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(54) **A MASK AND CONTROL METHOD**

(57) The invention provides a breathing assistance mask. A mask is provided that incorporates an air chamber, a filter, a fan arrangement, a sensor arrangement and a controller. The fan arrangement ventilates the mask. The sensor arrangement detects a breathing cycle of a user. The controller identifies a normal cyclic breathing period and a disturbed breathing period. Speaking and laughing are the most usual reasons for disturbances to the breathing cycle. When a normal cyclic breathing

period is identified, the controller controls the fan arrangement in a first mode in synchronism with the cyclic breathing. However, when a disturbed breathing period is identified, the controller controls the fan arrangement in a second mode which is not in synchronism with the timing of inhalation and exhalation. Breathing in the mask is thus facilitated both during normal and disturbed breathing.

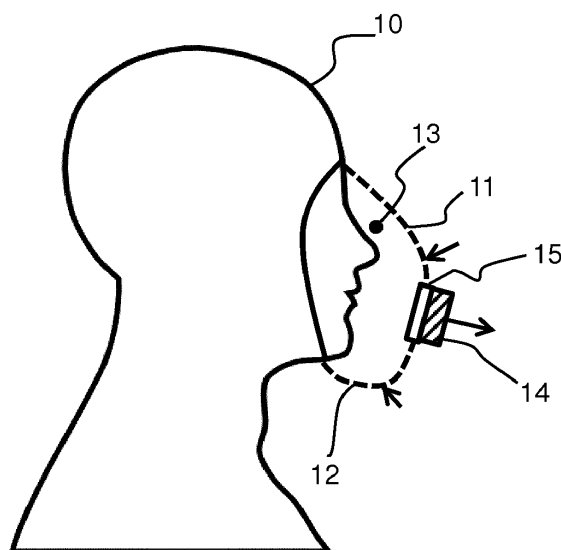


FIG. 4

Description

FIELD OF THE INVENTION

[0001] This invention relates to a mask and control method particularly to a mask for providing filtered air to the wearer of the mask, with the flow assisted by a fan arrangement.

BACKGROUND OF THE INVENTION

[0002] Air pollution is a worldwide concern. 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. Also 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] A significant contributor to air pollution is particulate matter suspended in the air. Particle pollution comes both from natural sources (such as volcanoes, dust storms, forest and grassland fires, living vegetation and sea spray) and from human activities (such as burning of fuels, transportation, power plants and various industrial processes). Besides these primary sources of particles, there are also secondary sources, which are fine particles generated through complicated atmospheric chemistry reactions of gas pollutants. Secondary sources include inorganic fine particles (e.g. sulfates, nitrates and ammonium salts generated by SO₂, NO₂, NH₃) and organic fine particles (generated by oxidation of volatile organic gases).

[0004] Official outdoor air quality standards define particle matter concentration as mass concentration per unit volume (e.g. µg/m³). A particular concern is pollution with particles having a diameter less than 2.5 µm (termed "PM2.5") as they are able to penetrate into the gas exchange regions of the lung (alveoli), and very small particles (<100 nm) may pass through the lungs to affect other organs.

[0005] 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 and the market for masks in China and elsewhere has seen a great surge in recent years. For example, it is estimated that over 1.9 billion masks were sold in China in 2014 and this number has since increased by over 20% year-on-year. However, during use, the temperature and relative humidity inside the mask increases and combined with the pressure difference inside the mask relative to the outside, makes breathing uncomfortable. To improve comfort and effectiveness, a fan can be added to the mask which draws in air through a filter. 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 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 have been numerous approaches to improving the user experience when wearing a powered mask. The approaches have tended to focus on regulation of fan speeds, both to improve user comfort and to improve the electrical efficiency of the fan.

[0009] For example, GB 2 032 284 discloses a respirator in which the pressure inside a mask is measured by a pressure sensor and the fan speed is varied in dependence on the sensor measurements.

[0010] However, speaking inside a powered mask is difficult as speech interferes with the regulation of the fan speed. US 2016/0271429 discloses a breathing apparatus with a breath monitoring apparatus. When speech is detected, the speech signal is removed from the detection signal so that only signals arising from the breathing of the user regulate the fan speed. However, this approach fails to take into account the disturbance to the user's inhalation/exhalation cycle when speaking.

[0011] There remains a need for further improvements in the comfort of the user when using a mask, especially during disturbances to the inhalation/exhalation cycle of the user.

SUMMARY OF THE INVENTION

[0012] The invention is defined by the claims.

[0013] According to examples in accordance with an aspect of the invention, there is provided a mask comprising:

- an air chamber;
- a filter;
- a fan arrangement for ventilating the mask;
- a sensor arrangement for detecting a breathing cycle of a user; and
- a controller which is adapted to:

identify a normal cyclic breathing period from the sensor arrangement output, and in response control the fan arrangement in a first mode in synchronism with the cyclic breathing; and
identify a disturbed breathing period from the sensor arrangement output, and in response control the fan arrangement in a second mode which is not in synchronism with the timing of

inhalation and exhalation.

[0014] The mask of the present invention ensures that during normal breathing (i.e. the breathing cycle of the user is not disturbed due to speaking etc.), breathing is assisted by the fan arrangement by controlling the fan arrangement in a first mode. However, when the user's breathing is disturbed, the fan arrangement cannot keep pace with the breathing cycle of the user. In this case, the mask of the present invention controls the fan arrangement to ventilate the mask and reduce the temperature and the relative humidity inside the mask by controlling the fan arrangement in a second mode. When the user resumes normal breathing, the fan arrangement again synchronizes with the breathing cycle of the user. The mask of the present invention ultimately makes breathing in the mask more comfortable when the breathing of the user is disturbed, e.g. during speaking.

[0015] In one embodiment, the sensor arrangement comprises a differential pressure sensor for determining a difference in pressure between air outside the air chamber and air inside the air chamber. Differential pressure sensors are readily available and easy to use.

[0016] In another embodiment, the fan arrangement comprises an inlet fan and an outlet fan. The fans improve ventilation of the mask to reduce the temperature and relative humidity inside the mask. An inlet fan brings fresh air into the mask and an outlet fan expels the air breathed out by the user from inside the mask to the outside.

[0017] In one aspect, during the first mode the controller is adapted to operate the inlet fan at a first speed during inhalation and a second, lower, speed during exhalation, and operate the outlet fan at a third speed during exhalation and a fourth, lower, speed during inhalation. In this way, the breathing cycle is fully assisted. The inlet and outlet fans synchronize with the breathing cycle of the user; the inhalation cycle is assisted by the inlet fan and the exhalation cycle is assisted by the outlet fan.

[0018] The second speed and the fourth speed may be zero. This minimizes battery use when the breathing cycle is in the opposite phase to the respective fan.

[0019] In another aspect, during the second mode the controller is adapted to operate the inlet fan and the outlet fan continuously during the disturbed breathing period. In this way, the mask is continuously ventilated to reduce the temperature and the relative humidity inside the mask whilst the user's breathing is disturbed and to compensate for the short duration of inhalation that will follow the disturbance to the breathing.

[0020] In one embodiment, the sensor arrangement comprises a temperature sensor and/or a relative humidity sensor. Again, temperature and relative humidity sensors are readily available and easy to use.

[0021] During the first mode, the controller may be adapted to operate the fan arrangement additionally in dependence on the temperature and/or relative humidity level in the air chamber. In this way, during normal breathing, the controller takes into account the temperature

and/or relative humidity level inside the mask and ensures that the fan arrangement provides the most appropriate ventilation for the user in the conditions inside the mask, whilst also taking into account the power consumption.

[0022] During the second mode, the controller may be adapted to operate the fan arrangement to maintain a temperature and/or relative humidity level in the air chamber. This improves user comfort during the disturbed breathing period.

[0023] In one aspect, the controller is adapted to detect the disturbed breathing period by counting peaks within a time window, wherein the disturbed breathing period is detected based on a count exceeding a threshold. This is a simple way of detecting the disturbed breathing period so that the fan arrangement can be controlled accordingly.

[0024] The disturbed breathing period may for example arise as a result of speaking or laughing. Each of these is characterized by repeated outward exhalations spaced by shorter but deeper inhalations. In another aspect, the controller is adapted to distinguish between speaking and laughing based on the amplitude of the peaks. Speaking and laughing are the most usual reasons for disturbances to the breathing cycle.

[0025] In an aspect of the invention, there is provided a method of controlling a mask, which mask comprises an air chamber, a filter, and a fan arrangement for ventilating the mask, wherein the method comprises:

detecting a breathing cycle of a user;
identifying a normal cyclic breathing period, and in response controlling the fan arrangement in a first mode in synchronism with the cyclic breathing; and
identifying a disturbed breathing period, and in response controlling the fan arrangement in a second mode which is not in synchronism with the inhalation and exhalation.

[0026] The fan arrangement may comprise an inlet fan and an outlet fan and wherein the method comprises, during the normal cyclic breathing period, operating the inlet fan at a first speed during inhalation and a second, lower, speed during exhalation, and operating the outlet fan at a third speed during exhalation and a fourth, lower, speed during inhalation.

[0027] During the second mode, the controller may be adapted to operate the inlet fan and the outlet fan continuously during the disturbed breathing period.

[0028] In another aspect of the invention, there is provided a computer program comprising computer program code means which is adapted, when said computer program is run on a computer, to implement the method defined above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Examples of the invention will now be described

in detail with reference to the accompanying drawings, in which:

Fig. 1 shows the pressure versus time breathing cycle inside a mask generated by a user wearing the mask and breathing normally;

Fig. 2 shows the pressure versus time breathing cycle inside a mask generated by a user wearing the mask while speaking;

Fig. 3 shows the pressure versus time breathing cycle inside a mask generated by a user wearing the mask while laughing;

Fig. 4 shows a mask containing a fan arrangement;

Fig. 5 shows one example of the components of a mask containing an inlet fan and an outlet fan;

Fig. 6 shows the pressure versus time breathing cycle inside a mask generated by a user wearing the mask and breathing normally, and the pressure versus time inside the mask generated by an inlet fan and an outlet fan in response to the breathing of the user.

Fig. 7 shows a time window in which the local exhalation peaks are counted;

Fig. 8 shows a mask operating method of the present invention; and

Fig. 9 shows a preferred embodiment of the mask operating method of the present invention for a mask containing an inlet fan and an outlet fan.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0030] The invention provides a breathing assistance mask. A mask is provided that incorporates an air chamber, a filter, a fan arrangement, a sensor arrangement and a controller. The fan arrangement ventilates the mask. The sensor arrangement detects a breathing cycle of a user. The controller identifies a normal cyclic breathing period and a disturbed breathing period. Speaking and laughing are the most usual reasons for disturbances to the breathing cycle. When a normal cyclic breathing period is identified, the controller controls the fan arrangement in a first mode in synchronism with the cyclic breathing. However, when a disturbed breathing period is identified, the controller controls the fan arrangement in a second mode which is not in synchronism with the timing of inhalation and exhalation. Breathing in the mask is thus facilitated both during normal and disturbed breathing.

[0031] Fig. 1 shows the pressure versus time breathing cycle inside a mask generated by a user wearing the mask and breathing normally. The y-axis is the differential pressure/Pa and the x-axis is time/seconds. The breathing cycle has peaks and troughs corresponding to exhalation and inhalation, respectively.

[0032] The breathing cycle is the pattern of inhalation and exhalation timings. It may be represented by any suitable parameter which varies on inhalation/exhalation versus time. Usually the breathing cycle is represented

as pressure versus time, but other parameters may be used, such as oxygen and/or carbon dioxide concentration, temperature, relative humidity, etc.

[0033] During inhalation, the pressure inside the mask decreases (negative pressure relative to the external ambient pressure) and during exhalation, the pressure inside the mask increases (positive pressure). The frequency and amplitude of the breathing cycle are relatively stable. The duration of inhalation is about 1.5 s and the duration of exhalation is about 3.5 s.

[0034] Fig. 2 shows the pressure versus time breathing cycle inside a mask generated by a user wearing the mask while speaking.

[0035] Speaking occurs in the exhalation cycle and small fluctuations in the pressure can be seen during the exhalation cycle. Thus, there are more closely spaced local exhalation peaks between the inhalation periods. Inhalation is short (about 500 ms) and there is a relatively large decrease in pressure inside the mask as the user takes a short but deep breath. The peak amplitude of the pressure during the inhalation cycle during speaking is larger than the peak amplitude of the pressure during the inhalation cycle during normal breathing.

[0036] Fig. 3 shows the pressure versus time breathing cycle inside a mask generated by a user wearing the mask while laughing.

[0037] Laughing also occurs in the exhalation cycle and large fluctuations in the pressure can be seen during the exhalation cycle. Again, there are more closely spaced local exhalation peaks between the inhalation periods. These fluctuations are larger than the fluctuations during speaking. In some instances, the pressure inside the mask during laughing exceeds 40 Pa in the exhalation cycle.

[0038] Fans generate a flow of air through the mask to reduce the temperature and relative humidity inside the mask and to regulate the pressure difference inside the mask relative to the outside. The fans are able to track the breathing cycle of the user, to make breathing in the mask more comfortable. For example, an inlet fan present in a mask may rotate during inhalation and may stop rotating during exhalation, with a time lag when the fan first starts up and a time lag between the user inhaling/exhaling and the adjustment of the fan speeds. Usually, this time lag is not a problem as the time lag is negligible compared to the overall duration of the inhalation and exhalation cycles of the user (a typical duration of inhalation is 1.5 s and a typical duration of exhalation is 3.5 s as can be seen in Fig. 1).

[0039] However, this time lag is problematic when the breathing is disturbed such as during speaking or laughing etc. In such breathing periods, the duration of inhalation is short (typically 500 ms) and it has been found that the fans cannot keep pace with the inhalation/exhalation cycle of the user. This may lead to the fans counteracting each other, disrupting the flow of air through the mask and increasing the pressure inside the mask relative to the outside, making breathing uncomfortable.

For example, an inlet fan may be rotating during exhalation and an outlet fan may be rotating during inhalation.

[0040] Speaking and laughing are two breathing periods in which the breathing of the user is disturbed. Both speaking and laughing are associated with a short duration of inhalation and a fluctuation of the exhalation cycle as can be seen in Figs. 2 and 3. Other breathing periods associated with a short duration of inhalation and a fluctuation in the exhalation cycle include singing, whistling, humming, sighing, coughing, breath holding and yawning.

[0041] In each of these instances, there is an increased number of local exhalation peaks as explained above, so that a count of exhalation peaks within a time window will exceed a threshold value. Thus, a disturbed breathing period has a short inhalation cycle (typically 500 ms) and a fluctuating exhalation cycle relative to a normal cyclic breathing period.

[0042] In a preferred embodiment, speaking is associated with a first threshold value, whereas laughing is associated with a second, higher, threshold value. The disturbance detected may be caused by singing, whistling, humming, yawning, breath holding and sighing, and it may also be possible to distinguish between some or all of these with the use of more complicated thresholds.

[0043] In the mask of the invention, an algorithm is implemented and the breathing cycle, usually the peaks corresponding to the exhalation cycle of the user, is monitored. This monitoring is able to distinguish between a normal cyclic breathing period and a disturbed breathing period and control the fan arrangement accordingly. During normal cyclic breathing, the fan arrangement is run in a first mode in synchronism with the cyclic breathing of the user. During disturbed breathing, the fan arrangement is run in a second mode which is not in synchronism with the cyclic breathing of the user. Overall, this makes breathing in the mask more comfortable whatever the breathing period.

[0044] Fig. 4 shows a mask of the invention containing a fan arrangement.

[0045] A user 10 is shown wearing a face mask 11 which covers at least the nose and mouth of the user. The purpose of the mask is to filter air before it is breathed in by the user. For this purpose, in Fig. 1, the mask body itself acts as an air filter 12. Air is drawn into an air chamber 13 formed by the mask by inhalation. During inhalation, an outlet valve 15 such as a check valve is closed due to the low pressure in the air chamber 13.

[0046] When the subject breathes out, air is exhausted through the outlet valve 15. This valve is opened to enable easy exhalation, but is closed during inhalation. A fan arrangement 14 ventilates the mask and in the embodiment shown, assists in the removal of air through the outlet valve 15. 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 15 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 12. However, it may instead be an electronically controlled valve.

[0047] The fan arrangement 14 may comprise an inlet fan or an outlet fan to ventilate the mask. An inlet fan draws air through the filter 12 from outside the air chamber 13 into the air chamber. An inlet fan may be positioned before or after the filter 12. An outlet fan draws air from inside the air chamber 13 to the outside. In this embodiment, the exhaust air would not need to pass through the filter, but it could be drawn through the filter by the outlet fan as well.

[0048] During a normal cyclic breathing period, an inlet fan or an outlet fan assists the breathing of the user. For example, if an inlet fan is present, it may be switched on during inhalation and switched off during exhalation. Alternatively, if an outlet fan is present, it may be switched off during inhalation and switched on during exhalation.

[0049] In another aspect, the fan arrangement 14 comprises an inlet fan and an outlet fan. In this way, the inhalation/exhalation cycle is fully assisted. The inlet and outlet fans synchronize with the breathing cycle of the user; inhalation is assisted by the inlet fan to bring fresh air into the mask and exhalation is assisted by the outlet fan to expel the air breathed out by the user from inside the mask to the outside.

[0050] When the mask is not in use, it may be switched off. In one embodiment, the mask comprises a switch for starting and stopping the fan arrangement 14. This would allow the user to have full control over when to start and stop the fan arrangement. For example, the user could ensure that the fan arrangement is switched off at all times when the mask is not in use. When the mask is switched on, the fan arrangement may start operating with the first or second mode being determined by the controller. Alternatively, there may instead be detection using a sensor arrangement of when the mask is being worn to provide automatic control of the fan arrangement. The mask may then go straight into its operating mode.

[0051] Fig. 5 shows one example of the components of a mask containing an inlet fan and an outlet fan. The same components as in Fig. 4 are given the same reference numbers.

[0052] In addition to the components shown in Fig. 4, Fig. 5 shows an inlet fan 16 having an inlet fan blade 16a and an inlet fan motor 16b, an outlet fan 17 having an outlet fan blade 17a and an outlet fan motor 17b, a controller 20, a local battery 21 and a sensor arrangement 22 for detecting a breathing cycle of the user.

[0053] In one example, the fan motors 14b and 15b are electronically commutated brushless motors. Electronically commutated brushless motors are preferred for efficiency and longevity reasons. 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.

[0054] The sensor arrangement 22 for detecting a breathing cycle of the user may be a differential pressure sensor for determining a difference in pressure between air outside the air chamber and air inside the air chamber. For example, for a known pressure (e.g. atmospheric pressure) at one side of the inlet and outlet fans, the pressure monitoring enables determination of a pressure, or at least a pressure change, on the other side of the inlet and outlet fans. This other side is for example a closed chamber which thus has a pressure different to atmospheric pressure. In this way, inhalation and exhalation may be detected.

[0055] By detecting equal pressure on each side of the inlet and outlet fans, it can then be determined that the chamber is not closed but is connected to atmospheric pressure on both sides. In this way, no inhalation and exhalation is detected. This can also signal that the mask is not being worn, and can thus be used to switch off the fans to save power.

[0056] A suitable differential pressure sensor is one from Sensirion (Trade Mark) such as SDP 31 having a measurement range of -500 to 500 Pa, a zero point accuracy of 0.1 Pa and a flow stop response time of less than 3 ms. Such a sensor can track the breathing cycle of the user in real time. Preferably, the sensor comprises a differential pressure sensor having a measurement range of -500 to 500 Pa. This covers the breathing pressure range. Other sensors may also be used to determine whether a user is inhaling or exhaling. For example, temperature, relative humidity, carbon dioxide, oxygen or a combination of any of the above sensors may be used.

[0057] The pressure difference information is transmitted to the controller 20. The controller 20 then identifies a normal cyclic breathing period or a disturbed breathing period. In response, the controller 20 controls the inlet fan 16 and outlet fan 17 in a first mode during a normal cyclic breathing period and in a second mode during a disturbed breathing period. In the first mode, the controller controls the inlet fan 16 and the outlet fan 17 in synchronism with the cyclic breathing. In the second mode, the controller controls the inlet fan 16 and the outlet fan 17 not in synchronism with the timing of inhalation and exhalation.

[0058] If a normal cyclic breathing period is identified, the controller also determines whether the user is inhaling or exhaling. For example, a decrease in pressure in the air inside the air chamber relative to the air outside the air chamber would correspond to an inhalation and an increase in pressure in the air inside the air chamber relative to the air outside the air chamber would correspond to an exhalation.

[0059] In use during a normal cyclic breathing period, the inlet fan 16 and the outlet fan 17 may be run such that during the first mode the controller 20 is adapted to operate the inlet fan 16 at a first speed during inhalation and a second, lower, speed during exhalation, and operate the outlet fan 17 at a third speed during exhalation and a fourth, lower, speed during inhalation. The first and

second speeds of the inlet fan 16 and the third and fourth speeds of the outlet fan 17 refer to rotation speeds.

[0060] When a transition from exhalation to inhalation is determined, the controller 20 sends a signal to the inlet fan motor 16b to increase the rotation speed of the inlet fan blade 16a from the second speed to the first speed. The controller 20 also sends a signal to the outlet fan motor 17b to decrease the rotation speed of the outlet fan blade 17a from the third speed to the fourth speed. In this way, during inhalation, the inlet fan 16 is run at the first speed and the outlet fan 17 is run at the fourth speed. This compensates for the decrease in pressure inside the mask during inhalation.

[0061] Conversely, if a transition from inhalation to exhalation is determined, the controller 20 sends a signal to the outlet fan motor 17b to increase the rotation speed of the outlet fan blade 17a from the fourth speed to the third speed. The controller 20 also sends a signal to the inlet fan motor 16b to decrease the rotation speed of the inlet fan blade 16a from the first speed to the second speed. In this way, during exhalation, the outlet fan 17 is run at the third speed and the inlet fan 16 is run at the second speed. This compensates for the increase in pressure inside the mask during exhalation.

[0062] When both an inlet fan 16 and an outlet fan 17 are present, the second speed of the inlet fan 16 is preferably the same as the fourth speed of the outlet fan 17. This provides a consistent user experience, in terms of feel and sound.

[0063] The first speed of the inlet fan 16 may be the same as or different to the third speed of the outlet fan 17, depending on the design of the inlet and outlet flow paths of the mask and the differential pressure inside the mask created by the inlet fan 16 and the outlet fan 17. For example, if air is drawn into the mask through the filter and drawn out of the mask through a valve, the inlet fan 16 would need to generate a higher pressure than the outlet fan 17. This could be achieved using a first speed for the inlet fan 16 that is higher than the third speed for the outlet fan 17.

[0064] The second speed and the fourth speed may be zero or a minimum non-zero speed. In one embodiment, the second speed and the fourth speed are zero. This minimizes battery use when the breathing cycle is in the opposite phase to the respective fan. Alternatively, the second speed and the fourth speed could be non-zero. One of the benefits of running the inlet fan 16 at a minimum non-zero second speed and the outlet fan 17 at a minimum non-zero fourth speed is that the fans are run at a low idling speed which uses minimal power, but reduces latency. Further, continuously running the inlet and outlet fans at least at a minimum level ensures that there is minimal delay when switching the operation of the inlet fan to the outlet fan during the transition between inhalation and exhalation, and when switching the operation of the outlet fan to the inlet fan during the transition between exhalation and inhalation. The impulse required to change the fan speed during use is thus reduced so

that the desired fan speed changes can be made more quickly. Thus, the air flow in the mask may be synchronized more easily with the breathing cycle of the user, ultimately making breathing in the mask more comfortable.

[0065] The fan speeds may be tailored to the breathing of the user (e.g. breath frequency and tidal volume) and may be adjusted to take into account different breathing scenarios (e.g. exertion like walking and running).

[0066] The speeds to be used may be determined during a calibration process or they may be provided by the fan manufacturer. The calibration process for example involves analyzing the fan speed information over a period during which the user is instructed to inhale and exhale regularly with normal breathing. The captured fan speed information can then be used to determine the appropriate fan speeds. The controller may also provide for settings for the user to regulate the higher first and third speeds, and the lower second and fourth speeds, and any intermediate speeds.

[0067] In a most simple example, the rotation speeds of the inlet fan 16 and the outlet fan 17 alternate between two set values, with the changes in rotation speed implemented at the detected transitions between inhalation and exhalation.

[0068] There may also be a number of intermediate rotation speeds at which the inlet and outlet fans may be run between the first and third speeds and between the second and fourth speeds. However, the second and fourth speeds normally set the minimum rotation speed. The minimum rotation speed ideally provides an optimum balance between lag time and power efficiency. The first and third speeds are typically dependent on the breathing of the user (e.g. breath frequency and tidal volume) and could be adjusted to take into account different breathing scenarios (e.g. exertion like walking and running). In one simple embodiment, the first and third speeds set the maximum rotation speed. In this way, the first and third speeds ideally provide an optimum balance between lag time and power efficiency on the one hand, and assistance given to the user on the other.

[0069] The rotation speeds of the inlet and outlet fans are for example controlled by a pulse width modulation signal, whereby the duty cycle controls the rotation speed.

[0070] Fig. 6 shows the pressure versus time breathing cycle 61 inside a mask generated by a user wearing the mask and breathing normally (i.e. breathing pressure plus fan pressure), and the pressure versus time 62 inside the mask generated by an inlet fan 16 and an outlet fan 17 in response to the breathing of the user. The left-hand scale is the pressure inside the mask and the right-hand scale is the fan pressure. Fig. 6 starts on an exhalation. When the user exhales and the pressure 61 generated by the user increases, the pressure 62 generated by the fans decreases to balance the differential pressure inside the mask. This is achieved by running the inlet fan 16 at the second speed and the outlet fan 17 at the third speed

so that the rotation speed of the outlet fan 17 is higher than the rotation speed of the inlet fan 16. On detection of the subsequent inhalation, when the user inhales and the pressure 61 generated by the user decreases, the pressure 62 generated by the fans increases to balance the differential pressure inside the mask. This is achieved by running the inlet fan 16 at the first speed and the outlet fan 17 at the fourth speed so that the rotation speed of the inlet fan 16 is higher than the rotation speed of the outlet fan 17. In this way, the air flow in the mask is synchronized with the cyclic breathing cycle of the user, ultimately making breathing in the mask more comfortable.

[0071] During a typical exhalation cycle, the pressure inside a mask rapidly increases during the transition between inhalation and exhalation before slowly decreasing to a differential pressure of zero. However, the decrease in pressure during the exhalation cycle is not constant and the pressure fluctuates, increasing and decreasing in small increments, during the overall decrease in pressure. This can be seen in Figs. 1-3 and in Fig. 6 in which there are a number of peaks and troughs in the breathing cycle.

[0072] The breathing cycle fluctuates from its baseline cycle when the user's breathing is disturbed. The baseline cycle has a series of peaks and troughs in the breathing cycle corresponding to exhalation and inhalation, respectively. When a user makes a sound through their mouth, including speaking, laughing, singing, whistling, humming, sighing, coughing and yawning, their breathing is disturbed. On inhalation, the user will take a short but deep breath and on exhalation, the breathing cycle will fluctuate depending on the particular sound being made. The duration of inhalation may be so short that the fan arrangement 14 is not able to keep pace with the breathing cycle of the user when the user's breathing is disturbed. The user may also deliberately hold their breath. Therefore, in order to avoid the fan arrangement 14 interfering with the user's breathing, the fan arrangement 14 is run in a second mode which is not in synchronism with the timing of inhalation and exhalation. By this it is meant that there is no longer a direct correlation between the way the fan arrangement is controlled and the timing of inhalation and exhalation phases. For example, the fan arrangement control is independent of the breathing cycle changes during the disturbed breathing period but is instead controlled in a way which only takes account of the fact the a disturbed breathing period is currently detected.

[0073] When an inlet fan 16 and an outlet fan 17 are present, during the second mode the controller may be adapted to operate the inlet fan 16 and/or the outlet fan 17 continuously for example at a single speed, during the disturbed breathing period. In this way, the inlet fan 16 and/or the outlet fan 17 may be run continuously to generate a consistent air pressure inside the fan, regardless of whether the user is inhaling or exhaling. For example, the inlet fan 16 may be run at the first speed and/or the outlet fan 17 may be run at the third speed. This en-

sure that the mask is continuously ventilated to reduce the temperature and the relative humidity inside the mask whilst the user's breathing is disturbed and to compensate for the short duration of inhalation that will follow the disturbance to the breathing.

[0074] In one example, the sensor arrangement 22 comprises a temperature sensor and/or a relative humidity sensor.

[0075] During the first mode, the controller 20 may be adapted to operate the fan arrangement 14 additionally in dependence on the temperature and/or relative humidity level in the air chamber. In this way, during normal breathing, the controller takes into account the temperature and/or relative humidity level inside the mask and ensures that the mask provides the most appropriate ventilation for the user in the conditions inside the mask, whilst also taking into account the power consumption.

[0076] During the second mode, the controller may be adapted to operate the fan arrangement to maintain a temperature and/or relative humidity level in the air chamber but independently of the timing of inhalations and exhalations as explained above. This improves user comfort during the disturbed breathing period. For example, a temperature and/or relative humidity sensor is used to measure the temperature and/or relative humidity inside the mask and to determine the fan arrangement working speed in the second mode. In this regard, the fan arrangement may have different working speeds in the second mode, e.g. low, medium and high, and the working speed may increase proportionally with the temperature and/or relative humidity inside the mask. The speed of the second mode may be determined by comparing the temperature (T) and/or relative humidity (RH) values inside the mask with pre-set temperature and/or relative humidity values. For example, the pre-set temperatures may be 26°C (T₁) and 30°C (T₂) and the pre-set relative humidity values may be 50% (RH₁) and 80% (RH₂). Then, if T > T₂ or RH > RH₂, the fan arrangement in the second mode has a high working speed. However, if T₁ ≤ T ≤ T₂ or RH₁ ≤ RH ≤ RH₂, the fan arrangement in the second mode has a medium working speed. Or, if T < T₁ or RH < RH₁, the fan arrangement in the second mode has a low working speed.

[0077] In one example, the sensor arrangement 22 comprises a differential pressure sensor for determining a difference in pressure between air outside the air chamber 13 and air inside the air chamber 13 and a temperature sensor and/or a relative humidity sensor. These sensors can work together in combination with the controller 20 to identify the breathing period of the user and to determine the first mode and the second mode of the fan arrangement 14.

[0078] As explained above, the disturbed breathing period may be detected based on the presence of local exhalation peaks. Fig. 7 shows a time window in which the local exhalation peaks are counted. These local exhalation peaks arise during an overall exhalation period, i.e. they are not spaced by an inhalation period.

[0079] The time window 71 determines the length of time of the breathing cycle that is being monitored. It corresponds to the real time data storage depth in the controller's flash memory. Thus, the time window is a sliding time window that provides a snapshot of the current breathing cycle of the user, allowing the fan arrangement to be controlled in real time. For example, the time window 71 can be set at 1 s and the sensor can be sampling the breathing cycle at a rate of 10 Hz, giving ten samples of the breathing cycle in the time window 71.

[0080] The fluctuation of the user's breathing cycle may be monitored by counting exhalation peaks within a time window 71, wherein the disturbed breathing period is detected based on a count exceeding a threshold. The threshold may be determined by reference to the number of peaks in a normal cyclic breathing period within a time window of the same duration. The threshold is a value which exceeds the number of exhalation peaks in a normal cyclic breathing period within a time window of the same duration. Thus, the number of exhalation peaks within a time window 71 may be compared to the number of peaks in a normal cyclic breathing period within a time window of the same duration in order to identify a disturbed breathing period. The threshold may vary from user to user and the threshold may be determined for the user during a calibration process.

[0081] When the user's breathing is not disturbed, the count is below the threshold. The fluctuation of the exhalation cycle is minimal and the controller 20 operates the fan arrangement 14 in the first mode as described above. However, when the user's breathing is disturbed, the count exceeds a threshold. Fluctuation of the breathing cycle is identified and the controller 20 operates the fan arrangement 14 in the second mode as described above.

[0082] Counting exhalation peaks within a time window corresponds to determining a frequency of local exhalation peaks within the breathing cycle and comparing this frequency to those expected in the baseline breathing cycle, i.e. the normal cyclic breathing period. A threshold frequency value may be used to determine whether the user's breathing is disturbed.

[0083] When the user's breathing returns to normal, i.e. the user is no longer making a sound through their mouth and the normal cyclic breathing period resumes, the controller 20 determines that the frequency has dropped below the threshold frequency value and the fan arrangement 14 again tracks the breathing of the user. The fan arrangement 14 operates again in the first mode.

[0084] In this way, the breathing cycle of the user is continuously monitored and the controller 20 can recognize different breathing periods. The controller 20 is able to select the fan working mode (first or second mode) and control the fan arrangement 14 depending on the breathing period identified.

[0085] The system may be able to distinguish between laughing and speaking, based on the differences between the profiles of Figs. 2 and 3.

One difference is the timing of the local peaks, i.e. the frequency of occurrence of the local peaks.

[0086] For example, the frequency of local exhalation peaks may be higher when the user is laughing compared to when the user is speaking (because laughing is a sequence of bursts which are typically shorter than variations through speech). During speaking, the frequency of exhalation peaks may exceed a first threshold but not a second, higher, threshold. During laughing, the frequency of exhalation peaks may exceed the second, higher, threshold. Thus, first and second different thresholds for the count value (i.e. frequency) may be applied. The first and second thresholds may be determined during a calibration process. The first threshold is preferably at least 0.5 Hz, more preferably at least 1 Hz. The second threshold is preferably at least 5 Hz, more preferably at least 10 Hz.

[0087] Thus, laughing and speaking may thus be differentiated based only on the frequency of the local peaks. However, a preferred approach is described below which takes account of the size of the local peaks within the sliding time window. For this purpose, a peak to valley amplitude is calculated.

[0088] For example, the amplitude of the local exhalation peaks may be determined by calculating the peak to valley amplitude as follows. Four differential pressure values P at times t , $t-1$, $t-2$, $t-3$ and $t-4$ are mentioned to explain the process.

[0089] One time point, for example $P(t-1)$, is identified as a valley when the pressures for the time points at each side are higher, i.e. $P(t) - P(t-1) > 0$ and $P(t-1) - P(t-2) < 0$.

[0090] Another time point, for example $P(t-3)$, is identified as a peak when the pressures for the time points at each side are lower, i.e. $P(t-2) - P(t-3) < 0$ and $P(t-3) - P(t-4) > 0$.

[0091] The peak to valley amplitude is then $P(t-3) - P(t-1)$. This provides a measure of the local peak height. This local peak may be between inhalation and exhalation pressures or between two inhalation pressures or between two exhalation pressures.

[0092] As can be seen in Figs. 2 and 3, speaking is characterized by small local fluctuations in the breathing cycle during the disturbed period, whereas laughing is characterized by large local fluctuations. Thus, there are amplitude differences as well as frequency differences.

[0093] A running count of large peak to valley occurrences and small peak to valley occurrences can then be made to distinguish between laughing and speaking. An amplitude threshold is then set for each detected peak to valley amplitude.

[0094] For example, counter₁ corresponds to the number of peaks in the time window when the amplitude exceeds the threshold and counter₂ corresponds to the number of peaks in the time window when the amplitude is below the threshold. A total peak counter is defined by counter₁ + counter₂. This total peak count is used to distinguish between the normal breathing cycle and the disturbed breathing cycle in the manner explained above.

It indicates the total number of peaks in the time window.

[0095] For the time period of a disturbed breathing cycle, if counter₁ is higher than counter₂, the user is laughing and if counter₁ is less than counter₂, the user is speaking.

[0096] When laughing is detected, the controller may be further adapted to transmit this information to an external device. In this way, the user may have a record of the number of times they have laughed whilst wearing the mask. Such an intelligent mask could help to improve user engagement. For example, the mask could either congratulate the user if the number of times the user has laughed is high or encourage the user to laugh more if the number of times the user has laughed is low.

[0097] In this way, there is a threshold for the frequency of all local peaks and a threshold relating to the amplitude of those local peaks. There may also be one or more additional threshold values relating to the breathing cycle to further distinguish between different types of breathing period. This information may be transmitted to an external device for subsequent analysis.

[0098] The controller 20 may be further adapted to transmit the data relating to the breathing cycle to an external device. For example, the external device may be a smartphone of the user and the transmission may be wireless via Wi-Fi, Bluetooth, ZigBee or other wireless technologies.

[0099] Fig. 8 shows a mask operating method of the invention. The method is for controlling a mask, which mask comprises an air chamber 13, a filter 12, and a fan arrangement 14 for ventilating the mask. The method comprises the following steps.

[0100] In step 72, detecting a breathing cycle of a user.

[0101] In step 74, identifying a normal cyclic breathing period, and in response controlling the fan arrangement 14 in a first mode in synchronism with the cyclic breathing.

[0102] In step 76, identifying a disturbed breathing period, and in response controlling the fan arrangement 14 in a second mode which is not in synchronism with the inhalation and exhalation. Typically, this step is performed when the user is speaking or laughing.

[0103] The fan arrangement 14 may comprise an inlet fan 16 and an outlet fan 17 and the method may comprise during the normal cyclic breathing period, operating the inlet fan 16 at a first speed during inhalation and a second, lower, speed during exhalation, and operating the outlet fan 17 at a third speed during exhalation and a fourth, lower, speed during inhalation.

[0104] The controller 20 may be adapted to operate the inlet fan 16 and the outlet fan 17 continuously during the disturbed breathing period.

[0105] Fig. 9 shows a preferred mask operating method for a mask containing an inlet fan 16 and an outlet fan 17.

[0106] In step 80, the software is initialized, including setting the default working mode of the fan arrangement 14, setting the default temperature and relative humidity ranges and setting the differential pressure values for the

fan arrangement 14.

[0107] In step 81, the temperature and/or relative humidity and the differential pressure inside the mask are sampled.

[0108] In step 82, the sampled temperature and/or relative humidity are compared with the default temperature and/or relative humidity ranges to determine the working speed of the fan arrangement.

[0109] In step 83, the default working mode of fan arrangement is adjusted to the determined working speed of the fan arrangement.

[0110] In step 84, the type of breathing period is determined as explained above, by setting the time window, and counting peaks in the time window (and optionally also analyzing the peak to valley amplitudes).

[0111] For the normal breathing cycle, in step 85, the inlet fan 16 and the outlet fan 17 are run in the first mode based on the count of the exhalation peaks within the time window being at or below a threshold. It is determined whether the user is inhaling or exhaling.

[0112] In step 86, the inlet fan 16 is run at the first (high) speed and the outlet fan 17 at the fourth (low) speed, when the user is inhaling.

[0113] In step 87, the outlet fan 17 is run at the third (high) speed and the inlet fan 16 at the second (low) speed, when the user is exhaling.

[0114] For the disturbed breathing cycle, in step 88, the inlet fan 16 and the outlet fan 17 are run in the second mode, specifically running the inlet fan 16 at the first (high) speed and the outlet fan 17 at the third (high) speed, when the count of the exhalation peaks within the time window exceeds a threshold.

[0115] In step 89, it is determined that the user is speaking based on the count of the high and low amplitude peaks within the time window.

[0116] In step 90, it is determined that the user is laughing based on the count of the high and low amplitude peaks within the time window.

[0117] The present invention also provides a computer program comprising computer program code means which is adapted, when said computer program is run on a computer, to implement the method of the present invention.

[0118] The method of the present invention makes 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 may be programmed using software (e.g. microcode) to perform the required functions. In one aspect, the mask further comprises a microcontroller unit for processing a count of the exhalation peaks within a time window and for controlling the fan arrangement mode. A controller may however be implemented with or without employing a processor, and also may be 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.

[0119] 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).

[0120] 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.

[0121] The controller may be further adapted to transmit data relating to the breathing cycle to an external device. In this way, the user may have a record of the number of times their breathing has been disturbed due to speaking, laughing etc.

[0122] Preferably, the mask further comprises a battery to power the fan arrangement 14, the sensor arrangement 22 and the controller 20.

[0123] The mask may be for covering only the nose and mouth (as shown in Fig. 4) or it may be a full face mask.

[0124] The example shown is a mask for filtering ambient air. However, the mask may be used with a breathing gas from an external supply, for example a breathing assistance device, such as a continuous positive air pressure (CPAP) system.

[0125] The mask design described above has the main air chamber formed by the filter material, through which the user breathes in air. The filter comprises a filter member in series with an inlet fan, when present. The outer wall of the air chamber may define the filter. Alternatively, a filter may be provided only at the location of the inlet fan, when present, in combination with a non-permeable outer housing. In this case, the inlet fan assists the user in drawing in air through the filter, thus reducing the breathing effort for the user. An inlet valve may be provided adjacent to the inlet fan, when present, and an outlet valve may be provided adjacent to the outlet fan, when present. In one aspect, the mask further comprises a valve for exhausting air from inside the air chamber 13 to the outside.

[0126] It will be seen that the invention may be applied to many different mask designs, with fan-assisted inhalation and exhalation, and with an air chamber formed by a filter membrane or with a sealed hermetic air chamber.

[0127] 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.

[0128] Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. A mask (11) comprising:

an air chamber (13);
a filter (12);
a fan arrangement (14) for ventilating the mask;
a sensor arrangement (22) for detecting a breathing cycle of a user (10); and
a controller (20) which is adapted to:

identify a normal cyclic breathing period from the sensor arrangement output, and in response control the fan arrangement (14) in a first mode in synchronism with the cyclic breathing; and
identify a disturbed breathing period from the sensor arrangement output, and in response control the fan arrangement (14) in a second mode which is not in synchronism with the timing of inhalation and exhalation.

2. A mask as claimed in claim 1, wherein the sensor arrangement (22) comprises a differential pressure sensor for determining a difference in pressure between air outside the air chamber (13) and air inside the air chamber (13).

3. A mask as claimed in claim 1 or 2, wherein the fan arrangement (14) comprises an inlet fan (16) and an outlet fan (17).

4. A mask as claimed in claim 3, wherein during the first mode the controller (20) is adapted to operate the inlet fan (16) at a first speed during inhalation and a second, lower, speed during exhalation, and operate the outlet fan (17) at a third speed during exhalation and a fourth, lower, speed during inhalation.

5. A mask as claimed in claim 4, wherein the second speed and the fourth speed are zero.

6. A mask as claimed in claim 4 or 5, wherein during the second mode the controller (20) is adapted to operate the inlet fan (16) and the outlet fan (17) continuously during the disturbed breathing period.

7. A mask as claimed in any preceding claim, wherein

the sensor arrangement (22) comprises a temperature sensor and/or a relative humidity sensor.

8. A mask as claimed in claim 7, wherein during the first mode the controller (20) is adapted to operate the fan arrangement (14) additionally in dependence on the temperature and/or relative humidity level in the air chamber (13).

9. A mask as claimed in claim 7 or 8, wherein during the second mode the controller (20) is adapted to operate the fan arrangement (14) to maintain a temperature and/or relative humidity level in the air chamber (13).

10. A mask as claimed in any preceding claim, wherein the controller (20) is adapted to detect the disturbed breathing period by counting peaks within a time window (71), wherein the disturbed breathing period is detected based on a count exceeding a threshold.

11. A mask as claimed in claim 10, wherein the controller (20) is adapted to distinguish between speaking and laughing based on the amplitude of the peaks within the disturbed breathing period.

12. A method of controlling a mask (11), which mask comprises an air chamber (13), a filter (12), and a fan arrangement (14) for ventilating the mask, wherein the method comprises:

detecting a breathing cycle of a user (10);
identifying a normal cyclic breathing period, and in response controlling the fan arrangement (14) in a first mode in synchronism with the cyclic breathing; and
identifying a disturbed breathing period, and in response controlling the fan arrangement (14) in a second mode which is not in synchronism with the inhalation and exhalation.

13. A method as claimed in claim 12, wherein the fan arrangement (14) comprises an inlet fan (16) and an outlet fan (17) and wherein the method comprises, during the normal cyclic breathing period, operating the inlet fan (16) at a first speed during inhalation and a second, lower, speed during exhalation, and operating the outlet fan (17) at a third speed during exhalation and a fourth, lower, speed during inhalation.

14. A mask as claimed in claim 12 or 13, wherein during the second mode the controller (20) is adapted to operate the inlet fan (16) and the outlet fan (17) continuously during the disturbed breathing period.

15. A computer program comprising computer program code means which is adapted, when said computer

program is run on a computer, to implement the method of any one of claims 12 to 14.

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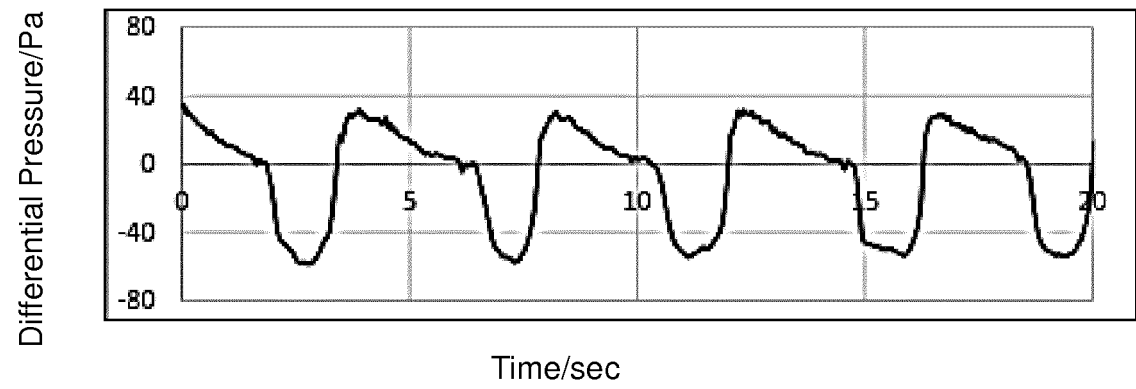


FIG. 1

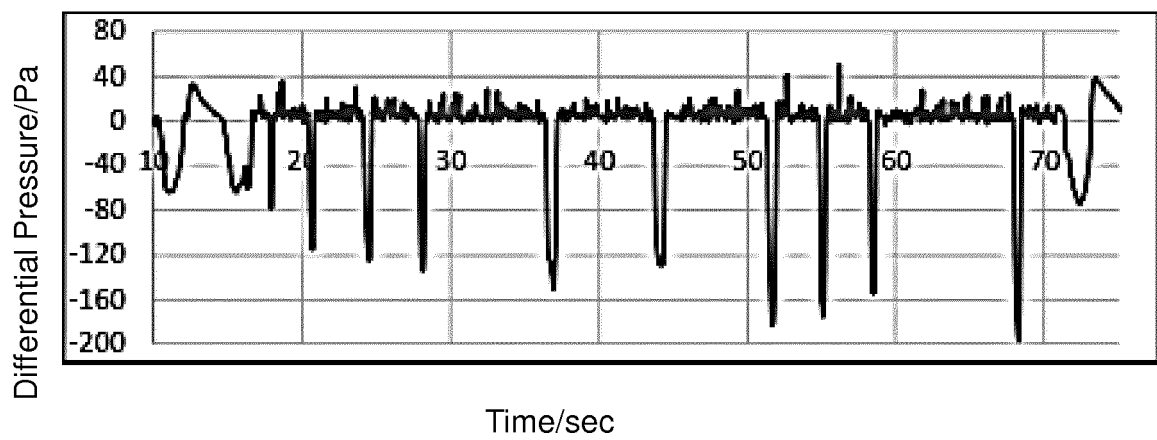


FIG. 2

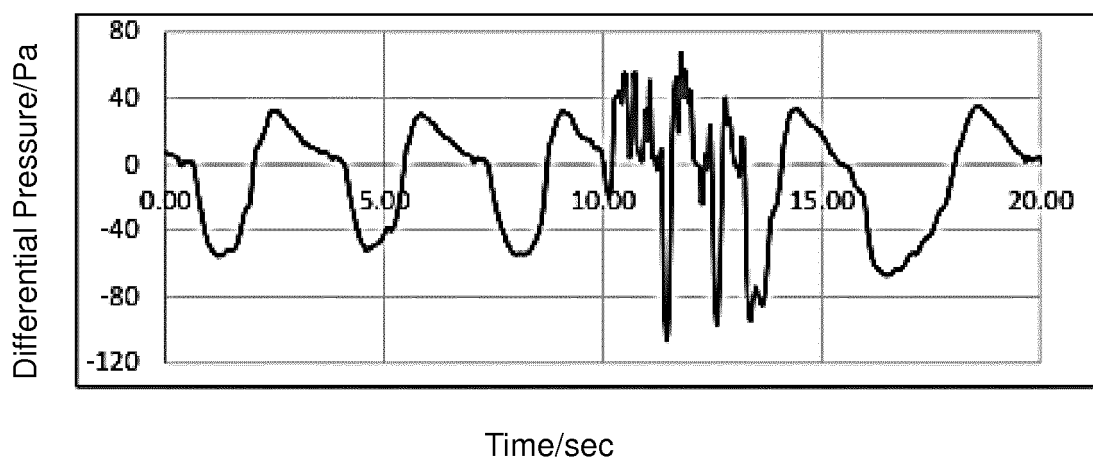


FIG. 3

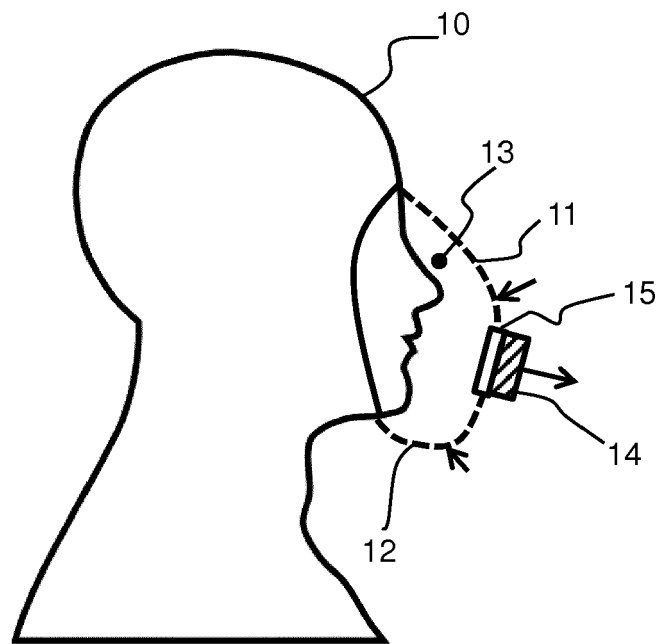


FIG. 4

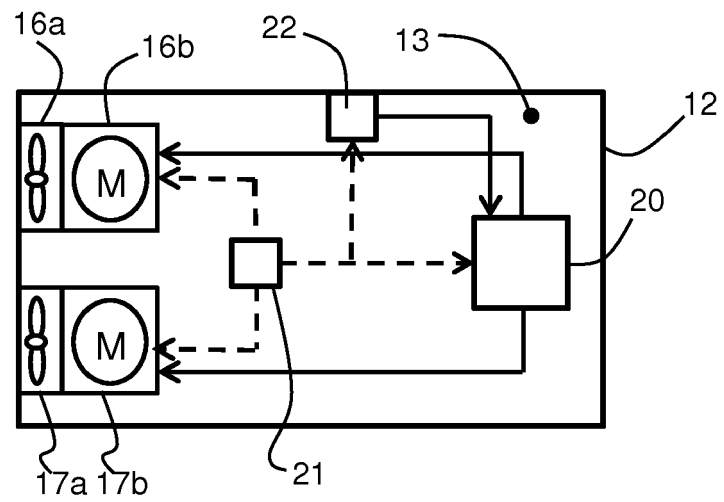


FIG. 5

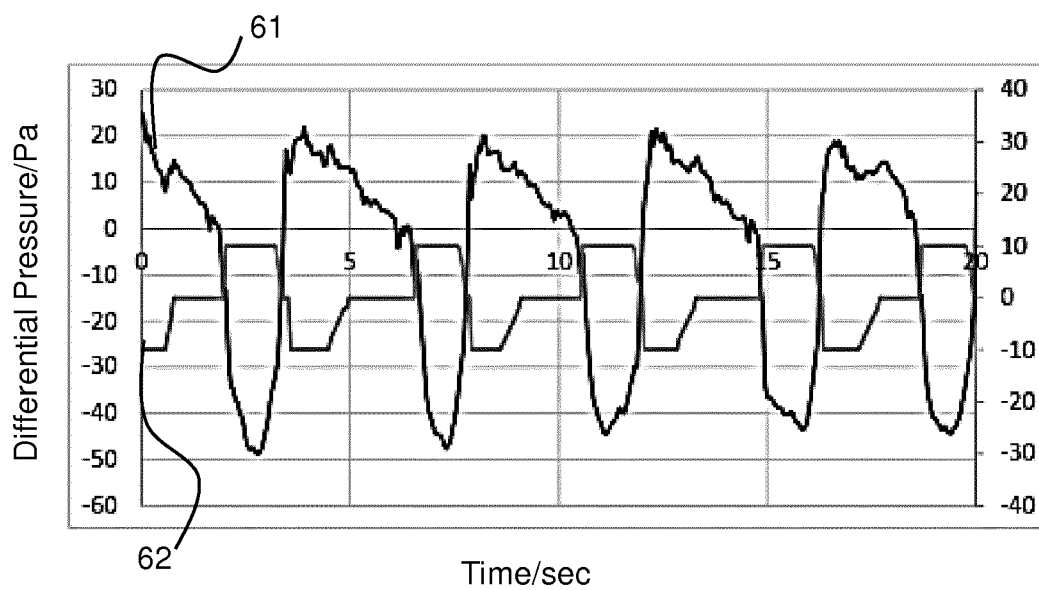


FIG. 6

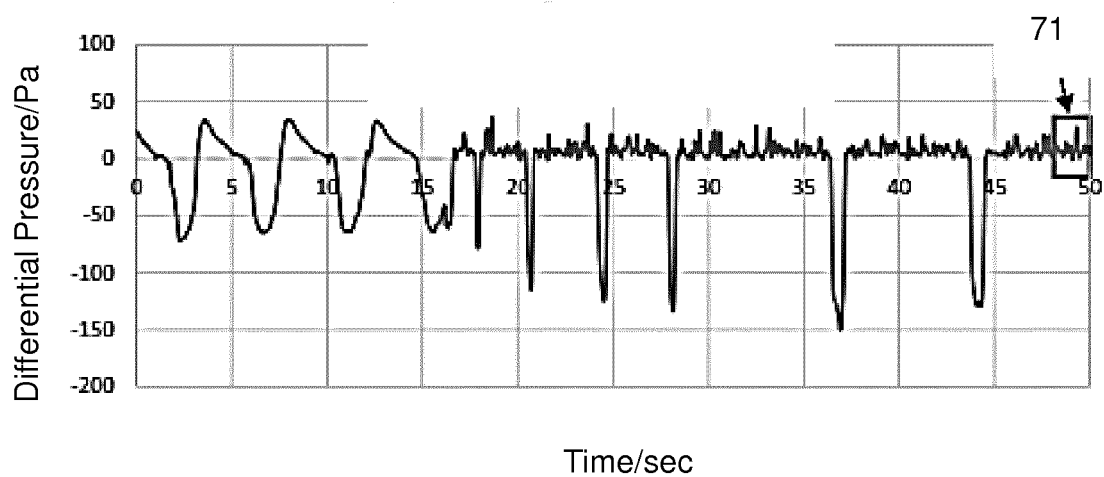


FIG. 7

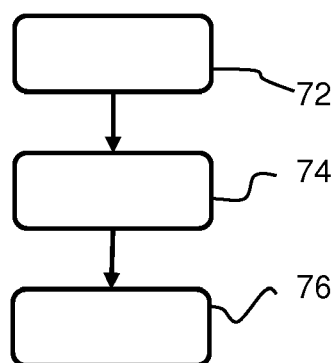


FIG. 8

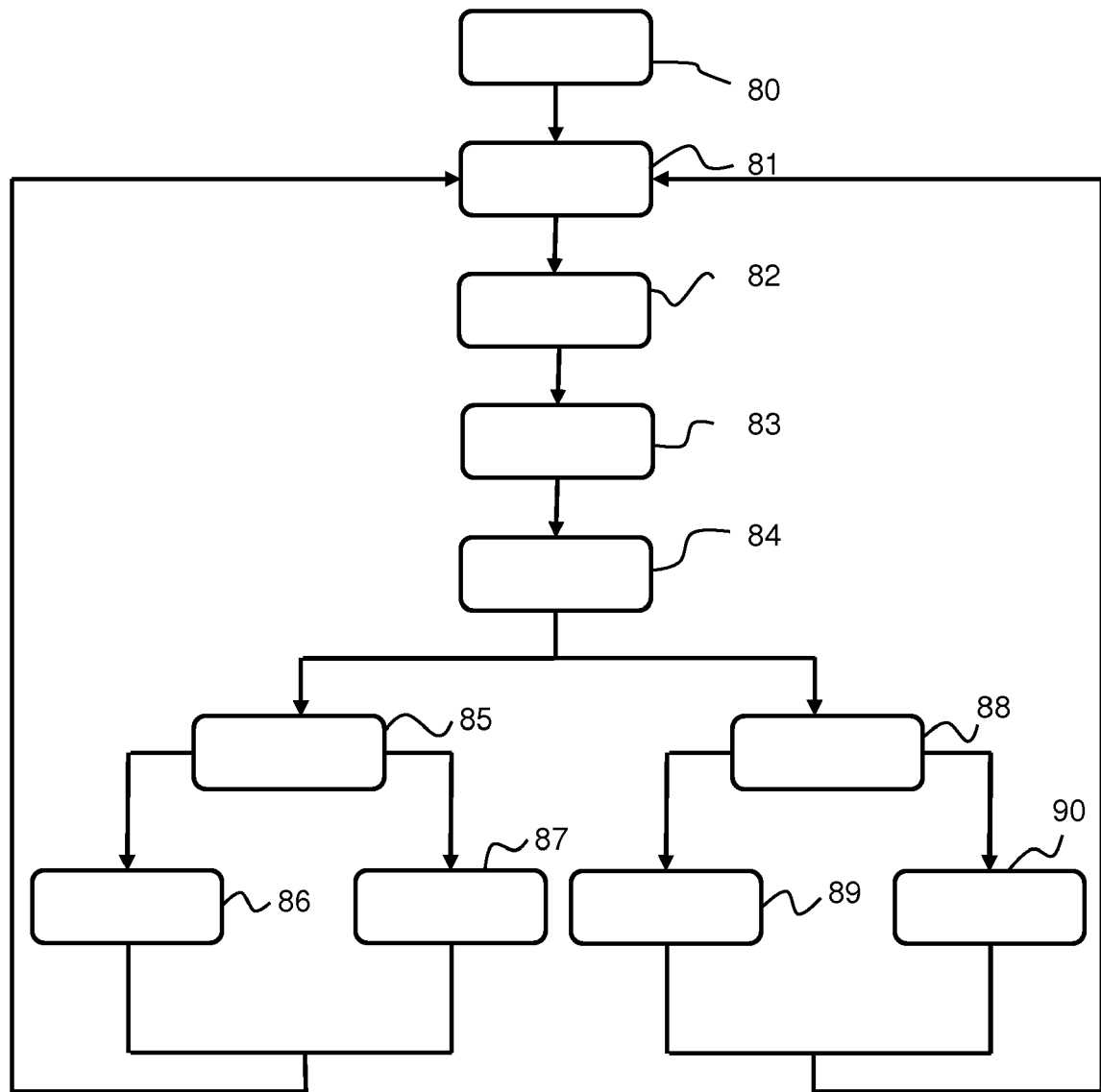


FIG. 9



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Place of search The Hague		Date of completion of the search 14 November 2017	Examiner Andlauer, Dominique
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