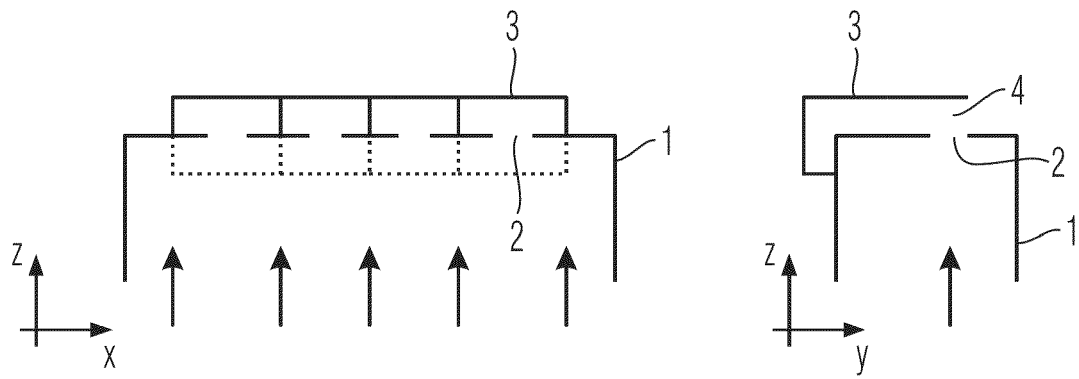


Fig. 3(b)

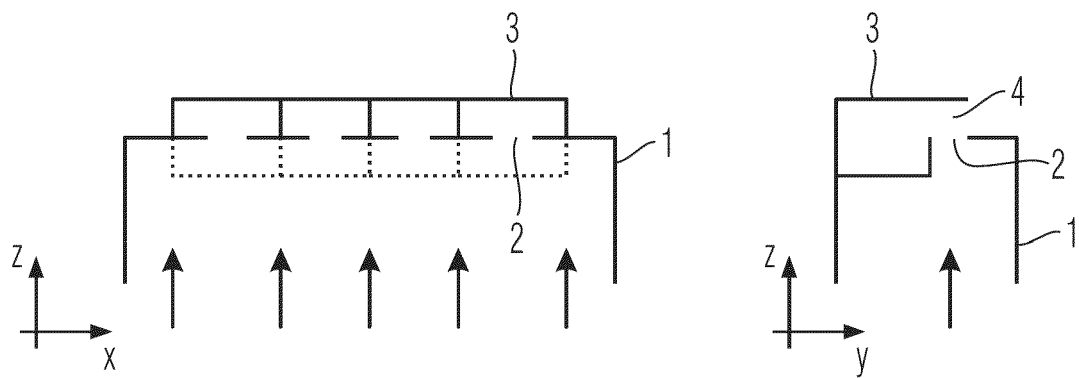


Fig. 3(c)

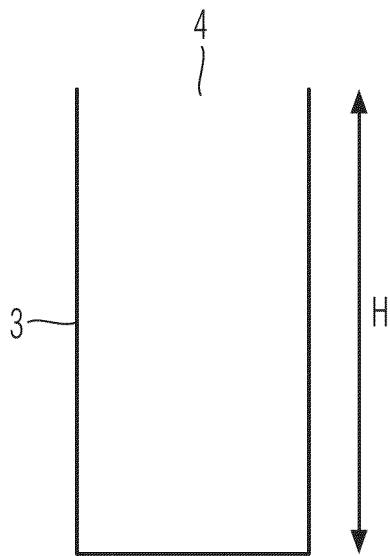


Fig. 4(a)

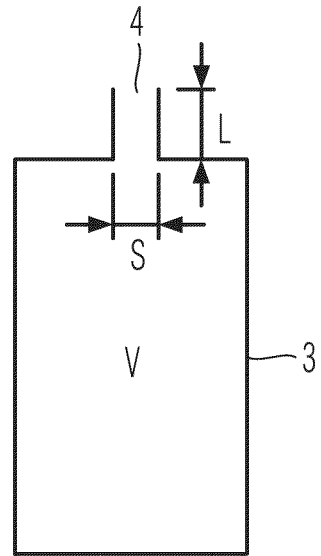


Fig. 4(b)

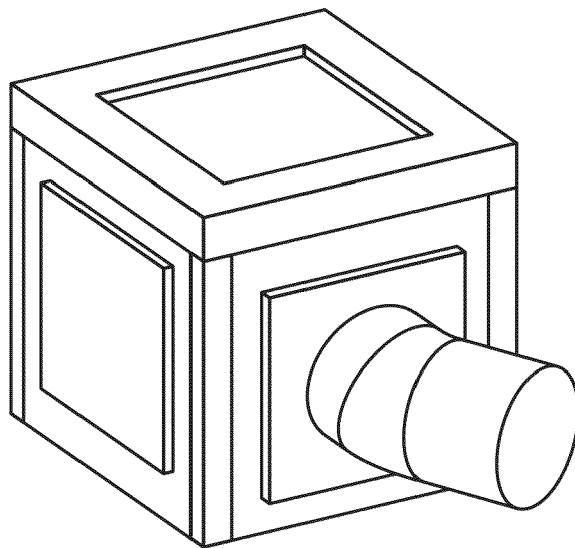


Fig. 5

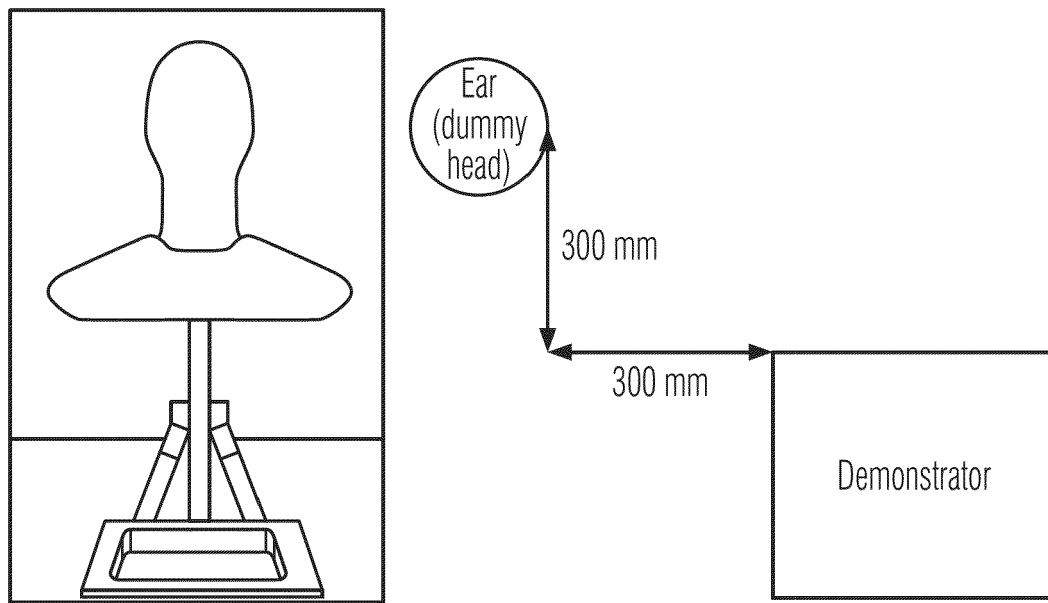


Fig. 6

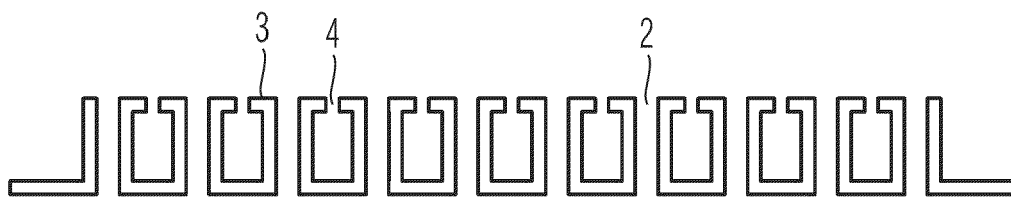


Fig. 7

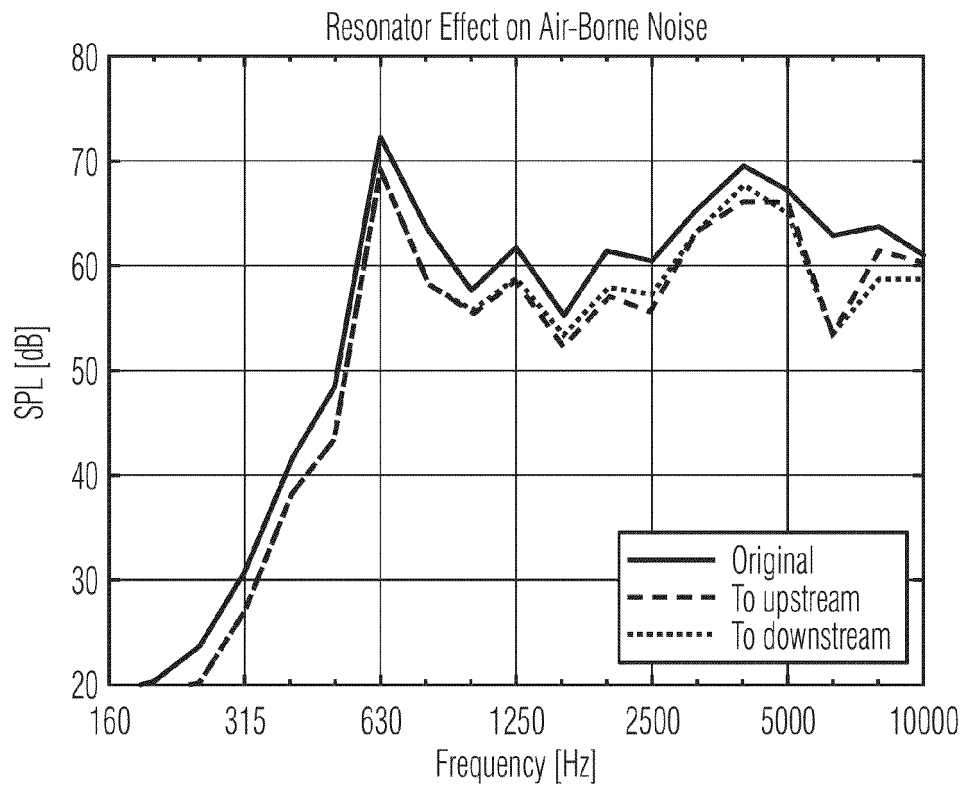


Fig. 8

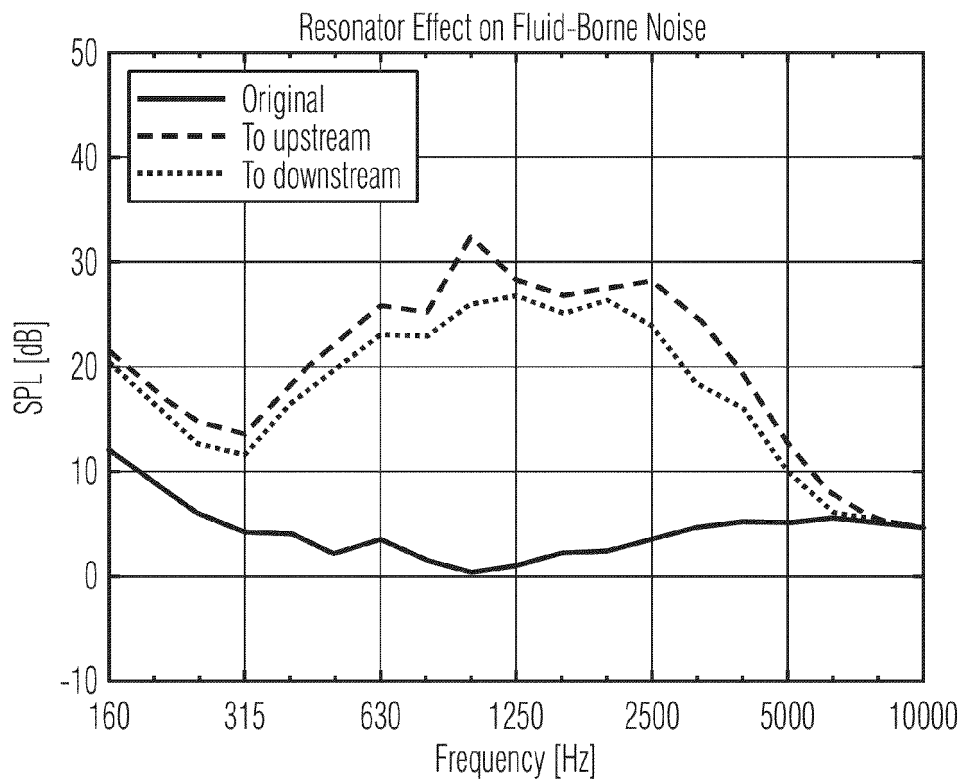


Fig. 9

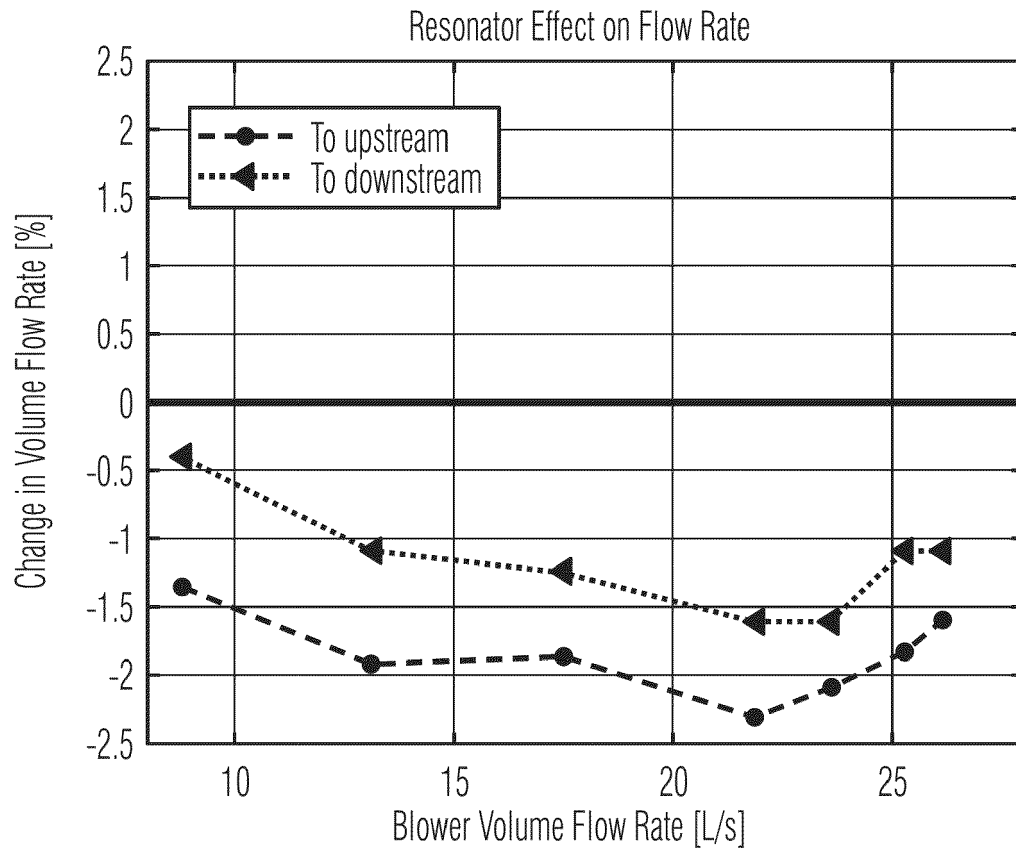


Fig. 10



EUROPEAN SEARCH REPORT

Application Number

EP 22 15 8036

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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A	US 5 869 792 A (ALLEN DONALD L [CA] ET AL) 9 February 1999 (1999-02-09) * column 3, line 65 - column 7, line 45; figures 1-15 *	1, 2, 5-7, 10	
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TECHNICAL FIELDS
SEARCHED (IPC)

F04D

The present search report has been drawn up for all claims

2

Place of search

Date of completion of the search

Examiner

The Hague

2 August 2022

Nobre Correia, S

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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 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 (F04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

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5

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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