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(54) A POLLUTION MASK WITH POLLUTION SENSING

(57) A pollution mask includes detection of inhalation and exhalation portions of the breathing cycle of the user. A particle or pollution sensor is used for sensing inside the air chamber and providing a sensing result. Sensing results are combined in respect of a plurality of inhalation portions or exhalation portions to derive a combined sensing result. This enables a sufficient sensing time period during only inhalation portions or during only exhalation portions, in order to obtain an accurate sensing result.

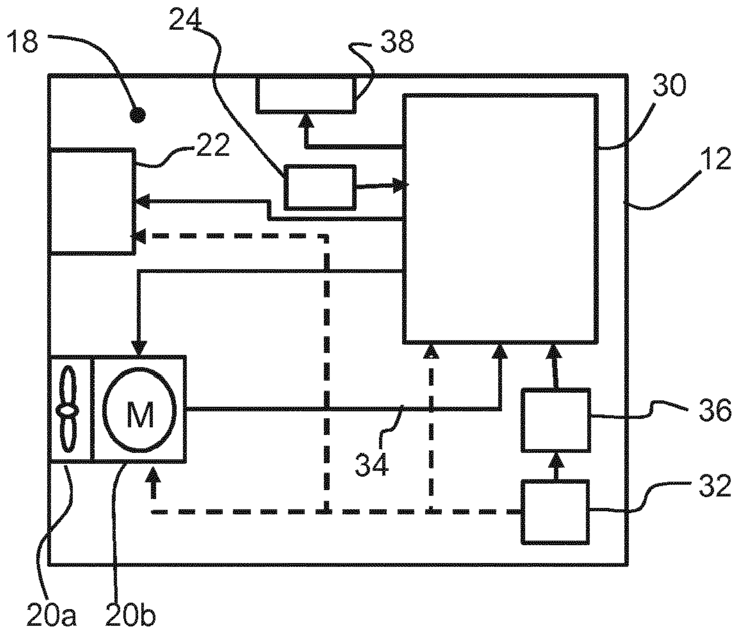

FIG. 2

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Description

FIELD OF THE INVENTION

[0001] The invention relates to pollution masks, and in particular masks which incorporate pollution sensing.

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.

[0004] A most basic passive mask comprises an outer wall which, the mask is worn, defines air chamber between the outer wall and the face of the user. A filter forms a boundary between the air chamber and the ambient surroundings outside the air chamber. Thus, the user breathes and out through the filter.

[0005] 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.

[0006] 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.

[0007] Furthermore, in a conventional passive (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.

[0008] 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.

[0009] 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.

[0010] 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. For example the pressure sensor measurements can be used to detect the breathing cycle of the user, and the fan may be controlled in dependence on the stage within the breathing cycle.

[0011] There are alternatives to the of a pressure sensor for monitoring the pressure inside a mask. WO 2018/215225 discloses a mask 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, the breathing pattern of the user can be tracked.

[0012] When the mask is being worn, there is a desire to detect the air quality inside the mask to show that the filter is working and is correctly functioning to remove the air pollution, as expected.

[0013] Thus, it is known that it is desirable to incorporate a pollution sensor inside a mask. However, inside a mask, the air alternates between inhaled air (coming through the filter and into the lungs) and exhaled air. The duration of the breathing cycle for example ranges between 4 seconds (sitting) to 2 seconds (running).

[0014] An average pollution level inside a mask over time is of some limited interest. However, the pollution sensing is of more interest specifically for inhaled (and/or exhaled) air. It would therefore be desirable to enable pollution sensing during a selected part of the respiration cycle, e.g. inhalation only. Many sensors require some time to reach a stable sensing signal (e.g. 10 seconds for some types optical particle sensor). This is not because of the physical detection process but in order to have enough samples to give a reliable result.

[0015] In the case of a mask, the time for one inhalation or exhalation cycle is not sufficient to give a stable reading. It therefore remains a problem to provide detection which is linked to the breathing cycles of the user.

SUMMARY OF THE INVENTION

[0016] The invention is defined by the claims.

[0017] According to examples in accordance with an aspect of the invention, there is provided a pollution mask comprising:

- an outer wall for, when the mask is worn, defining an air chamber between the outer wall and the face of the user;
- a filter which forms a boundary between the air chamber and the ambient surroundings outside the air chamber;
- a detecting circuit for detecting inhalation and exhalation portions of the breathing cycle of the user;
- a particle or pollution sensor for sensing inside the air chamber and providing a sensing result; and
- a controller which is adapted to:
  - combine sensing results in respect of a plurality of inhalation portions and derive a combined in-

halation sensing result; and/or

combine sensing results in respect of a plurality of exhalation portions and derive a combined exhalation sensing result.

[0018] 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.

[0019] This pollution mask has a particle or pollution sensor which samples data across multiple breathing cycles so that sufficient data is obtained from either the inhalation or exhalation cycles to combine to a single reading. The number of breathing cycles needed for example depends on the duration of each breathing cycle, with more breathing cycles needed for faster breathing.

[0020] Even in combination, the inhalation portions and exhalation portions still cover only a fraction of the overall breathing time. The complete breathing cycle consists of the inhalation and exhalation portions, but during the transitions between these portions, there will be mixing of the inhaled/exhaled air. Therefore, the sampling may exclude time periods corresponding to these transition phases and only sample the air during the core of each phase.

[0021] The mask for example further comprises 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. Thus, the invention may be applied to an active mask. This for example already includes a detecting circuit for detecting inhalation and exhalation portions of the breathing cycle of the user, because this information may be used for fan control. For example, the fan speed may be controlled in synchronism with the breathing cycles of the user, in order to save power. It may for example turn off during inhalation or during exhalation. The invention can thus be implemented with little additional overhead.

[0022] The detecting circuit is for example for detecting inhalation and exhalation portions based on the pressure inside the air chamber (and in particular relative to the ambient pressure). The pressure increases during exhalation and decreases during inhalation.

[0023] The detecting circuit may comprise a pressure sensor such as a cavity pressure sensor or a differential pressure sensor.

[0024] Alternatively, the detecting circuit may comprise a means for determining a rotation speed of the fan and a controller adapted to derive a pressure between the air chamber and the ambient surroundings from the rotation speed of the fan, such that the fan speed is used as a proxy of pressure measurement.

[0025] In this way the fan speed (for a fan which drives air into the chamber and/or expels it from the chamber) is 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. This avoids the need for a separate pressure sensor.

[0026] 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.

[0027] 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.

[0028] 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.

[0029] The controller may be adapted to:

collect sensing results continuously during a plurality of breathing cycles; and

create a sub-set of the sensing results relating to the plurality of inhalation portions to derive the combined inhalation sensing result; and/or

create a sub-set of the sensing results relating to the plurality of exhalation portions to derive the combined exhalation sensing result.

[0030] Thus, in practice, the sensor may continuously measure, and the sensing results are post-processed to create the samples which are linked to the breathing cycles.

[0031] Alternatively, the controller may be adapted to:

perform sensing at selected times corresponding to the plurality of inhalation portions to derive the combined inhalation sensing result; and/or

perform sensing at selected times corresponding to the plurality of exhalation portions to derive the combined exhalation sensing result.

[0032] In this case, the sensor may be turned off, or isolated from the air flow, outside the selected times.

[0033] The controller may be adapted to:

implement a lower pressure threshold below which the inhalation portions are identified; and/or
implement an upper pressure threshold above which the exhalation portions are identified.

[0034] Thus, the inhalation and exhalation is detected based on pressure thresholds.

[0035] In one set of examples, the lower and/or upper pressure thresholds are set in dependence on the breathing rate. More rapid breathing (e.g. during exercise) is generally deeper breathing with a larger pressure swing. Thus, different thresholds may be applied for different exercise levels.

[0036] In another set of examples, the lower and/or upper pressure thresholds are dynamically adapted based on the pressure inside the air chamber during preceding inhalation and/or exhalation portions. In this way, different breathing cycles will result in different sampling windows.

[0037] The particle or pollution sensor for example comprises an optical light scattering based sensor. It may be for measuring a particle concentration for example a PM2.5 level.

[0038] The filter for example comprises an outer wall of the air chamber and 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 and enables a large filter area, because the mask body performs the filtering function. 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.

[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 time 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] The invention also provides a method of measuring a particle or pollution level inside an air chamber of a pollution mask, the method comprising:

detecting inhalation and exhalation portions of the breathing cycle of the user;
sensing a particle or pollution level inside the air chamber of the mask; and
combining sensing results in respect of a plurality of inhalation portions and deriving a combined inhalation sensing result; and/or
combining sensing results in respect of a plurality of exhalation portions and deriving a combined exhalation sensing result.

[0041] The method may comprise collecting sensing results continuously during a plurality of breathing cycles, and:

creating a sub-set of the sensing results relating to the plurality of inhalation portions to derive the combined inhalation sensing result; and/or
creating a sub-set of the sensing results relating to the plurality of exhalation portions to derive the combined exhalation sensing result.

[0042] The sensing may instead be performed at selected times corresponding to the plurality of inhalation portions to derive the combined inhalation sensing result and/or at selected times corresponding to the plurality of exhalation portions to derive the combined exhalation sensing result.

[0043] The inhalation and/or exhalation may be detected by implementing a lower pressure threshold below which the inhalation portions are identified and/or implementing an upper pressure threshold above which the exhalation portions are identified. The lower and/or upper pressure thresholds maybe set in dependence on the breathing rate. They may be dynamically adapted based on the pressure inside the air chamber during preceding inhalation and/or exhalation portions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0044] Examples of the invention will now be described in detail with reference to the accompanying drawings, in which:

Figure 1 shows a pollution mask including particle or pollution sensing.
Figure 2 shows one example of the components of the pressure monitoring system;
Figure 3A shows a rotation signal during inhalation and during exhalation and Figure 3B shows how a fan rotation speed varies over time; and
Figure 4 shows a circuit for controlling the current through one of the stators of a brushless DC motor;
Figure 5 shows a generic design of an optical particle sensor which may be used as the sensor;
Figure 6 shows the approach of the invention in schematic form;
Figure 7 shows three breathing waveforms for breathing while sitting, walking and running;
Figure 8 shows three breathing waveforms together with a static threshold for breathing while sitting, walking and running;
Figure 9 shows three breathing waveforms together with a dynamic threshold for breathing while sitting, walking and running; and
Figure 10 shows a method of measuring a particle or pollution level inside an air chamber of a pollution

mask.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0045] The invention will be described with reference to the Figures.

[0046] It should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the apparatus, systems and methods, are intended for purposes of illustration only and are not intended to limit the scope of the invention. These and other features, aspects, and advantages of the apparatus, systems and methods of the present invention will become better understood from the following description, appended claims, and accompanying drawings. It should be understood that the Figures are merely schematic and are not drawn to scale. It should also be understood that the same reference numerals are used throughout the Figures to indicate the same or similar parts.

[0047] The invention provides a pollution mask which includes detection of inhalation and exhalation portions of the breathing cycle of the user. A particle or pollution sensor is used for sensing inside the air chamber and providing a sensing result. Sensing results are combined in respect of a plurality of inhalation portions or exhalation portions to derive a combined sensing result. This enables a sufficient sensing time period during only inhalation portions or during only exhalation portions, in order to obtain an accurate sensing result.

[0048] Figure 1 shows a pollution mask including particle or pollution sensing.

[0049] 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.

[0050] The mask detects the breathing cycles of the user, and the timing of the breathing cycles is monitored. In the example shown, during inhalation, an outlet valve 22 such as a check valve is closed due to the low pressure in the air chamber 18.

[0051] The mask further comprises a sensor 24, for measuring a particle or pollution level inside the air chamber 18. It generates a sensing result.

[0052] In the example shown in Figure 1, the sensor 24 is in series with the fan, and the fan thereby generates the flow through the sensor. The sensor may be mounted behind the fan and check valve. The electrical components are for example all integrated together, which reduces the amount of wiring needed. However, the sensor may be located in another position inside the mask cavity if the air flow can pass through.

[0053] Sensing the air quality inside a mask enables reassurance to be given to the user that the filter is working and that the air inside the mask is healthy. Simply measuring the air quality inside the mask is not sufficient if the sensor response time is greater than the individual portions of the breathing cycle since the sensing will then mix inhaled and exhaled air. The user typically wants to know the quality of the inhaled air, and this should not be mixed with the exhaled air since exhaled air may be cleaner due to deposition of particles within the lungs. Therefore, an average measurement of the air quality inside the mask over a long time period (of multiple breaths) is not optimal.

[0054] 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.

[0055] 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 based on the sensing of the breathing cycles.

[0056] The breathing cycles are detected based on pressure changes in the mask volume. There will be a varied pressure inside the chamber if the mask is worn and the user is breathing. 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.

[0057] 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. The rotation speed of the fan may thus be used as a proxy for a measurement of pressure across the fan. This is a preferred implementation because it uses fewer sensors.

[0058] However, the concept of the invention may be implemented with pressure sensors for obtaining the breathing characteristics.

[0059] For a known pressure (e.g. atmospheric pressure) at one side of the fan, the pressure (or proxy 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.

[0060] The pressure variation, as detected based on monitoring the fan rotation speed or by pressure measurement, is then used to obtain information about the breathing of the user. In particular, a first value may represent the depth of breathing and a second value may represent the rate of breathing.

[0061] 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 of these two cases the fan itself is used so that no additional sensors are required.

[0062] Figure 2 shows one example of the components of the system. The same components as in Figure 1 are given the same reference numbers.

[0063] In addition to the components shown in Figure 1, Figure 2 shows the controller 30, a local battery 32 and a means 36 for determining the fan rotation speed.

[0064] The controller 30 performs detection of the breathing cycle timing, as mentioned above, as well the function of sensor signal processing. In particular, it is used to combine sensing results in respect of a plurality of inhalation portions and derive a combined inhalation sensing result. It may additionally, or alternatively, combine sensing results in respect of a plurality of exhalation portions and derive a combined exhalation sensing result.

[0065] The means 36 for determining the fan rotation speed is one possible implementation of a detecting circuit for detecting inhalation and exhalation portions of the breathing cycle of the user. Another possible implementation makes use of a pressure sensor as mentioned above.

[0066] Figure 2 shows an output 38 for providing output information to the user. It could be an integrated display, but more preferably it is a wireless communications transmitter (or transceiver) for sending data to a remote device such as a smartphone, which can then be used as the final user interface for providing data to the user, and optionally for receiving control commands from the user for relaying to the controller 30.

[0067] 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.

[0068] 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.

[0069] 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.

[0070] 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.

[0071] 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.

[0072] In addition to controlling the outlet valve, the controller may turn off the fan during an inhalation time or an exhalation time. This gives the mask different operating modes, which may be used to save power.

[0073] 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. 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.

[0074] Figure 3A shows schematically the rotor position (as a measured sensor voltage) against time.

[0075] 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.

[0076] Figure 3A 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.

[0077] Figure 3B shows the frequency variation over time, by plotting the fan rotation speed versus time. There is a maximum difference in fan rotation speed Δfan between successive maxima and minima, and this correlates with the depth of breathing. This is the first value derived from the fan rotation signal. The time between these points is used to derive the second value, for example the frequency corresponding to this time period (which is then twice the breathing rate).

[0078] Note that the first value may be obtained from the raw fan rotation signal or there may be smoothing carried out first. Thus, there are at least two different two ways to calculate the maximum swing, based on untreated real-time speeds or treated speeds. In practice, there is noise or other fluctuations added on the real-time signals. A smoothing algorithm may be used to treat the real-time signal and calculate the first value from the smoothed signal.

[0079] 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.

[0080] In one example, 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.

[0081] 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.

[0082] 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.

[0083] 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.

[0084] With different fan and valve configurations the measurement of the fan rotation speed enables control to achieve increased comfort.

[0085] 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.

[0086] 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.

[0087] Figure 4 shows an H-bridge circuit which functions as an inverter to generate an alternating voltage to the stator coils 50 of the motor 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. The switches are controlled by signals which depend on the rotor position, and these rotor position signals may be used to monitor the fan rotation.

[0088] Figure 5 shows a generic design of an optical particle sensor which may be used as the sensor 24.

[0089] There is a gas flow 60 from an inlet 61 to an outlet 62 of the overall sensor device. An infrared LED 64 (λ = 890 nm) is used to illuminate the gas flow to enable optical detection of entrained particles based on optical measurements of scattering. The LED is to one side of the detection volume and the sensing is carried out at the opposite side. An alternative design may make use of reflection of light.

[0090] The optical sensor 66 comprises a photodiode sensor 68 and a focusing lens 70 at which scattered light is collected.

[0091] A flow through the sensor device is provided by the breathing of the user. The air flow carries the particles through the detection volume.

[0092] A controller 74 (which may be implemented as part of the controller 30) controls the processing of the sensor signals and operation of the light source.

[0093] The detection volume is for example part of a housing which is placed on a printed circuit board with the electronics to convert the signal due to the particles into a count. The internal shape of the housing is such that leakage of LED light directly towards the photodiode sensor, which would give a background signal, is minimal. By electronically filtering out any remaining DC signal, the pulsed particle signal remains.

[0094] This signal is amplified and compared with a threshold voltage. Above a certain particle size, the peak height is sufficient to pass the threshold. The threshold thus implements a band pass filtering function. In one example of signal processing, the pulse is counted and the pulse length is measured, resulting in a low-pulse occupancy time (LPO%).

[0095] Thus, there are two basic outputs. One is a simple particle count, which is a count of the number of detection peaks which exceed the threshold set. The other is the proportion of the time that there is detection above the threshold. Thus, for a particular threshold level, if the total time for which a signal is at or above the threshold is 700 ms within a 1 s window, then the low-pulse occupancy time is 70%. The low pulse occupancy measure enables a simple binary coding of the sensor output over time; for example a binary zero output if the detected signal is above the threshold, and a binary 1 if the detected signal is below the threshold. The summed time durations of the digital zero periods correspond to the low pulse occupancy time. The combined time of the digital zero periods (per fixed unit of time) is then proportional to the analogue output signal.

[0096] In this type of sensor, the amplitude of the analog signal is proportional to the particle size, whether using particle counting or low pulse occupancy measurement. The threshold is implemented as a threshold voltage applied to a comparator which controls the particle size sensitivity of the sensor system.

[0097] Larger particles scatter a larger amount light, hence generate a larger signal amplitude at the photodetector. This analog signal (after appropriate filtering and amplification stages) is provided to the comparator.

[0098] The threshold voltage provided to the comparator sets the boundary limit for this analog signal. For example, a 1V threshold means that all signals above 1V will be registered as a detection signal, hence corresponding to all particle sizes that generate an analog signal above 1V. Likewise, a 2V threshold raises the boundary for allowing only larger sized particles to generate an output.

[0099] For simplicity a 1V threshold voltage may correspond to signals generated for particles of 1μm diameter and above, whereas as 2V threshold may correspond to particles of 2μm diameter and above.

[0100] The sensor may be used to generate a single particle count e.g. PM2.5, or different thresholds may be applied for different particle size ranges (also known as 'size bins'). For example, for a particle size range between 1μm and 2μm, the number of signals generated at these threshold voltages are subtracted.

[0101] The sensor described above basically comprises:

a housing having an inlet and an outlet with a gas flow between them;

a light source and an optical detector for making optical scattering measurements within a detection volume, wherein the detector signal is correlated with (and for example proportional to) particle size; and

a signal processor comparing the detector signal with a threshold. The threshold may be fixed (for a single size detection function) or it may be adjustable.

[0102] This is just one generic example of optical sensor. Other known optical sensor designs may be used.

[0103] However, many such sensors require some time to generate a stable result. For example, PM 2.5 sensors are known having a 10 seconds or longer settling time. The time may be even longer for ultrafine particle (UFP) sensors. The time required may also depend on the pollution concentration, wherein at lower concentrations the time required is longer.

[0104] This time delay to get a stable signal is not due to a physical limitation of the sensor but because sufficient samples are required to get a stable reading. The sensor is for example continuously generating data, but it takes some time before a reliable result is given.

[0105] Figure 6 shows the approach of the invention in schematic form.

[0106] The plot shows the breathing cycle, where a positive value represents exhalation and a negative value represents inhalation. This may be measured by a differential pressure sensor or by the fan motor current as explained above.

[0107] Sampling windows are defined, such as windows A, B, C which represent exhalation phases (EP) and windows X, Y, X which represent inhalation phases (IP).

[0108] The sensor is used to sample these data windows across multiple breathing cycles in order to obtain sufficient data from either inhalation portions or exhalation portions for a single reading. The number of breathing cycles needed depends on the duration of each individual breathing cycle. For example, more breathing cycles are needed during faster breathing.

[0109] In this way, sufficient samples are obtained for combination to define individual sensor (combined) readings with sufficient accuracy. For example, by combining multiple samples from inhalation cycles, the sensor can gather enough samples to create a measurement of the inhaled air (after the filter). Similarly, the exhalation samples can be combined to give sufficient samples to create a measurement.

[0110] Depending on the flow to be analyzed, the sensor may only detect inhaled or exhaled air.

[0111] One basic approach is to perform continuous monitoring and to use post-processing to select the required portions of the full data stream. Since the final sensing result needs serval breathing cycles, the delay in waiting for the full data stream and performing post processing is not significant, for example a 10 second delay to generate an output is not significant.

[0112] However, real time sensing may also be performed. The controller for example receives real time sensing data from the sensor. The volume of data is compared with a predefined threshold. If the sampled data reaches the threshold, then the data can be used for a pollution level calculation, otherwise the data can be discarded.

[0113] Another approach is to perform sensing only during the sampling windows. The sensor may be turned off between those times, or it may be physically only exposed during the intended portions of the cycle, with no sensor reading during the other portions.

[0114] The preferred option is for the sensor to be continuously sampling. The controller then determines which period of the sampling data will be used to calculate the pollution level inside the mask cavity, based on the breath signal tracking (by the fan signal or the pressure sensor signal).

[0115] Figure 7 shows three breathing waveforms. Figure 7A shows breathing while sitting, Figure 7B shows breathing while walking and Figure 7C shows breathing while running.

[0116] It can be seen that user activity changes the breathing rate and depth of breathing.

[0117] The time windows should therefore be adapted to the nature of the breathing of the user. In particular, the time windows should have a width such that they capture the main core part of the inhalation or exhalation cycle, without being so wide that they overlap with time periods of mixed inhalation and exhalation. In particular, in the transitions between inhalation and exhalation phases, there will be mixing of the inhaled/exhaled air.

[0118] For this purpose, the system dynamically adjusts the sampling time based on changes in the breathing cycle, in particular the breathing rate, for example in response to a change in user activity.

[0119] Even within the same general type of activity, each individual breathing cycle is different. Thus, it is also possible to adapt the sampling window within individual breathing cycles in an even more dynamic way.

[0120] Figure 8 shows three breathing waveforms together with a static threshold. Figure 8A shows breathing while sitting with a first threshold, Figure 8B shows breathing while walking with a second threshold (lower than the first, i.e. more negative) and Figure 8C shows breathing while running with a third threshold (lower than the second, i.e. more negative).

[0121] The sampling time periods are shown as t1 to t12. The width is variable since it corresponds to the time within each breathing cycle during which the signal (pressure or proxy pressure) is below the threshold. Thus, it depends on the time-width the actual breathing cycle.

[0122] When breathing in, once the user start to breathe in, the pressure inside the cavity become negative. At the beginning of the inhalation phase, the cavity still has some air which from the user's previous exhalation. The pressure is quickly decreased and the particle sensor sampling starting time can be set to the time once the pressure reaches the negative threshold.

[0123] In the example of Figure 8, the threshold value is pre-defined as a static value, which is typically the half peak pressure value of the breathing cycle. Half peak pressure is just one example, and other ways to set the threshold may be used.

[0124] In another example, the threshold value can be a self-set dynamic value.

[0125] Figure 9 shows three breathing waveforms together with a dynamically auto-adjusting threshold. Figure 9A shows breathing while sitting, Figure 9B shows breathing while walking and Figure 9C shows breathing while running.

[0126] The mask system for example records the data of the preceding breathing cycle or set of breathing cycles. The threshold may be set at half (or other fraction) of the peak pressure value of the preceding breathing cycle, or a combination of a set of previous breathing cycles. In this way, the system can adapt to different activities, different users and influences caused by different leakage amounts.

[0127] In order to ensure a sufficient time period during which data is sampled, the controller keeps a timing count. The controller for example starts a timer once the pressure drops below the threshold, and stops the timer once the pressure increases above the threshold (i.e. measuring the time duration of the sampling periods t1 to t12).

[0128] The time periods are added from different cycles to form an overall timing value. When the overall timing value reaches the desired sampling time, the sensor has enough data to calculate the a sensing result, such as a PM value.

[0129] The sensor needs to gather sufficient samples from the cores of the inhalation (or exhalation) phases to determine the pollutant value. For example, if the core of the inhalation phase (where data is reliable) is 2 seconds and the sensor requires 10 seconds of data to derive a stable value, a total of 5 breathing cycles will be combined to generate a sensor reading.

[0130] The mask may be for covering only the nose and mouth (as shown in Figure 1) or it may be a full face mask. The mask is for filtering ambient air.

[0131] The mask design described above has the main air chamber formed by the filter material, through which the user breathes in air. 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.

[0132] The invention may use the detected the pressure variations caused by breathing for controlling an inlet valve and/or the outlet valve.

[0133] One option as discussed above is 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).

[0134] 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 4 cmH2O 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.

[0135] It will thus 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.

[0136] In all cases, the pressure inside the air chamber preferably remains below 2 cmH2O, or even below 1 cmH2O or even below 0.5 cmH2O, 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.

[0137] The mask is preferably battery operated so the low power operation is of particular interest.

[0138] Figure 10 shows a method of measuring a particle or pollution level inside an air chamber of a pollution mask.

[0139] Step 80 is an initialization step, which includes setting a pressure threshold in step 80a, setting the required sensor sampling time in step 80b (a typical sampling time is 10 seconds) and setting a timer to zero in step 80c.

[0140] The threshold pressure is used to determine when to start to sample using the sensor and when to stop. The timer is used to record the senor sampling time.

[0141] In step 82, the user starts to use the mask, and the system starts to sample the pressure thereby tracking the breathing of the user.

[0142] In step 84 the sampled pressure is compared with the threshold pressure (Th) to determine whether a stable portion of the breathing period, within the inhalation period (in this example) is reached.

[0143] If the pressure remains higher than the threshold value it means the breathing has not reached the stable (core) period of the cycle so the method returns to step 82 (i.e. the YES outcome shown) and pressure continues to be monitored.

[0144] When the pressure has dropped below the threshold value (i.e. the NO outcome shown) it means the particle sensor sampling period is reached.

[0145] The method then proceeds to step 86 at which the timer is started to record the sampling time period.

[0146] In step 88, the sensor is started (or exposed to the air flow), to obtain sensing data such as a particle count.

[0147] In step 90, the pressure continues to be monitored and the sensing continues to take place.

[0148] In step 92 the pressure is compared with the threshold pressure.

[0149] If the pressure is less than the threshold value it means the breathing cycle is still in the stable period, so the method returns to step 90 (i.e. the NO outcome shown) and the sensor continues sampling.

[0150] If the pressure is higher than the threshold value it means the stable sampling period is finished (i.e. the YES outcome shown). The timer is then stopped in step 94. The newly recorded time is the sampling time of the current cycle. However, the total sampling time is recorded by the timer.

[0151] Steps 84 to 94 thus implement detection of the inhalation portion of one breathing cycle of the user and measurement of the time duration of the sampling.

[0152] The (summed) time is compared with the set sampling period T (e.g. 10 seconds) in step 96. If the desired total sampling time is not yet reached (i.e. the NO outcome) it means the particle sensor data is not yet enough to obtain a reliable PM value. The method returns to step 82. The timer will then continue to record, i.e. the current timer value is used as the beginning value of the next timing recording.

[0153] If the (summed) time has reached or exceeded the sampling period T (the YES outcome), it means the sensor already has sufficient data to calculate the PM value.

[0154] In step 98 the combined sensing result is obtained, such as a PM2.5 value. The timer is then reset to zero in step 100 and the method returns to step 82.

[0155] By cycling through steps 82 to 96 a number of times, a combined sensing result is obtained respect of a plurality of inhalation (or exhalation) portions.

[0156] Note that an alternative to the method show is to obtain sensor data continuously but to select suitable data sampling periods using a similar approach to that explained above.

[0157] The mask may be supplemented with additional functionality and user interface options but these are outside the scope of this disclosure.

[0158] 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.

[0159] 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).

[0160] 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 maybe 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.

[0161] 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. A single processor or other unit may fulfill the functions of several items recited in the claims. 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. If the term "adapted to" is used in the claims or description, it is noted the term "adapted to" is intended to be equivalent to the term "configured to". Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. A pollution mask comprising:

   an outer wall (12) for, when the mask is worn, defining an air chamber (18) between the outer wall and the face of the user;
   a filter (16) which forms a boundary between the air chamber and the ambient surroundings outside the air chamber;
   a detecting circuit for detecting inhalation and exhalation portions of the breathing cycle of the user;
   a particle or pollution sensor for sensing inside the air chamber and providing a sensing result; and
   a controller (30) which is adapted to:

   combine sensing results in respect of a plurality of inhalation portions and derive a combined inhalation sensing result; and/or
   combine sensing results in respect of a plurality of exhalation portions and derive a combined exhalation sensing result.

2. A pollution mask as claimed in claim 1, further comprising:
   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,

3. A pollution mask as claimed in claim 1 or 2, wherein the detecting circuit is for detecting inhalation and exhalation portions based on the pressure inside the air chamber.

4. A pollution mask as claimed in claim 3, wherein the detecting circuit comprises:

   a pressure sensor; or
   a means (34, 36) for determining a rotation speed of the fan and a controller adapted to derive a pressure between the air chamber and the ambient surroundings from the rotation speed of the fan, such that the fan speed is used as a proxy of pressure measurement.

5. A pollution mask as claimed in any one of claims 1 to 4, wherein the controller is adapted to:
   collect sensing results continuously during a plurality of breathing cycles; and

   create a sub-set of the sensing results relating to the plurality of inhalation portions to derive the combined inhalation sensing result; and/or
   create a sub-set of the sensing results relating to the plurality of exhalation portions to derive the combined exhalation sensing result.

6. A pollution mask as claimed in any one of claims 1 to 4, wherein the controller is adapted to:

   perform sensing at selected times corresponding to the plurality of inhalation portions to derive the combined inhalation sensing result; and/or
   perform sensing at selected times corresponding to the plurality of exhalation portions to derive the combined exhalation sensing result.

7. A pollution mask as claimed in any one of claims 1 to 6, wherein the controller is adapted to:

   implement a lower pressure threshold below which the inhalation portions are identified; and/or
   implement an upper pressure threshold above which the exhalation portions are identified.

8. A pollution mask as claimed in claim 7, wherein:

   the lower and/or upper pressure thresholds are set in dependence on the breathing rate; or
   the lower and/or upper pressure thresholds are dynamically adapted based on the pressure inside the air chamber during preceding inhalation and/or exhalation portions.

9. A pollution mask as claimed in any one of claims 1 to 8, wherein the particle or pollution sensor comprises an optical light scattering based sensor.

10. A mask as claimed in any one of claims 1 to 9, wherein the filter comprises an outer wall (16) of the air chamber.

11. A method of measuring a particle or pollution level inside an air chamber of a pollution mask, the method comprising:

    detecting inhalation and exhalation portions of the breathing cycle of the user;
    sensing a particle or pollution level inside the air chamber of the mask; and
    combining sensing results in respect of a plurality of inhalation portions and deriving a combined inhalation sensing result; and/or
    combining sensing results in respect of a plurality of exhalation portions and deriving a combined exhalation sensing result.

12. A method as claimed in claim 11, comprising:
    collecting sensing results continuously during a plurality of breathing cycles; and

    creating a sub-set of the sensing results relating to the plurality of inhalation portions to derive the combined inhalation sensing result; and/or creating a sub-set of the sensing results relating to the plurality of exhalation portions to derive the combined exhalation sensing result.

13. A method as claimed in claim 11, comprising:

performing sensing at selected times corresponding to the plurality of inhalation portions to derive the combined inhalation sensing result; and/or
performing sensing at selected times corresponding to the plurality of exhalation portions to derive the combined exhalation sensing result.

14. A method as claimed in any one of claims 11 to 13, comprising:
implementing a lower pressure threshold below which the inhalation portions are identified and/or implementing an upper pressure threshold above which the exhalation portions are identified.

15. A pollution mask as claimed in claim 14, wherein:

the lower and/or upper pressure thresholds are set in dependence on the breathing rate; or
the lower and/or upper pressure thresholds are dynamically adapted based on the pressure inside the air chamber during preceding inhalation and/or exhalation portions.

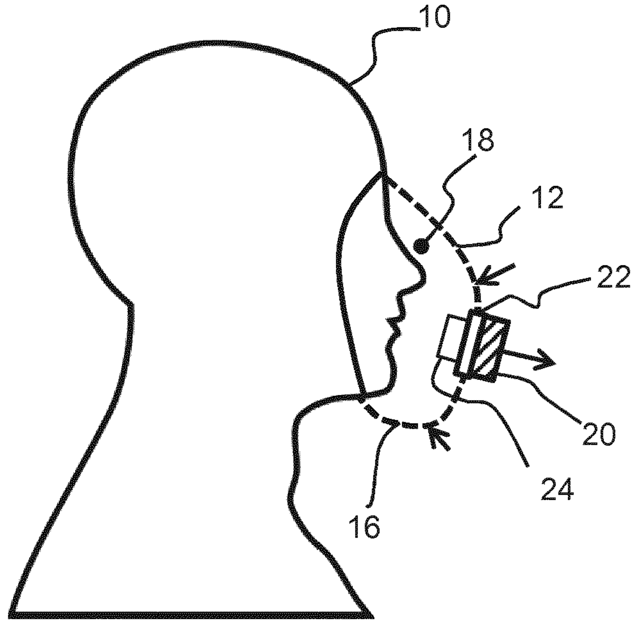


FIG. 1

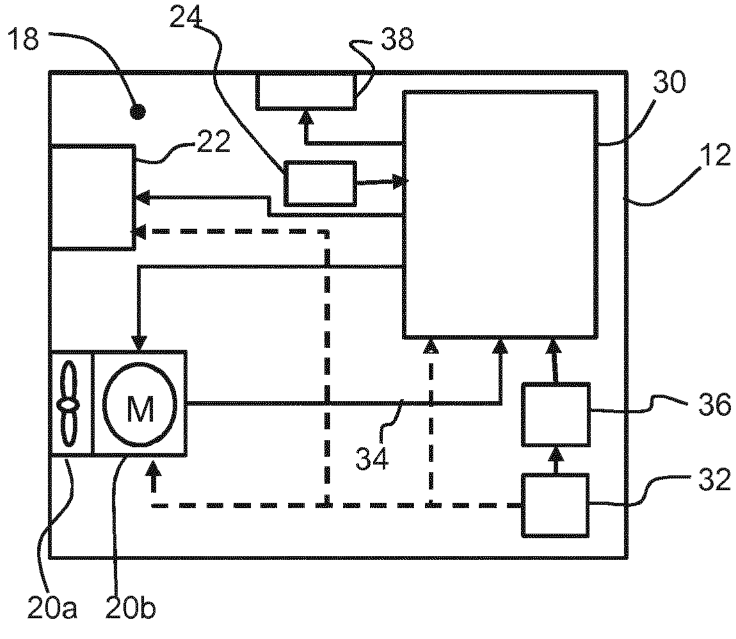


FIG. 2

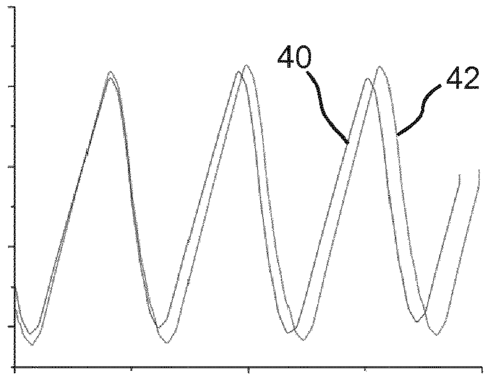


FIG. 3A

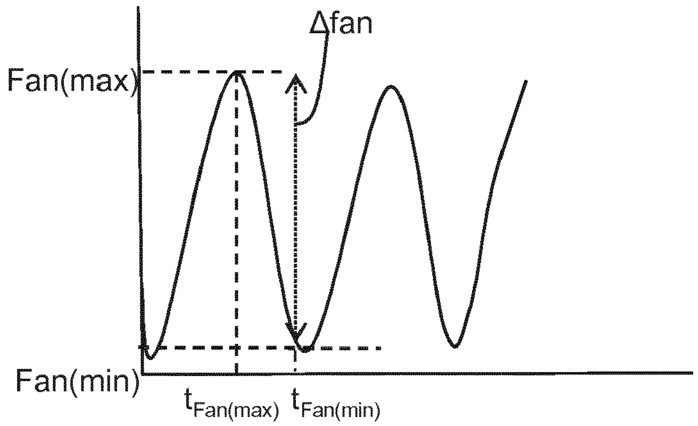


FIG. 3B

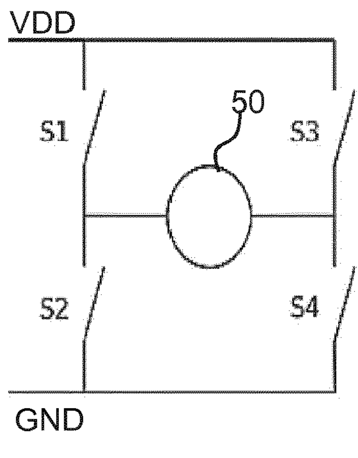


FIG. 4

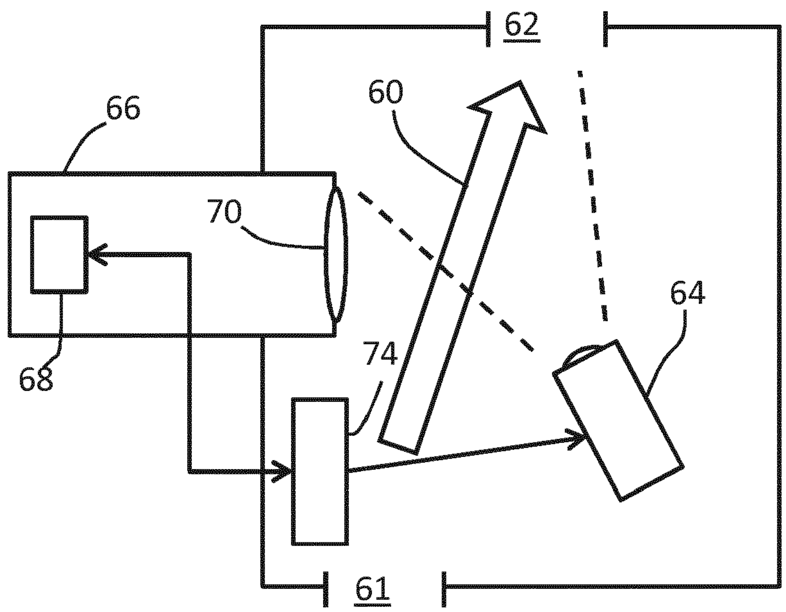


FIG. 5

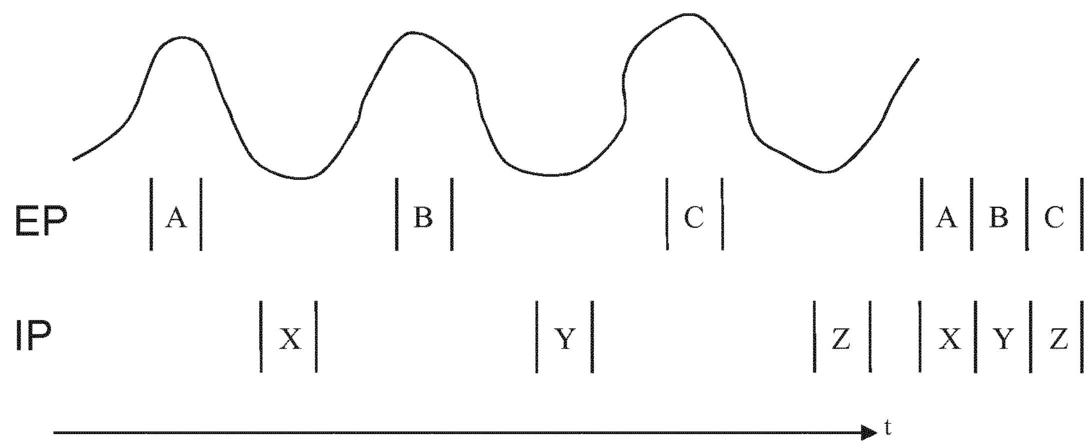


FIG. 6

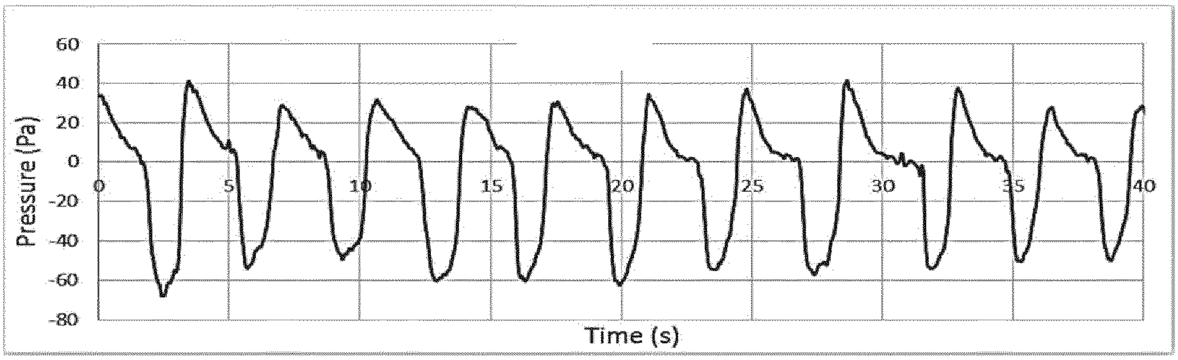


FIG. 7A

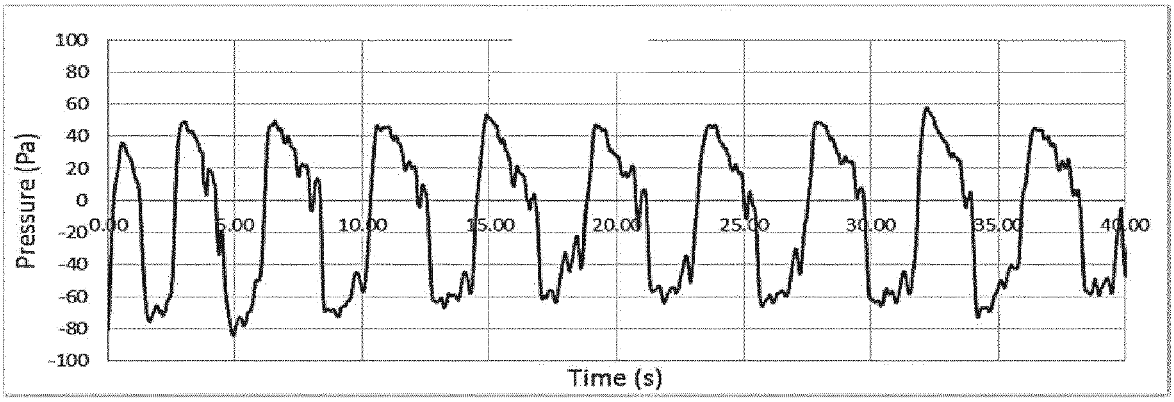


FIG. 7B

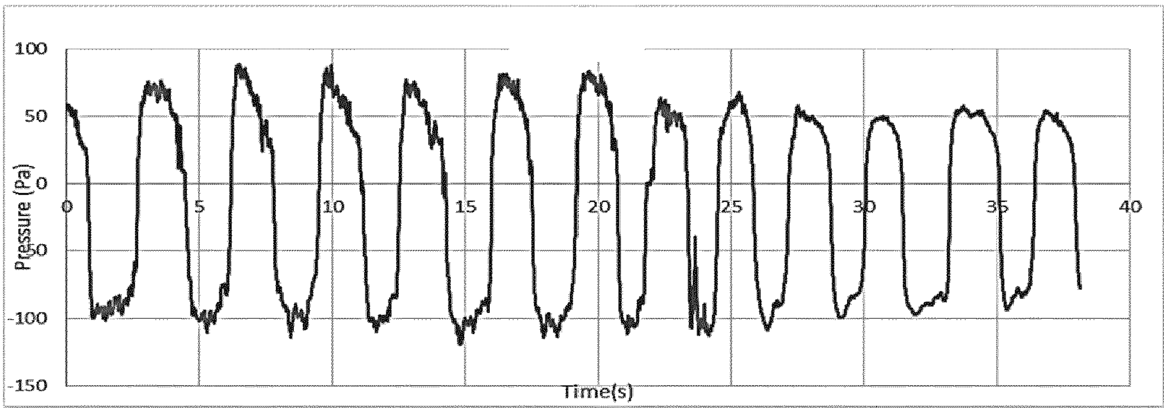


FIG. 7C

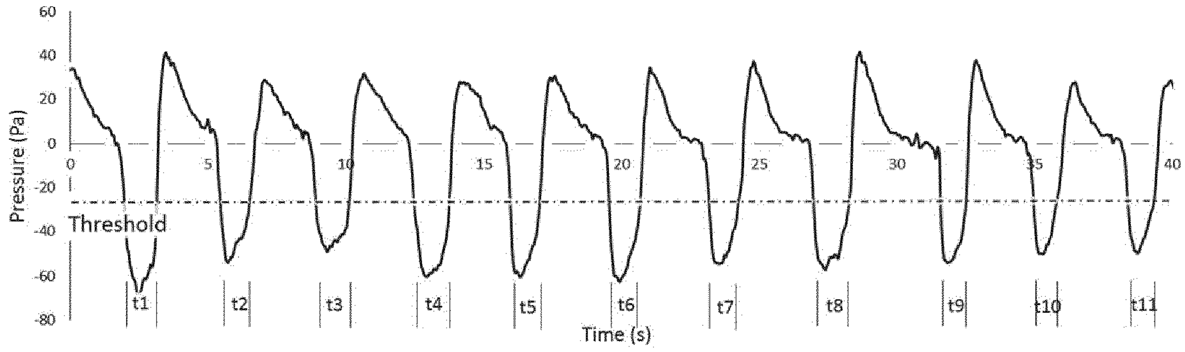


FIG. 8A

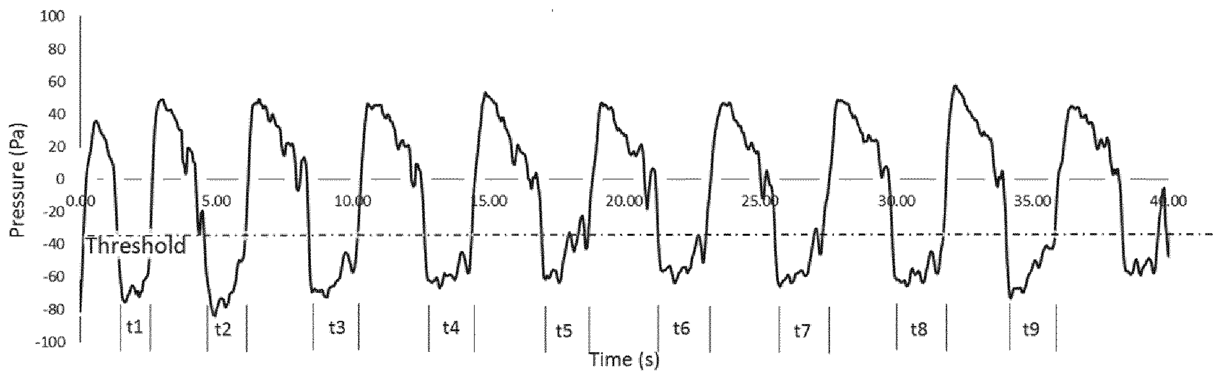


FIG. 8B

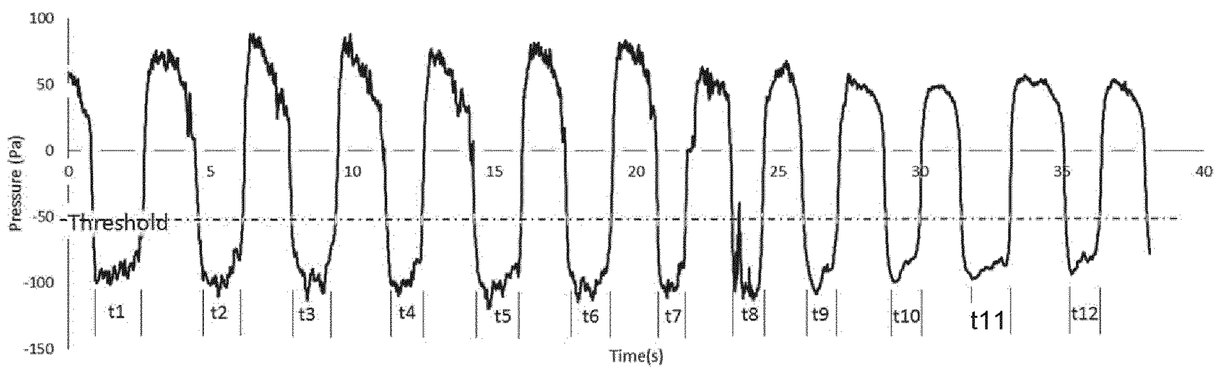


FIG. 8C

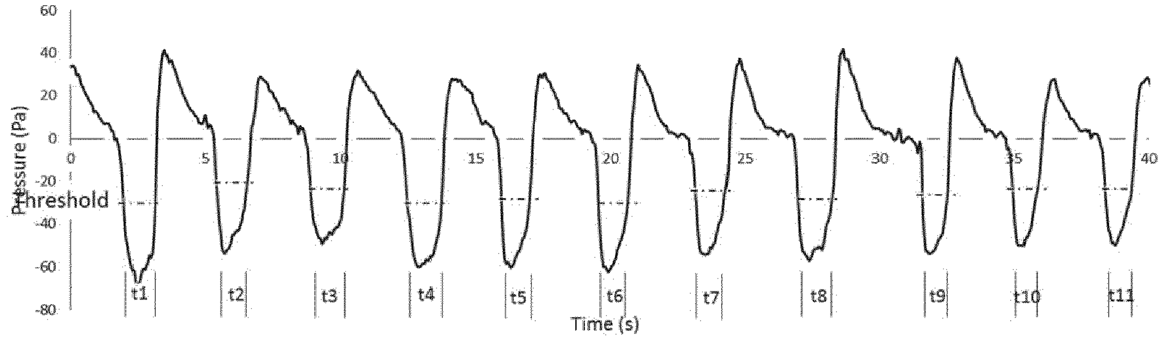


FIG. 9A

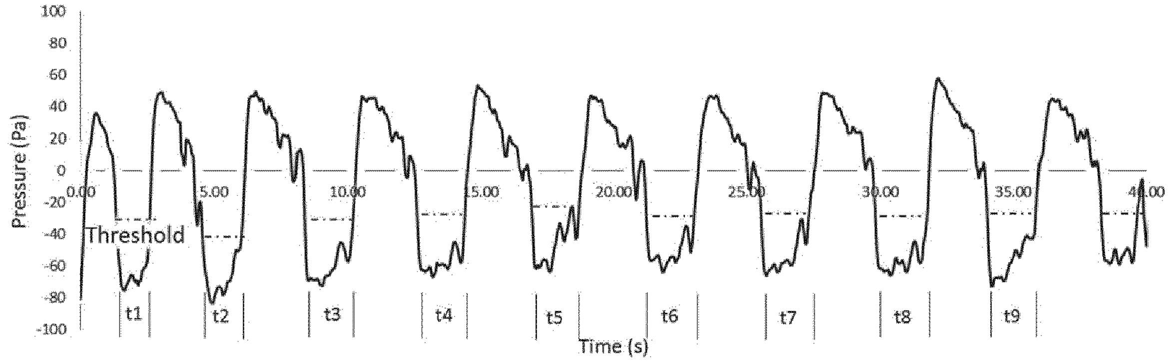


FIG. 9B

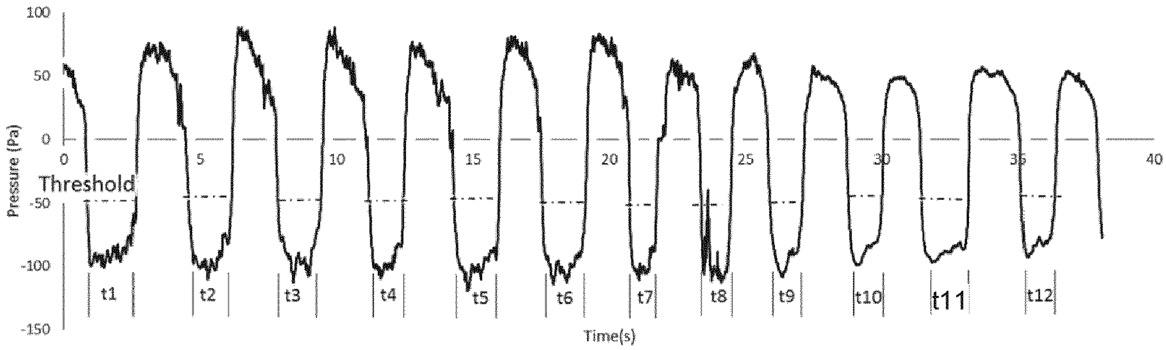
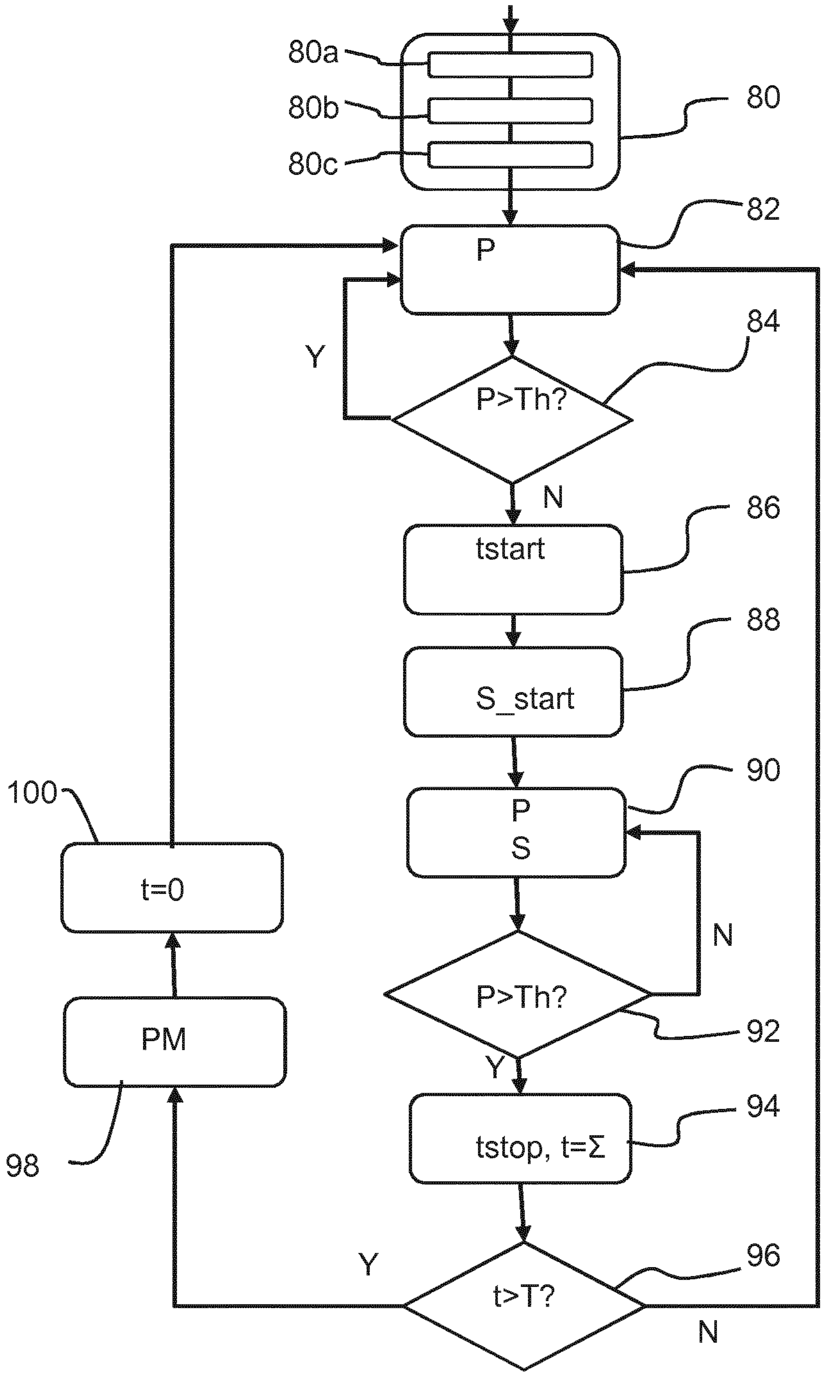


FIG. 9C


80a
80b
80c
80
82
P
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Y
P>Th?
N
86
tstart
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S_start
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P
S
100
t=0
N
P>Th?
92
PM
Y
94
tstop, t=Σ
98
96
Y
t>T?
N

FIG. 10

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EUROPEAN SEARCH REPORT

Application Number
EP 19 19 7165

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A62B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	9 March 2020	Andlauer, Dominique

CATEGORY OF CITED DOCUMENTS

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