



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
07.08.2024 Bulletin 2024/32

(51) International Patent Classification (IPC):
G10K 11/178^(2006.01)

(21) Application number: **23154360.4**

(52) Cooperative Patent Classification (CPC):
G10K 11/17857; G10K 11/17881; G10K 2210/106; G10K 2210/3216

(22) Date of filing: **31.01.2023**

(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 ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(72) Inventors:
• **Orosz, Gergely**
Abingdon, OX14 4FB (GB)
• **Banovic, Luka**
2000 Maribor (SI)

(74) Representative: **Patentni Biro AF d.o.o.**
Kotnikova 32, p.p. 2706
1001 Ljubljana (SI)

(71) Applicant: **Irnas d.o.o.**
2000 Maribor (SI)

(54) **A SYSTEM AND A METHOD FOR ACOUSTIC NOISE CONTROL**

(57) The present invention belongs to the field of acoustics, more particularly to devices and methods for minimizing noise of various devices. The invention relates to a system and a method for acoustic noise control of various noise generating devices, such as heat pumps, AC systems, compressor systems, ventilation, and other HVAC systems, as well as motors, engines and similar. The essence of the invention is positioning and orienta-

tion of the source of cancellation sound, i.e., the secondary noise source, which is installed at, next to, or in the vicinity of the noise source to be cancelled, i.e., the primary noise source, and most importantly in the same compartment as the primary noise source. The same compartment means that there are no obstacles (physical barriers) between the source of cancellation sound and primary noise source.

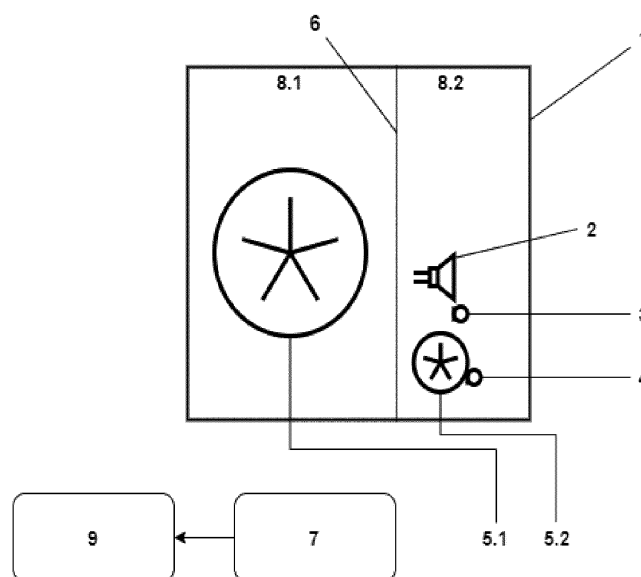


Figure 1

Description**Field of the invention**

[0001] The present invention belongs to the field of acoustics, more particularly to devices and methods for minimizing noise of various devices. The invention relates to a system and a method for acoustic noise control of various noise generating devices, such as heat pumps, AC systems, compressor systems, ventilation, and other HVAC systems, as well as motors, engines and similar.

Background of the invention and the technical problem

[0002] Noise produced by various devices, such as heat pumps, motors, etc., can be annoying. Due to its long wavelength, low-frequency noise is hard to attenuate with passive noise reduction methods. It is also much less attenuated in the airpath and therefore travels very long distances in air (compared to higher frequency sounds). This is especially emphasized in areas populated with object of comparable sizes where the wave can refract and diffract around. Consequently, there is a need for systems and methods arranged to control the noise in low frequency spectrum of various devices. Passive noise control technology, i.e., use of absorptive materials or noise partitions, enclosures, barriers, and silencers, can be ineffective, thus making it a less preferred way of solving noise reduction problems. On the contrary, Active Noise Control (ANC) can be very efficient in reducing low-frequency noise compared to passive noise control solutions. Additionally, ANC can be configured without physically changing the system components themselves.

[0003] ANC based on destructive interference of acoustic sound waves, is a technology that uses additional noise to reduce the problematic noise. It is based on the principle of superposition of sound waves. Generally, sound is a pressure wave, which is traveling in space. If another, second sound wave having the same amplitude but opposite phase to the first sound wave can be created, the first wave can be cancelled in the manner described in patent application US2011274283A1. For cancellation, the cancellation wave needs to be matched to the first one both spatially and temporally, as the wave changes as a function of space and time.

[0004] Several solutions aim to control operation noise, but their operation is hampered. For example, patent application EP3240974A2 discloses a method and system for influencing the sound emission of a heat pump or of an air-conditioning system, wherein a device component in the form of a fan or a compressor are operated in an external device, thereby emitting sound. For the self-adaptive noise control, a noise level of the ambient noise is measured in the region of the external device by means of a measuring unit, and an upper rotational speed limit of the device component is determined as a function of the noise level, and the rotational speed for the operation of the device component is limited by the rotational speed limit. In practice this means that this system adjusts fan and compressor operation to compensate for noise, which influences the heat pump performance. Intervening with heat pump performance is undesirable.

[0005] Similarly, patent application US20180163989A1 for a system and method for controlling a sound level in a heating, ventilation, and air conditioning (HVAC) system uses a sound controller configured to maintain a sound level of the refrigeration unit at the selected sound level. This means that the HVAC system is not necessarily operating at optimal conditions.

[0006] Therefore, the present invention aims to design a system and a method for acoustic noise control of various sources of noise, for example heat pumps, that will cancel the sound of the source, for example of the heat pump, without affecting its operation and/or performance.

State of the art

[0007] Document DE102019202077A1 relates to heat pump vibration control, wherein the heat pump has:

- a compressor device;
- at least one sensor for detecting vibrations of the compressor device and/or a housing and for transmitting the detected data to a control device; and
- at least one actuator controlled by the control device for mechanically exciting the compressor device and/or the housing with a signal in the opposite direction to the detected vibrations.

[0008] An Active Noise Control system described in patent application US2007003071 controls noise produced by a noise source comprises:

- an acoustic sensor to sense a noise pattern and to produce a noise signal corresponding to the sensed noise pattern,
- an estimator to produce a predicted noise signal by applying an estimation function to the noise signal, wherein the predicted noise signal includes an estimation of a predicted sample of the noise signal, which is successive to a

current sample of the noise signal, and wherein the estimator is to estimate the predicted sample by applying the estimation function to the current sample and to one or more samples preceding the current sample of the noise signal; and

- an acoustic transducer to produce a noise destructive pattern based on the predicted noise signal.

[0009] The acoustic transducer comprises a speaker,

wherein said acoustic sensor comprises an array of two or more microphones, wherein the two or more microphones are in two or more, respective, locations, wherein the two or more microphones are adapted to achieve coherence between the sensed noise pattern and the noise produced by the noise source, by considering at least one or more of:

- geometric structure of a path between said microphones and the noise source;
- aerodynamic attributes of the path between said microphones and the noise source;
- surface roughness along the path between said microphones and the noise source;
- turbulent airflow along the path between said microphones and the noise source;
- formation of acoustic signals along the path between said microphones and the noise source.

[0010] This solution needs to have a recording of the actual noise, at least one reference signal recorded closer to the noise source and this signal needs to be correlated to the cancelled noise in the target zone. The system filters this signal to transform it into the cancellation loudspeaker drive signal.

Description of the invention

[0011] The present invention is directed towards cancellation of sounds without the need for a recording of the primary sound, i.e. the sound to be cancelled. In contrast to US2007003071 the system according to the invention is based on feed forward tonal ANC, wherein the reference signals that are transformed into the cancellation signals are pure sinusoidal waves of a single frequency (each).

[0012] The main objective of the invention is to create maximum destructive interference at the source of the noise by matching the acoustic noise spatially and temporally, adjusting the phase and amplitude of the cancellation signal, in order to create an omnidirectional sound cancellation effect. The efficiency of the system mostly depends on the directivity pattern, orientation, and positioning of the cancellation source, which has not yet been addressed by prior art documents. The technical problem is solved as defined in the independent claim, while preferred embodiments of the invention are described in dependent claims.

[0013] The following expressions used throughout the text have the following meaning:

Primary noise source	source of noise to be cancelled, for example the noise of a heat pump, a compressor of the heat pump, an air conditioning unit, a motor, or any other noise-generating device, also termed disturbance, as it is a disturbing feature in the environment.
----------------------	---

Secondary noise source	source of cancellation noise, i.e., the noise used to cancel the primary noise.
Compartment	any confined space inside which there are no physical barriers.
Low frequency noise	Noise with a wavelength longer than the longest enclosure dimension.
Mid frequency noise	Noise with a wavelength longer than the shortest enclosure dimension.
High frequency noise	Noise with a wavelength shorter than the shortest enclosure dimension.
Reference signal	A set of internally/mathematically generated sinusoidal signals that match the frequency of the targeted narrow- band noise component.
Error signal	Signal recorded at the cancellation location by the error microphone. During operation this signal is the sum of primary and secondary noise.

(continued)

Disturbance signal	Noise only due to the primary noise source, excluding the effect of the control system. When ANC is off error = disturbance. When the controller is on, the error signal becomes smaller than the disturbance as the controller works to minimise this signal.
Secondary path transfer function	signal transformation from the controller output to the error microphone.
Harmonic	Integer multiples of a fundamental frequency.

[0014] The essence of the invention is positioning and orientation of the source of cancellation sound, i.e., the secondary noise source, which is installed at, next to, or in the vicinity of the noise source to be cancelled, i.e., the primary noise source, and most importantly in the same compartment as the primary noise source. As defined above, the same compartment means that there are no obstacles (physical barriers) between the source of cancellation sound and primary noise source. The size, i.e., dimensions of the compartment are preferably smaller than the wavelength of the noise to be cancelled to cancel low frequency noise. The cancellation sound source is preferably a speaker an acoustic exciter or vibration exciter, which is configured to emit a secondary noise that spatially and temporally matches the primary source, but with a suitable phase shift/lag. Active noise control is thus achieved within the compartment, but this can also reduce the amount of sound energy radiated out of this compartment that contains the source, hence achieving noise reduction outside of the controlled compartment, which is important for users.

[0015] In a possible embodiment, the cancellation source can be positioned as close to the acoustic centre of the primary noise source, as the separation between the two noise sources is thus much smaller than the wavelength of the noise to be cancelled.

[0016] One cancellation source can cancel noise from at least one primary noise source provided they are all in that compartment, i.e., not having a barrier between them. In case several primary noises are present in different compartments, one cancellation source is provided in each of the compartments and operated (controlled) separately as the frequency and operation of the primary noise source is not necessarily the same. However, interdependency is possible, but needs to be accounted for in control algorithm design. For example, when two microphones for emitting cancellation noise are installed in two different compartments, some information must be shared between the two controllers so they don't bother one another, because cancellation signals from both loudspeakers will also reach the neighbouring compartment.

[0017] Further, an error microphone is measuring the sound in the compartment as measured at the error microphone and its measurements represent an input for an algorithm that is adjusting operation of the cancellation noise source to minimize the sound pressure. Ideally, the secondary noise is the exact opposite of the primary noise and their sum is zero. In practice, it is more realistic that their sum is smaller than the primary noise and the error is the residual noise that is still present after cancellation. The error microphone arranged to be installed in the vicinity of the primary noise source, for example compressor of the heat pump, wherein the measured sound at its location is acquired by the controller. The error microphone can be installed on a holder or suspended on a cable or placed in any other suitable manner that ensures location in the air near the primary noise source.

[0018] Control of the system according to the invention is achieved with a suitable controller. The controller of the system receives input from the error microphone and adjusts parameters of the source of cancellation noise based on frequency analysis.

[0019] The invention includes a method to determine the primary noise, i.e., the disturbance, while the system is operating; this is done by subtracting the known cancellation signal from the recorded total signal, ending up with the disturbance (uncancelled). During operation of the system the following equation describes the situation:

$$\text{error signal} = \text{disturbance} + \text{control effort} \times \text{secondary path transfer function}$$

wherein $\times$ denotes convolution and the control effort is the secondary noise signal at source or control output signal.

[0020] The system records the error signal with the error microphone, knows the control effort and in form of the system calibration, it has an estimate of the secondary path transfer function. Therefore, the equation can be rearranged to:

$$\text{disturbance} = \text{error signal} - \text{control effort} \times \text{secondary path transfer function}$$

[0021] By solving this calculation, the disturbance signal, i.e., what the noise would be without the noise control

(cancellation sound) can be estimated during operation without turning the controller off. Since the effect of the controller can effectively be removed, this signal can be used for continuous frequency detection.

[0022] Another advantage of calculating the disturbance signal is that it allows real-time ANC performance monitoring and stability control. The performance of the ANC system can be measured as the difference in sound pressure with and without the controller. Having an estimate of the disturbance and an actual recording of the error signal allows real time performance monitoring without temporarily disabling and enabling the controller. The obtained performance metric for each controlled components can be compared to expected levels and if the readings deviate, instabilities or other anomalies can be detected. Accordingly, control parameter updates can be made to attempt to return to a stable operating state. If this is not possible, the controller can be disabled remotely and an engineer can be notified. This way, the system can detect and address instabilities automatically.

[0023] A single channel feed-forward tonal ANC can work with one microphone in the enclosure; however, it is preferred to use two microphones, one of them being the error microphone and the second is a microphone for measuring frequency of the primary noise source. Namely, in order to suitably operate and adjust the secondary noise source with the controller, at least one set of reference signals is generated based on the frequency reading from the microphone dedicated for frequency detection of the primary noise source using the acoustic disturbance in the enclosure, wherein the reference signals that are transformed into the cancellation signals are pure sinusoidal waves of a single frequency (each). Reference signals for transformation into cancellation signals are generated internally/mathematically to match the frequency of the tone to be cancelled in any manner known to a skilled person, hence in comparison to broadband ANC there is no actual noise signal recording necessary. Using a microphone for frequency measurement in the enclosure is the least intrusive and cheapest method to detect frequency and does not require any modifications to the noise source. However, the microphone could also be any suitable sound or vibration measurement device, such as an accelerometer or other sensor that provides output based on which the frequency of operation of the primary noise can be deduced, or any device that can measure rotational speed/angular velocity of a relevant component of the machine.

[0024] The microphone for measuring frequency of the noise to be cancelled is installed at, next to or in the vicinity of the primary noise source so that the correct primary noise is measured, as this is the noise to be cancelled and on which the secondary noise source is based. The frequency measurement microphone is positioned such that it is influenced as little as possible by the cancellation noise. The controller based on the signal from the frequency measurement microphone determines the controller target frequencies using any suitable method, such as a Fast Fourier Transform (FFT), wherein spectral peaks/local maxima related to the relevant rotation frequencies are detected in the frequency domain. Relevant target frequencies can also be determined in the time or frequency domains in any suitable manner known to the skilled person. For example, a Hall effect sensor, a tachometer, stroboscope or similar can be used. A rotating source also creates a complex structure of harmonic components. Further, analysis can be performed on the frequency spectrum in any manner known to the skilled person, to determine the order of the most dominant component in the noise spectrum and the corresponding frequencies suitable for active noise control in a particular installation.

[0025] The system preferably performs the following steps:

- the sound/vibration measurement device captures primary noise as close as possible to the noise source,
- Fast Fourier transformation is performed to obtain the frequency domain representation (spectrum) of the captured noise signal.
- the algorithm is executed to find local maxima in the spectrum. The search is limited to a frequency range where the first detected local maximum likely corresponds to the fundamental frequency or a low order harmonic of the angular velocity of primary noise source or any other dominant disturbance created by the primary noise source.
- the algorithm also determines the order of the detected component and the corresponding fundamental frequency and/or the remaining harmonic frequencies are calculated based on this information in any known manner,
- The algorithm identifies frequencies suitable for active noise control and assigns these to the reference signal generation component of the system, enabling control of these frequencies.

[0026] Success of harmonics detection is marked and if for a pre-defined time (for example 10 to 60 seconds), the frequency and harmonics are consistent, the noise source is considered to be in a "stable state", and noise cancellation is activated. At any detected change outside of pre-set boundaries, cancellation is turned off until stable state is reached again. With this method the adverse effects of this active control system going unstable are minimised.

[0027] The system for acoustic noise control according to the preferred embodiment of the invention comprises:

- the controller (also termed control electronics) comprising:
 - a microcontroller, a PC, a real-time computer, a Digital-Signal-Processor (DSP), Field-Programmable-Gate-Array (FPGA), or other suitable devices arranged to run an algorithm for adapting signal processing parameters

to alter the cancellation wave's amplitude and phase to minimize loudness at the measurement position (at noise source),

- sound input and output channels, wherein the input channel is configured to convert an error microphone and frequency detection microphone signals to digital input data, while the output channel is for converting digital output data to the cancellation sound source signal, at least one source of cancellation sound installed at, next to or in the vicinity of the noise source in the same compartment as the noise source with no physical obstacles between the source of cancellation sound and source of the noise to be cancelled, said source of cancellation sound being controlled by the controller and arranged to emit sound with desired and adjustable parameters, i.e., amplitude, frequency, and phase, to achieve maximal possible destructive acoustic interference at the error microphone,
- the error microphone,
- the sound/vibration measurement device, preferably the microphone configured to detect frequency of the primary noise source.

[0028] In a preferred embodiment, the controller runs an adaptive algorithm that adapts its performance based on the error signal obtained with the error microphone. The system makes small steps in every control loop to minimize noise at the error microphone. Instability can occur if the system for any reason makes a step in the wrong direction that increases noise compared to the last loop. In most minor cases the system can recover in consequent loops, but divergence can also occur, which practically means that the controller makes the primary noise source louder. This can occur due to an unexpected external event, transducer failure or improper controller settings.

[0029] The system preferably comprises sound-based predictive maintenance algorithms with machine learning. Thus, the system according to the invention is adaptive, i.e., based on previous situations, noises and suitable cancellation sound parameters defines the optimal operation parameters to achieve effective noise cancelling. Machine learning may be implemented in any manner known to the skilled person, wherein training sets are previous operation parameters of the system and/or simulation results.

[0030] In a preferred embodiment, the controller is connected to a cloud or a computer linked to the internet, thus enabling real-time monitoring, tuning and remote updating. Acoustic performance data may be collected remotely in order to improve the system stability. Any adjustments may be done without disturbing any users or inhabitants of the area around the noise source.

[0031] The computer monitors the primary noise parameters and determines the operational logic based on this (when it is turned off/on, when it is louder, etc.). The controller executes cancellation of the primary noise, wherein the computer executes adjustments and sends instructions to the controller. The computer preferably allows remote access via VPN and is connected to a cloud having a database, in which all data from all connected devices (sources of primary noise) are stored for analysis, future settings and possible machine learning.

[0032] The method according to the invention performed by the system as described above comprises the following steps:

- measuring the frequency of the primary noise source, thus generating a reference signal for the controller,
- generating a sound wave or waves with the cancellation noise source based on the reference signal, with actively regulated amplitude, frequency, and phase, to achieve destructive acoustic interference at measurement position (location of the error microphone),
- measuring the sound pressure level at the error microphone in real-time, and adjusting the mentioned parameters of cancellation sound wave, if necessary,
- performing iteration through different settings of the above-mentioned parameters with the algorithm ran by the controller to achieve minimal loudness at the measurement position (at noise source),
- tracking of frequency of operation using the sound/vibration measurement device.

[0033] The controller runs the algorithm, which utilises filters and other signal processing algorithms for the acoustic analysis and adjustment of the system according to the invention denoting all things related to processing that is done to the signals from the point they enter the controller to the point they exit it. The controller thus adjusts/updates a pair of filters that together change amplitude and phase of the output, i.e., the source of the cancellation sound. These filters cannot change the controller target frequency, that happens by altering the frequency of the reference signal in the reference generation part of the system.

[0034] Main advantages of the invention as described above are:

- the system does not influence the heat pump settings or configuration (operation mode) and thus does not compromise the efficiency of heat pump performance,
- the system requires no access to heat pump electronics or firmware,

- potential tonal noise originating from components other than the fan or the compressor can be cancelled as well, and
- the system may be integrated as an add-on product/solution or can be installed during manufacturing of heat pumps.

[0035] The invention will be further described using examples and figures, which show:

Figure 1 A typical heat pump assembly showing fan and compressor as main primary noise sources, and a particular embodiment of the noise cancelling system in place

Figure 2 System electronics and cloud components breakdown

Figure 3 Measurements of noise reduction on an actual heat pump during real-time operation, which is at 122Hz is approximately 12 dB using the system according to the preferred embodiment, wherein said measurements were performed in the exterior of the heat pump enclosure to assess the effect of the system in a user-oriented manner.

[0036] The system and the method for acoustic noise control is particularly useful for noise control of heat pumps but can also be adapted for noise control of AC systems, compressor systems, ventilation, and other HVAC systems, as well as motors, engines and similar, as mentioned above. The detailed description of the invention will be presented in connection with heat pumps.

[0037] A typical heat pump outdoor unit as shown in figures 1 and 2 comprises two primary components that are identified as most common noise sources: the fan 5.1 and the compressor 5.2, as shown in figure 1. The major noise source is usually the outdoor unit. The system according to the preferred embodiment performs low frequency acoustic noise cancellation at-source, i.e., the cancellation noise source 2 is installed in the interior of said outdoor unit, placed in the compressor 5.2 compartment 8.2. It could also be installed in the fan 5.1 unit 8.1, depending on which noise source is louder. Two different cancellation noise sources 2 could also be installed, each in its own compartment 8.1, 8.1. inside one enclosure 1, i.e., one in the compressor compartment 8.2 and one in the fan compartment 8.1. Both compartments 8.1 and 8.2 are divided with a wall 6, hence constituting two separate compartments, each thus needing its own cancellation source 2. Namely, installation is such that there is no barrier between the cancellation noise source 2 and the compressor 5.2 of the outdoor unit, which is the main noise source. The size, i.e., dimensions of this compartment are smaller than the wavelength of the noise to be cancelled. The cancellation sound source 2 is preferably a speaker an acoustic exciter or vibration exciter, which is configured to emit a secondary noise that spatially and temporally matches the primary source, but with a suitable phase shift/lag.

[0038] The system for acoustic noise control according to the preferred embodiment of the invention comprises:

- a controller 7 (also termed control electronics) comprising:

- a microcontroller, a PC, a real-time computer, a Digital-Signal-Processor (DSP), Field-Programmable-Gate-Array (FPGA), or other suitable devices arranged to run an algorithm for adapting signal processing parameters to alter the cancellation wave's amplitude and phase to minimize loudness at the measurement position (at noise source),

- sound input and output channels, wherein the input channel is configured to convert an error microphone 3 and frequency detection microphone 4 signals to digital input data, while the output channel is for converting digital output data to the cancellation sound source signal, at least one source of cancellation sound 2 installed at, next to or in the vicinity of the noise source in the same compartment 8.1, 8.2 as the noise source 5.1, 5.2 with no physical obstacles between the source of cancellation sound and source of the noise to be cancelled, said source of cancellation sound being controlled by the controller and arranged to emit sound with desired and adjustable parameters, i.e., amplitude, frequency, and phase, to achieve maximal possible destructive acoustic interference at the error microphone,
- an error microphone 3 for measuring the sound in the compartment 8.1, 8.2 (disturbance, i.e. primary noise, and the cancellation signal), which represents an input for an algorithm that is adjusting operation of the cancellation noise source 2, wherein the error microphone 3 is installed in the vicinity of the compressor 5.2 of the heat pump, wherein the measured sound at its location is acquired by the controller 7, and wherein the error microphone 3 is installed on a holder or suspended on a cable or placed in any other suitable manner that ensures location in the air near the primary noise source 5.2,
- the frequency measurement device 4, preferably a microphone configured to provide output based on which the frequency of operation of the primary noise 5.1, 5.2 can be determined, installed as close as possible to the compressor 5.2, away from the direct view of the cancellation loudspeaker, so that the compressor noise is dominating at the microphone.

[0039] The described preferred system buffers samples, approximately 1s, of audio data from the frequency detection microphone. A Fast Fourier Transform (FFT) of this finite buffer gives a frequency spectrum, and the algorithm finds a frequency bin with the highest energy in the range where peak noise is expected. The range may be 80-200 Hz. The frequency that corresponds to the highest energy bin gives an approximate target frequency. A 1 second long FFT gives a 1 Hz frequency resolution which is typically insufficient (for instance the system may detect 100 Hz but the actual frequency may be 100.46 Hz). In order to refine the detected frequency, the neighbouring bins are used to determine how much energy is 'leaked' to adjacent frequency bins and uses this information to estimate what exact frequency would 'distribute' energy in three frequency bins this way. This algorithm cannot identify what component it finds in the harmonic chain, it just detects the most dominant component in the set range. For instance, the system may detect 180Hz. If this is the third harmonic, frequencies 60 Hz, 120 Hz, 180 Hz, 240 Hz and 300 Hz are controlled. If this is the second harmonic, frequencies 90 Hz, 180 Hz, 270 Hz are controlled, etc.

[0040] Operation of heat pumps is tracked to identify different operation modes. The frequency measurement device is configured to measure the compressor frequency/rotation speed acoustically. Based on this the cancellation sound may be adjusted and optimal or near-optimal ANC is achieved. An alternative to this is a digital connection between the heat pump control unit and the ANC system where the pump controller could send rotation speed data to the ANC. Another alternative is rotation speed measurement using a tachometer or an accelerometer. The advantage of acoustic frequency measurement is that there is no modification needed to the compressor or heat pump control electronics.

[0041] Figure 2 shows a configuration of the system with remote control, wherein each system with the microcontroller 7.1 and the computer 7.2 is connected to a cloud 9 and a server 9.1, wherein a database 9.2 with all data is established and a dashboard 9.3 is configured to show data of primary noises 5.1, 5.2, cancellation noises emitted by the cancellation sound source(s) 2, settings, etc.

[0042] The above-described preferred system has been used on an operating heat pump operating in real settings. Figure 3 shows results of the noise reduction 1m away from the heat pump. The measurements show a noise reduction at 122Hz of approximately 12 dB (difference in tonal component level at 122 Hz with and without the control system operating).

Reference signs overview:

[0043]

- 1 Enclosure
- 2 Cancellation sound source
- 3 Error microphone
- 4 Frequency detection device
- 5.1 Primary noise source (fan)
- 5.2 Primary noise source (compressor)
- 6 Wall between compartments
- 7 System control electronics
- 7.1 Microcontroller
- 7.2 a computer connected to the internet
- 7.3 Audio amplifier
- 8.1 Fan Compartment
- 8.2 Compressor compartment
- 9 Cloud system
- 9.1 Server
- 9.2 Database
- 9.3 Dashboard

Claims

1. A system for acoustic noise control comprising:

- at least one source (2) of cancellation sound, i.e., a secondary source, which is configured to emit the secondary noise that spatially and temporally matches a primary noise (5.1, 5.2) to be cancelled, but with a suitable phase shift/lag, wherein said secondary source (2) is installed at, next to, or in the vicinity of a source of the primary noise (5.1, 5.2), in a same compartment (8.1, 8.2) as the primary noise source (5.1, 5.2) without any physical barriers (6) between the primary (5.1, 5.2) and the secondary source (2),

- an error microphone (3) installed in the vicinity of the primary noise source (5.1, 5.2) and arranged to measure the sound, which is a combination of the primary and secondary noise, in the compartment (8.1, 8.2), wherein measurements of the error microphone (3) represent an input for an algorithm run on a controller (7) that is arranged for adjusting operation of the cancellation noise source (2),
 - the controller (7) for controlling the system arranged to receive input from the error microphone (3) and to adjust parameters of the cancellation noise source (2).

2. The system according to claim 1, wherein the compartment (8.1, 8.2) has dimensions smaller than the wavelength of the noise to be cancelled.

3. The system according to any preceding claims, wherein the system further comprises a sound/vibration measurement device (4) configured measure frequency of the primary noise (5.1, 5.2), preferably a microphone or an accelerometer.

4. The system according to any preceding claims, wherein the system further comprises sound input and output channels, wherein the input channel is configured to convert an error microphone (3) and frequency detection device (4) signals to digital input data, while the output channel is for converting digital output data to the cancellation sound source (2) signal, said source of cancellation sound being controlled by the controller (7) and arranged to emit sound with desired and adjustable parameters to achieve maximal possible cancellation of the primary noise source (5.1, 5.2).

5. The system according to the preceding claim, wherein said parameters are one or more selected in the group comprising: amplitude, frequency, and phase of sound emitted by the cancellation sound source (2).

6. The system according to any of the preceding claims, wherein the controller based on measurements by the frequency measurement device (4) determines a target frequency based on a Fast Fourier Transform (FFT), wherein peaks in the frequency domain are detected and harmonic analysis is performed in any manner known to a skilled person in fundamental to detect which harmonic a detected peak is and which is the most dominant component, wherein the cancellation sound source (2) is adjusted by the controller (7) accordingly.

7. The system according to any preceding claims, wherein the error microphone (3) is installed on a holder or suspended on a cable or placed in any other suitable manner that ensures location in the air near the primary noise source (5.1, 5.2).

8. The system according to any of the preceding claims, wherein the cancellation sound source (2) is a speaker an acoustic exciter or vibration exciter.

9. The system according to any of the preceding claims, wherein the cancellation sound source (2) is positioned as close to the acoustic centre of the primary noise source (5.1, 5.2) as possible.

10. The system according to any of the preceding claims, wherein more cancellation sound sources (2) are present to cancel one or more primary sources (5.1, 5.2).

11. The system according to any of the preceding claims, wherein the system is arranged to determine the primary noise, i.e., the disturbance during operation of the system by subtracting the known cancellation sound signal from the measured total sound by the error microphone (3), ending up with the disturbance.

12. The system according to any of the preceding claims, wherein the controller is connected to a cloud (9) or a computer (7.2) linked to the internet, to enable real-time monitoring, tuning and remote updating.

13. The system according to the preceding claim, wherein

the computer (7.2) is arranged to monitor the primary noise parameters, to determine the operation based on this, to execute adjustments of the cancellation and to send instructions to the controller (7), and wherein the cloud (9) has a database (9.2), in which all data from all connected sources of primary noise are stored for analysis, future settings and possible machine learning.

14. The system according to any of the preceding claims used for noise control of heat pumps, wherein the cancellation noise source (2) is installed in the interior of an outdoor unit of the heat pump, preferably in the compressor (5.2)

compartment (8.2).

15. A method for acoustic noise control performed with the system according to any of the preceding claims, wherein said method comprises the following steps:

- a) measuring the frequency of the primary noise source (5.1., 5.2), thus generating a reference signal for the controller (7),
- b) generating a sound wave or waves with the cancellation sound source (2) based on the reference signal, with actively regulated amplitude, frequency, and phase, to achieve destructive acoustic interference at measurement position (location of the error microphone),
- c) measuring the sound pressure level at the error microphone (3) in real time, and adjusting the mentioned parameters of cancellation sound source (2), if necessary,
- d) adapting signal processing parameters to alter the cancellation wave's amplitude and phase with the algorithm ran by the controller (7) to minimize loudness at the measurement position (at primary noise source),
- e) tracking of frequency of operation using the sound/vibration measurement device (4).

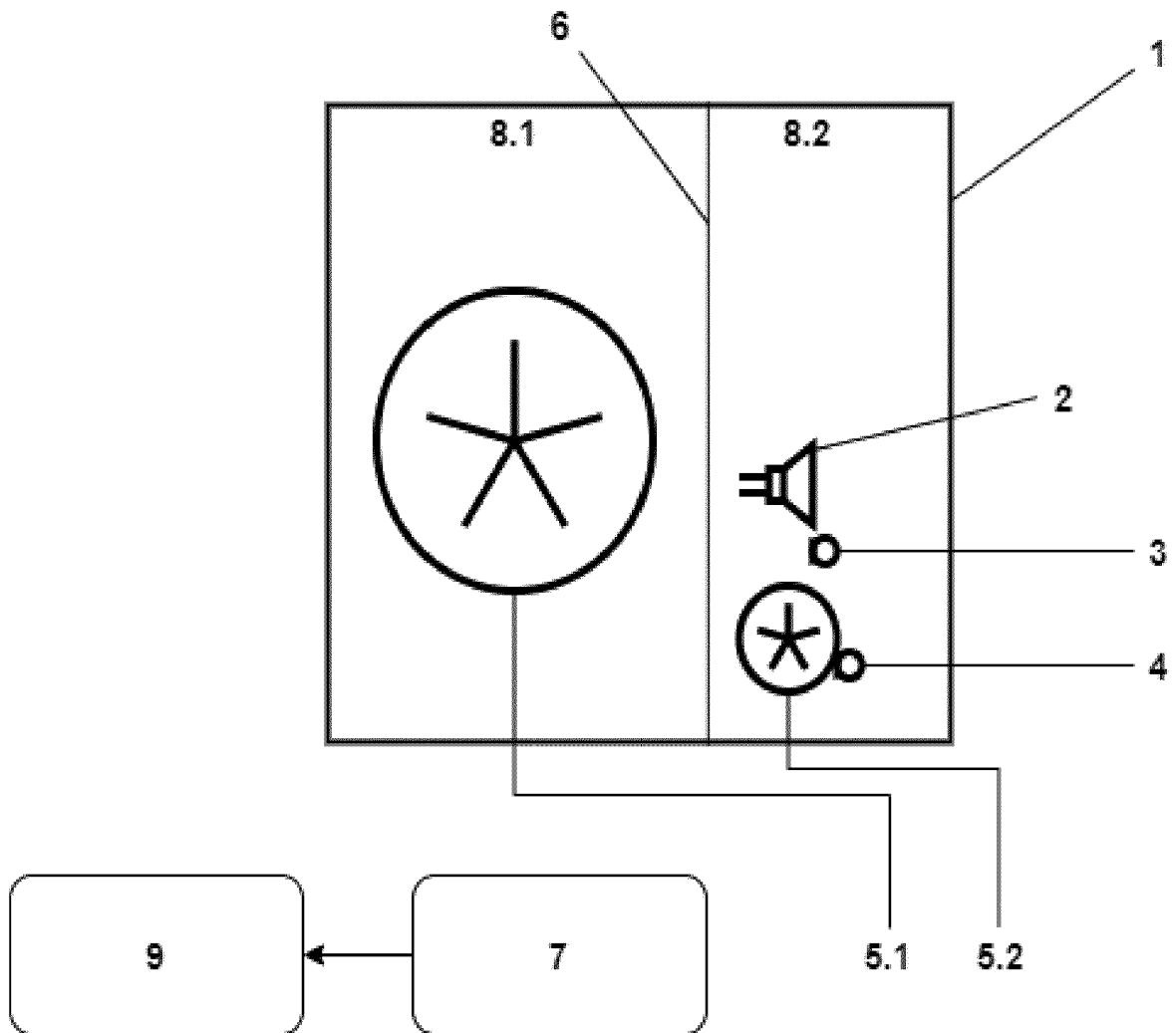


Figure 1

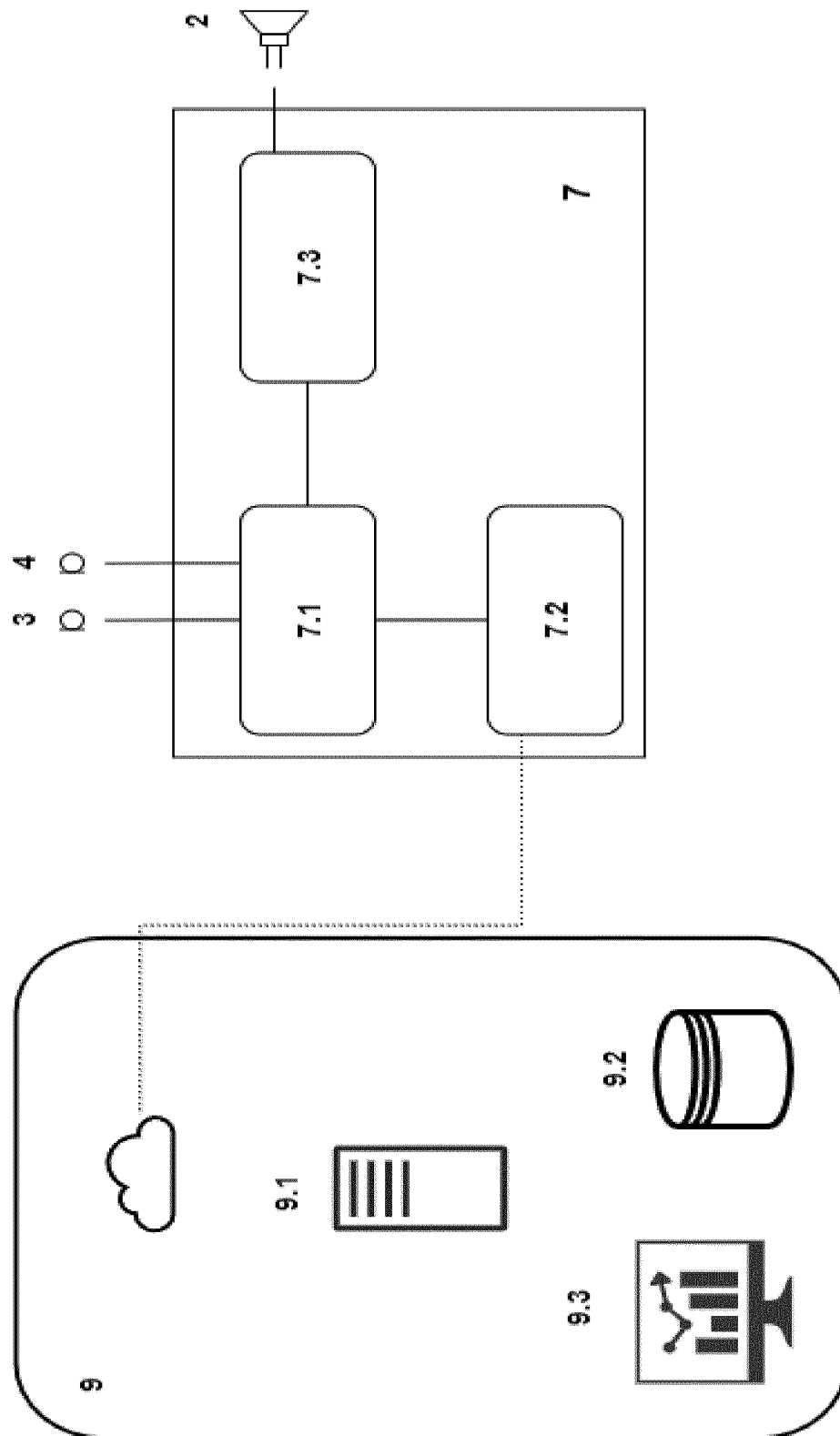


Figure 2

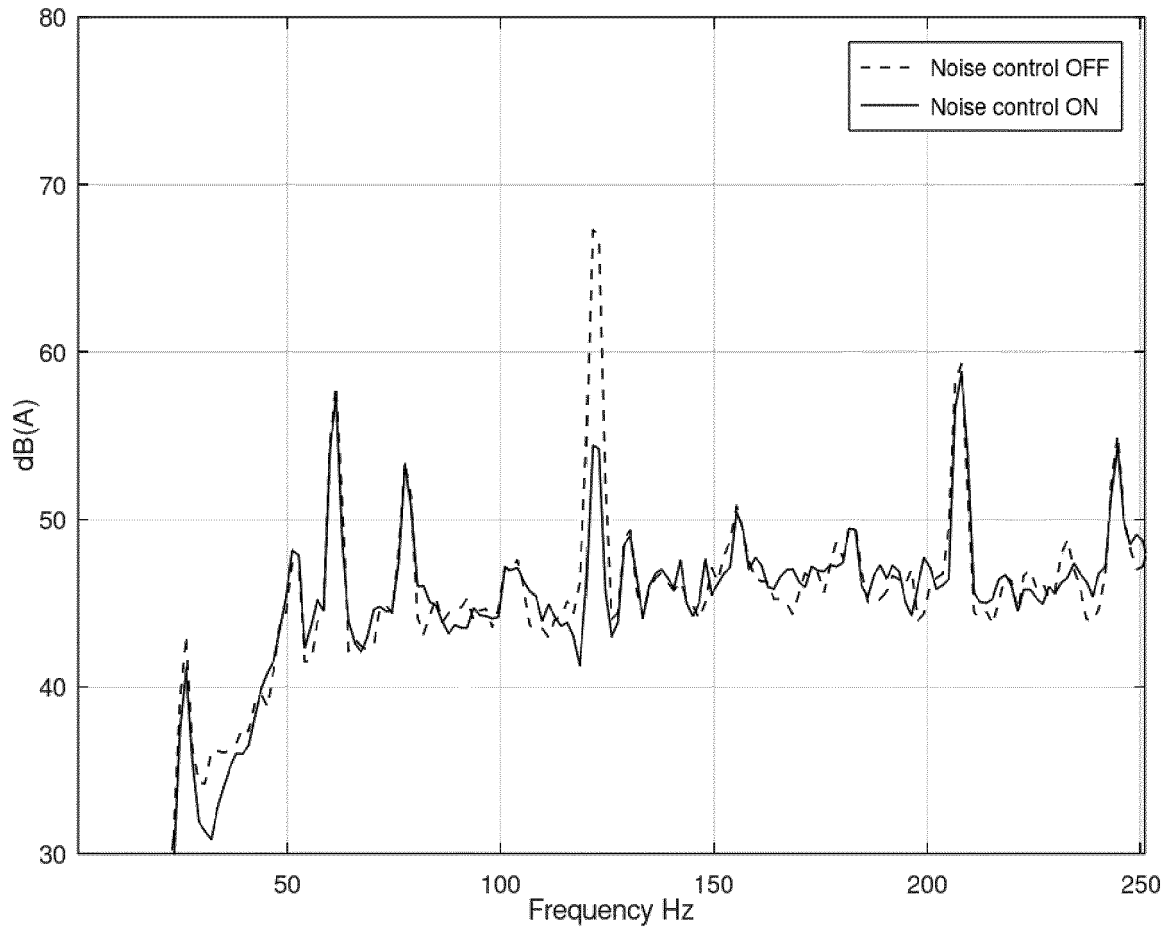


Figure 3



EUROPEAN SEARCH REPORT

Application Number

EP 23 15 4360

5

10

15

20

25

30

35

40

45

50

55

2

EPO FORM 1503 03:82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 94/09484 A1 (NOISE CANCELLATION TECH [US]; FULLER CHRIS [US] ET AL.) 28 April 1994 (1994-04-28)	1, 3-5, 7-11, 15	INV. G10K11/178
Y	* page 3, line 5 - page 5, line 32; claims 1-16; figures 1-6 *	2, 6, 12-14	
Y	EP 0 847 576 B1 (UNITED TECHNOLOGIES CORP [US]) 21 June 2000 (2000-06-21) * paragraph [0010] - paragraph [0056]; claims 1-10; figures 1-17 *	2, 6	
Y	EP 4 068 275 A1 (SILENCER DEVICES LLC [US]) 5 October 2022 (2022-10-05) * paragraphs [0013], [0102] - paragraph [0116]; claims 1-7; figures 1-22 *	12, 13	
Y	EP 3 240 974 B1 (ROTEX HEATING SYSTEMS GMBH [DE]) 17 April 2019 (2019-04-17) * paragraph [0018] - paragraph [0024]; claims 1-9; figures 1-2 *	14	
			TECHNICAL FIELDS SEARCHED (IPC)
			G10K
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 26 June 2023	Examiner Oliveira Braga K., A
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	

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

EP 23 15 4360

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 The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

26-06-2023

10

15

20

25

30

35

40

45

50

55

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9409484 A1	28-04-1994	CA 2145862 A1	28-04-1994
		WO 9409484 A1	28-04-1994
EP 0847576 B1	21-06-2000	DE 69608964 T2	19-10-2000
		EP 0847576 A1	17-06-1998
		JP H11512194 A	19-10-1999
		KR 19990044336 A	25-06-1999
		US 5699437 A	16-12-1997
		WO 9708683 A1	06-03-1997
EP 4068275 A1	05-10-2022	AU 2018215536 A1	12-09-2019
		AU 2021257956 A1	25-11-2021
		AU 2023200080 A1	09-02-2023
		BR 112019016114 A2	14-04-2020
		CA 3052459 A1	09-08-2018
		CN 110383373 A	25-10-2019
		EP 3577643 A1	11-12-2019
		EP 4068275 A1	05-10-2022
		ES 2918204 T3	14-07-2022
		IL 268402 A	26-09-2019
		JP 7163315 B2	31-10-2022
		JP 2020507818 A	12-03-2020
		JP 2022191431 A	27-12-2022
		KR 20190116988 A	15-10-2019
		RU 2019127923 A	09-03-2021
		SG 10202111371X A	30-12-2021
		SG 11201907104T A	27-08-2019
		US 2018226064 A1	09-08-2018
		US 2020342845 A1	29-10-2020
		US 2022068252 A1	03-03-2022
		WO 2018144995 A1	09-08-2018
		ZA 201905788 B	31-08-2022
EP 3240974 B1	17-04-2019	DE 102014226997 A1	30-06-2016
		EP 3240974 A2	08-11-2017
		WO 2016107815 A2	07-07-2016

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 2011274283 A1 [0003]
- EP 3240974 A2 [0004]
- US 20180163989 A1 [0005]
- DE 102019202077 A1 [0007]
- US 2007003071 A [0008] [0011]