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(54) **CENTRIFUGAL SEPARATOR WITH PRESSURE SENSOR ARRANGEMENT**

(57) A centrifugal separator (100) for crankcase gas is disclosed, comprising a separator housing (110), defining a separation space (120), and a plurality of separation members (132) rotatably arranged in the separation space. A first gas passage (141) and a second gas passage (142) extend through the separator housing to guide a flow of the gas through the separation members to allow at least some of the contaminants to be separated from the flow of gas. Further, the separator comprises a sensor housing (155) and a sensor arrangement (150), wherein the sensor arrangement is arranged in the sensor housing and operable to generate a sensor output indicative of a pressure in the first gas passage and a pressure in the second gas passage, and/or a difference between a pressure in the first gas passage and a pressure in the second gas passage.

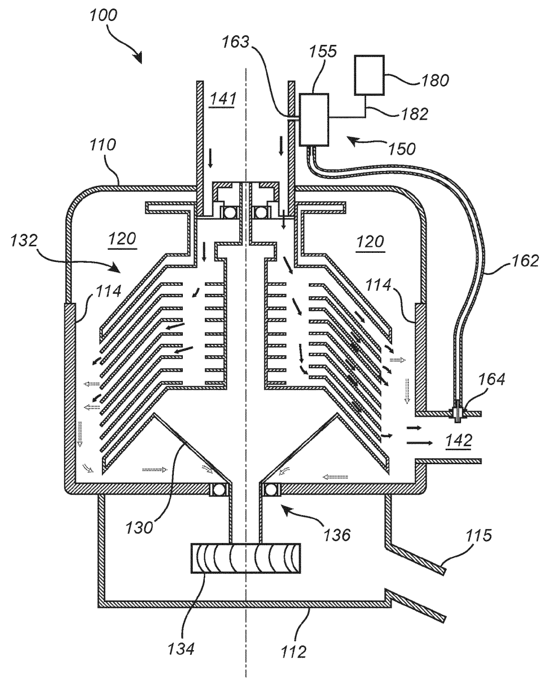

Fig. 2

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Description

Technical Field

[0001] The present disclosure relates to centrifugal separators for cleaning a flow of gas, and more specifically for separating contaminants from a flow of gas from a crankcase of an internal combustion engine.

Background

[0002] High-pressure gas in the combustion chambers of an internal combustion engine tends to leak past the piston rings into the crankcase of the engine. If not ventilated, the gas may cause a pressure increase in the crankcase, which risks impeding the operation of the engine. Typically, the gas contains contaminants such as unburned fuel, particulate matter, and traces of oil from the reservoir of oil held in the crankcase. Releasing the vented gas directly into the atmosphere contributes to air pollution, which is harmful to the environment and poses a human health hazard.

[0003] To mitigate these issues, a crankcase ventilation system may be used, comprising a centrifugal separator for separating oil and particulate matter from the vented gas. The cleaned gas may then be redirected back into the engine's intake for re-burning to further reduce emissions from the engine.

[0004] As the cleaning and recycling of the gas from the crankcase often plays a critical role in reducing emissions and maintaining engine health, it is desirable to monitor the operation of the separator and verify that the crankcase ventilation system has not been tampered with.

Summary

[0005] It is an object of the present disclosure to provide a technology that addresses at least some of the above concerns.

[0006] According to a first aspect, there is provided a centrifugal separator for separating contaminants from a flow of gas from a crankcase of an internal combustion engine. The centrifugal separator comprises a separator housing defining at least a part of a separation space, and a plurality of separation members rotatably arranged in the separation space. The centrifugal separator further comprises a first gas passage and a second gas passage, each extending through the separator housing and being configured to guide the flow of gas through the separation space and the plurality of separation members to allow at least some of the contaminants to be separated from the flow of gas. The centrifugal separator also comprises a sensor housing and a sensor arrangement arranged within the sensor housing. The sensor arrangement is operable to generate a sensor output indicative of a pressure in the first gas passage and a pressure in the second gas passage, and/or a difference between the pressure in the first gas passage and the pressure in the second gas passage.

[0007] According to a second aspect, there is a provided a method for determining a state of a centrifugal separator for separating contaminants from a flow of gas from a crankcase of an internal combustion engine. The method comprises guiding, by means of a first gas passage and a second gas passage, the flow of gas through a plurality of separation members arranged in a separation space at least partly defined by a separator housing, wherein each of the first gas passage and the second gas passage extends through the separator housing. The method further comprises rotating the separation members to separate at least some of the contaminants from the flow of the gas, receiving, from a sensor arrangement arranged in the same sensor housing, a sensor output indicative of a pressure in the first gas passage and a pressure in the second gas passage, and/or a difference between the pressure in the first gas passage and the pressure in the second gas passage. Further, the method comprises determining a state of the centrifugal separator based on the sensor output.

[0008] The separator typically forms part of a crankcase ventilation system in which blow-by gas from the combustion chamber is guided from the crankcase to the separator for cleaning, and back to the combustion chamber for re-burning. By monitoring the pressure of the gas guided through the ventilation system, it may be possible to determine whether the crankcase ventilation system is working as intended or if it is malfunctioning. More specifically, the pressure in the first gas passage and the second gas passage, which typically form an inlet/outlet of the separator, can be used to detect a malfunction of the separator. The malfunction may, for example, be caused by the separator being bypassed, the separator inlet being disconnected, or the output from the separator being released to the atmosphere instead of being returned to the combustion chamber. The pressures measured at the inlet and the outlet may be compared with predetermined reference values to detect possible error states. The predetermined reference values may, for example, be associated with a normal operation of the separator (i.e., when the separator and the crankcase ventilation system work as intended) and may represent typical pressure levels for a given operational mode of the internal combustion engine and the separator. Any deviations from the reference values may indicate an error state, in which the separator has been bypassed, disconnected, or otherwise tampered with.

[0009] The pressure in the first and second gas passages may be measured by separate sensor elements, such as a first sensor element for the first gas passage and a second sensor element for the second gas passage. These sensor elements may be arranged in the same physical location, such as within the same housing or physical enclosure, and operable to generate the output indicating the respective pressures. In some examples, however, the sensor arrangement may comprise a differential pressure sensor arranged in the sensor housing to measure a pressure difference between the first and second inlet. This may be achieved by a single sensor element, such as a sensor element comprising a diaphragm which on one side is exposed to the pressure in the first gas passage and on the other side is exposed to the pressure in the second gas passage.

[0010] Beneficially, the sensor arrangement allows for the sensor output to be retrieved from a single physical location, i.e., without using separate sensors arranged at the respective gas passage. As it may be difficult to arrange separate sensors at each of the first and second gas passages due to mechanical constraints and lack of available space, the present sensor arrangement allows for a more flexible technology where the sensor arrangement can be arranged in a location which is more easily accessed and where there is more available space. The sensor arrangement may further allow for simplified cabling, as the cabling may be routed to a single location instead of two separate locations. This may save costs both in terms of material and time for assembly and installation.

[0011] The sensor arrangement may be fluidically coupled to each of the first gas passage and the second gas passage to allow the respective pressures to be transmitted to, and measured by, the sensor arrangement. The fluidic coupling may be achieved in various ways, depending on the configuration and location of the sensor arrangement. The fluidic coupling may, for example, be achieved by means of one or more conduits running between the first or second gas passage and the sensor arrangement, or a passage or opening in the sensor housing interfacing with a corresponding opening or passage in a wall defining the first or second gas passage.

[0012] Thus, in an example, the sensor arrangement may be arranged at the first gas passage and coupled to the second gas passage by means of a conduit. The conduit may form a fluidic connection that allows the sensor arrangement to measure a pressure transferred from the second gas passage. The conduit may, for example, be formed by a tube, such as a flexible tube, that can be coupled to a fitting or nipple at the second gas passage and routed between the second gas passage and the sensor arrangement. The sensor housing may be attached to an exterior of the first gas passage, or a part of the separator housing forming at least a part of the first gas passage. The sensor arrangement may be fluidically coupled to the first gas passage by means of a connector or connecting passage through a wall enclosing the first gas passage.

[0013] In further examples, the sensor arrangement may be arranged at the second gas passage. Similar to above, the sensor arrangement may be fluidically coupled to the first gas passage by means of a conduit running therebetween and to the second gas passage via an opening in the sensor housing interfacing with an opening in a wall of the first gas passage.

[0014] In yet a further example, the sensor arrangement may be arranged at a location separate from the first gas passage and the second gas passage, and fluidically coupled to each of the gas passages by means of a respective conduit.

[0015] It will be appreciated that the specific location of the sensor arrangement may be determined by mechanical constraints and available space for the particular separator and engine configuration. Hence, the sensor arrangement may be arranged at the first gas passage, the second gas passage, or elsewhere depending on the available space, the ease with which the sensor housing can be fastened (permanently or detachably) to the exterior of the separator housing or the respective passages, as well as the accessibility of these locations during assembling.

[0016] As mentioned above, the sensor arrangement may comprise a sensor element, such as a diaphragm sensor element, forming a differential pressure sensor measuring the difference between the pressure in the first gas passage and the second gas passage. The differential pressure sensor may be arranged such that a first side of the sensor element is exposed to the pressure in the first gas passage and a second side of the sensor element is exposed to the pressure in the second gas passage.

[0017] Alternatively, or additionally, the sensor arrangement comprises a first sensor element arranged to generate a first sensor signal indicative of the pressure in the first gas passage and a second sensor element arranged to generate a second sensor signal indicative of the pressure in the second gas passage. In different words, there may be provided separate sensor elements for the different gas passages, which are arranged in the same sensor housing. Thus, the first sensor element may be fluidically coupled to the first gas passage, whereas the second sensor element may be fluidically coupled to the second gas passage. Each of the first and second sensor elements may be of a diaphragm sensor type similar to the differential pressure sensor above. However, in the present example, the diaphragm sensor may use the ambient atmosphere as a reference pressure. Thus, a first side of the diaphragm may be exposed to the pressure in the first/second gas passage, and the other side of the diaphragm exposed to the ambient air.

[0018] The first gas passage may form a gas inlet for supplying the flow of gas to the separation space. Accordingly, the second gas passage may form a gas outlet for discharging the flow of gas from the separation space. It will be appreciated that additional components, such as sensors and valves, may be provided at the inlet or outlet. In an example, a pressure regulating valve may be arranged the outlet, thereby occupying space that otherwise could have been used for the sensor arrangement. It may therefore be beneficial to install the sensor arrangement at the gas inlet instead, Further, it may be easier to fasten the sensor housing to the inlet wall than to the outlet wall, as the latter risks affecting or damaging the pressure regulating valve.

[0019] The sensor output may be used to determine the pressure in the first gas passage and the pressure in the second gas passage, respectively. Alternatively, or additionally, the difference between the pressure in the first gas passage and the pressure in the second gas passage, also referred to as the pressure drop over the separator or the differential pressure, may be determined. The pressure information, i.e., the respective pressures in the first and second gas passages or the pressure drop over the separator, may be used to determine the state of the separator. The state may typically refer to an operational state, indicating whether the separator operates as intended or not. Deviating pressure values, i.e., pressures and differential pressures deviating from predetermined reference values or ranges, may indicate that the separator, for example, has been bypassed or that the outlet and/or inlet of the separator has been disconnected from the rest of the crankcase ventilation system. This may be indicated as a faulty state or malfunction state, or that that the crankcase ventilation system has been tampered with.

[0020] The internal combustion engine, ICE, may typically be configured to propel a vehicle or a vessel, such as a lorry or a ship. The ICE may however also be a stationary engine, for instance driving an electric power generator.

[0021] By "separator" is typically meant a centrifugal separator comprising a plurality of separation members rotated by means of a rotor shaft to separate contaminants from the flow of gas. The rotor may be driven by a flow of pressurised oil, or by means of an electric motor. The plurality of separation members may typically be a stack of conical discs, and the separator may hence be considered to represent a disc stack centrifuge.

[0022] The terms upstream and downstream may be used to denote a direction or position seen along a flow direction of the gas. Upstream may be understood as closer to a source of the flow and downstream as farther away from the source of the flow.

[0023] The gas passages may typically be understood as passages through which the flow of gas can enter and exit, respectively, the separation space of the separator. Hence, a gas passage may also be referred to as an outlet or an inlet of the separator.

[0024] Further features and advantages of the invention will become apparent from the following description of preferred embodiments of the invention, given by way of example only, which is made with reference to the accompanying drawings.

Brief Description of the Drawings

[0025] Various aspects and examples of the present disclosure will be readily understood from the embodiments discussed in the following detailed description and the accompanying drawings, in which:

Figure 1 is a schematic representation of an engine and a crankcase ventilation system according to some examples.

Figure 2 shows a cross section of a centrifugal separator according to some examples.

Figure 3 shows a cross section of a sensor arrangement arranged within a sensor housing according to some examples.

Figure 4 is a flow chart outlining a method for determining a state of a centrifugal separator according to some examples.

Detailed Description

[0026] Figure 1 is a schematic illustration of an internal combustion engine 10, which typically operates by combusting a fuel-air mixture within a cylinder to generate a high-pressure gas that causes a piston to move in a reciprocating movement. The reciprocating movement is converted by a crankshaft 14 into a rotation motion that can be used to propel a vehicle or drive a generator, for example.

[0027] During the combustion process, some of the high-pressure gases and a small amount of the fuel-air mixture may leak past the piston rings into the crankcase 12. This crankcase gas, also referred to as "blow-by" gas, needs to be ventilated from the crankcase 12 so as to not impede the operation of the engine 10. As the crankcase gas typically contains unburnt fuel, oil vapour, and combustion byproducts, it is desirable to subject the vented gas to a cleaning process.

[0028] Figure 1 shows an example of a crankcase ventilation system in which the crankcase gas is guided from the crankcase 12 to a centrifugal separator 100 by means of a first gas conduit 171. The separator 100 is operable to clean the crankcase gas by separating contaminants such as oil and particulate matter from the crankcase gas. The cleaned crankcase gas may then, according to some examples, be redirected back by a second gas conduit 172 into the engine's intake for reburning. The separated oil may preferably be returned to the crankcase 12 via a return conduit 173.

[0029] The first gas conduit 171 may be coupled to a first gas passage 141 of the separator 100, which in the present example may extend through a housing of the separator 100 to form a gas inlet through which a flow of crankcase gas may be supplied to the separator 100. Similarly, the second gas conduit 172 may be coupled to a second gas passage 142 of the separator 100, which may extend through the housing to form a gas outlet through which the cleaned flow of crankcase gas may be discharged from the separator 100. In different words, the first gas passage 141 and the second gas passage 142 may be arranged to guide the flow of gas through the separator 100 to allow at least some of the contaminants in the gas to be removed by the separator 100.

[0030] As illustrated in the present figure, the separator 100 may comprise a sensor arrangement 150 operable to generate a sensor output indicating a pressure characteristic of the flow of crankcase gas. The sensor arrangement 150 may, for example, generate information indicating a pressure in the first gas passage 141 and a pressure in the second gas passage 142, and/or a difference between the pressure in the respective gas passages 141, 142. The sensor arrangement 150 is arranged in a sensor housing 155, which in turn may be coupled, directly or indirectly, to the first and second gas passages 141, 142 to allow the respective pressures to be measured. In the example shown in figure 1, the sensor housing 155 is fluidically coupled to the first gas passage 141 by a first sensor conduit 161 and to the second gas passage 142 by a second sensor conduit 162. The first and second sensor conduits 161, 162 may, for example, be formed of tubes or hoses arranged to transfer the pressure in the respective gas passages 141, 142 to one or more sensor elements arranged in the housing 155.

[0031] As will be discussed in greater detail in connection with figure 4, the sensor arrangement 150 may be employed to determine a status of the separator 100. More specifically, deviations in the pressure in the gas inlet 141, the gas outlet 142, or in the pressure drop between the gas inlet 141 and the gas outlet 142, may indicate a malfunction of the separator 100 or that the crankcase ventilation system has been tampered with. The pressure at the gas inlet 141 and at the gas outlet 141 of a properly operating separator 100 typically depends on several parameters, such as the inherent pump effect provided by the separator 100, the flow of blow-by gas from the crankcase, and the under-pressure generated by downstream components such as a turbocharger. Generally, the blow-by gas can either be sucked through the separator 100 (which is typically the case in which the inherent pump effect of the separator 100 exceeds the flow of the blow-by gas) or pushed through the separator 100 (which is typically the case when the flow of the blow-by gas exceeds the pump effect of the separator 100). In case the blow-by gas is sucked through the separator 100, this may result in an inlet pressure being below the atmospheric pressure. In case the blow-by gas is pushed through the separator 100, this may result in an inlet pressure exceeding the atmospheric pressure. Should the gas inlet 141 be disconnected from the flow of blow-by gas, the separator 100 will draw air from the ambient atmosphere instead, which may result in a gas inlet pressure slightly below the atmospheric pressure. Disconnecting the gas outlet 142 from the downstream parts of the crankcase ventilation system may result in a gas outlet pressure close to the atmospheric pressure.

[0032] As illustrated above, the pressure conditions at the gas inlet 141 and the gas outlet 142 may vary, inter alia, with the balance between the flow of blow-by gas vented from the crankcase and the pump effect provided by the separator 100. To determine the state of the separator 100 or the crankcase ventilation system, the measured pressures at the gas inlet 141 and the gas outlet 142 may be compared with a set of reference values that is specific for the actual operating conditions, such as the operation point, rotational speed, and load of the engine as well as the rotational speed of the separator. These reference values may be predetermined and stored in a table, associating a certain operating condition with a certain pressure. During operation, a measured pressure at the gas inlet 141 or the gas outlet 142 can be compared with a predetermined reference value associated with one or more of the operating conditions at which the pressure was measured, and a state of the separator 100 or crankcase ventilation system determined accordingly.

[0033] Figure 2 shows an example wherein the sensor arrangement 150 is arranged at the gas inlet 141 of the separator 100, and more specifically attached to an outer wall of the gas inlet 141. The sensor arrangement 150 is fluidically coupled to the gas inlet 141 by means of a connector 163, such as a nipple, extending through the wall enclosing the gas inlet 141 to allow the pressure in the gas inlet 141 to be transmitted to a sensor element (not shown) in the sensor housing 155. The sensor arrangement 150 is further fluidically coupled to the gas outlet 142 by means of a conduit, or sensor conduit 162, extending between the sensor housing 155 and the gas outlet 142. The conduit 162 may, in some examples, be formed of a hose or tube, such as a flexible tube, allowing the pressure in the gas outlet 142 to be measured by a sensor element (not shown) in the sensor housing 155. The sensor conduit may be fluidically coupled to the gas outlet by means of a connector 164 which, similarly to the connector 163 at the gas inlet 141, may extend through a wall of the gas outlet 142. In the present example, the connector 163 is a nipple to which the sensor conduit 164 can be attached.

[0034] The sensor arrangement 150 is communicatively coupled to a control unit 180, which may be arranged within the sensor housing 155 or at another location, physically separate from the sensor housing 155. In the present example, the control unit 180 is an external unit arranged at a distance from the sensor housing 155 and communicatively coupled to the sensor element(s) by a wired connection or cabling 182.

[0035] It will be appreciated that the sensor placement is an illustrative example only, and that the sensor housing 155 can be arranged at other locations as well. Thus, in other examples, the sensor housing 155 can be arranged at the gas outlet 142, at a lateral side of the separator housing 110, or at another structure not forming part of the separator 100.

[0036] The separator 100 shown in figure 2 may be similarly configured as the separator 100 discussed above in connection in figure 1. Thus, the separator 100 may be a centrifugal separator configured to separate a liquid phase from a gaseous phase by means of a rotational movement of the rotor. The separation takes place in a separator housing 110 defining at least a part of a separation space 120, in which a plurality of separation members 132 are rotatably arranged. The separation members 132 are attached to a rotor 130 extending through the separation space 120 in an axial direction X, around which the rotor and the separation members 132 are arranged to rotate during operation. The rotor 130 may be journalled in the separator housing 110 by ball bearings, roller bearings, or plain bearings, and may be brought to rotate about the axis X by a driving member 134. The driving member 134 may be a turbine wheel driven by a stream of oil, such as engine lubricating oil, directed against the turbine wheel 134. Other driving means are also possible, such as an electric motor.

[0037] The separation members 132 provide a separation aid in the form of a stack of frustoconical separation discs. Interspaces are provided between the separation discs 132, through which the crankcase gas can travel from an inner periphery towards an outer periphery while being separated into the liquid phase and the gaseous phases as the separation members 132 rotate in the separation space 120. In figure 2, only some of the separation discs 132 are indicated. It will be appreciated that while the frustoconical separation discs 132 in the present example are stacked with their wide ends facing downwards, other configurations are also possible. In an example, the separation discs may be stacked with their wide ends facing upwards. In further examples, other types of separation aids may be utilised, including, e.g., axially extending vanes projecting radially outwards from the rotor shaft 130. The separation members may as an alternative comprise a number of filter elements.

[0038] During operation, the flow of crankcase gas is guided into the separator 100 by means of the gas inlet 141, which in the present example is arranged in an upper, centre portion of the separator housing 110. The gas enters the stack of separation members 132 from a central portion thereof. As the separation members 132 rotate, heavy constituents such as oil particles are separated from the gas and propelled as droplets against a circumferential inner wall surface 114 of the separator housing 110. The separated liquid phase may be transported by gravity along the inner wall 114 and through a lower bearing 136, or via through holes next to the lower bearing 136, to a lower end portion 112 of the separator 100 and further through a liquid outlet 115. Should the separator 100, during use, be arranged in a different orientation, the liquid outlet 114 may be arranged at a portion of the housing 110 being the lowest one, with respect to the direction of gravity. The flow of crankcase gas, gaseous phase, and liquid phase through the separator 100 are indicated by arrows in figure 2.

[0039] Figure 3 is a schematic cross section of a sensor arrangement 150 according to some examples, which may be similarly configured as the sensor arrangement 150 discussed above in connection with figures 1 and 2. Thus, the sensor arrangement 150 may be arranged within a single sensor housing 155 configured to be coupled to each of the first and second gas passages 141, 142 to allow the pressure in the respective gas passages 141, 142 and/or a pressure differential therebetween, to be measured.

[0040] In the present example, the sensor arrangement 150 comprises a first sensor element 151 for measuring the pressure in the gas inlet 141 and a second sensor element 152 for measuring the pressure in the gas outlet 142. As indicated, both sensor elements 151, 152 are co-located within the same sensor housing 155, thereby facilitating assembly and cabling.

[0041] One or both of the sensor elements 151, 152 may be of a diaphragm type, which on a first side may be exposed to the pressure in the gas inlet/outlet 141, 142 and on the other side may be exposed to a reference pressure, such as the ambient atmosphere. Other types of sensors are however possible.

[0042] The sensor housing 155 comprises connectors, or fittings, for connecting the sensor element(s) 151, 152 to the pressurised gas that is to be measured in the respective gas passages 141, 142. In the present example, a first connector 153 is arranged to be fitted with a corresponding first nipple 163 at the gas inlet 141, thereby providing a fluidic connection to the first sensor element 151. Further, a second connector 154 is arranged to be fitted with the gas conduit 162 to provide a fluidic coupling between the gas outlet 142 and the second sensor element 152. Thus, each of the first connector 153 and the second connector 154 may form a pass-through in the sensor housing 155 to allow the sensor elements 151, 152 arranged therein to measure a pressure characteristic of the gas supplied to the separator 100 and discharged from the separator 100, respectively.

[0043] Each of the sensor elements 151, 152 may be coupled by electric leads to an electronic circuitry 158 for processing the signals generated by the sensor elements 151, 152. The electrical leads and the electronic circuitry 158 are schematically indicated in the present figure. The electronic circuitry 158 may, in turn, be connected to a contact interface 159 of the housing 155. The contact interface 159 may be arranged to be releasably connected to a cabling arrangement 182 connecting the sensor arrangement 150 with a control unit 180 as shown in figure 2. The contact interface 159 may, in some examples, be arranged to supply the sensor arrangement 150 with electric power and/or allow the sensor output to be retrieved from the sensor arrangement 150.

[0044] The sensor housing 155 may further comprise a mounting feature, such as a protruding tab or flange, arranged to be attached to an exterior of the separator housing 110 or wall enclosing the gas inlet 141. The flange may comprise a hole for a fastener, such as a screw, that can be attached directly to the separator housing 110 or the wall of the gas inlet 141. It should however be noted that this is a specific, illustrative example and that the sensor housing 155 can be mounted in other ways as well, depending on the design and configuration of the crankcase ventilation system, the separator design, and the available space.

[0045] Figure 4 is a flowchart illustrating a method in which a centrifugal separator is operated. The centrifugal separator may be similarly configured as the ones discussed above with reference to figures 1-3 and may thus be arranged for separating contaminants from a flow of gas from a crankcase 12 of an internal combustion engine 10. The separator 100 may therefore form part of a crankcase ventilation system, and the method may be used for determining a state of the crankcase ventilation system, and in particular for determining if the separator is malfunctioning or has been tampered with.

[0046] The method in figure 4 will now be described with reference to the crankcase ventilation system, the separator, and the sensor arrangement shown in figures 1-3.

[0047] In an example, the method comprises guiding 210, by means of the first gas passage 141 and the second gas passage 142, the flow of gas through the plurality of separation members 132 arranged in the separation space 120 defined by the separator housing 110. The flow of gas, which also may be referred to as crankcase gas or vented gas, may be provided to the first gas passage 141 via the first gas conduit 171 and discharged to the second gas conduit 172 via the second gas passage 142. The first gas passage 141 may hence form a gas inlet 141 of the separator 100, and the second gas passage 142 a gas outlet 142.

[0048] The separation members 132 are rotated 220 around the rotational axis X to separate at least some of the contaminants from the flow of gas that passes between the gas inlet 141 and the gas outlet 142 and cause the contaminants to be propelled against the inner wall surface 114 of the separator housing 110. As previously mentioned, the rotational movement of the separation members 132 may be provided by an oil flow driving a turbine wheel 134 or an electric motor.

[0049] Sensor output may be received 230 from the sensor arrangement 150 during operation of the separator 100, indicating a pressure in the gas inlet 141 and a pressure in the gas outlet 142. The pressure in the gas inlet and the gas outlet may be measured relative to a reference pressure such as the atmospheric pressure, or as a differential pressure between the gas inlet 141 and the gas outlet 142. In case of the latter, the sensor arrangement 150 may comprise a differential pressure sensor, such as a diaphragm sensor element as previously described. A difference in inlet pressure and outlet pressure may cause the diaphragm to deflect, allowing the sensor output to be based on the deflection.

[0050] In case the inlet pressure and the outlet pressure are measured independently from each other, two separate sensor elements 151, 152 may be used to generate the sensor output. Thus, the method may comprise receiving, from a first one of the sensor elements 151, a first sensor signal indicative of the pressure in the gas inlet 141 and receiving, from a second one of the sensor elements 152, a second sensor signal indicative of the pressure in the gas outlet 142.

[0051] The retrieved pressure information, such as the pressure in the gas inlet 141, the pressure in the gas outlet 142, and the differential pressure, may be compared with predetermined reference values to determine the state of the separator 100. If a retrieved pressure deviates from a reference value, for example by exceeding or being below the reference value, or lying outside a predetermined range, this may indicate that the separator 100 (or some other part of the crankcase ventilation system) is malfunctioning and/or has been tampered with.

[0052] As used in the present disclosure, the term "state" of the separator (or, more generally, of the crankcase ventilation system) typically refers to the condition or performance of the separator. More specifically, the state may refer to the separator's capability to remove contaminants from the vented crankcase gas and prevent them from being discharged to the atmosphere. In an operational or normal state, the flow of gas is directed through the separator for cleaning and is then redirected back to the engine's intake. The state may be determined by verifying that the pressure at the gas inlet and the pressure at the gas outlet (or a difference between the two) lie within predetermined reference ranges. In a degraded or malfunction state, wherein the separator may have been tampered with or bypassed, the one or more of the pressures may deviate from the expected ranges.

[0053] The sensor output also be used as feedback when controlling 250 the operation of the separator. The determined state may, for example, be used for controlling the rotational speed of the separation members 132. Should the pressure difference between the gas inlet and the gas outlet, for example, be lower than a reference difference, the rotor 130 may be brought to operate at an increased rotational speed so as to increase the inherent pump effect of the separator 100 and hence the pressure difference.

[0054] It will be appreciated that transitions between a normal state and a malfunction state may occur gradually over time, for example due to normal wear of the separator. Therefore, it may be of interest to regularly monitor the pressure in the gas inlet and the pressure in the gas outlet and compare the information with a predetermined or normal value or range, or with earlier measurements to detect drifts over time.

[0055] The control unit 180 of the present disclosure may generally comprise one or more processors and one or more non-transitory computer-readable media storing first computer executable instructions that, when executed by the one or more processors, cause the medical device to perform at least parts of the actions shown in figure 4 and described above. Generally, the control unit 180 may comprise circuitry which is configured to implement (using one or more non-transitory computer-readable media) the functionality described herein. Suitable processors for the execution of a program of instructions include, by way of example, both general and special purpose microprocessors, and the sole processor or one of multiple processors or cores, of any kind of computer. The processors can be supplemented by, or incorporated in, ASICs (application-specific integrated circuits). Those skilled in the art will understand that the above-described exemplary embodiments may be implemented in any suitable software, hardware, or firmware configuration or combination thereof. An exemplary hardware platform for implementing the exemplary embodiments may include, for example, an Intel x86 based platform with compatible operating system, a Windows OS, a Mac platform and MAC OS, a mobile device having an operating system such as iOS, Android, etc. In a further example, the exemplary embodiments of the above-described method may be embodied as a program containing lines of code stored on a non-transitory computer readable storage medium that, when compiled, may be executed on a processor or microprocessor.

[0056] Additionally, variations to the disclosed embodiments can be understood and effected by the skilled person in practising the claimed invention, from a study of the drawing, the disclosure, and the appended claims. Moreover, in the drawings and specification, there have been disclosed preferred embodiments and examples of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for the purpose of limitation. The scope of the invention is set forth in the following claims, in which the word 'comprising' does not exclude other elements or steps, and the indefinite article 'a' or 'an' does not exclude a plurality.

Claims

1. A centrifugal separator (100) for separating contaminants from a flow of gas from a crankcase (12) of an internal combustion engine (10), comprising:

a separator housing (110) defining at least a part of a separation space (120);
a plurality of separation members (132) rotatably arranged in the separation space;
a first gas passage (141) and a second gas passage (142), each extending through the separator housing and being configured to guide the flow of gas through the separation space and the plurality of separation members to allow at least some of the contaminants to be separated from the flow of gas;
a sensor arrangement (150) operable to generate a sensor output indicative of a pressure in the first gas passage and a pressure in the second gas passage, and/or a difference between a pressure in the first gas passage and a pressure in the second gas passage; and
a sensor housing;
wherein the sensor arrangement is arranged within the sensor housing (155).

2. The centrifugal separator according to claim 1, wherein the sensor arrangement is arranged at the first gas passage, and wherein the centrifugal separator further comprises a conduit (162) forming a fluidic connection between the sensor arrangement and the second gas passage.

3. The centrifugal separator according to claim 2, wherein the conduit is formed by a flexible tube.

4. The centrifugal separator according to any of the preceding claims, wherein the sensor arrangement comprises a diaphragm sensor element (153) configured to on a first side be exposed to the pressure in the first gas passage and on a second side be exposed to the pressure in the second gas passage.

5. The centrifugal separator according to claim 1, wherein the sensor arrangement comprises a first sensor element (151) arranged to generate a first sensor signal indicative of the pressure in the first gas passage, and a second sensor element (152) arranged to generate a second signal indicative of the pressure in the second gas passage.

6. The centrifugal separator according to claim 5, wherein the sensor arrangement is arranged at the first gas passage, and wherein the centrifugal separator further comprises a conduit forming a fluidic connection between the second sensor element and the second gas passage (162).

7. The centrifugal separator according to claim 6, wherein the conduit is formed by a flexible tube.

8. The centrifugal separator according to any of the preceding claims, wherein the sensor housing is releasably attached to an exterior of the separator housing.

9. The centrifugal separator according to any of the preceding claims, wherein the first gas passage is an inlet for supplying the flow of the gas to the separation space and the second gas passage is an outlet for discharging the flow of the gas from the separation space.

10. A method (200) for determining a state of a centrifugal separator for separating contaminants from a flow of gas from a crankcase of an internal combustion engine, comprising:

guiding (210), by means of a first gas passage and a second gas passage, the flow of gas through a plurality of separation members arranged in a separation space at least partly defined by a separator housing, wherein each of the first gas passage and the second gas

passage extends through the separator housing;
rotating (220) the separation members to separate at least some of the contaminants from the flow of gas;
receiving (230), from a sensor arrangement arranged in a same sensor housing, a sensor output indicative of a pressure in the first gas passage and a pressure in the second gas passage, and/or a difference between a pressure in the first gas passage and a pressure in the second gas passage; and
determining (240) a state of the centrifugal separator based on the sensor output.

11. The method according to claim 10, comprising:

exposing a first side of a diaphragm sensor element of the sensor arrangement to the pressure in the first gas passage;
exposing a second side of the diaphragm sensor element to the pressure in the second gas passage; and
generating the sensor output based on a deflection of the diaphragm sensor element.

12. The method according to claim 10, comprising:

receiving, from a first sensor element, a first sensor signal indicative of the pressure in the first gas passage;
receiving, from a second sensor element, a second sensor signal indicative of the pressure in the second gas passage; and
generating the sensor output based on the first sensor signal and the second sensor signal.

13. The method according to any of claims 10-12, comprising:

determining, based on the sensor output, a pressure difference between the first gas passage and the second gas passage;
comparing the pressure difference with a reference difference; and
determining the state of the centrifugal separator based on the comparison.

14. The method according to any of claims 10-13, further comprising controlling (250) the rotating of the separation members based on the state of the centrifugal separator.

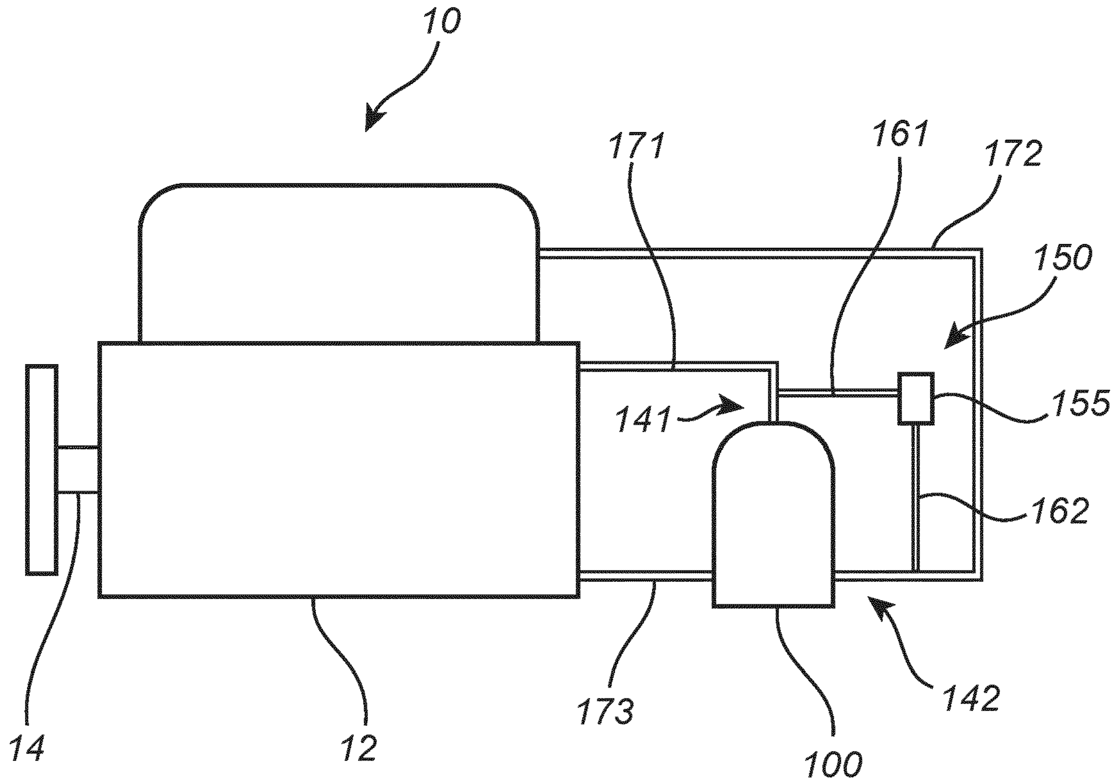

Fig. 1

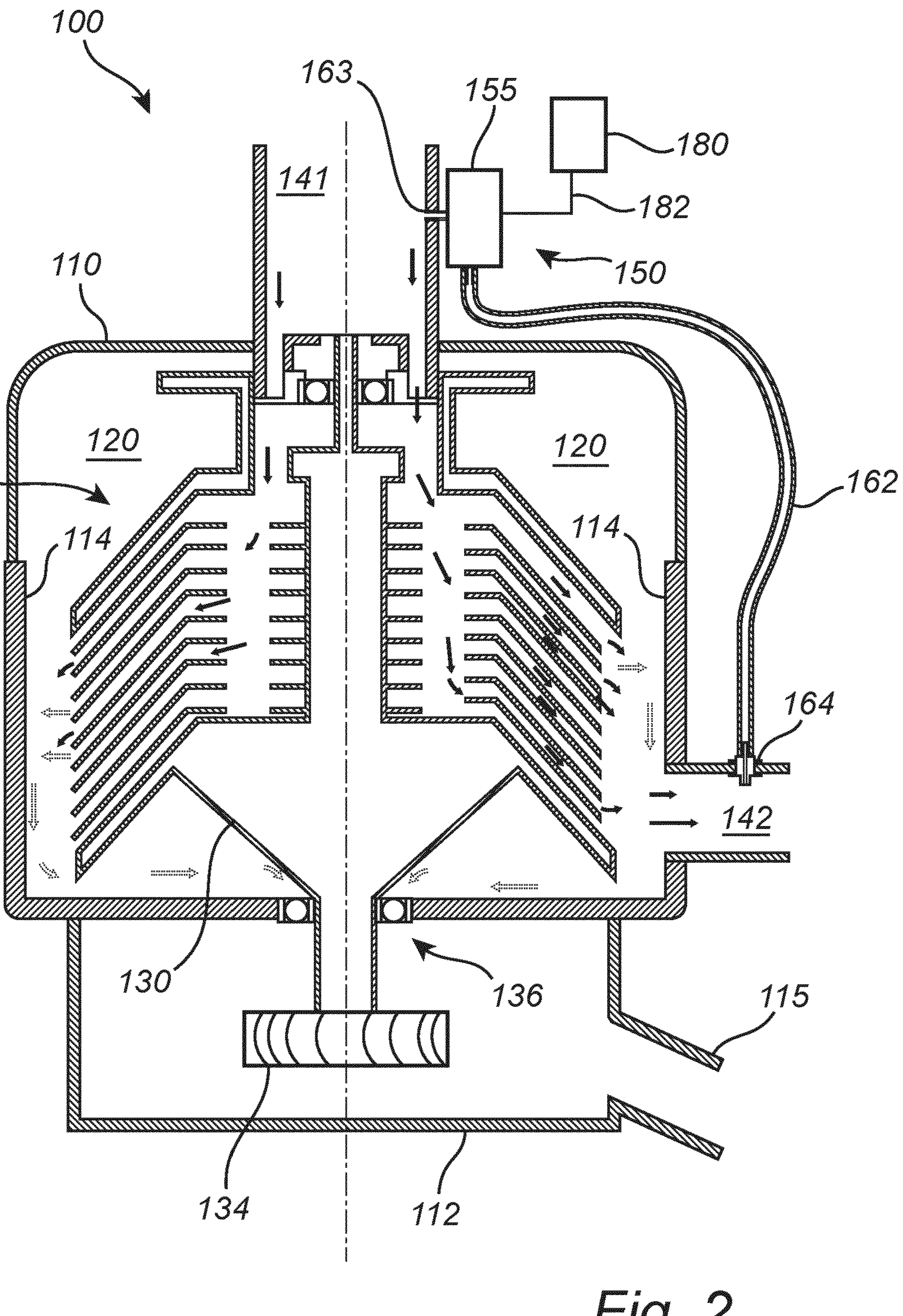
100
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Fig. 2

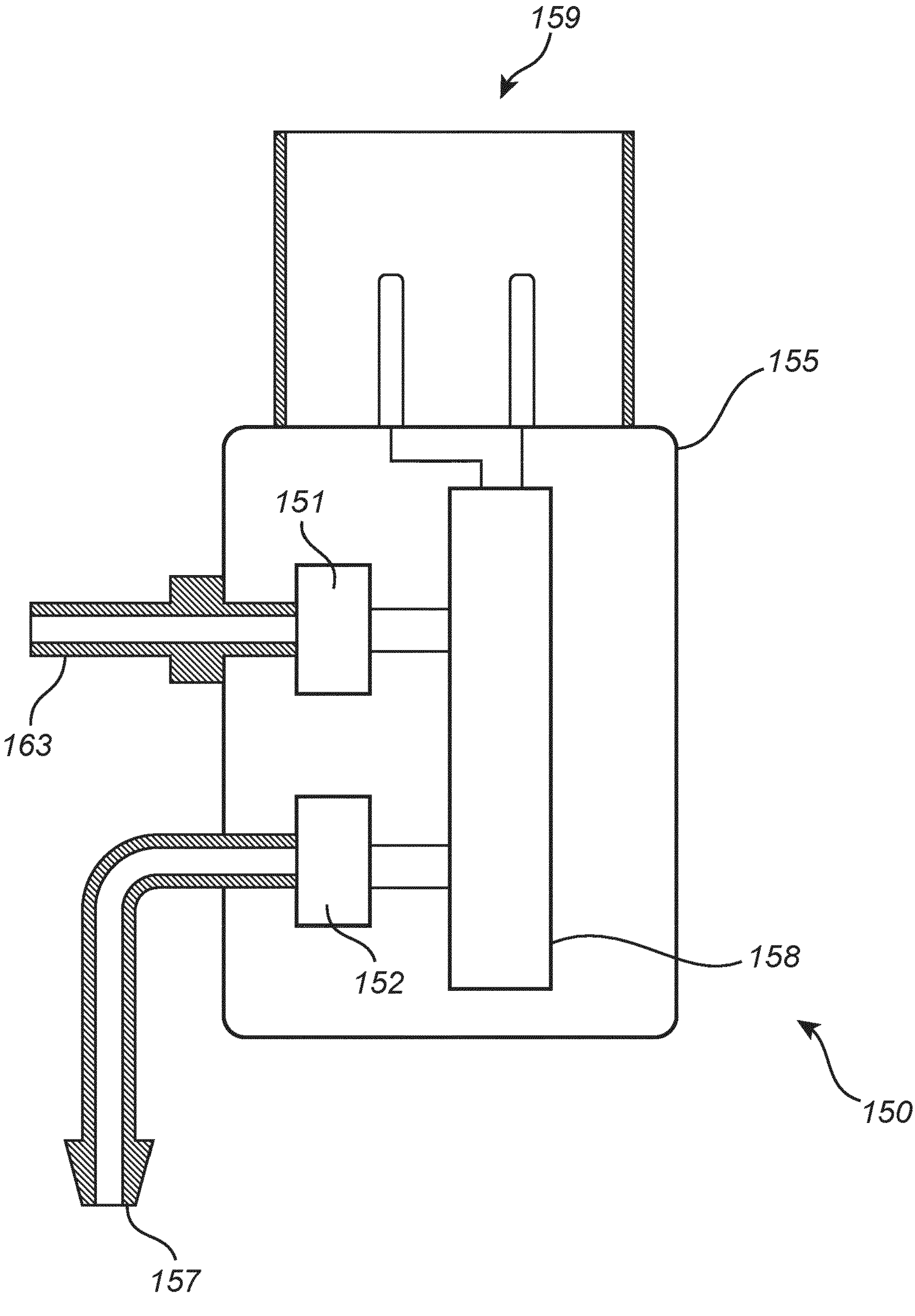

Fig. 3

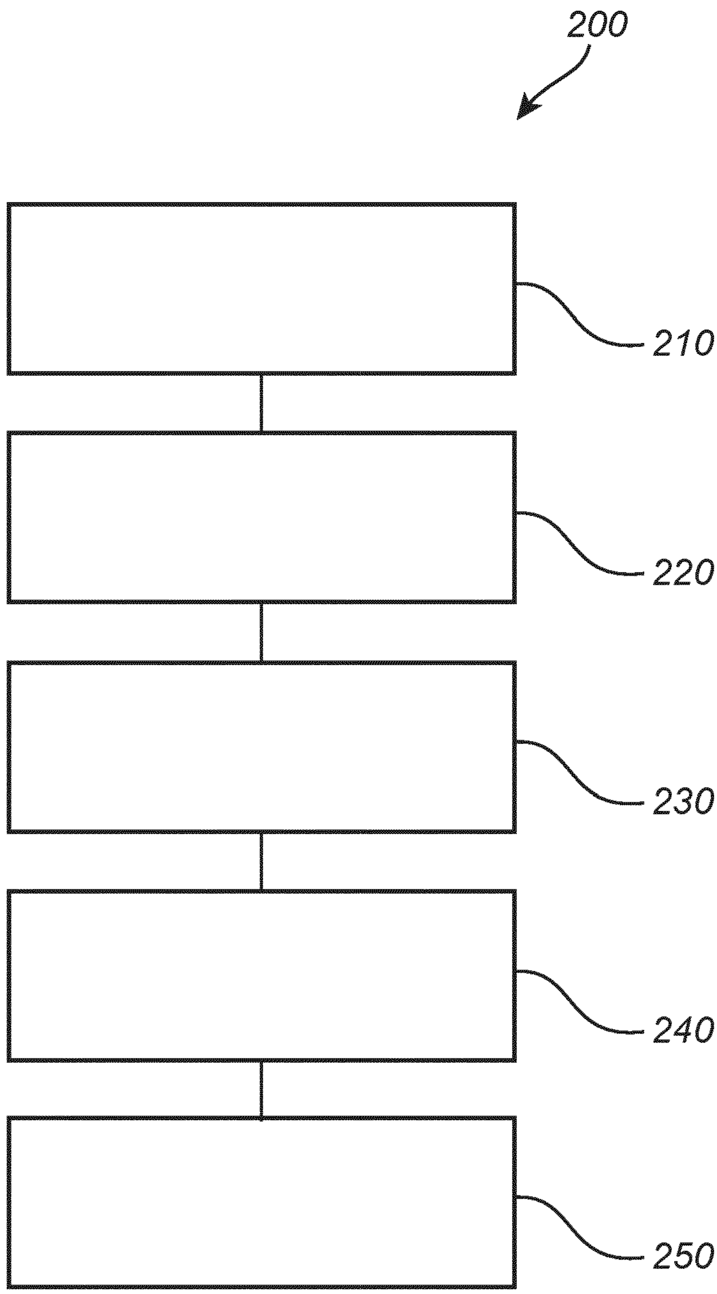

Fig. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 23 21 8172

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Place of search	Date of completion of the search	Examiner
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