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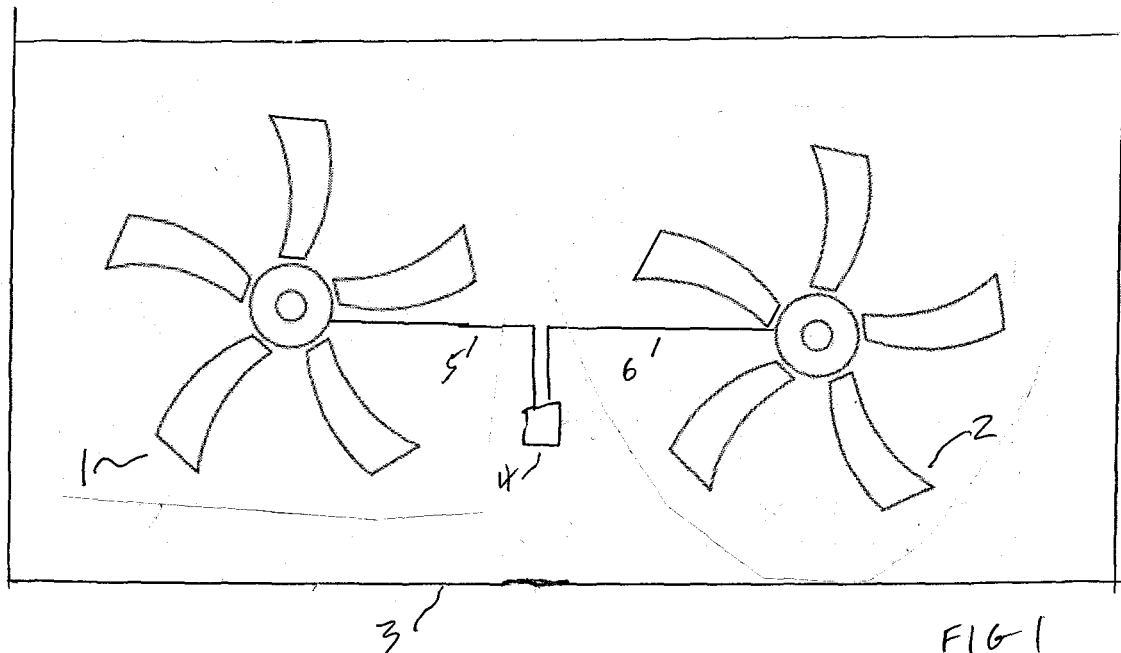
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(54) **Noise masking**

(57) An installation is disclosed comprising two or more fans (1,2), wherein one or more parameters of fan design and operating speed is adjusted to cause sound

masking to lower omitted noise levels.
The noise masking involves generating a sound floor, and maintaining noise levels from other fans below that of the sound floor. Various methods are disclosed.



Description

[0001] This invention relates to noise masking. In particular, it relates to masking techniques for hiding noise from machines. These machines may be fans provided in fan trays or otherwise provided, or other machines.

[0002] Fans are used in many different industries, including the computer and telecommunications industries. Fan cabinets are commonly located in data centres housing a plurality of computer assets, such as servers, and so on. They may also be located in base stations or other telecommunications installations. Fan installations, however, create noise.

[0003] In simple terms, a fan generally comprises a number of blades which rotate around a shaft. Typically, a number of rolling element bearings will be provided. Fan noise can be derived from several components. A first component might be broadband noise which is caused by the turbulence of air flow as it is exhausted by the fan. A second component of the noise might be called narrowband or tonal noise as it is generated in restricted wavebands and this can arise through blade pass noise. As a fan blade passes a nearby support, a pressure wave is produced and this is known as blade pass noise. If the fan rotates at a constant speed, then a periodic sequence of pressure waves produces a fundamental tone derived from the blade passing frequency (BPF) plus higher order harmonics. BPF (in Hz) is calculated as the number of blades times speed in revolutions per minutes (rpm)/60.

[0004] A further noise component derives from variations in the noise due to the rolling element bearings during the life of the fan. During its lifetime, friction in the bearings increase and also cracks might occur which can cause particular frequencies to become excited. As defects or wear develops, harmonics of these fundamental frequencies may also occur and these characteristic frequencies and their harmonics also add to the emitted acoustic noise of the fan.

[0005] There are generally allowable limits for noise from fan installations. One such limit is defined by the NEBS (Network Equipment Building Standards). In NEBS standard GR-63-CRRE limits are set for various sound levels in network facilities. For example, equipment to be located in a power room may have a maximum sound level of 83 dBA. However, the equipment installed in a control centre where normal speech and telephone communications are required may have a level of no more than 65 dBA. ISO standard 996-2:1987 also recommends that a penalty be added when measuring overall sound level if significant tones (ie single band or narrow band tones) are emitted. While standards differ, the level of a tone in this regime is compared to that of its neighbouring spectral components and the penalty is assigned to the overall noise levels if the difference exceeds a specified amount, such as 5 dBA.

[0006] Telecommunications cabinets tend to higher and higher heat dissipation requirement and therefore with each new generation of telecommunications equip-

ment it is necessary for cooling fans to run faster than before, however, this produces an even greater problem of keeping within allowable noise limits.

Description of Prior Art

[0007] Existing methods of noise attenuation involve passive or active noise control.

[0008] Passive noise control involves the use of insulation, sound absorbing material or mufflers to attenuate noise. For example, material having these properties can be placed to the air flow to absorb noise.

[0009] A simple form of active noise control of fans is to use variable speed control and these involves monitoring temperature and running fans at speeds dependent upon the cooling currently required for the equipment, as opposed to constantly running at maximum speed.

[0010] Another type of active noise control uses noise cancellation and aims to attenuate noise using destructive interference between the unwanted noise and an electronically generated sound which has an inversion of the unwanted noise.

[0011] Presently available attenuation methods have disadvantages. In passive noise control, if too much of the empty space around a fan tray is filled with insulating or attenuating material, then undesirable back pressure may be created. Particularly where much broadband fan noise exists, it is desired to absorb low to mid frequency noise and large amounts of material are required. However, it is desirable to reduce rather than increase the size of fan cabinets and consequently there is even less room for sound absorbing material.

[0012] Active noise control using noise cancellation is effective and feasible in small enclosed spaces such as in the cockpit of cars or aircraft and in ducting where global cancellation can be achieved by multiple speakers and feedback microphones. It is, however, extremely difficult if the directionality of noise is not controlled. In telecommunications equipment, noise is generally emitted in all directions. Achieving active noise control which is effective in all directions is very difficult.

[0013] The present invention arose in an attempt to provide improved attenuation of noise levels from fan trays, but has application beyond this.

Summary of the Invention

[0014] According to the present invention, in a first aspect, there is provided a method of controlling noise from a fan installation comprising at least two fans, comprising using the noise emitted by at least one of the fans to generate a noise floor from masking noise from the other fan or from each other fan.

[0015] It is an acoustic phenomena that, once a noise floor has been established, if additional noise at a lesser amplitude is added this will not add to the noise floor. Thus, in embodiments of the present invention, noise masking is achieved by creating a noise floor from at

least one of the fans, below which noise from the other or each other fans are not discernable. This noise masking is therefore used to 'hide' sound noise which is at a level below the noise floor in order to reduce the overall emitted and measurable noise level from a fan tray.

[0016] Many different techniques may be used.

[0017] For example, selection of one or more of; the relative speed of each of the fans; the size and type of bearings used; the size and shape of bearing used and/or the size, shape and/or number of fan blades.

[0018] Alternatively or in addition, the signal phases of the fans may be controlled to create destructive interference between the fans.

[0019] In some embodiments, the fans may be controlled to have noise envelopes which are substantially identical but of different amplitude.

[0020] In some embodiments, two or more identical fans may be used, operated at different speeds such that the noise floor of one of the fans masks the noise generated by the other fan or the other fans.

[0021] The fans may be operated in close proximity, for example in a fan tray.

[0022] The fan installation may include an enclosure which houses said one or more fans and also electronic equipment cooled by the fans.

[0023] In a second aspect, the invention provides an installation comprising two or more fans, wherein the noise emitted from one or more of the fans is used to generate a noise floor, for masking noise from the other fan or from each other fan.

[0024] In some embodiments, this may be achieved by varying any one or more physical parameters such as, but not limited to, the relative speed of the fans; the size and type of bearing used and/or the size, shape and number of fan blades.

[0025] Alternatively, or in addition, the signal phase of the fans may be controlled to create destructive rather than constructive inference between the fans.

[0026] However, other parameter may be adjusted beyond, or as an alternative to, any of the above parameters, for achieving the desired masking.

[0027] A feedback loop may be used to detect one or more tonal noise components and to generate an output narrowband noise in the spectral region of said tonal component or components, in order to partially mask the affect of this or these tonal components and hence not incur a potential penalty under applicable standards.

[0028] This aspect is particularly useful if the noise emitted by a fan has specific tones (ie narrowband tones) or several noise components that peak significantly above surrounding or adjacent frequency components. The generated narrowband noise is more pleasant to listen to and can avoid penalties being occurred when masking emitted noise levels.

Brief Description of the Drawings

[0029] Embodiments of the invention will now be de-

scribed, by way of example only, with reference to the accompanying schematic drawings in which;

Figure 1 shows a fan tray having two fans;

Figure 2 shows a spectral plot of acoustic noise of a single fan running at different speeds;

Figure 3 is a spectral plot of acoustic noise of the second fan operating at two different speeds;

Figure 4 is a spectral plot of acoustic noise for both the first and second fans running at the same speed;

Figure 5 is a spectral plot showing two fans of the same type running simultaneously, a first running at a constant speed and the second running at a variable speed;

Figure 6 shows the overall noise level for two fans of the same type in which one fan is running simultaneously and the second at varying speed, and

Figure 7 shows a speaker systems playing narrow-band noise in close proximity to a fan.

Detailed Description

[0030] Figure 1 shows a fan tray 3 incorporating two fans 1 and 2. These are either controlled by separate controllers or alternatively a single controller or controller board may be provided with separate outputs to each fan. In the embodiment which is shown a single controller 4 is provided having a separate output 5, 6 for powering fans 1, 2 respectively.

[0031] Control arrangements can control each respective fan totally independently and at different power, voltage, speed, phase etc. By way of example, the fans are manufactured by EBM-Papst. Fan 1 is an EBM Papst 3214JN, DC fan, size 92 x 92 x 38mm, and Fan 2 is an EBM-Papst 6248N, DC Fan, size 172 x 172 x 51mm. The dimensions refer to the fact that these fans are mounted within casings (not shown in the figure for clarity) which are generally square having length and width (for the 3214 SN) of 92 mm and a depth (within which the blades are mounted) of 38 mm.

[0032] In tests, acoustic measurements were made by enclosing the fans in an enclosure with a microphone and measuring noise levels detected by the microphone. Spectral analysis was then performed upon these measurements. Spectral analysis decomposes the acoustic noise signal into frequency components. The influence of individual mechanical components of the fan can be ascertained from these components. The combined effect of all noise sources together is measured and it is the maximum amplitude of each spectral component that creates the noise floor.

[0033] Figure 2 shows spectral plots which were obtained by running fan 1 at three different speeds. These are 1,800 rpm (plot 10) 3,600 rpm (plot 11) and 4,800 rpm (plot 12). Since the noise floor is the maximum amplitude of each spectral component it is seen that the noise floor is created by the topmost plot, ie the fan running at 4,800 rpm. As stated above, it is an acoustic phe-

nomena that once a noise floor has been established, if additional noise at a lesser amplitude is added this will not add to the noise floor. Thus, in the plot of Figure 2 if the noise floor is created by plot 12 of a fan running at 4,800 rpm, then if an additional identical fan is added, which is operating at 1,800 rpm (plot 10) this will not add to the noise floor since its spectral plot is always lower, over its whole frequency extent than plot 12. However, an additional identical fan running at 3,600 rpm (plot 11) will add slightly to the noise floor as one component C1 rises slightly over the noise floor (plot 12) at around 5kHz.

[0034] Figure 3 shows the second fan 2 running at two different speeds 2,300 rpm (plot 13) and 3,600 rpm (plot 14).

[0035] Figures 2 and 3 show that for each fan the same tonal characteristics exists regardless of the speed ie the general shape of the envelope of the plots for each fan are the same, but the overall amplitude of some of the tonal (narrowband) components increase slightly with speed. The broadband noise increases significantly with speed.

[0036] Figure 4 shows plots of fan 1 running at 3,600 rpm (plot 15) and fan 2 running at 3,600 rpm (plot 16). It is seen from this that two different size fans running at the same speed have very different spectral characteristics. Note that the smaller fan (fan 1) has lower airflow.

[0037] Figure 5 shows the spectral plot of the acoustic noise emitted from two fans of the same type (fan 1) running simultaneously. In these plots, the first fan 1a was always running at 4,800 rpm while the second fan was set at varying speeds. There is in fact very little change to the spectral plot in the first three plots; plot 17 shows fan 1a at 4,800 rpm and fan 1b at 0 rpm, plot 18 shows fan 1a at 4,800 rpm and fan 1b at 1,800 rpm and plot 19 shows fan 1a 4,800 rpm and fan 1b at 3,600 rpm. However, once the two fans are both running at 4,800 rpm (plot 20 shown in dashed lines for clarity in the figure) then a large increase across the spectrum is seen relative to the spectral plot of one fan alone running at 4,800 rpm.

[0038] Note that all the spectral plots shown are of frequency against noise level (dBA).

[0039] Figure 6 shows the overall noise levels (in dBA) when one fan, of type fan 1 (see above) is running at 4,800 rpm and the second fan is set at varying speeds. Measurements are taken as the speed of the second fan increase from 0 rpm up to 4,800 rpm (the same as fan 1a). Note that for this plot sound pressure level (SPL) measurements were performed in a small enclosed environment and as a result the measurements are not calibrated. They are therefore provided only as a means to determine general and relative changes in SPL (not absolute changes).

[0040] When only one fan is running at 4,800 rpm, the noise level is recorded at 58.5 dBA. The addition of a second fan running at 1,800 rpm (P_1) does not contribute to noise levels and actually decreases the noise level to around 57.7 dBA. This may be attributed to some form of noise cancellation as measurements were performed

in an enclosed environment. No further addition to the noise level is noted as the speed of the second fan is gradually increased until the speed of the second fan is around 3,600 rpm, about which point the noise level increases to 58.8 dBA. At this level, it is reasonable to assume that the noise emitted from the second fan has crept above the noise floor created by the first fan running at 4,800 rpm. Comparison with Figure 2 will show that at 3,600 rpm some of the spectral components are just beginning to peak above the equivalent components of a fan running at 4,800 rpm, which supports this theory. Reverting back to Figure 6, further increasing the speed of the second fan increases the emitted noise levels as more components become visible. Once the two fans are operating at 4,800 rpm then the measured noise is somewhere between 61 - 61.5 dBA (p_2). A second fan, of the same type, might therefore be operated at speeds of up to, say, about two thirds the speed of the first fan in some embodiments.

[0041] Accordingly, in embodiments of the invention, an acceptable noise floor is created, which has a noise level below allowable noise limits, using the noise emissions of one or more carefully designed fans or combination of fans. Below this noise floor, the noise emissions of the remaining fans are undetectable (provided they keep below the noise floor) and therefore do not contribute to the overall noise levels. Thus, it will be appreciated that the precise design of the combination of, for example, fans speeds, fan types, bearing types used together in a fan tray can significantly reduce noise levels.

[0042] The size and type of bearings used may be varied in order to set the noise floor. Bearing size and type (eg physical shape, method of operation or mounting of bearings, material from which the bearings are made, or otherwise) affects the spectral location of characteristic defect frequencies and their harmonics. Thus by altering these parameters of the bearings, the noise floor can be adjusted.

[0043] Similarly, other mechanical features can be varied. The shape of the fan blades, or the number of blades, for example, can affect the location of the BPFs and their harmonics, and so these can also be varied in order to set the noise floor.

[0044] As discussed above, when noise levels emitted by telecommunications equipment are measured, penalties can be incurred for tones or spectral components that peak significantly over their neighbours. Fan noise comprises broadband noise as well as discrete tones, which are due to BPF (blade passing frequencies) and its harmonics and potentially-bearing defect frequencies. These tones are partially masked by the surrounding broadband noise. However, if these tones are significantly higher than the surrounding broadband noise then a penalty is incurred. Also, this noise can be extremely irritating to the human auditory systems.

[0045] Thus, in some embodiments of the invention these tonal components are masked by generating and playing narrowband noise in the spectral region of the

tone, through a speaker in close vicinity to the fan. This is shown schematically in Figure 7. This type of active noise control does not usually attempt exact tone cancellation (which is very difficult when the sound image is not in an enclosed environment). The amplitude and spectral location of the narrowband noise emitted by the speaker can be adapted dependent on the speed of the fan using a feedback system. This feedback system can simply be coupled to a tachometer output.

[0046] Figure 7 illustrates the flow of this. A tachometer output T from a fan 1 is used to calculate location and amplitude of the tonal component 30. This system feeds into a noise generator 31 which generates a narrowband noise signal 32 which is output to a speaker 33. The speaker produces the required narrowband noise signal. This feedback system could also be in the form of a peak detection system, which automatically detects the location of the tone.

[0047] Note that the addition of this narrowband noise contributes far less to the overall measured sound levels than the incurred penalty if this technique is not applied. This resultant noise is more pleasant to listen to and the measured noise levels would not be subject to penalties usually attributed to distinct tones in noise.

[0048] As described with reference in Figure 1, it is most preferable that the individual fans are controlled by a separate power line such they can be independently controlled to have different speeds/phases. This may be done from a single controller or each fan may have its own controller.

[0049] In some embodiments, the fans may be controlled in phase so that destructive interference occurs between the noise levels of the fans. At a simple level this could mean the noise peaks of a particular noise frequency of a first fan coincide with troughs of that frequency of a second fan, so that these interfere to cancel each other out. Other more sophisticated techniques will be apparent.

[0050] Although two fans are shown in Figure 1 and described in the examples, the invention may also be applicable to environments where any other number of fans is provided, such as for example four fans. In effect, one or more of the fans is used to create a noise floor and the noise generated by the remaining fans is tailored to "hide" under this, ie be masked by it.

[0051] The fans may be operated so that their waveforms follow generally similar envelopes (ie peaks and troughs roughly spectrally aligned), as shown in the various examples given for example, with peaks and troughs generally lying in the same relative position in order to maximise the effect of the noise floor and the ability of the noise floor to hide the noise generated by other fans. They may however be operated in other ways in which one fan creates a noise floor below which the noise from other fans are hidden.

[0052] Note also that in some embodiments the noise envelope of the second (hidden) and/or further fans may be allowed to 'peak' above the envelope of the masking

fan (as shown at a frequency of around 17 KHz in Figure 3 for example), provided the peak is less than that allowed by standards without penalties (eg those set by ISO996-2: 1987).

Claims

1. A method of controlling noise from a fan installation comprising at least two fans, comprising using the noise emitted by at least one of the fans to generate a noise floor for masking noise from the other or each other fan.
2. A method as claimed in Claim 1, wherein one or more parameters are varied, to create the noise floor, the parameters being selected from; the relative speed of each of the fans; the size and type of bearing used; and the size, shape and number of fan blades.
3. A method as claimed in Claim 1 or 2, wherein the signal phases of the fans are controlled to create destructive interference.
4. A method as claimed in any preceding claim, wherein the fans are controlled to have noise envelopes which are spectrally similar in terms of spectral location peaks and troughs, but of different amplitude, whereby the noise envelope of a first fan substantially masks the noise envelope of a second fan.
5. A method as claimed in any preceding claim, wherein the noise envelopes of the fans are different but the noise floor of one substantially masks that of the other.
6. A method as claimed in any preceding claim, wherein two fans are operated at different speeds.
7. A method as claimed in Claim 5, wherein two fans are operated, a first one at a first speed and a second one at a second speed, the second speed being up to approximately two thirds that of the first speed.
8. A method as claimed in any of Claims 1 to 5, wherein two fans of different diameters are operated at the same speed, the waveforms of the fans being such that for any frequency, the amplitude of the noise of the smaller fan never exceeds that of the larger fan.
9. A method as claimed in any preceding claim, including identifying one or more tonal noise components, and generating and outputting narrowband noise in the spectral region of said tonal components in a feedback system.
10. A method as claimed in any preceding claim, wherein

the fans are controlled, independently, from a single controller.

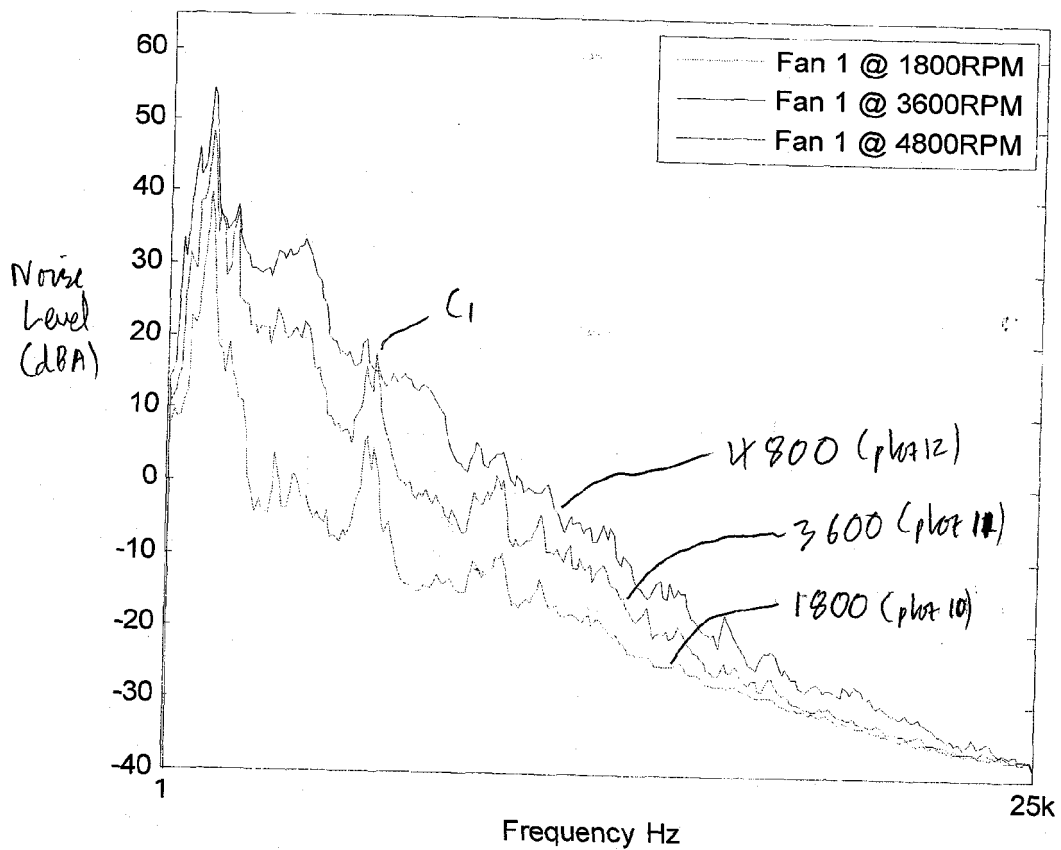
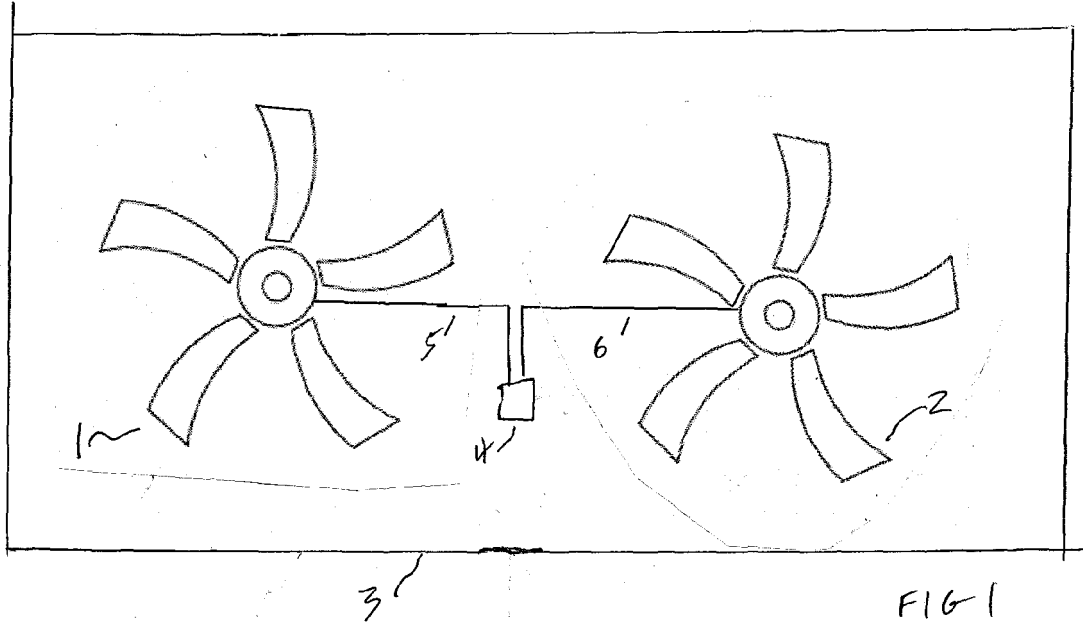
11. An installation comprising two or more fans, wherein the noise emitted from one or more of the fans is used to generate a noise floor, for masking noise from the other fan or each of the other fans. 5
12. An installation as claimed in Claim 11, including a single controller, adapted to control the speed and/or phase of each of the fans independently. 10
13. An installation as claimed in Claim 11 or Claim 12, wherein one or more parameters are varied, to create the noise floor, the parameters being selected from;
the relative speed of each of the fans; the size and type of bearing used; and the size, shape and number of fan blades. 15
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14. An installation as claimed in any of Claims 11 to 13, including means for controlling the signal phase of the fans to create destructive interference.
15. An installation as claimed in any of Claims 11 to 14, including a feedback loop for determining one or more tonal noise components, and generating and outputting narrowband noise in the spectral region of said tonal component. 25
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16. An installation as claimed in Claim 15, including a tachometer; an apparatus for using signals generated by the tachometer to calculate spectral location and amplitude of narrowband noise; a noise generator and a speaker. 35

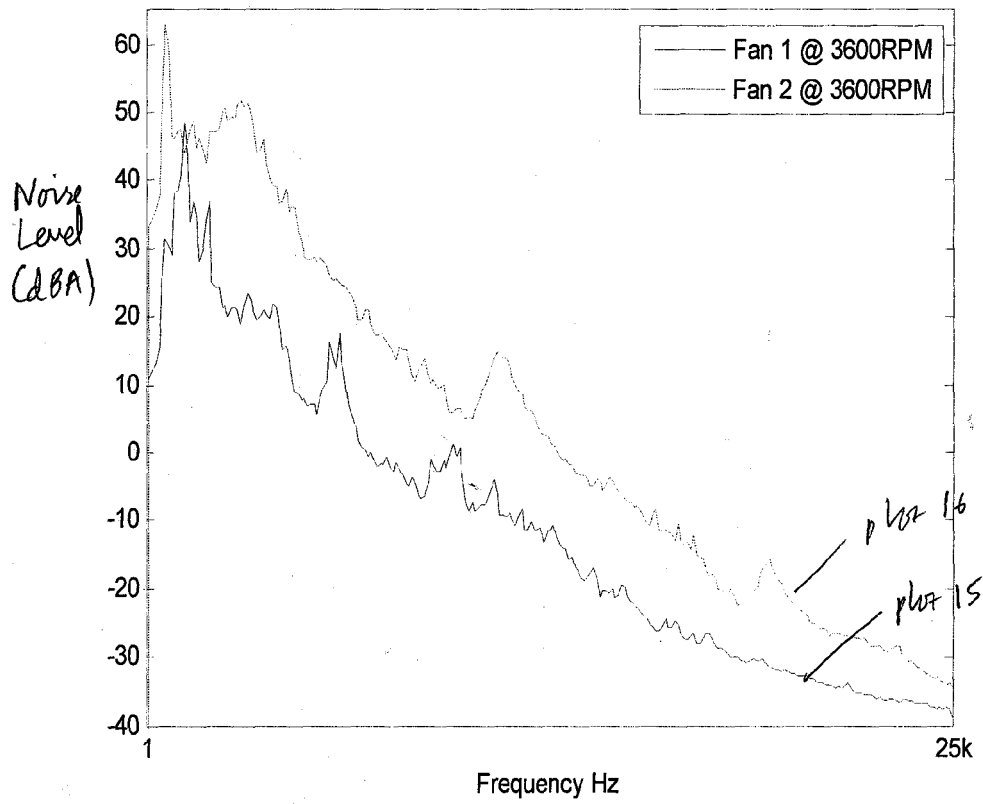
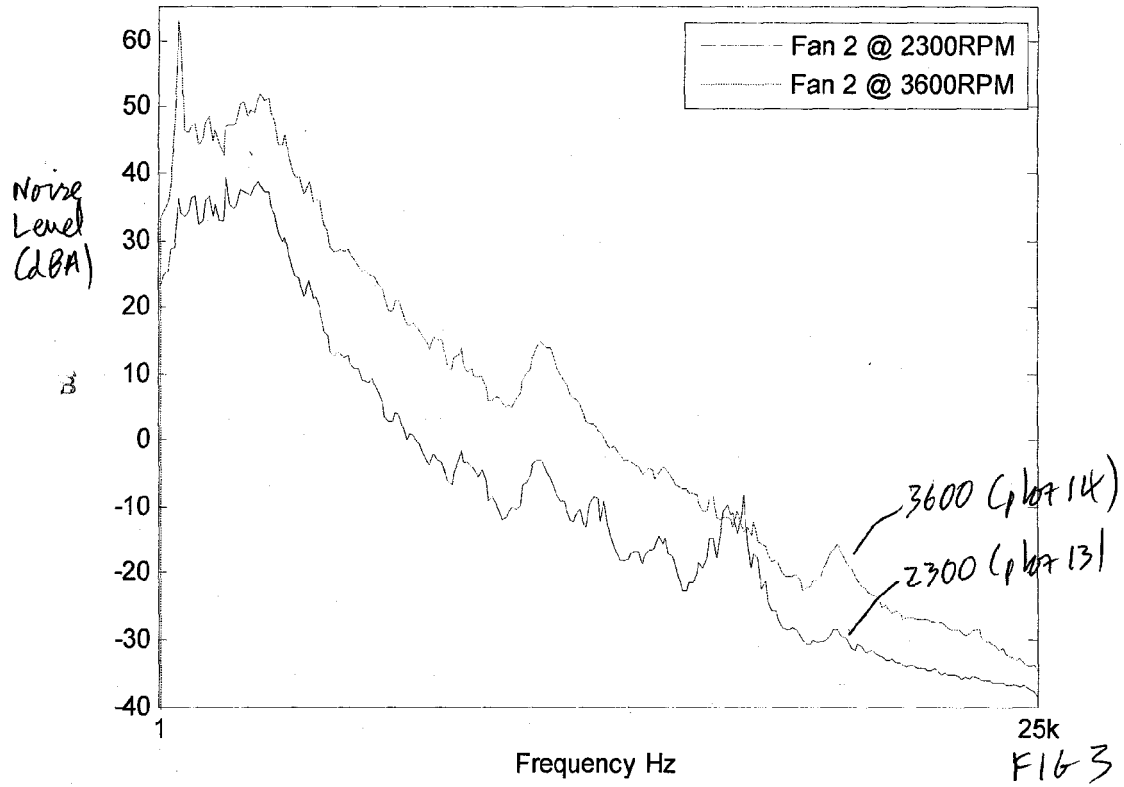
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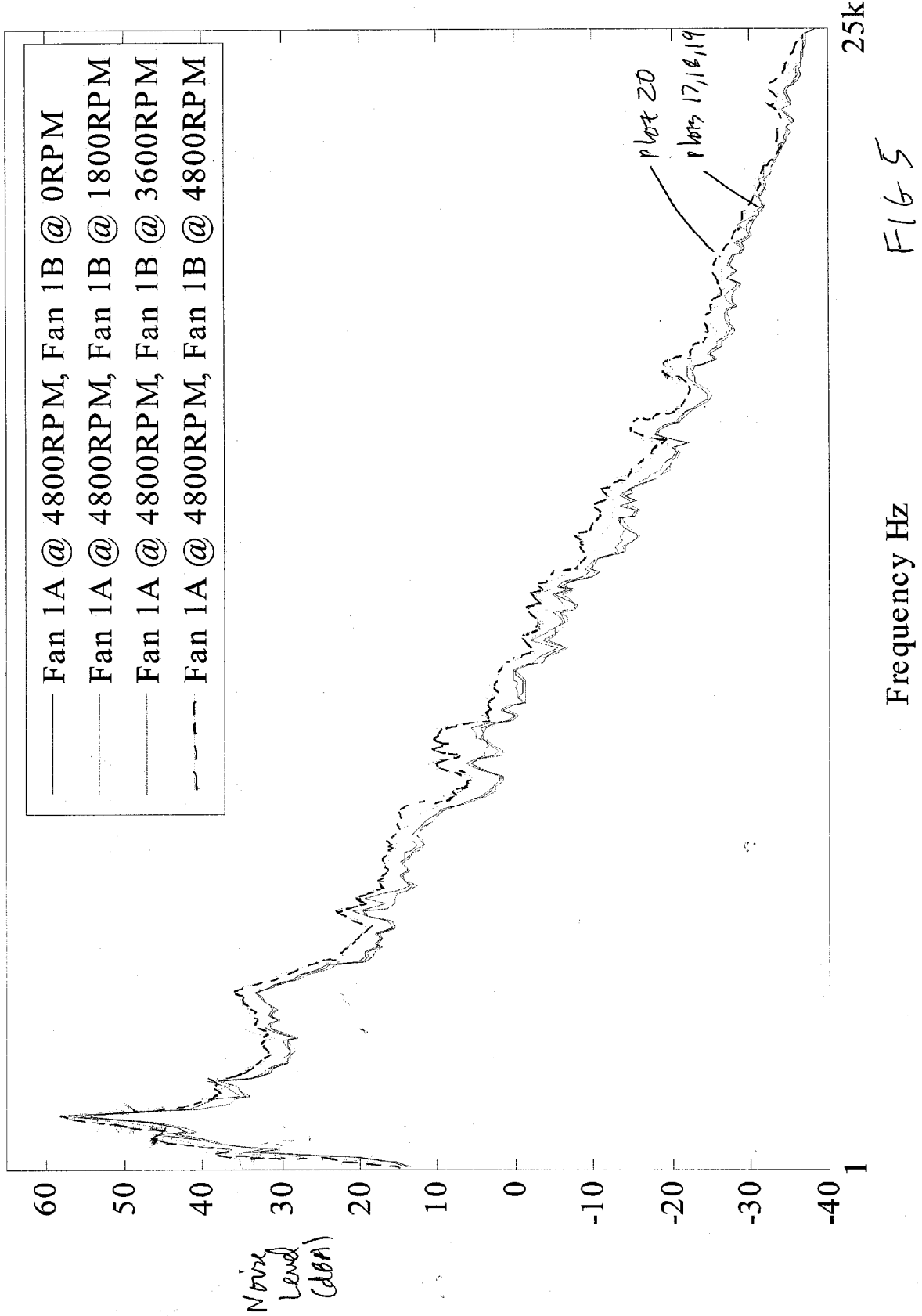
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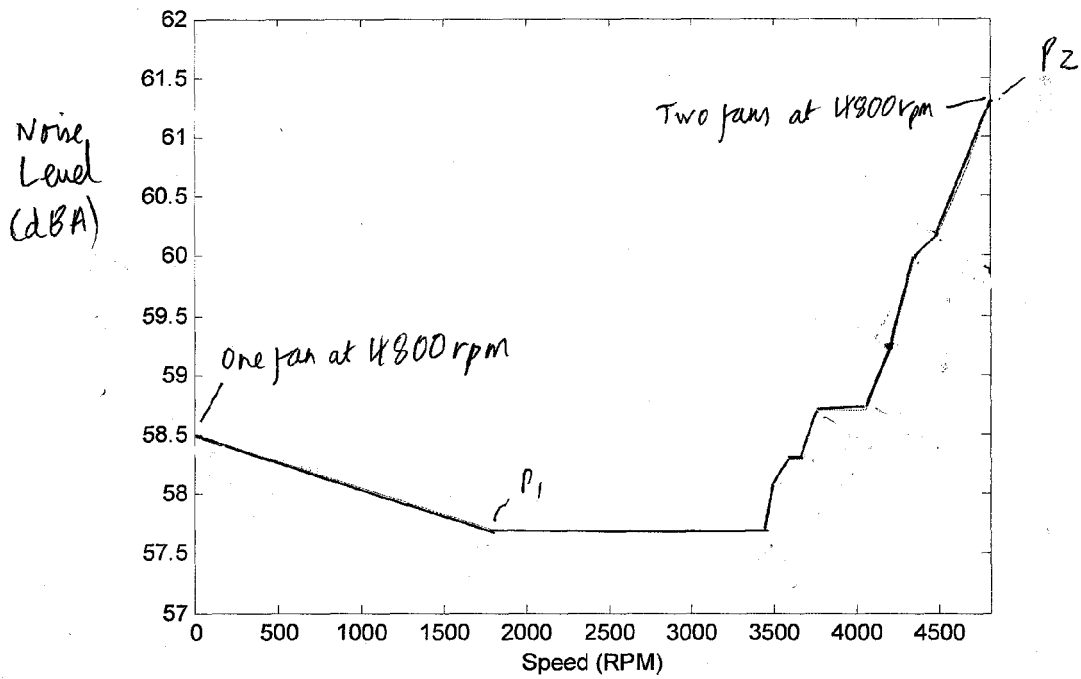


FIG 6

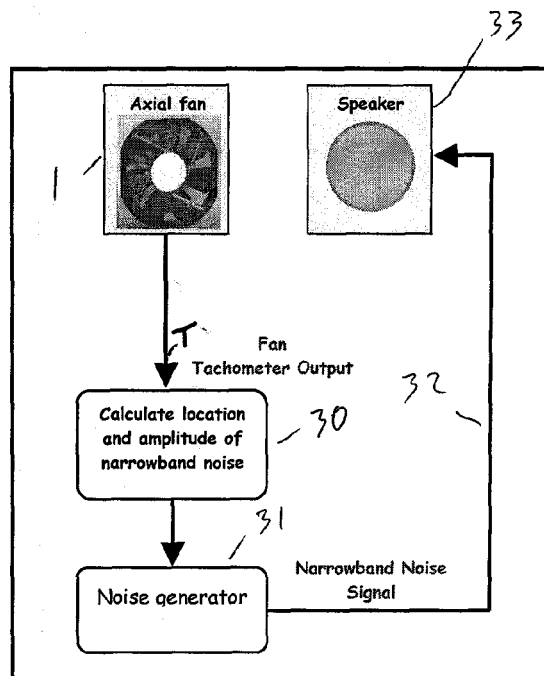


FIG 7



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Application Number
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EPO FORM 1503 03.02 (P04C01)



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