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(54) A POLLUTION MASK AND CONTROL METHOD

(57) A fan rotation speed or change in fan rotation speed is monitored of a mask, and from this a first value relating to magnitude of a pressure fluctuation across the fan and a second value relating to a rate of pressure fluctuation are obtained. It can then be determined whether or not the mask is worn based on the first and second values. This provides a reliable detection of whether or not the mask is worn and it requires a small amount of sampling data of the fan rotation signal, hence saving power.

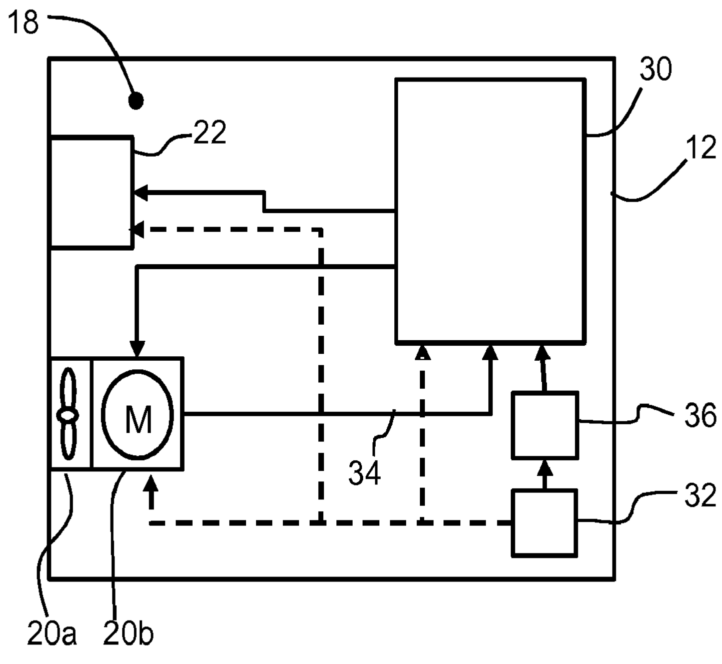


FIG. 2

EP 3 677 312 A1

Description

FIELD OF THE INVENTION

[0001] This invention relates to a pollution mask, for providing filtered air to the wearer of the breathing apparatus, with the flow assisted by a fan.

BACKGROUND OF THE INVENTION

[0002] The World Health Organization (WHO) estimates that 4 million people die from air pollution every year. Part of this problem is the outdoor air quality in cities. The worst in class are Indian cities like Delhi that have an annual pollution level more than 10 times the recommended level. Well known is Beijing with an annual average 8.5 times the recommended safe levels. However, even in European cities like London, Paris and Berlin, the levels are higher than recommended by the WHO.

[0003] Since this problem will not improve significantly on a short time scale, the only way to deal with this problem is to wear a mask which provides cleaner air by filtration. To improve comfort and effectiveness one or two fans can be added to the mask. These fans are switched on during use and are typically used at a constant voltage. For efficiency and longevity reasons these are normally electrically commutated brushless DC fans.

[0004] The benefit to the wearer of using a powered mask is that the lungs are relieved of the slight strain caused by inhalation against the resistance of the filters in a conventional non-powered mask.

[0005] Furthermore, in a conventional non-powered mask, inhalation also causes a slight negative pressure within the mask which leads to leakage of the contaminants into the mask, which leakage could prove dangerous if these are toxic substances. A powered mask delivers a steady stream of air to the face and may for example provide a slight positive pressure, which may be determined by the resistance of an exhale valve, to ensure that any leakage is outward rather than inward.

[0006] There are several advantages if the fan operation or speed is regulated. This can be used to improve comfort by more appropriate ventilation during the inhalation and exhalation sequence or it can be used to improve the electrical efficiency. The latter translates into longer battery life or increased ventilation. Both of these aspects need improvement in current designs.

[0007] To regulate the fan speed, the pressure inside the mask can be measured and both pressure as well as pressure variation can be used to control the fan.

[0008] For example, the pressure inside a mask can be measured by a pressure sensor and the fan speed can be varied in dependence on the sensor measurements. A pressure sensor is costly so it would be desirable to provide an alternative method of monitoring pressure inside a mask. Such pressure information may be used to control a fan within a powered mask, but it may be used as part of any other fan-based system where pressure information is desired.

[0009] Fan-operated masks are battery-operated devices, so that it is desirable to reduce power consumption to a minimum as well as keeping the cost to a minimum. One issue is that the fan may be left on when the mask is not being worn, and this results in unnecessary power consumption. It is possible to provide sensors dedicated to detecting when the mask is worn, but this increases the cost of the breathing mask.

[0010] When putting on the mask, a user typically activates a switch to switch on the fan. This switch adds cost to the mask, takes up space and switching on is inconvenient. An automatic electronic switch-on function would avoid disadvantages. However, this normally also requires a dedicated sensor that senses the use of the mask.

[0011] It would therefore be desirable to find a lower cost solution to detecting that the mask is worn, to enable worn to not-worn transitions and/or not worn to worn transitions to be detected.

[0012] The applicant has proposed, but not yet published, a solution in which a rotation speed of the fan is used as a proxy for pressure measurement. A pressure or a pressure change is determined based on the rotation speed of the fan. Using this pressure information it can be determined whether the mask is worn or not. This approach is described in EP 17185742.8.

[0013] When the detected pressure variation drops below a threshold, it is determined that the mask is not worn and the fan can be turned off.

[0014] This method can work well if the fan speed signal is sampled at a high sampling rate, because detailed analysis of the signal can then be conducted. However, it would be preferred to have a lower sampling rate in order to save power.

[0015] Particularly if a low sampling rate is adopted, there can arise situations where the mask turns off even though it is still worn. If the system sampling rate is too low, although the power consumption will be low, a reliable breathing signal may not be obtained. For example, a short spike in the breathing signal during talking may be missed if the sampling rate is too low. This may result in a false turn off signal.

[0016] If the system sampling rate is too high, the breathing can be tracked well, but the background noise will also be included, and there will be high power consumption.

[0017] If the user is talking, their breathing is much shallower than normal breathing and this may not be detected. Simply setting a different threshold may not be suitable because the mask may then be turned on even though it is not worn, based on detection of slight pressure changes which are not the result of breathing.

[0018] There is therefore a need for more accurate breathing detection and in a way which avoids the need for processing a large amount of sampled fan rotation data.

SUMMARY OF THE INVENTION

[0019] The invention is defined by the claims.

[0020] According to examples in accordance with an aspect of the invention, there is provided a pollution mask comprising:

an air chamber;
a filter, for example a filter which forms a boundary directly between the air chamber and the ambient surroundings outside the air chamber;
a fan for drawing air from outside the air chamber into the air chamber and/or drawing air from inside the air chamber to the outside;
a means for determining a rotation speed of the fan; and
a controller which is adapted to:

derive from the determined fan rotation speed or change in fan rotation speed a first value which, when the mask is worn, relates to a depth of breathing and a second value which, when the mask is worn, relates to a rate of breathing; and
determine whether or not the mask is worn based on the first and second values.

[0021] The first value relates to a depth of breathing when there is breathing detected, and by this is meant there is a positive correlation between the first value and the depth of breathing. The second value relates to a rate of breathing when there is breathing detected, and by this is meant there is a positive correlation between the second value and the rate of breathing.

[0022] More generally, the first value may for example relate to (i.e. correlate with) a magnitude of a pressure fluctuation across the fan (whether or not this pressure fluctuation is caused by breathing) and the second value may for example relate to (i.e. correlate with) a rate of a pressure fluctuation (whether or not this pressure fluctuation rate is caused by breathing). The pressure fluctuations are caused by breathing when the mask is worn and in normal use, whereas any detected pressure fluctuations when the mask is not worn will be caused by other factors.

[0023] The invention relates to a pollution mask. By this is meant a device which has the primary purpose of filtering ambient air to be breathed by the user. The mask does not perform any form of patient treatment. In particular, the pressure levels and flows resulting from the fan operation are intended solely to assist in providing comfort (by influencing the temperature or relative humidity in the air chamber) and/or to assist in providing a flow across a filter without requiring significant additional breathing effort by the user. The mask does not provide overall breathing assistance compared to a condition in which the user does not wear the mask.

[0024] In this system, a fan speed (for a fan which drives air into the chamber and/or expels it from the chamber) may be used as a proxy of pressure measurement. To measure the fan speed, the fan itself may be used so that no additional sensors are required. The chamber may be closed in normal use, so that pressure fluctuations in the chamber have an influence on the load conditions of the fan and hence alter the fan electrical characteristics. Similarly, the fan electrical characteristics may determine the nature of the chamber, for example its volume, and if it is an open or closed volume.

[0025] In order to detect if the mask is worn, the fan rotation signal is analyzed so that false positives (i.e. the mask is wrongly detected as not worn) and false negatives (the mask is wrongly detected as worn) are avoided. This is achieved by taking account both of the pressure fluctuation level, which is indicative of the depth of breathing when breathing is detected, as well as the rate of pressure fluctuation, which is indicative of the breathing rate when breathing is detected. In this way, normal breathing may be detected (as in the already proposed but unpublished solution of the applicant) but also the pressure fluctuations relating during speaking may also be detected. This enables reliable detection of breathing with a reduced sampling rate.

[0026] By determining if the mask is worn, the mask design enables power to be saved when the mask is not being worn, but without requiring any additional sensors. In particular, if there is no detected pressure differential across the mask, this indicates that both sides are at atmospheric pressure and the mask is not being worn. In effect, there is no longer a closed or partially closed chamber, so that the air chamber is open to the atmosphere. The fan may be turned off if it is detected that the mask is not worn. A threshold may be set for this detection, but the false detection outcomes are avoided by additionally taking account of the rate of pressure fluctuation.

[0027] The first value is for example a maximum swing in fan rotation speed during a sampling window, and the controller is adapted to set a first threshold to the first value. This swing is representative of the degree of pressure fluctuation, and hence for breathing it relates to the depth of breathing.

[0028] The sampling window is chosen to be sufficient to capture at least one full breathing cycle, for example 6 seconds to capture a full breathing cycle at the lowest breathing rate of 10 breaths per minute. The data sampling rate within the window can be selected to be as low as possible to save power and data processing. The sampling rate may be fixed so that it can cope with the fastest breathing rate. For example, for a fastest breathing rate of 30 breaths per minute, the sampling rate may be 2Hz (4 times the maximum breathing frequency).

[0029] However, an alternative option is to sample the fan rotation speed, while breathing is detected, at a rate which depends on the second value. In this way, a lowest sampling rate can be maintained, to save power,

[0030] The first threshold is for example dependent on the average fan rotation speed. Thus, the change in fan rotation speed caused by breathing may depend on the fan rotation speed itself. A greater change in fan rotation speed may result from a given breathing pattern when the fan is driven to a faster speed.

[0031] The average fan rotation speed may be obtained by measurement of preceding samples, or it may be known from the drive signal applied to the fan by the controller. Both of these options are intended to be covered.

[0032] The second value is for example a frequency based on the time between a consecutive maxima and minima in the fan rotation speed. For breathing, this is half the breathing period.

[0033] The controller may then be adapted to determine that there is breathing detected and hence the mask is worn when the first value exceeds the threshold and the second value lies in a predetermined range. Thus, to detect breathing, a certain depth of breathing is required to be detected as well as a certain range of breathing rates.

[0034] The predetermined range is for example 12 to 30 cycles per minute, corresponding to the typical range of breathing rates.

[0035] The controller may be adapted to apply a time period during which breathing must continuously not be detected before determining that the mask is not worn. In this way, the risk of falsely turning off the fan is reduced.

[0036] The filter for example forms a boundary directly between the air chamber and the ambient surroundings outside the air chamber. This provides a compact arrangement which avoids the need for flow transport passageways. It means the user is able to breathe in through the filter. The filter may have multiple layers. For example, an outer layer may form the body of the mask (for example a fabric layer), and an inner layer may be for removing finer pollutants. The inner layer may then be removable for cleaning or replacement, but both layers may together be considered to constitute the filter, in that air is able to pass through the structure and the structure performs a filtering function.

[0037] The filter thus preferably comprises an outer wall of the air chamber and optionally one or more further filter layers. This provides a particularly compact arrangement and enables a large filter area, because the mask body performs the filtering function. The ambient air is thus provided directly to the user, when the user breathes in, through the filter.

[0038] A maximum pressure in the air chamber in use is for example below 4cm H_2O, for example below 2cm H_2O, for example below 1cm H_2O, higher than the pressure outside the air chamber. If the fan is for providing an increased pressure in the air chamber (e.g. a flow into the air chamber during inhalation), it is only required to provide a small increased pressure, for example for assisting inhalation of the user.

[0039] The fan may be only for drawing air from inside the air chamber to the outside. In this way, it may at the same promote a supply of fresh filtered air to the air chamber even during exhalation, which improves user comfort. In this case, the pressure in the air chamber may be below the outside (atmospheric) pressure at all times so that fresh air is always supplied to the face.

[0040] In one example, the fan is driven by an electronically commutated brushless motor, and the means for determining rotation speed comprises an internal sensor of the motor. The internal sensor is already provided in such motors to enable rotation of the motor. The motor may even have an output port on which the internal sensor output is provided. Thus, there is a port which carries a signal suitable for determining the rotation speed.

[0041] Alternatively, the means for determining the rotation speed may comprise a circuit for detecting a ripple on the electrical supply to a motor which drives the fan. The ripple results from switching current through the motor coils, which cause induced changes in the supply voltage as a result of the finite impedance of the input voltage source.

[0042] The fan may be a two-wire fan and the circuit for detecting a ripple comprises a high pass filter. The additional circuitry needed for a motor which does not already have a suitable fan speed output can be kept to a minimum.

[0043] The mask may further comprise an outlet valve for controllably venting the air chamber to the outside. The outlet valve may comprise a passive pressure-regulated check valve or an actively driven electrically controllable valve. This may be used to make the mask more comfortable. During inhalation, by closing the valve (actively or passively), it is prevented that unfiltered air is drawn in. During exhalation, the valve is opened so that breathed out air is expelled.

[0044] The controller may be adapted to determine a respiration cycle, and to control the controllable valve in dependence on the phase of the respiration cycle. The pressure monitoring thus provides a simple way to determine inhalation phases, which may then be used to control the timing of a venting valve of the mask or to determine whether or not the mask is worn and hence in use.

[0045] The controller may be adapted to turn off the fan during an inhalation time. This may be used to save power. Shutting down the fan during inhalation may be desirable for a user who does not have difficulty breathing through the filter, to save power if configured in such a way.

[0046] Thus, the system may enable the mask to be operated in different modes as well as being turned off when it is not being worn.

[0047] The mask may further comprise:

a detection circuit for detecting induced current or voltage spikes caused by rotation of the fan when the fan is not being electrically driven; and

a start-up circuit for starting electrical driving of the fan in response to an output from the detection circuit,

[0048] This feature enables the fan to be started when a mask is worn, by detecting electrical spikes causes by manual rotation of the fan. This rotation is for example caused by the user wearing the mask and breathing through the fan, when the fan is not electrically driven. These movements are then detected, in order to provide automatic turn on of the fan. This approach does not require active sensing that the mask is worn but instead, the breathing of the user provides the energy for the sensing function. The sensing may be integrated into the fan circuitry with low overhead and low power consumption.

[0049] In this way, the fan may be used as a sensor for detecting transition from a worn to not worn status as well as from a not worn to a worn status of the mask.

[0050] Examples in accordance with another aspect of the invention provide a method of controlling a pollution mask, comprising:

drawing gas into and/or out of an air chamber of the mask using a fan which forms a boundary directly between the air chamber and the ambient surroundings outside the air chamber;
determining a rotation speed of the fan;
deriving from the determined fan rotation speed or a change in fan rotation speed a first value which, when the mask is worn, relates to a depth of breathing and a second value which, when the mask is worn, relates to a rate of breathing; and
determining whether or not the mask is worn based on the first and second values.

[0051] The first value may be a maximum swing in fan rotation speed during a sampling window, and the method comprises setting a first threshold to the first value, the second value may be a frequency based on the time between a consecutive maxima and minima in the fan rotation speed, and the method may further comprise determining that there is breathing detected and hence the mask is worn when the first value exceeds the threshold and the second value lies in a predetermined range.

[0052] The fan may be turned off if it is detected that the mask is not worn.

[0053] The fan speed is thus used as a proxy for measurement of a pressure or relative pressure and this proxy measurement is used to detect whether or not the mask is being worn based on both the depth of breathing and rate of breathing. These must both be consistent with breathing of the user.

[0054] The method may comprise driving the fan using an electronically commutated brushless motor, and the rotation speed is determined by an internal sensor of the motor. Alternatively, the rotation speed may be obtained by detecting a ripple on the electrical supply to a motor which drives the fan. This may be applied to any type of motor, such as a conventional DC motor with brushes.

[0055] The mask may comprise an electrically controllable valve for controllably venting an air chamber to the outside. A respiration cycle may then be determined from the pressure monitoring system, and the method may comprise controlling the controllable valve in dependence on the phase of the respiration cycle. The mask may instead simply have a pressure-regulating release valve.

BRIEF DESCRIPTION OF THE DRAWINGS

[0056] Examples of the invention will now be described in detail with reference to the accompanying drawings, in which:

Figure 1 shows a pressure monitoring system implemented as part of a face mask;
Figure 2 shows one example of the components of the pressure monitoring system;
Figure 3 shows a rotation signal during inhalation and during exhalation; and
Figure 4 shows a circuit for controlling the current through one of the stators of a brushless DC motor;
Figure 5 shows a detection circuit and start-up circuit applied to the circuit of Figure 4;
Figures 6A to 6C show different sampling options for sampling a fan rotation signal;
Figure 7 shows the pressure variation and variation in fan speed for different breathing types including talking;
Figure 8 shows the pressure variation and variation in fan speed during talking;
Figure 9 shows a first mask operating method; and
Figure 10 shows a second mask operating method.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0057] The invention provides a pollution mask. A fan rotation speed or change in fan rotation speed is monitored, and from this a first value relating to magnitude of a pressure fluctuation across the fan and a second value relating to a rate of pressure fluctuation are obtained. It can then be determined whether or not the mask is worn based on the first and second values. This provides a reliable detection of whether or not the mask is worn and it requires a small amount of sampling data of the fan rotation signal, hence saving power.

[0058] A first detection function is to provide fan rotation speed monitoring (as a proxy for pressure measurement) and use this to detect if the mask is worn or not, and in particular it enables a transition from worn to not worn to be detected. A second detection function is to enable a transition from not worn (and with the mask fan turned off) to worn to be detected.

[0059] Both detection functions aim to avoid requiring significant power consumption from any sensors, and without requiring significant additional hardware complexity.

[0060] Figure 1 shows a monitoring system implemented as part of a face mask.

[0061] A subject 10 is shown wearing a face mask 12 which covers the nose and mouth of the subject. The purpose of the mask is to filter air before it is breathed in the subject. For this purpose, the mask body itself acts as an air filter 16. Air is drawn in to an air chamber 18 formed by the mask by inhalation. During inhalation, an outlet valve 22 such as a check valve is closed due to the low pressure in the air chamber 18.

[0062] The filter 16 may be formed only by the body of the mask, or else there may be multiple layers. For example, the mask body may comprise an external cover formed from a porous textile material, which functions as a pre-filter. Inside the external cover, a finer filter layer is reversibly attached to the external cover. The finer filter layer may then be removed for cleaning and replacement, whereas the external cover may for example be cleaned by wiping. The external cover also performs a filtering function, for example protecting the finer filter from large debris (e.g. mud), whereas the finer filter performs the filtering of fine particulate matter. There may be more than two layers. Together, the multiple layers function as the overall filter of the mask.

[0063] When the subject breathes out, air is exhausted through the outlet valve 22. This valve is opened to enable easy exhalation, but is closed during inhalation. A fan 20 assists in the removal of air through the outlet valve 22. Preferably more air is removed than exhaled so that additional air is supplied to the face. This increases comfort due to lowering relative humidity and cooling. During inhalation, by closing the valve, it is prevented that unfiltered air is drawn in. The timing of the outlet valve 22 is thus dependent on the breathing cycle of the subject. The outlet valve may be a simple passive check valve operated by the pressure difference across the filter 16. However, it may instead be an electronically controlled valve.

[0064] There will only be a raised pressure inside the chamber if the mask is worn. In particular the chamber is closed by the face of the user. The pressure inside the closed chamber when the mask is worn will also vary as a function of the breathing cycle of the subject. When the subject breathes out, there will be a slight pressure increase and when the subject breathes in there will be a slight pressure reduction.

[0065] If the fan is driven with a constant drive level (i.e. voltage), the different prevailing pressure will manifest itself as a different load to the fan, since there is a different pressure drop across the fan. This altered load will then result in a different fan speed.

[0066] The first detection function is based in part on the recognition that the rotation speed of a fan may be used as a proxy for a measurement of pressure across the fan. It is also based in part of the recognition that pressure levels and cyclic frequency rates may be used to determine whether or not the mask is worn. The invention combines these considerations to create a mask which can save power by switching off when it is not worn, and without requiring complex or costly additional sensors.

[0067] For a known pressure (e.g. atmospheric pressure) at one side of the fan, the pressure monitoring enables determination of a pressure, or at least a pressure change, on the other side of the fan. This other side is for example a closed chamber which thus has a pressure different to atmospheric pressure. However, by detecting an equal pressure on each side the fan, it can then be determined that the chamber is not closed but is connected to atmospheric pressure on both sides.

[0068] This absence of a fan speed variation may thus be used to determine that the mask is not worn and hence not in use. This information can be used to switch off the fan to save power.

[0069] The applicant has already proposed (but not yet published) a pressure monitoring system which has a means for determining a rotation speed of the fan and a controller for deriving a pressure or detecting a pressure change from the rotation speed of the fan. It is then also proposed to use that pressure information to determine whether the mask is worn or not.

[0070] The means for determining a rotation speed may comprise an already existing output signal from the fan motor or a separate simple sensing circuit may be provided as an additional part of the fan. However, in either case fan itself is used so that no additional sensors are required.

[0071] Figure 2 shows one example of the components of the proposed pressure monitoring system. The same components as in Figure 1 are given the same reference numbers.

[0072] In addition to the components shown in Figure 1, Figure 2 shows a controller 30, a local battery 32 and a means 36 for determining the fan rotation speed.

[0073] The fan 20 comprises a fan blade 20a and a fan motor 20b. In one example, the fan motor 20b is an electronically commutated brushless motor, and the means for determining rotation speed comprises an internal sensor of the motor. Electronically commutated brushless DC fans have internal sensors that measure the position of the rotor and switch the current through the coils in such a way that the rotor rotates. The internal sensor is thus already provided in such motors to enable feedback control of the motor speed.

[0074] The motor may have an output port on which the internal sensor output 34 is provided. Thus, there is a port which carries a signal suitable for determining the rotation speed.

[0075] Alternatively, the means for determining the rotation speed may comprise a circuit 36 for detecting a ripple on the electrical supply to the motor 20b. The ripple results from switching current through the motor coils, which cause induced changes in the supply voltage as a result of the finite impedance on the battery 32. The circuit 36 for example comprises a high pass filter so that only the signals in the frequency band of the fan rotation are processed. This provides an extremely simple additional circuit, and of much lower cost than a conventional pressure sensor.

[0076] This means the motor can be of any design, including a two-wire fan with no in-built sensor output terminal. It will also work with a DC motor with brushes.

[0077] The controller may use the rotation speed information, based on the corresponding pressure information, to determine a respiration cycle.

[0078] If the outlet valve 22 is an electronically switched value, the respiration cycle timing information may then be used to control the outlet valve 22 in dependence on the phase of the respiration cycle. The pressure monitoring thus provides a simple way to determine inhalation phases, which may then be used to control the timing of the outlet valve 22 of the mask.

[0079] In addition to controlling the outlet valve, the controller may turn off the fan during an inhalation time or an exhalation time. The controller may also turn off the fan if it is detected that the fan is not worn. This gives the mask different operating modes, which may be used to save power.

[0080] For a given drive level (i.e. voltage) the fan speed increases at lower pressure across the fan because of the reduced load on the fan blades. This gives rise to an increased flow. Thus, there is an inverse relationship between the fan speed and the pressure difference.

[0081] This inverse relationship may be obtained during a calibration process or it may be provided by the fan manufacturer. The calibration process for example involves analyzing the fan speed information over a period during which the subject is instructed to inhale and exhale regularly with normal breathing. The captured fan speed information can then be matched to the breathing cycle, from which threshold values can then be set for discriminating between inhalation and exhalation.

[0082] Figure 3 shows schematically the rotor position (as a measured sensor voltage) against time.

[0083] The rotational speed may be measured from the frequency of the AC component (caused by the switching events in the motor) of the DC voltage to the fan. This AC component originates from the current variation that the fan draws, imposed on the impedance of the power supply.

[0084] Figure 3 shows the signal during inhalation as plot 40 and during exhalation as plot 42. There is a frequency reduction during exhalation caused by an increased load on the fan by the increased pressure gradient. The observed frequency changes thus results from the different fan performance during the breathing cycle.

[0085] During the exhalation, fan operation forces air out of the area between face and mask. This enhances comfort because exhalation is made easier. It can also draw additional air onto the face which lowers the temperature and relative humidity. Between inhalation and exhalation, the fan operation increases comfort because fresh air is sucked into the space between the face and the mask thereby cooling that space.

[0086] During inhalation, the outlet valve is closed (either actively or passively) and the fan can be switched off to save power. This provides a mode of operation which is based on detecting the respiration cycle.

[0087] The precise timing of the inhalation and exhalation phases can be inferred from previous respiration cycles, if the fan is turned off for parts of the respiration cycle, and hence not giving pressure information.

[0088] For the fan assisted exhalation, power needs to be restored just before the exit valve opens again. This also makes sure that the next inhale-exhale cycle remains properly timed and sufficient pressure and flow are made available.

[0089] Around 30% power savings are easily achievable using this approach, resulting in prolonged battery life. Alternatively, the power to the fan can be increased by 30% for enhanced effectiveness.

[0090] With different fan and valve configurations the measurement of the fan rotation speed enables control to achieve increased comfort.

[0091] In fan configurations where the filter is in series with the fan the pressure monitoring may be used to measure the flow resistance of the filter, in particular based on the pressure drop across the fan and filter. This can be done at switch on, when the mask is not on the face for a period of time. That resistance can be used as a proxy for the age of the filter.

[0092] The first detection function as described above makes use of the fan to provide a proxy pressure measurement which is then used to detect that the mask is not worn. The pressure information may also be used for many other functions as described above. This first detection function requires the fan to be active, so it enables the transition from worn (with the fan on) to not worn to be detected. When the mask is to be worn again (or for the first time), the user may operate a manual switch to start the fan again.

[0093] However, it would be desirable to be able to switch the fan on automatically when the mask is to be worn, either the first time, or after any preceding automatic shut-down. This may be achieved using dedicated sensors, but this would require them to be permanently active, or at least making periodic sensing operations. This would re-introduce complexity to the mask and result in undesired power consumption.

[0094] The second detection function mentioned above avoids the need for a main switch or any sensors. Indeed, the fan itself is again used as a sensor. With special electronics this sensing task can be performed even when the fan is switched off.

[0095] When the mask with the fan is put on the face and the user starts to breathe, the fan will rotate even when not switched on because air is forced through the fan. The speed detection function is based on determining this rotation without the use of additional sensors with the fan switched off. That signal is subsequently used to switch on the fan for proper operation of the mask.

[0096] As mentioned above, a fan using an electronically commutated brushless DC motor has internal sensors that measure the position of the rotor and switch the current through the coils in such a way that the rotor rotates.

[0097] However, when the fan is switched off there is no longer a signal relating to the speed of rotation of the fan even if the fan is rotated mechanically.

[0098] Figure 4 shows an H-bridge circuit which functions as an inverter to generate an alternating voltage to the stator coils 50 from a DC supply VDD, GND. The inverter has a set of switches S1 to S4 to generate an alternating voltage across the coil 50.

[0099] When the fan is turned off, no electrical signal can be obtained from the power wires VDD, GND. However, electrical signals are generated due to electromagnetic induction, because when the fan is forced to rotate, the stator coil 50 moves relative to the magnets in the rotor.

[0100] These induced signals cannot be measured on the supply wires because the coils are connected to an electronic circuit which is generally deactivated when there is no driven fan rotation. Only if the electronic switches are connected in the right manner can these signals can be measured at the supply wires.

[0101] This problem can be solved by using the pulses generated directly on one of the poles of the stator coil.

[0102] This approach is explained with reference to Figure 5.

[0103] The H-bridge circuit is provided between a high voltage rail VDD and a virtual ground. The virtual ground GND is connected to a low voltage rail VDD- through a transistor arrangement Q1.

[0104] The virtual ground may vary between VDD+ and VDD- depending on the operating state of the circuit.

[0105] The fan has a switch control circuit 52, and the fan circuitry, including the switches, coils and control circuit, are connected to VDD+ and GND as the supply voltage lines. The control circuit provides the switching signals to the switches, but to avoid cluttering Figure 5, these control signal lines are not shown. The control circuit for example include Hall sensors for rotor position sensing.

[0106] One coil terminal Co1 provides an output to a detection circuit 54. Since there is a DC voltage superimposed, a high pass filter of capacitor C1 and resistor R1 is used between the detection circuit 54 and the coil terminal Co1. The pulses that come from the high pass filter are rectified by a diode D2 and cause charge to be stored in a storage capacitor C2.

[0107] The storage capacitor builds up a base voltage for the transistor arrangement Q1 (shown as a Darlington pair of bipolar transistors). The storage capacitor prevents the transistor arrangement quickly switching on and off in phase with the pulses.

[0108] Once enough charge is stored on the capacitor C2, the transistor arrangement Q1 will turn on (creating a closed circuit) and the fan will start to run because the supply voltage is then increased to the full VDD+ top VDD- voltage swing. That running generates enough pulses to keep the fan running.

[0109] This provides a very simple implementation.

[0110] To switch off the fan using the circuit of Figure 5, for example based on the detection that the mask is not worn as explained above, the base of the transistor arrangement Q1 may be driven to ground long enough to stop the fan from rotating. This may be achieved using a shut-down circuit 51 such as a transistor which discharges the capacitor C2.

[0111] For ultra-low power, the switch Q1 can be replaced with a MOSFET and optionally a gate amplifier. Digital logic circuits can be used to route the coil rotation signal and mask worn or not worn signal to the gate driver.

[0112] When the fan is off in Figure 5, all of the switches S1 to S4 are open (not actuated). There is no power supplied at all.

[0113] The pulses that charge the capacitor C2 will raise the voltage of the base of Q1 and eventually turn it ON. The level of the virtual ground GND is then pulled down to VDD-. At that moment, current can flow from VDD+ to VDD-. This give s power to the coils and the control circuit 52 of the fan that subsequently starts to run as long as there is enough voltage.

[0114] When C2 is charged and Q1 is on the shut down circuit 51 is used to discharge the capacitor C2 to stop the fan. For example, an npn transistor or a FET transistor maybe used to short circuit the capacitor C2. The shorting signal may be derived from a breathing pattern. If there are no measured frequency fluctuations, the capacitor C2 is shorted to turn off the transistor arrangement, and thereby reduce the supply voltage because GND- rises back up towards the voltage VDD+.

[0115] This invention provides an enhancement to the automatic turn off function as described above, namely the detection that the mask is not worn. The detection that the mask is not worn is used in the same way as explained above, but the detection is made more accurate while also enabling a low sampling rate of the fan rotation signal to be achieved.

[0116] The invention may be implemented using the system as shown in Figure 2 but with a different method and hence analysis implemented by the controller.

[0117] As in the system described above, analysis of the fan rotation signal (by looking at the fan rotation speed or change in fan rotation speed) yields a first value relating to magnitude of a pressure fluctuation across the fan. This first value, when consistent with a breathing signal, thus relates to the depth of breathing. The first value may comprise the difference between the maximum fan rotation speed and the minimum fan rotation speed during a sampling window. In addition, a second value is derived which relates to a rate of pressure fluctuation, i.e. a rate of breathing when consistent with a breathing signal.

[0118] The normal adult breathing frequency range is 12-18 breaths per minute (BrPM). When a subject starts to exercise, the breathing frequency will also increase. In extremely high intensity activity, the breathing rate can reach 30 BrPM.

[0119] The sampling of the fan rotation signal needs to be carried out at a rate sufficient to collect the variations resulting from the breathing signals. In order to sample the fan rotation signal without distortion to the components caused by breathing, according to Shannon sampling theory, the sampling rate should be at least 2 times the maximum signal frequency (fs≥2fmax). Here the maximum breathing frequency is 30 BrPM, namely 0.5Hz.

[0120] Thus, one approach is to set fs≥2fmax=1Hz. Thus, in theory, a 1 Hz sampling rate may be used. However, in reality, a 1Hz sampling rate is not enough.

[0121] Figure 6A shows a fan speed signal (y-axis) over time (x-axis) for a sampling period of 2s at 30 BrPM. With a sampling rate of 1Hz and the sampling points may all be when the fan speed is zero.

[0122] Thus, at least a 2Hz sampling rate is needed as shown in Figures 6B and 6C. Thus, a 2Hz sampling rate is a minimal sampling rate for a 30 BrPM breathing signal.

[0123] It thus follows that

$$\mathrm{fs} = 4\mathrm{f}$$

[0124] Here fs is the minimal sampling rate and f is the real time breathing frequency.

[0125] There are two possible methods to set the sampling rate.

[0126] In reality, the breathing frequency will not maintain a stable value, but instead it depends on the user breathing characteristics (normal breathing, talking, laughing etc.). This means there is no fixed minimal sampling rate.

[0127] One method is to set the sampling rate based on the fastest breathing frequency, as the worst case situation. Based on this fastest breathing frequency, a fixed sampling rate may be set. This is not a power-efficient approach, since in some low breathing frequency cases, this sampling rate will be higher than is actually required. The fastest breathing frequency of 30 BrPM means the fixed sampling rate maybe 2Hz.

[0128] The alternative method is to set the sampling rate in a dynamic way based on a previous number, such as one or two, of breathing cycles. As a result, the frequency fs is dynamically adjusted in real time depending on the breathing characteristics.

[0129] The breathing frequency can be determined in real time using:

$$\mathrm{f} = 1/2(\mathrm{t}_{\mathrm{max}} - \mathrm{t}_{\mathrm{min}})$$

t_{max} is the time moment of the maximum data points in the breathing cycle.

t_{min} is the time moment of the minimum data points in the breathing cycle.

[0130] In particular, a pair of consecutive minima and maxima are used to determine half of the cyclic period

[0131] The resulting frequency is then used to judge whether the frequency corresponds to a reasonable range for a breathing signal (12-30 BrPM). The frequency f is a second value relating to a rate of pressure fluctuation. If the rate i.e. frequency is in the allowed range, then the pressure fluctuation is caused by breathing, but if it is not, it may be caused by other air disturbances.

[0132] In addition to setting a suitable fan rotation signal sampling rate, the amount of sampled data which needs to be stored in a memory needs to be determined. The sampling time window (T) determines the required data buffer size and this data is updated (overwritten) in real time during breath tracking. The sampling time window needs to record at least one breathing cycle. Based on a breathing rate of 10 to 30 BrPM. the sample time period is 6 seconds based on 10 BrPM.

[0133] Threshold values for the first and second values are used to determine if the detected pressure signal is a real breathing signal or not. If the threshold values are not not properly set, it is likely that the fan will be turned off by mistake, or the mask may need to be turned off while it is still working.

[0134] Figure 7 shows the pressure (in Pa, plot 70, using the left y-axis) and fan rotation speed (in RPM, plot 72, using the right y-axis). A normal breathing phase 74, a light breathing phase 76 and a talking phase 78 are shown.

[0135] The first values, such as the difference between the maximum fan rotation speed and the minimum fan rotation speed during a sampling window, may be measured from Figure 7 to be:

Normal breathing: signal peak to valley value 7792-7310=482 RPM;

Light breathing: peak to valley value 7630-7518=112 RPM;

Talking: peak to valley value 7791-7487=304.

[0136] If using the normal breathing threshold when analyzing light breathing, the light breathing will be detected as no breathing. As a result, the breathing threshold should consider the worst case (lightest breathing). There is however a risk of false detection if the threshold is too low.

[0137] The lightest breathing volume takes place during a least active status (such as sitting) with a 0.5L breathing volume. Based on a breathing rate of 12 BrPM and 0.5L volume, the difference in fan rotation signal (ΔRPM) can be tested under different fan speed settings.

[0138] Table 1 below shows such test data based on 12 BrPM, 0.5L, with some leakage, under different fan speed settings.

Table 1

Fan speed setting	ΔRPM	Threshold
5000 RPM	165 RPM	82 RPM
6500 RPM	347 RPM	173 RPM
7400 RPM	365 RPM	132 RPM
8500 RPM	464 RPM	232 RPM

[0139] This table shows that the threshold may be set in dependence on the prevailing fan speed setting, i.e. the first threshold for the first value is preferably made dependent on the average fan rotation speed during the sampling window, which corresponds generally to the fan speed setting. The fan speed setting may be known to the controller and provided as input or the actual average fan speed maybe measured (e.g. based on a low pass filtered version of the fan rotation signal).

[0140] The threshold is set near half the ΔRPM value. This is because the use of a reduced sampling rate means the peak and valley of the real breathing signal may not be sampled as seen in Figure 6B.

[0141] Figure 8 shows plots similar to Figure 7 (pressure plot 70 and RPM plot 72) for the talking period. It shows that the pressure signal amplitude change during talking is more obvious than during normal breathing. However, the fan rotation signal shows a signal amplitude smaller than during normal breathing. This is because a pressure sensor has a response time much faster than the fan signal. The sudden inhaling after talking is detected by pressure sensing but the fan signal does not reflect this peak signal so quickly.

[0142] This is also an advantage of the use of the fan rotation signal. The fan rotation signal will react over a longer time so that a reduced sampling rate is able to capture the effect of the sudden inhaling signal after talking. For a 2Hz sample rate, at least a 0.5s time period is needed for the peak breathing signal.

[0143] Analysis of the talking breathing signal shows that the reaction of the fan rotation signal is always longer than 0.5s, so that even with the minimal 2Hz sampling rate, the fan rotation feedback signal can capture the talking signal whereas a pressure signal may not capture this breathing signal.

[0144] Table 2 below shows when the pressure peak occurs and when the rotation signal peak occurs for the 12 successive dips in the pressure signal 70 in Figure 8.

Table 2

Cycle	Pressure peak time(s)	RPM peak time(s)
1	0.5	0.8
2	1	1.1
3	0.3	0.6
4	0.2	0.6
5	0.5	0.6
6	0.5	0.9
7	0.5	0.9
8	0.3	0.6
9	1.3	1.7
10	0.6	0.8
11	0.7	0.4
12	0.6	0.4

[0145] The detection of breathing is based on applying a first threshold to the first value, e.g. ΔRPM > threshold and applying a range to the second value, e.g. $12 \leq f \leq 30$. If these conditions are both met, breathing is detected and the system will keep the fan on.

[0146] If $f < 12$ or $f > 30$ or ΔRPM ≤ threshold, the breathing has disappeared.

[0147] When breathing has disappeared, a delay time period may be applied during which breathing must continuously not be detected before determining that the mask is not worn. For example, a 10 second period maybe provided later before a turn off is implemented.

[0148] Figure 9 shows a mask operating method for detecting a worn to not worn transition. The method may optionally start by turning on the fan automatically in step 80.

[0149] The method then comprises:

in step 90, performing an initialization. This involves setting the data buffer sampling time (e.g. 6s), the sample rate (e.g. 2Hz), the first value threshold, the second value range, and the delay time period (e.g. 10 seconds). The first value threshold is set according to Table 1. This table may be different for different systems or fans.

in step 91, drawing air into and/or out of the mask air chamber using the fan;

in step 92, determining a rotation speed of the fan; and

in step 94, deriving from the determined fan rotation speed or change in fan rotation speed a first value relating to magnitude of a pressure fluctuation across the fan and a second value relating to a rate of pressure fluctuation.

[0150] In step 96, the method comprises determining whether the mask is worn or not based on the first and second values, as explained above. If the mask is not worn, and this is detected for the duration of the delay time, the fan may be switched off to save power.

[0151] This implements the first detection function explained above.

[0152] The method may comprise driving the fan using an electronically commutated brushless motor, and the rotation speed is determined by an internal sensor of the motor. Alternatively, the rotation speed may be obtained by detecting a ripple on the electrical supply to a motor which drives the fan.

[0153] The method may comprise determining a respiration cycle from the pressure monitoring system. When an electrically controllable outlet valve is used, it may be controlled dependence on the phase of the respiration cycle.

[0154] Figure 10 shows a mask operating method for detecting a not worn to worn transition. The method comprises:

in step 100, detecting induced current or voltage spikes caused by rotation of the fan when the fan is not being electrically driven; and

in step 102, starting electrical driving of the fan in response to the detected induced current or voltage spikes.

[0155] The method may also include (subsequently) turning off the fan in step 104 if it is detected that the mask is not worn. This detection may be based on steps 91 to 96 of Figure 9.

[0156] Similarly, the initial step 80 in Figure 6 of turning on the fan may be performed based on the steps 100 and 102 of the method of Figure 10.

[0157] The mask may be for covering only the nose and mouth (as shown in Figure 1) or it may be a full face mask.

[0158] The example shown is a mask for filtering ambient air.

[0159] The mask design described above has the main air chamber formed by the filter material, through which the user breathes in air.

[0160] An alternative mask design has the filter in series with the fan as also mentioned above. In this case, the fan assists the user in drawing in air through the filter, thus reducing the breathing effort for the user. An outlet valve enables breathed out air to be expelled and an inlet valve may be provided at the inlet.

[0161] The invention may again be applied for detecting the pressure variations caused by breathing for controlling the inlet valve and/or the outlet valve. The fan in this example needs to be turned on during inhalation, to assist the user in drawing air through the series filter, but it may be turned off during exhalation when the outlet valve is open. Thus, the pressure information derived may again be used to control the fan to save power when the fan operation is not needed. The detection of whether the mask is worn or not may also be implemented.

[0162] It will be seen that the invention may be applied to many different mask designs, with fan-assisted inhalation or exhalation, and with an air chamber formed by a filter membrane or with a sealed hermetic air chamber.

[0163] One option as discussed above is thus the use of the fan only for drawing air from inside the air chamber to the outside, for example when an exhaust valve is open. In such a case, the pressure inside the mask volume may be maintained by the fan below the external atmospheric pressure so that there is a net flow of clean filtered air into the mask volume during exhalation. Thus, low pressure may be caused by the fan by during exhalation and by the user during inhalation (when the fan may be turned off).

[0164] An alternative option is the use of the fan only for drawing air from the ambient surroundings to inside the air chamber. In such a case, the fan operates to increase the pressure in the air chamber, but the maximum pressure in the air chamber in use remains below 4cm H_2O higher than the pressure outside the air chamber, in particular because no high pressure assisted breathing is intended. Thus, a low power fan may be used.

[0165] In all cases, the pressure inside the air chamber preferably remains below 2cm H_2O, or even below 1 cm H_2O or even below 0.5cm H_2O, above the external atmospheric pressure. The pollution mask is thus not for use in providing a continuous positive airway pressure, and is not a mask for delivering therapy to a patient.

[0166] The mask is preferably battery operated so the low power operation is of particular interest.

[0167] The detection of the respiration cycle is a preferred feature as an additional use of the monitoring capability, but it is optional.

[0168] As discussed above, embodiments make use of a controller, which can be implemented in numerous ways, with software and/or hardware, to perform the various functions required. A processor is one example of a controller which employs one or more microprocessors that maybe programmed using software (e.g., microcode) to perform the required functions. A controller may however be implemented with or without employing a processor, and also maybe implemented as a combination of dedicated hardware to perform some functions and a processor (e.g., one or more programmed microprocessors and associated circuitry) to perform other functions.

[0169] Examples of controller components that may be employed in various embodiments of the present disclosure include, but are not limited to, conventional microprocessors, application specific integrated circuits (ASICs), and field-programmable gate arrays (FPGAs).

[0170] In various implementations, a processor or controller may be associated with one or more storage media such as volatile and non-volatile computer memory such as RAM, PROM, EPROM, and EEPROM. The storage media may be encoded with one or more programs that, when executed on one or more processors and/or controllers, perform the required functions. Various storage media may be fixed within a processor or controller or may be transportable, such that the one or more programs stored thereon can be loaded into a processor or controller.

[0171] Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. A mask comprising:

an air chamber (18);
a filter (16) for filtering air;
a fan (20) for drawing air from outside the air chamber (18) into the air chamber and/or drawing air from inside the air chamber to the outside;
a means (34, 36) for determining a rotation speed of the fan; and
a controller (30) which is adapted to:

derive from the determined fan rotation speed or change in fan rotation speed a first value which, when the mask is worn, relates to a depth of breathing and a second value which, when the mask is worn, relates to a rate of breathing; and
determine whether or not the mask is worn based on the first and second values.

2. A mask as claimed in claim 1, wherein the first value is a maximum swing in fan rotation speed during a sampling window, and the controller is adapted to set a first threshold to the first value.

3. A mask as claimed in claim 2, wherein the first threshold is dependent on the average fan rotation speed.

4. A mask as claimed in claim 2 or 3, wherein the second value is a frequency based on the time between a consecutive maxima and minima in the fan rotation speed.

5. A mask as claimed in claim 4, wherein the controller is adapted to determine that there is breathing detected and hence the mask is worn when the first value exceeds the threshold and the second value lies in a predetermined range.

6. A mask as claimed in any one of claims 1 to 5, wherein the fan rotation speed is sampled, while breathing is detected, at a rate which depends on the second value.

7. A mask as claimed in any one of claims 1 to 6, wherein the controller is adapted to apply a time period during which breathing must continuously not be detected before determining that the mask is not worn.

8. A mask as claimed in any one of claims 1 to 7, wherein the controller is adapted to turn off the fan if it is determined that the mask is not worn.

9. A mask as claimed in any one of claims 1 to 8, wherein the fan (20) is driven by an electronically commutated brushless motor, and the means for determining rotation speed comprises an internal sensor of the motor.

10. A mask as claimed in any one of claims 1 to 9, wherein the means (36) for determining rotation speed comprises a circuit for detecting a ripple on the electrical supply to a motor which drives the fan.

11. A mask as claimed in any one of claims 1 to 10, wherein the controller (30) is adapted to determine a respiration cycle from the derived pressure or pressure change, and:

to control an outlet valve (22) in dependence on the phase of the respiration cycle; and/or
to turn off the fan during an inhalation time.

12. A mask as claimed in any one of claims 1 to 11, further comprising:

a detection circuit for detecting induced current or voltage spikes caused by rotation of the fan when the fan is not being electrically driven; and
a start-up circuit for starting electrical driving of the fan in response to an output from the detection circuit.

13. A non-therapeutic method of controlling a pollution mask, wherein the pollution mask is not a mask for delivering therapy to a patient, the method comprising:

drawing gas into and/or out of an air chamber of the mask using a fan which forms a boundary directly between the air chamber and the ambient surroundings outside the air chamber;
determining a rotation speed of the fan;
deriving from the determined fan rotation speed or a change in fan rotation speed a first value which, when the mask is worn, relates to a depth of breathing and a second value which, when the mask is worn, relates to a rate of breathing; and
determining whether or not the mask is worn based on the first and second values.

14. A method as claimed in claim 13, wherein the first value is a maximum swing in fan rotation speed during a sampling window, and the method comprises setting a first threshold to the first value, wherein the second value is a frequency based on the time between a consecutive maxima and minima in the fan rotation speed, and wherein the method further comprises determining that there is breathing detected and hence the mask is worn when the first value exceeds the threshold and the second value lies in a predetermined range.

15. A method as claimed in claim 13 or 14 comprising turning off the fan if it is detected that the mask is not worn.

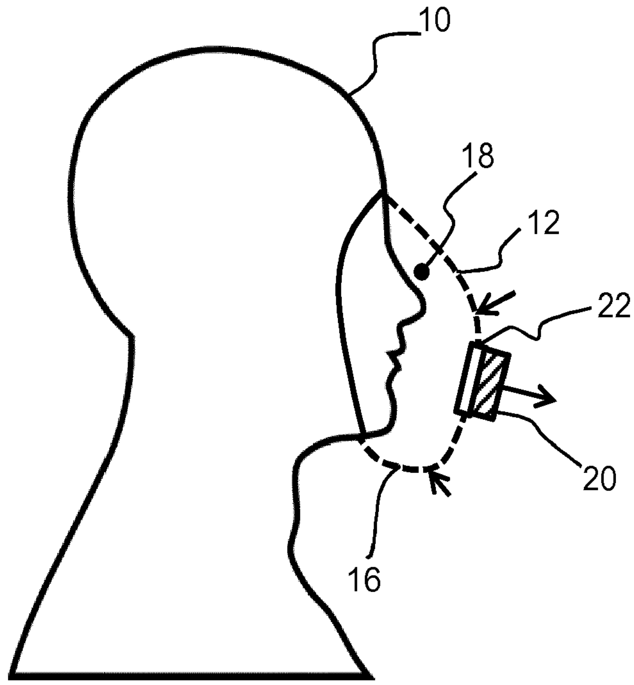


FIG. 1

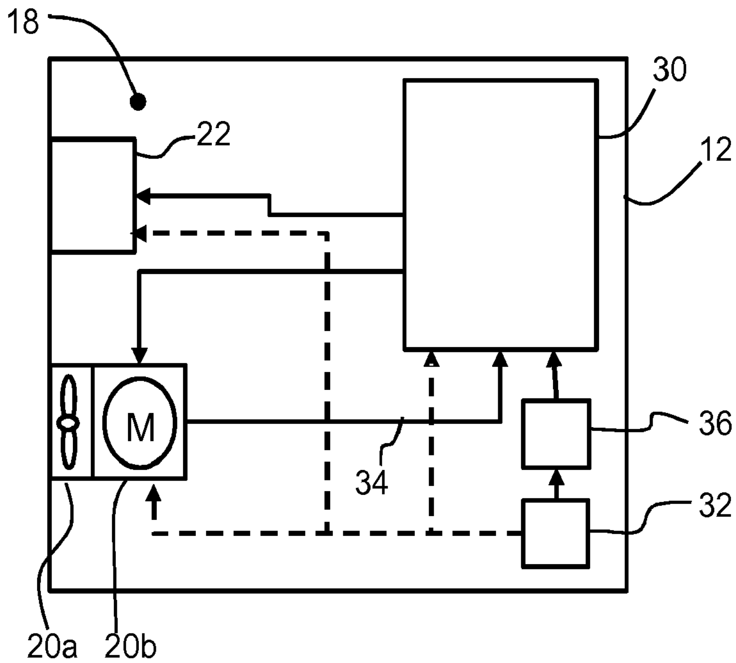


FIG. 2

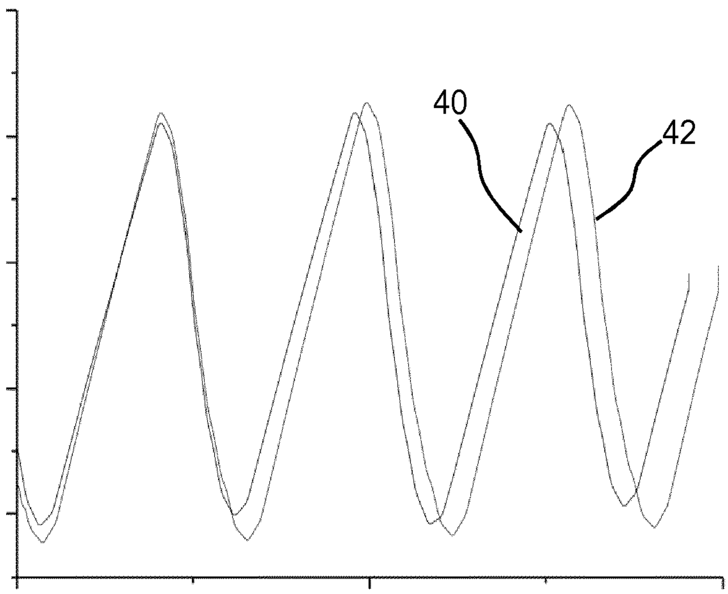


FIG. 3

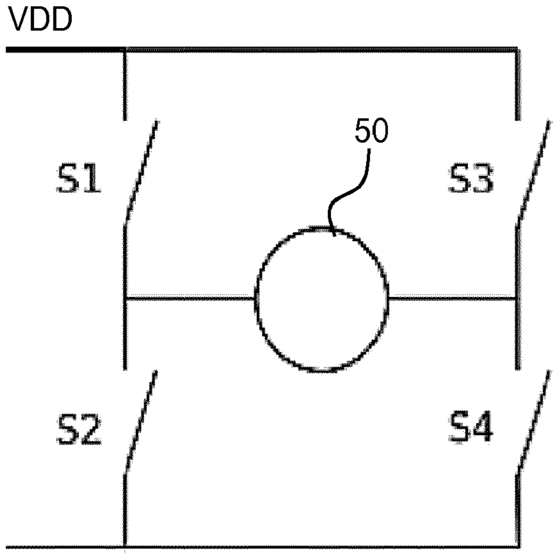


FIG. 4

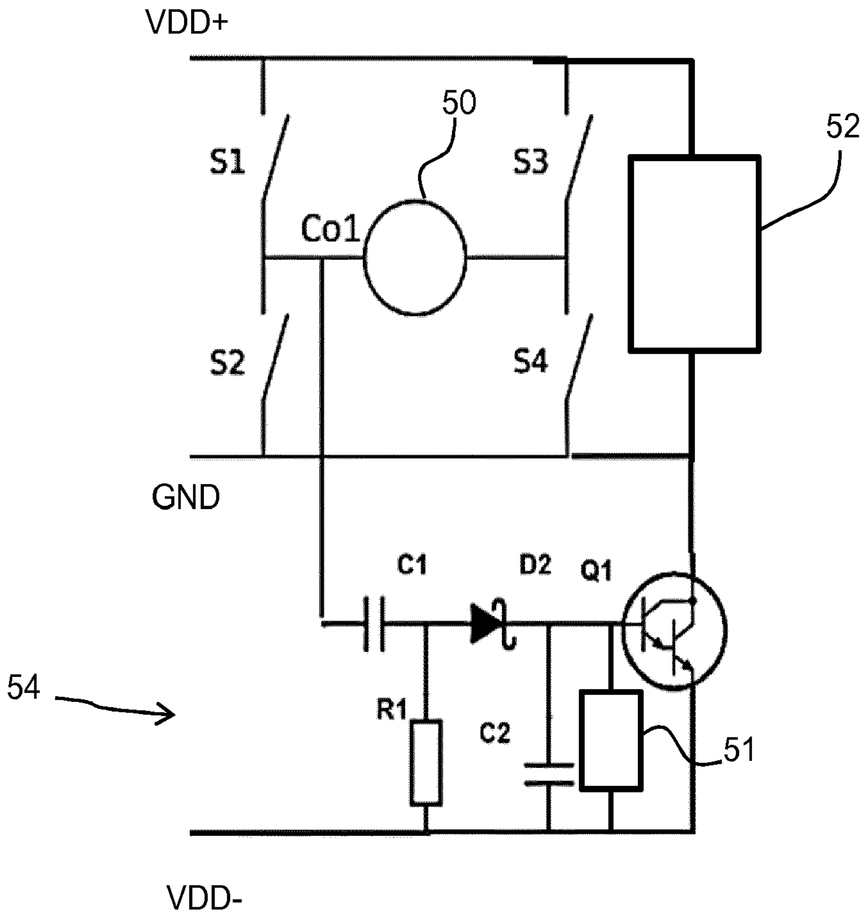


FIG. 5

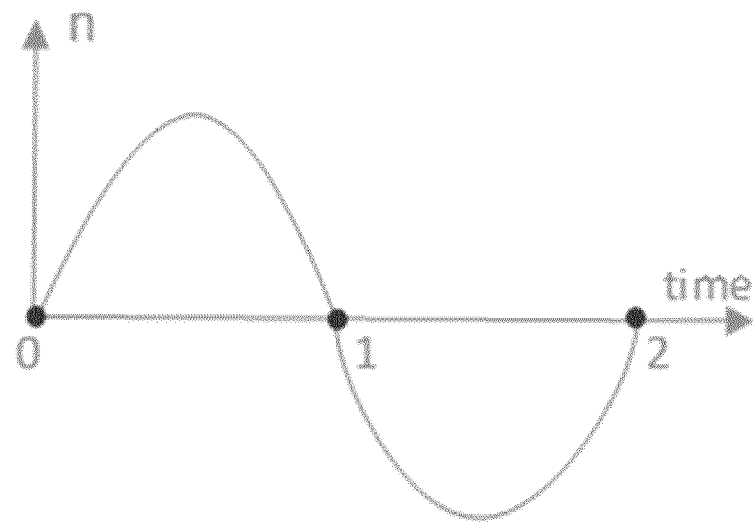


FIG. 6A

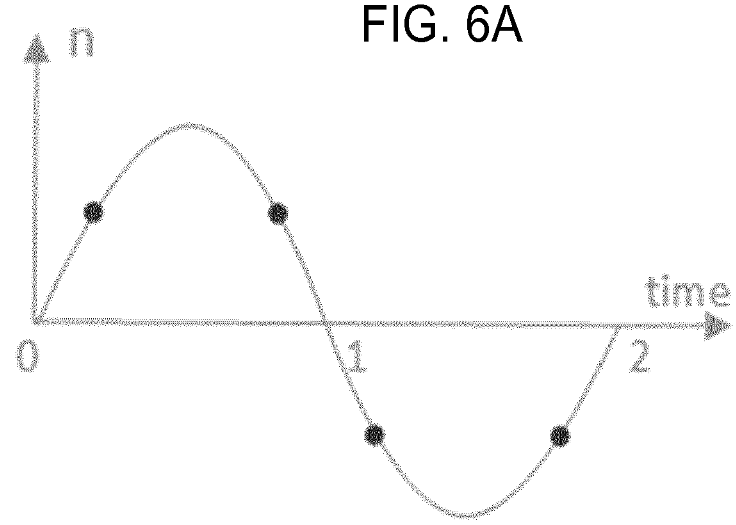


FIG. 6B

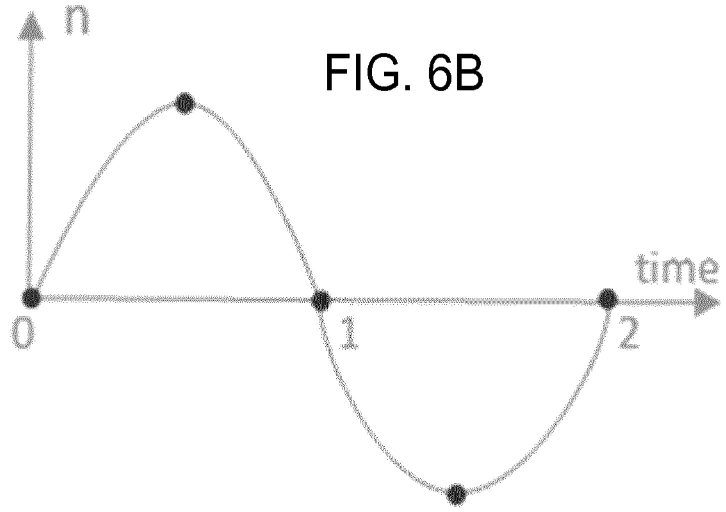
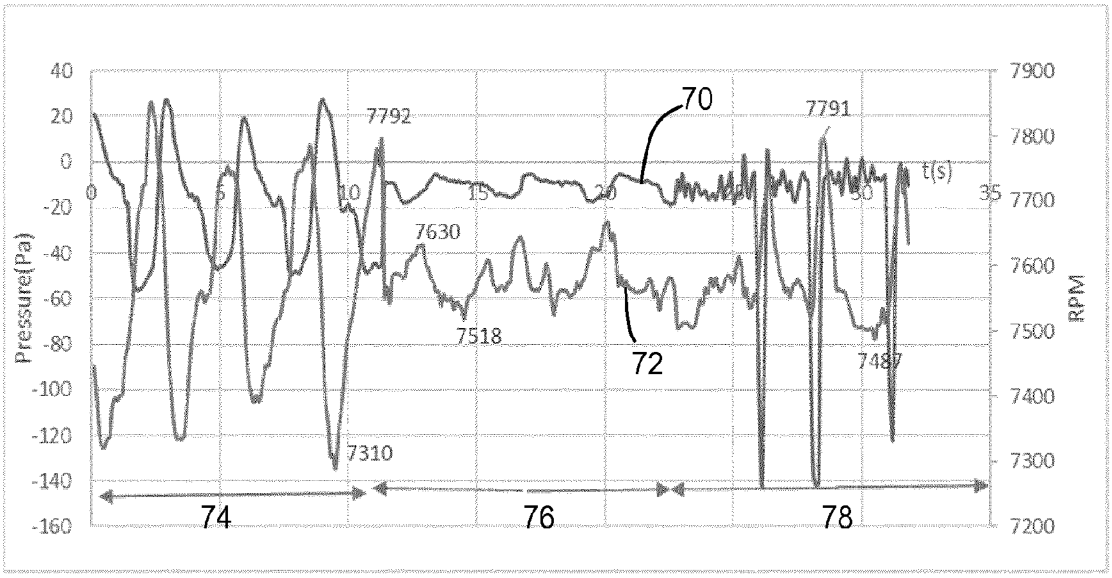


FIG. 6C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7600
7500
7400
7300
7200
RPM
0
5
10
15
20
30
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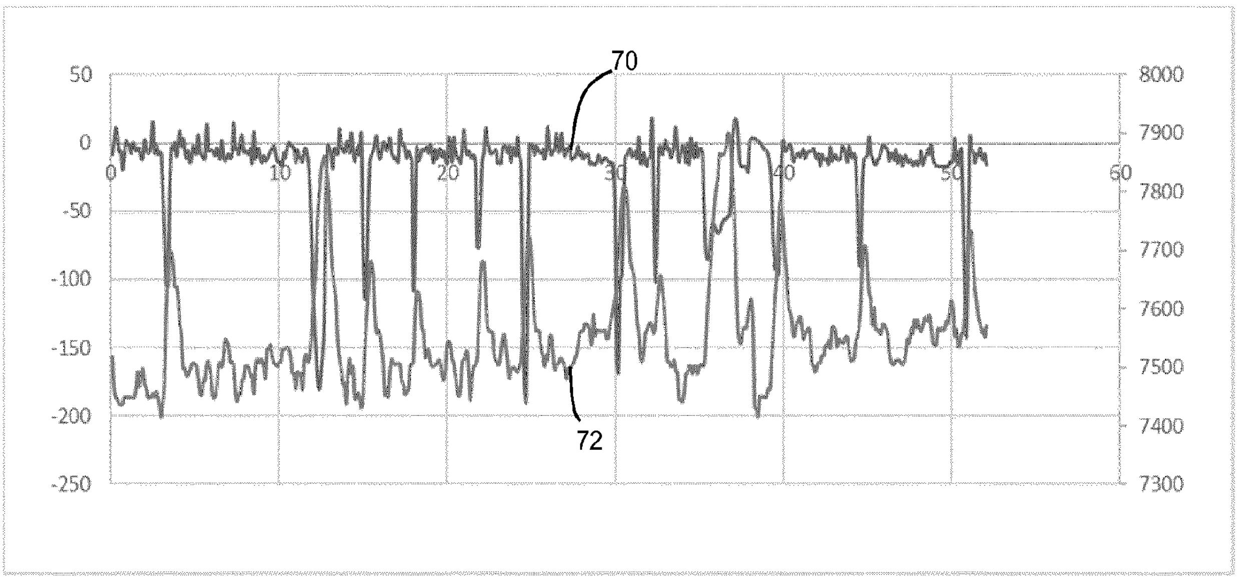
FIG. 7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70
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FIG. 8

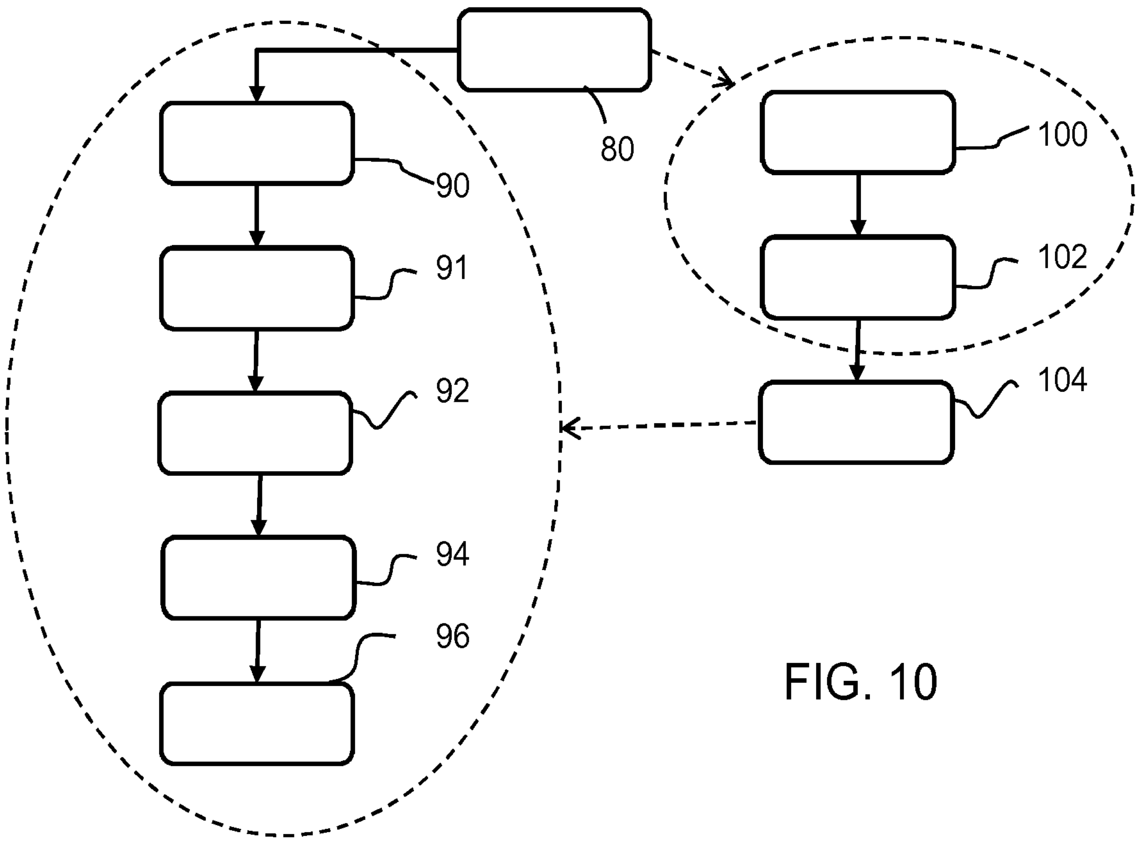

FIG. 10

FIG. 9

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EUROPEAN SEARCH REPORT

Application Number
EP 19 15 0469

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A,D	WO 2018/215225 A1 (KONINKLIJKE PHILIPS NV [NL]) 29 November 2018 (2018-11-29) * claim 1 * * page 13, lines 31-34 * * page 14, lines 2,7-9 * -----	1-15	INV. A62B18/00
A	EP 0 661 071 A1 (RESCARE LTD [AU]) 5 July 1995 (1995-07-05) * column 7, lines 15-31 * -----	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			A62B

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
The Hague	13 June 2019	Andlauer, Dominique

CATEGORY OF CITED DOCUMENTS

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13-06-2019

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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