Title: CONTROL APPARATUS AND METHOD FOR A MOTOR VEHICLE

Abstract: There is provided control apparatus for a motor vehicle, the apparatus comprising: control means (10); and pressure sensor means (9) for measuring a pressure difference between first and second locations (159A, 159B) of an engine aftertreatment system, the apparatus being configured to generate a pressure difference signal in dependence on the difference in pressure between the first and second locations, the pressure difference signal being indicative of a pressure drop across a particle filter (3) of the aftertreatment system, wherein the pressure difference signal generated by the apparatus has a greater sensitivity to pressure differences over a first range of pressure differences than over a second range of pressure differences that is greater than the first range, the control means being configured to output a control signal in dependence at least in part on the pressure difference signal.

FIGURE 3(a)
CONTROL APPARATUS AND METHOD FOR A MOTOR VEHICLE

TECHNICAL FIELD
The present disclosure relates to a control apparatus and method and particularly, but not exclusively, to a control apparatus and method for a motor vehicle engine aftertreatment system. Aspects of the invention relate to a control apparatus, a control apparatus in combination with an engine aftertreatment system, a vehicle and a method.

BACKGROUND
It is known to provide an engine aftertreatment apparatus for treating exhaust gases generated by an engine fuelled by diesel oil. Diesel engine platforms employ a diesel particle filter (DPF) or catalysed diesel particle filter (cDPF) to reduce tail pipe emissions of soot in order to comply with legislative regulations. The emissions are required to be monitored by onboard diagnostic (OBD) systems meeting the specifications of a prescribed standard, currently the "OBD-N" specification. This specification requires that aftertreatment systems are monitored for total, partial or intermediate failure of particle filtration capability as well as detecting a missing or cracked DPF/cDPF. Legislative requirements have driven automotive manufacturers to use an exhaust gas monitoring strategy that employs pressure sensor means in the form of a differential pressure sensor for measuring a pressure drop across the DPF/cDPF and a separate particle matter (PM) sensor for detecting slipped soot in order to ensure that the requirements are met. By slipped soot is meant soot not collected by the DPF/cDPF, for example due to cracking of the DPF/cDPF.

FIG. 1(a) illustrates a portion of a known engine aftertreatment system, shown at 50 in FIG. 1(a). The portion of the aftertreatment system 50 shown is coupled to an outlet of an exhaust turbocharger 10T that is in turn coupled to an exhaust outlet of an engine (not shown in FIG. 1). Gases exhausted by the exhaust turbocharger 10T are fed to a diesel oxidation catalyst (DOC) module 52 and subsequently to a catalysed diesel particle filter (cDPF) 53. Following treatment by the DPF 53 the gases pass through a selective catalytic reduction (SCR) module 54. As the gases pass from the DPF 53 to the SCR module 54, urea is injected into the gas flowstream from a urea tank 56 by means of a urea injector 57. A mixer element 58 provided in the exhaust gas flowstream downstream of the injector 57 promotes mixing of urea with the exhaust gases.

The aftertreatment system 50 has a differential pressure sensor module 59 having a pair of probes 59A, 59B and a sensor portion 59S. The probes 59A, 59B are provided at a
respective one of a pair of pressure tapping points 59TA, 59TB as shown in FIG. 1(a). First probe 59A is provided at tapping point 59TA at an exhaust gas inlet to the DPF 53 whilst second probe 59B is provided at tapping point 59TB at an exhaust gas outlet of the DPF 53. The module 59 is configured to output a differential pressure signal 590UT in the form of an electrical potential that is indicative of the difference between the pressures at the locations of the respective probes 59A, 59B. The greater the pressure difference between the locations of the respective probes 59A, 59B, the greater the potential difference between the pressure difference signal 590UT and ground. The pressure difference signal is supplied to a powertrain control module or controller 10C configured to control the engine of the vehicle (not shown).

In the known system 50, the probes 59A are in the form of hollow nozzles that couple to the DPF 53 at the respective tapping points 59TA, 59TB. The nozzles are in turn coupled to respective hoses that are coupled to the sensor portion 59S of the module 59. The respective probes 59A, 59B are in fluid communication with opposite sides of a sensor membrane (not shown) comprised by the sensor portion 59S. The module 59 determines the difference in pressure between the probes 59A in dependence on the pressure difference across the membrane, the pressure difference causing distortion of the membrane. The distortion is detected by the sensor portion 59S.

FIG. 1(b) illustrates the relationship between the pressure difference signal 590UT and pressure difference across the DPF 53. Trace 59TC is the sensor transfer curve and indicates the value of electrical potential (in arbitrary units) of output signal 590UT as a function of actual pressure difference. It can be seen that the relationship is substantially linear over the range of pressures shown. The range of pressures shown include the range from a negative pressure difference (below zero) of around -150mbar where the pressure at probe 59B is greater than that at probe 59A through a pressure of substantially zero (for which the differential pressure sensor module 59 is configured to output a signal 590UT at a potential of around 780 arbitrary units) to a pressure difference of substantially 750mbar (for which the differential pressure sensor module 59 is configured to output a signal 590UT at a potential of around 3860 arbitrary units), where the pressure at probe 59A is greater than that at probe 59B. The gradient of the sensor transfer curve 59TC is approximately 4.1 arbitrary units per mbar.

The module 59 is configured such that the pressure difference at which the output signal 590UT saturates, 750mbar, i.e. at which the output signal 590UT is at a maximum, is
higher than the maximum expected pressure drop when the DPF 53 has reached a particle loading at which regeneration of the DPF 53 is required. Accordingly, the sensor module 59 is in principle capable of detecting both the absence of a DPF 53 (for which the pressure difference will be close to zero) and the presence of a DPF 53 requiring regeneration (for which the pressure difference will be relatively high). Furthermore, because the sensor module 59 is capable of sensing a negative pressure difference between the probes 59A, 59B, the module 59 is capable of detecting a situation in which the respective probes 59A, 59B are connected to the wrong tapping points 59TA, 59TB ports of the DPF 53. That is, a situation in which probe 59B is connected at tapping point 59TA and probe 59A is connected at tapping point 59TB. If the pressure difference signal 590UT is of a sufficiently low potential, indicative that the probes 59A, 59B are wrongly connected, an error signal is output by the powertrain control module 10C.

The powertrain control module 10C is configured to trigger regeneration of the DPF 53 when the differential pressure signal exceeds a predetermined threshold value indicative that the DPF 53 is approaching saturation. In one known arrangement the powertrain control module 10C causes regeneration by causing an increase in the amount of unburned fuel present in the exhaust gas flowstream. The unburned fuel is subject to combustion in the DOC 52 which raises the temperature of the DPF 53 sufficiently to cause oxidation of soot particles that have accumulated therein.

In order to verify that the DPF 53 is not cracked or damaged, resulting in failure to trap soot particles, the powertrain control module 10C receives a signal from a particulate matter (PM) sensor 61. The PM sensor 61 is arranged to collect particle matter that has passed the DPF 53 (if present), referred to as slipped particle matter, on a ceramic plate upon which a set of interdigitated electrodes are located. Collected soot particles form a short circuit between the electrodes resulting in a change of electrical conductivity therebetween. This is in turn used to infer the amount of soot collected on the ceramic plate of the sensor 61. The sensor 61 is regenerated regularly by heating. An electrical signal, referred to herein as a particle loading signal 61OUT, is output by the sensor 61 to the powertrain control module 10C indicative of the amount of particulate matter that has accumulated thereon, also referred to as the particle loading of the sensor 61.

In the event that the PM sensor 61 indicates a change in particle loading over a predetermined time period that exceeds a predetermined value, indicating a cracked or missing DPF 53, the powertrain control module 10C provides a corresponding warning...
signal to the driver. Typically, warning signals are provided in the form of illuminated lamps and/or text messages to the driver displayed on an instrument cluster of the vehicle. It is to be understood that in the case of a cracked or missing DPF 53, the pressure difference between the respective locations of the probes 59A, 59B will be relatively low.

The PM sensor 61 itself may be periodically 'regenerated' to remove accumulated soot by heating by means of heating means such as an electrical heater integrated therewith.

The PM sensor 61 may be a relatively expensive component and increases the cost and complexity of the aftertreatment system 50.

It is an aim of the present invention to address disadvantages associated with the prior art.

SUMMARY OF THE INVENTION

Aspects and embodiments of the present invention provide a control apparatus, a control apparatus in combination with an engine aftertreatment system, a vehicle and a method. Embodiments of the invention may be understood with reference to the appended claims.

In one aspect of the invention for which protection is sought there is provided a control apparatus for a motor vehicle. The apparatus may comprise control means and differential pressure sensor means. The control means may be configured to generate a pressure difference signal in dependence on a difference in pressure between first and second locations of an engine aftertreatment system, the pressure difference signal being indicative of a pressure drop across a particle filter of the aftertreatment system. The pressure difference signal may have a greater sensitivity to pressure differences over a first range of pressure differences than over a second range of pressure differences greater than the first range.

In another aspect of the invention for which protection is sought there is provided a control apparatus for a motor vehicle, the apparatus comprising control means and pressure sensor means for measuring a pressure difference between first and second locations of an engine aftertreatment system. The apparatus may be configured to generate a pressure difference signal in dependence on the difference in pressure between the first and second locations, the pressure difference signal being indicative of a pressure drop across a particle filter of the aftertreatment system. The pressure difference signal generated by the apparatus may have a greater sensitivity to pressure differences over a first range of pressure differences
than over a second range of pressure differences that is greater than the first range. The control means may be configured to output a control signal in dependence at least in part on the pressure difference signal.

5 The pressure sensor means may comprise one or more pressure sensor devices. It is to be understood that by reference to sensitivity of the pressure difference signal is meant a measure of how much the signal changes when the pressure of gas being measured by the sensor means changes by a given amount. Reference to the sensitivity of the sensor means refers similarly to the amount by which the pressure difference signal changes when the pressure of gas being measured by the sensor means changes by a given amount.

The control means may be provided by one or more controllers. It is to be understood that a control apparatus, a controller or controllers described herein may comprise a control unit or computational device having one or more electronic processors that provide the control means. The system may comprise a single control unit or electronic controller or alternatively different functions of the controller may be embodied in, or hosted in, different control units or controllers. As used herein the term "control unit" will be understood to include both a single control unit or controller and a plurality of control units or controllers collectively operating to provide the stated control functionality including the control means.

A set of instructions could be provided which, when executed, cause said computational device to implement the control techniques described herein. The set of instructions could be embedded in said one or more electronic processors. Alternatively, the set of instructions could be provided as software to be executed on said computational device. The controller may be implemented in software run on one or more processors. One or more other controllers may be implemented in software run on one or more processors, optionally the same one or more processors as the controller. Other arrangements are also useful.

Optionally, the apparatus comprises:

an electronic processor having an electrical input for receiving the pressure difference signal from a pressure sensor device of the pressure sensor means;

an electronic memory device electrically coupled to the electronic processor and having instructions stored therein,

wherein the apparatus being configured to output a control signal in dependence at least in part on the pressure difference signal comprises the processor being configured to access the memory device and execute the instructions stored therein.
In other words, the processor may be configured to access the memory device and execute the instructions stored therein such that it is operable to output the control signal in dependence at least in part on the pressure difference signal.

The pressure sensor means of the apparatus may be configured to generate a signal indicative of the pressure difference between the first and second locations. Alternatively, the pressure sensor means may output signals indicative of the actual pressure at the respective first and second locations. Accordingly, in some embodiments the electronic processor may be configured to generate the pressure difference signal in response to one or more signals indicative of pressure at the first and second locations at least, and to output the control signal in dependence at least in part on the pressure difference signal. The processor may be configured to determine the pressure difference signal, in response to the one or more signals, such that the pressure difference signal has a greater sensitivity to pressure differences over a first range of pressure differences than over a second range of pressure differences that is greater than the first range.

Optionally, the first range of pressure differences includes substantially zero pressure difference.

It is to be understood that the first range of pressure differences may include a range of pressure differences corresponding to a missing particle filter in a given aftertreatment system. The range of pressure differences may cover the expected range experienced by the aftertreatment over the expected range of operating conditions of the aftertreatment apparatus such as the expected range of powertrain torque loading, and engine speed.

Optionally, the first range of pressure differences includes a negative pressure difference of magnitude at least equal to the pressure difference across the particle filter with the engine at a minimum expected speed of substantially continuous operation under substantially no torque loading.

It is to be understood that operation of the engine at the minimum expected speed of substantially continuous operation may correspond to a minimum speed at which the engine may be configured to idle under conditions favouring the lowest speed at which the engine is permitted to idle. It is to be understood that the speed at which the engine idles may be dependent on a number of factors including the amount of electrical power being drawn by one or more vehicle electrical systems such as one or more lighting circuits, the torque...
loading on the engine due for example to operation of an engine-driven air-conditioning system, and an engine or transmission oil temperature. Accordingly, the negative pressure value may be of magnitude equal to or greater than the pressure difference across the particle filter when the engine is operating at its minimum permitted idle speed and with substantially no torque loading.

Optionally, the control means is configured to output a missing filter signal indicative that a particle filter of the aftertreatment system is not present in dependence on the pressure difference signal.

Optionally, the control means is configured to generate the missing filter signal if the pressure difference signal is below a predetermined filter-present threshold pressure difference signal value, the filter-present threshold pressure difference signal value having a value within the first range of pressure differences.

Some embodiments of the present invention have the advantage that the size of the first range of pressure differences includes substantially zero pressure drop corresponding to a missing particle filter, enabling reliable determination whether a particle filter is present, whilst at the same time allowing the apparatus to detect relatively high pressure differences exhibited in circumstances where a particle filter is relatively heavily loaded with particles and requires regeneration without requiring the provision of a particle matter (PM) sensor or detector (also referred to as a 'soot sensor'). Embodiments of the present invention enable a reliable determination to be made whether a particle filter is present, and whether a filter is ready for regeneration, using relatively low cost sensor means with no requirement to use an additional PM sensor. In some embodiments only a pair of sensors (responsive to pressure at the respective first and second locations) or a single differential pressure sensor (responsive to pressure at the respective first and second locations) is required.

It is to be understood that, if an apparatus were provided that was sufficiently sensitive to relatively small pressure differences to reliably detect the absence of a filter and had substantially the same sensitivity across the range of pressure differences required to be measured by the apparatus including the relatively high pressure differences indicative of a particle filter ready for regeneration, the sensor means would be prohibitively expensive. Embodiments of the present invention, which adjust the sensitivity of the sensor means in dependence on pressure value so as to solve the problem of detecting the absence of a filter and a heavily loaded filter, enable the provision of an apparatus at relatively low cost,
the cost being lower than the cost of providing a separate particle matter (PM) sensor in addition to pressure sensor means for detecting the pressure drop across the particle filter. Elimination of an additional sensor also has the advantage of reducing complexity and scope for malfunction of the apparatus.

Optionally, the predetermined filter-present threshold pressure difference signal value is determined in dependence at least in part on a signal indicative of a mass flow rate of engine intake air and/or exhaust gas mass flow rate.

Optionally, the pressure difference signal generated by the apparatus is arranged to have a first average gradient value over the first range of pressure differences, and a second average gradient value over the second range of differences, the second average gradient value being different from the first.

Optionally, the pressure difference signal generated by the apparatus is arranged to be substantially linear with pressure difference over the first range of pressure differences, having a first average gradient value over the first range of pressure differences, and substantially linear over the second range of pressure differences, having a second average gradient value over the second range of differences, the second average gradient value being different from the first.

Optionally, the second average gradient value is at least a factor of 1.5 different from the first average gradient value.

The second average gradient value may be at least a factor of 2.0 different from the first average gradient value.

The second average gradient value may be lower than the first average gradient value.

Advantageously, the control signal may comprise a regeneration signal indicative that regeneration of the diesel particle filter is required.

The regeneration signal may be generated if the pressure difference signal exceeds a predetermined value.
The predetermined value may correspond to a pressure difference corresponding to a DPF having a soot loading exceeding a predetermined amount such as 50% of a predetermined maximum allowable amount.

Optionally, the predetermined value corresponds to the pressure difference between the first and second locations with the particle filter having a soot loading corresponding to a predetermined amount, optionally a predetermined proportion of a maximum allowable amount.

Optionally, control means is configured to output a control signal in dependence on the pressure difference signal and in further dependence at least in part on a mass flow rate signal indicative of the value of mass flow rate of exhaust gases through the aftertreatment system.

It is to be understood that the pressure difference between the first and second locations is likely to depend on the mass flow rate of exhaust gases as well as the particle loading on the particle filter, i.e. the accumulated mass of particles in the filter. Accordingly, the control means may be configured to take into account the mass flow rate as well as the pressure difference when determining whether to generate the regeneration signal.

The apparatus may be configured to calculate the predetermined pressure difference value in dependence on the mass flow rate signal.

The apparatus may be configured wherein the predetermined pressure difference value is increased with increasing mass flow rate in proportion to the expected increase in pressure difference across the particle filter with increasing mass flow rate.

Optionally, the first range of pressure differences is at least 10% of the maximum range of pressure differences to which the sensor means may be exposed in use.

Optionally, the first range of pressure differences is at least 20% of the maximum range of pressure differences to which the sensor means may be exposed in use.

Optionally, the first range of pressure differences is around 40 to 60% of the maximum range of pressure differences to which the sensor means may be exposed in use.
In a further aspect of the invention for which protection is sought there may be provided an apparatus according to a preceding aspect in combination with at least a portion of an engine aftertreatment system, the at least a portion comprising a diesel particle filter, wherein the pressure sensor means is arranged to measure a pressure of exhaust gases upstream and downstream of the particle filter.

In a still further aspect of the invention for which protection is sought there may be provided an apparatus according to a preceding aspect in combination with at least a portion of an engine aftertreatment system, the at least a portion comprising a gasoline particle filter (GPF), wherein the pressure sensor means is arranged to measure a pressure of exhaust gases upstream and downstream of the particle filter.

In one aspect of the invention for which protection is sought there is provided an apparatus according to a preceding aspect in combination with an engine controller, wherein the engine controller is configured to receive the regeneration signal, the engine controller being configured to cause the engine to output exhaust gases enriched in unburned fuel in response to receipt of the regeneration signal.

 Optionally, the apparatus does not comprise a particle matter (PM) detector in addition to the pressure sensor means and control means.

In a further aspect of the invention for which protection is sought there is provided a vehicle comprising a body, a plurality of wheels, a powertrain to drive said wheels, a braking system to brake said wheels, and an apparatus according to a preceding aspect.

In an aspect of the invention for which protection is sought there is provided a method comprising measuring by means of pressure sensor means a pressure difference between first and second locations of an engine aftertreatment system. The method may comprise generating a pressure difference signal in dependence on the difference in pressure between the first and second locations, the pressure difference signal being indicative of a pressure drop across a particle filter of the aftertreatment system. The pressure difference signal may have a greater sensitivity to pressure differences over a first range of pressure differences than over a second range of pressure differences that is greater than the first range. The method may comprise outputting a control signal in dependence on the pressure difference signal.
Optionally, the first range of pressure differences includes substantially zero pressure difference.

The method may comprise outputting a missing filter signal indicative that a particle filter of the aftertreatment system is not present if the pressure difference signal indicates the pressure difference is below a predetermined filter-present threshold pressure difference value, the filter-present threshold pressure difference value having a value within the first range of pressure differences.

The method may comprise determining the filter-present threshold pressure difference value in dependence at least in part on a signal indicative of a mass flow rate of engine intake air and/or exhaust gas mass flow rate.

Optionally, the pressure difference signal is arranged to be substantially linear with pressure difference over the first range of pressure differences, having a first average gradient value over the first range of pressure differences, and substantially linear over the second range of pressure differences, having a second average gradient value over the second range of differences, the second average gradient value being different from the first.

Optionally, generating the control signal comprises generating a regeneration signal indicative that regeneration of the diesel particle filter is required, whereby the regeneration signal is generated if the pressure difference signal exceeds a predetermined value.

Optionally, the control means is configured to output the regeneration signal in dependence on the pressure difference signal and in further dependence at least in part on a mass flow rate signal indicative of the value of mass flow rate of exhaust gases through the aftertreatment system.

In an aspect of the invention for which protection is sought there is provided a carrier medium carrying computer readable code for controlling a vehicle to carry out the method of a preceding aspect.

In a further aspect of the invention for which protection is sought there is provided a computer program product executable on a processor so as to implement the method of a preceding aspect.
In a still further aspect of the invention for which protection is sought there is provided a computer readable medium loaded with the computer program product of a preceding aspect.

In an aspect of the invention for which protection is sought there is provided a processor arranged to implement the method of a preceding aspect, or the computer program product of a preceding aspect.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIGURE 1 is a schematic illustration of (a) a known engine exhaust gas aftertreatment apparatus and (b) a relationship between differential pressure output signal and differential pressure across the diesel particle filter shown in (a);

FIGURE 2 is a schematic illustration of a motor vehicle according to an embodiment of the present invention;

FIGURE 3 is a schematic illustration of (a) an engine exhaust gas aftertreatment apparatus of the vehicle of FIG. 2 and (b) a relationship between differential pressure output signal and differential pressure across the diesel particle filter shown in (a).

DETAILED DESCRIPTION

FIG. 2 shows a vehicle 100 according to an embodiment of the present invention. The vehicle 100 has an internal combustion engine 110 operable to provide motive torque to a
transmission 108. The vehicle 100 has a driveline 109 by means of which the transmission 108 may be coupled to a pair of rear wheels 103, 104 of the vehicle 100 by means of a rear prop shaft 109RP and rear drive unit 109RDU. The transmission 108 is releasably connectable to a pair of front wheels 101, 102 by means of a power transfer unit (PTU) 109PTU having a power transfer clutch (not shown), front prop shaft 109FP and front differential gear box 109FD, which also form part of the driveline 109. It is to be understood that the vehicle 100 of FIG. 2 is described herein by way of non-limiting example only and some embodiments of the invention may be configured for permanent front wheel or rear wheel drive only.

Exhaust gases generated by the engine 110 are drawn from the engine 110 by means of an exhaust turbocharger 110T and fed to an exhaust gas aftertreatment apparatus 150.

The exhaust gas aftertreatment apparatus 150 is shown in more detail in FIG. 3(a). Like features of the apparatus 150 of FIG. 2 to those of the apparatus of FIG. 1(a) are shown with like reference signs incremented by 100.

The aftertreatment apparatus 150 has pressure sensor means in the form of a differential pressure sensor module 159. Other pressure sensor means may be useful in some embodiments.

The aftertreatment apparatus 150 of the embodiment of FIG. 3(a) differs from the apparatus 50 of FIG. 1(a) at least in part in that the PM sensor 61 is not present, and the differential pressure sensor module 159 is configured to exhibit a substantially modified relationship between the pressure difference signal 1590UT output by the sensor module 159 and the pressure difference between the tapping points 159TA, 159TB at which first and second pressure probes 159A, 159B of the module 159 are provided.

The relationship between the pressure difference signal 1590UT and actual pressure difference between tapping points 159TA, 159TB is illustrated schematically in FIG. 3(b). It can be seen from FIG. 3(b) that the output signal ranges from a value of around 1540 arbitrary units when the differential pressure is substantially zero to a value of around 2800 units when the differential pressure is around 150mbar, in a substantially linear manner. The gradient of the sensor transfer curve 159TC therefore has an average value of approximately 8.4 units per mbar over this first, lower pressure range (0 to 150mbar). The differential pressure output signal subsequently rises to a value of around 3850 units at a
differential pressure of around 700 mbar. The gradient of the sensor transfer curve 159TC therefore has an average value of approximately 1.9 units per mbar over this second, higher pressure range (150 to 700 mbar), being lower by a factor of 4 than that over the first, lower range. In contrast, in the known differential pressure sensor arrangement of FIG. 1(a), the gradient of the sensor transfer curve 159TC is approximately 4.1 over both the lower and higher pressure ranges.

In the present embodiment the first range includes the range of pressures that are typically characteristic of a missing or cracked DPF 153, being the range from substantially 0 mbar to around 150 mbar whilst the second range includes the range of pressures characteristic of a DPF 153 that is ready to be regenerated, being a pressure difference of around 150 to 700 mbar. Because the signal to noise ratio (SNR) of the differential pressure output signal is higher over the first range of pressure differences than over the second, a more accurate determination of the pressure difference may be made over the lower pressure range compared with the prior art arrangement of FIG. 1, enabling a more accurate determination as to whether or not a DPF 153 is present or cracked. As a consequence of the increase in SNR, the reliability with which the powertrain control module 110C can determine whether or not a DPF 153 is present or cracked increases sufficiently to permit the PM sensor 61 required in prior art arrangements to be dispensed with.

Thus, in the embodiment of FIG. 3(a) the powertrain control module 110C is configured to detect the absence of DPF 153 and to provide a warning signal to a driver in the case that absence of DPF 153 is detected. The absence of a DPF 153 is detected when the differential pressure signal indicates a differential pressure value that is below a predetermined threshold value (but not low enough to indicate connection of the probes 159A, 159B to the wrong tapping points 159TA, 159TB). In the case that the pressure difference signal 1590UT is in a predetermined range, for example the range from around 1540 arbitrary units (corresponding to a pressure drop of substantially 0 mbar) to around 2800 arbitrary units (corresponding to a pressure drop of substantially 150 mbar), as shown in FIG. 3(b), the powertrain control module 110C determines that the DPF 153 is cracked or missing and outputs a corresponding warning signal. It is to be understood that the range of values of the pressure difference signal 1590UT indicative of a cracked or missing DPF 153 may be determined empirically by the skilled person for a given vehicle 100 and sensor arrangement.
The differential pressure sensor module 159 of the present embodiment includes control means in the form of an electronic controller that determines the electrical potential to which the differential pressure output signal 1590UT should be set in dependence on the difference in pressure between the locations at which the first and second pressure probes 159A, 159B are provided according to stored calibration data. In the present embodiment the electronic controller employs an algorithm to determine the required output potential according to the stored calibration data so that an output signal 1590UT is generated having a potential that has a linear dependence on the difference in pressures between the tapping points 159TA, 159TB over two respective pressure ranges, with a different gradient over the two ranges. In some alternative embodiments the controller may employ a look-up table or other database arrangement to determine output potential as a function of measured pressure difference. The sensor module 159 has a sensor portion 159S that includes a sensor membrane and the control means. Opposite sides of the sensor membrane are in fluid communication with respective nozzles of the probes 159A, 159B such that a pressure difference is established across the membrane corresponding to the pressure difference between the two tapping points 159TA, 159TB.

The present applicant has recognised that the PM sensor 61 of the known arrangement of FIG. 1(a) provides no contribution to control of the exhaust aftertreatment apparatus and merely acts as a monitor of the amount of soot accumulated by the sensor 61, providing a warning in the event the sensor 61 detects that the DPF 153 is absent or has cracked. In contrast, the sensor module 159 of the embodiment of the present invention illustrated in FIG. 3(a) triggers regeneration of the DPF 153 when required.

As noted above, embodiments of the present invention provide aftertreatment apparatus 150 that has the feature that a sensitivity of the differential pressure sensor module 159 to determining whether the DPF module 153 is absent or cracked is enhanced over a range of differential pressures across the DPF module 153 expected in the absence of the DPF module 153 or the presence of a cracked module 153, resulting in failure of the DPF 153 to trap soot particles entrained in engine exhaust gases. The applicant has recognised that this feature enables detection of a missing or cracked DPF 153 to take place in a manner that is sufficiently reliable to eliminate the need to provide separate means for detecting a missing or cracked DPF such as a PM sensor 61, whilst still enabling an aftertreatment system 150 to meet legislative requirements.
It is to be understood that the pressure sensor module 159 may be configured to be capable of detecting pressure differences that occur at the maximum expected exhaust gas flow rate through the DPF 153 (assuming the DPF 153 is present) for a given vehicle at a predetermined accumulated soot mass, for example a value of maximum possible accumulated soot mass for which the DPF 153 is permitted to operate. It is to be understood that this may correspond to a condition of the DPF 153 above which vehicle performance is compromised beyond that which is considered acceptable. The powertrain control module 110C may be configured to attempt to ensure that regeneration of the DPF 153 takes place before the DPF 153 reaches this condition.

Typical vehicle operation within towns and cities is found to be at an exhaust gas flow rate of up to around approximately 30% of the maximum flow rate a vehicle is capable of achieving, the 30% flow rate corresponding to exhaust gas mass flow rates of around 500kg per hour in some known vehicles. On average an aftertreatment system may operate with a soot loading of up to around 50% of the maximum allowable soot mass (around 20g in some known vehicles, the maximum soot mass being around 40g). Consequently the differential pressure sensor is required to have an accuracy of approximately 20% of the maximum allowable range.

A typical automotive standard pressure sensor would be quoted to have an accuracy of approximately 10% of full scale, which relates to approximately 50% of the typical range of operation of the sensor, the typical range corresponding to the range of soot loadings of up to 50% of the maximum allowable. This level of inaccuracy means that a high degree of filtering of the differential pressure output signal is required and the resulting signal is not sensitive enough for OBD use. This factor is a major reason why manufacturers install a separate PM sensor 61 in addition to a differential pressure sensor. As noted above the PM sensor 61 is not inexpensive, and may itself be prone to errors.

Embodiments of the present invention described herein employ a differential pressure sensor module 159 that has a variable sensitivity. The differential pressure sensor module 159 is configured such that at relatively low pressure differences the sensitivity is relatively high, yet at relatively high pressure differences the sensitivity is relatively low. If an aftertreatment system has a cracked or missing DPF 153, the pressure drop across the DPF 153 will be relatively low, in the pressure range for which the sensitivity of the sensor module 159 is relatively high. The presence of an aftertreatment system 150 with a cracked or
missing DPF 153 can therefore be accurately inferred from the pressure difference indicated by the differential pressure sensor module 159.

In some embodiments, the high sensitivity range of operation of the sensor module 159 includes the range of pressures expected in the case that the DPF 153 is cracked or missing under most or substantially all anticipated operating conditions, from low speed engine idle conditions to operations substantially at the highest expected engine load conditions. In some embodiments the high sensitivity range may also include the range of pressures expected in the case that the DPF 153 is operating with the DPF 153 at a particle loading that is around its normal operation design limit, at which regeneration of the DPF 153 would normally be triggered, for the range of expected engine loadings from low speed idle (low load) to relatively high engine load (resulting in relatively high exhaust gas flow rates). As discussed above, this normal operation design limit may be any suitable value but is typically around 50% of the maximum allowable soot loading, which may be referred to as saturation soot loading in some arrangements.

It is to be understood that for pressure differences expected in the case that the DPF 153 is more highly loaded than the normal operation design limit, the output signal 1590UT of the differential pressure sensor module 159 may enter the relatively low sensitivity region of operation of the pressure sensor module 159.

It is to be understood that, in some embodiments, the powertrain control module 110C may be configured to generate an engine torque loading signal indicative of estimated engine torque loading based on vehicle speed, rate of acceleration, engine speed and powertrain gear ratio (determined in the present embodiment in dependence on the selected gear of the transmission 108 and the gear ratio of the PTU 109PTU). The control module 110C may calculate, based on the estimated engine torque loading signal, the expected value of pressure difference signal 1590UT for a DPF 153 that has achieved its normal operation particle loading design limit. If the pressure difference signal 1590UT exceeds the expected value based on the estimated engine torque loading signal by a predetermined amount, the powertrain control module 110C may then determine that the DPF 153 has exceeded the normal operation design limit (50% soot loading in the present embodiment), and trigger regeneration of the DPF 153 at the next opportunity. Other arrangements may be useful in addition or instead in some embodiments.
In some embodiments, the range of pressure differences over which the differential pressure sensor module 159 exhibits the relatively high sensitivity characteristic may be limited to the range of pressure differences expected in the case of a missing or cracked DPF 153. This range of pressure differences may be determined empirically by the skilled person by either removing the filter portion from within the housing of the DPF 153 and monitoring the output signal 1590UT or installing a cracked DPF 153 and monitoring the output signal 1590UT.

It is to be understood that embodiments of the present invention may be suitable for substantially any engine aftertreatment systems employing an exhaust gas particle filter. For example embodiments the present invention may be useful in embodiments having a DPF, cDPF or a selective catalytic reduction (SCR) device in combination with a DPF, which may be referred to as a SCRF.

It is to be understood that the pressure values described herein are those that the present applicant has found in embodiments in which the engine is a diesel engine having a cylinder capacity of around 4 litres. In the case of smaller diesel engines, the size of the DPF, and therefore the particle mass corresponding to the normal operation design limit and maximum allowable particle loading may be lower than the values described herein (20g and 40g, respectively). Similarly, the pressure differences detected by the differential pressure sensor module 159 across the DPF 153 under maximum and minimum engine loading conditions, at different DPF particle loading values, may be different, all other factors being substantially the same or similar.

According to some embodiments of the invention, the relatively high sensitivity range of operation of the differential pressure sensor module 159 may be substantially 25% of the maximum range of differential pressures that are expected to be experienced during extremes of operation of the aftertreatment system, i.e. from engine idle (low torque loading) conditions with no DPF 153 present, to substantially 25% of the maximum torque loading conditions with a DPF 153 at its maximum permissible soot loading (maximum allowable particle loading, which may be substantially twice the normal operation design limit in some embodiments). In some embodiments the range may be substantially 25% of the range from a pressure difference corresponding to the negative of the pressure difference experienced under engine idle conditions (i.e. the pressure difference detected by the differential pressure module 159 with the sensor probes 159A, 159B in reverse positions to those shown in FIG. 3(a)) to that which occurs under the maximum torque loading conditions with
a DPF 153 at its maximum allowable particle loading. In some embodiments the relatively high sensitivity range of operation may be over a larger proportion of the maximum range of differential pressures, such as from 25% to 50%.

In some embodiments the relatively high sensitivity range of operation of the differential pressure sensor module 159 may be up to and include the maximum differential pressure expected during vehicle operation with the DPF 153 at its normal operation design limit soot loading.

Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of the words, for example "comprising" and "comprises", means "including but not limited to", and is not intended to (and does not) exclude other moieties, additives, components, integers or steps.

Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

Features, integers, characteristics, compounds, chemical moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith.
CLAIMS:

1. An apparatus for a motor vehicle, the apparatus comprising:
   control means; and
   pressure sensor means for measuring a pressure difference between first and
   second locations of an engine aftertreatment system,
   the apparatus being configured to generate a pressure difference signal in
   dependence on the difference in pressure between the first and second locations, the
   pressure difference signal being indicative of a pressure drop across a particle filter of the
   aftertreatment system,
   wherein the pressure difference signal generated by the apparatus has a greater
   sensitivity to pressure differences over a first range of pressure differences than over a
   second range of pressure differences that is greater than the first range,
   the control means being configured to output a control signal in dependence at least
   in part on the pressure difference signal.

2. An apparatus according to claim 1 wherein the first range of pressure differences
   includes substantially zero pressure difference.

3. An apparatus according to claim 1 or claim 2 wherein the first range of pressure
   differences includes a negative pressure difference of magnitude at least equal to the
   pressure difference across the particle filter with the engine at a minimum expected speed
   of substantially continuous operation under substantially no torque loading.

4. An apparatus according to any preceding claim wherein the control means is
   configured to output a missing filter signal indicative that a particle filter of the aftertreatment
   system is not present in dependence on the pressure difference signal.

5. An apparatus according to claim 4 wherein the control means is configured to
   generate the missing filter signal if the pressure difference signal is below a predetermined
   filter-present threshold pressure difference signal value, the filter-present threshold pressure
   difference signal value having a value within the first range of pressure differences.

6. An apparatus according to claim 5 wherein the predetermined filter-present threshold
   pressure difference signal value is determined in dependence at least in part on a signal
   indicative of a mass flow rate of engine intake air and/or exhaust gas mass flow rate.
7. An apparatus according to any preceding claim wherein the pressure difference signal generated by the apparatus is arranged to have a first average gradient value over the first range of pressure differences, and a second average gradient value over the second range of differences, the second average gradient value being different from the first.

8. An apparatus according to any preceding claim wherein the pressure difference signal generated by the apparatus is arranged to be substantially linear with pressure difference over the first range of pressure differences, having a first average gradient value over the first range of pressure differences, and substantially linear over the second range of pressure differences, having a second average gradient value over the second range of differences, the second average gradient value being different from the first.

9. An apparatus according to claim 7 or claim 8 wherein the second average gradient value is at least a factor of 1.5 different from the first average gradient value.

10. An apparatus according to claim 7 or claim 8 wherein the second average gradient value is at least a factor of 2.0 different from the first average gradient value.

11. An apparatus according to any one of claims 7 to 10 wherein the second average gradient value is lower than the first average gradient value.

12. An apparatus according to any preceding claim wherein the control signal comprises a regeneration signal indicative that regeneration of the diesel particle filter is required.

13. An apparatus according to claim 12 wherein the regeneration signal is generated if the pressure difference signal exceeds a predetermined value.

14. An apparatus according to claim 13 wherein the predetermined value corresponds to the pressure difference between the first and second locations with the particle filter having a soot loading corresponding to a predetermined amount, optionally a predetermined proportion of a maximum allowable amount.

15. An apparatus according to any preceding claim wherein the control means is configured to output a control signal in dependence on the pressure difference signal and in
further dependence at least in part on a mass flow rate signal indicative of the value of mass flow rate of exhaust gases through the aftertreatment system.

16. An apparatus according to claim 15 as depending through claim 13 configured to calculate the predetermined pressure difference value in dependence on the mass flow rate signal.

17. An apparatus according to claim 16 configured wherein the predetermined pressure difference value is increased with increasing mass flow rate in proportion to the expected increase in pressure difference across the particle filter with increasing mass flow rate.

18. An apparatus according to any preceding claim wherein the first range of pressure differences is at least 10% of the maximum range of pressure differences to which the sensor means may be exposed in use.

19. An apparatus according to any preceding claim wherein the first range of pressure differences is at least 20% of the maximum range of pressure differences to which the sensor means may be exposed in use.

20. An apparatus according to any preceding claim wherein the first range of pressure differences is around 40 to 60% of the maximum range of pressure differences to which the sensor means may be exposed in use.

21. An apparatus according to any preceding claim in combination with at least a portion of an engine aftertreatment system, the at least a portion comprising a diesel particle filter, wherein the pressure sensor means is arranged to measure a pressure of exhaust gases upstream and downstream of the particle filter.

22. An apparatus according to claim 12 or any claim depending therethrough in combination with an engine controller, wherein the engine controller is configured to receive the regeneration signal, the engine controller being configured to cause the engine to output exhaust gases enriched in unburned fuel in response to receipt of the regeneration signal.

23. An apparatus according to any preceding claim, wherein the apparatus does not comprise a particle matter (PM) detector in addition to the pressure sensor means and control means.
24. A vehicle comprising a body, a plurality of wheels, a powertrain to drive said wheels, a braking system to brake said wheels, and an apparatus according to any preceding claim.

25. A method comprising:
   measuring by means of pressure sensor means a pressure difference between first and second locations of an engine aftertreatment system;
   generating a pressure difference signal in dependence on the difference in pressure between the first and second locations, the pressure difference signal being indicative of a pressure drop across a particle filter of the aftertreatment system,
   whereby the pressure difference signal has a greater sensitivity to pressure differences over a first range of pressure differences than over a second range of pressure differences that is greater than the first range,
   the method comprising outputting a control signal in dependence on the pressure difference signal.

26. A method according to claim 25 whereby the first range of pressure differences includes substantially zero pressure difference.

27. A method according to claim 25 or 26 comprising outputting a missing filter signal indicative that a particle filter of the aftertreatment system is not present if the pressure difference signal indicates the pressure difference is below a predetermined filter-present threshold pressure difference value, the filter-present threshold pressure difference value having a value within the first range of pressure differences.

28. A method according to claim 27 comprising determining the filter-present threshold pressure difference value in dependence at least in part on a signal indicative of a mass flow rate of engine intake air and/or exhaust gas mass flow rate.

29. A method according to any one of claims 25 to 28 whereby the pressure difference signal is arranged to be substantially linear with pressure difference over the first range of pressure differences, having a first average gradient value over the first range of pressure differences, and substantially linear over the second range of pressure differences, having a second average gradient value over the second range of differences, the second average gradient value being different from the first.
30. A method according to any one of claims 25 to 28 whereby generating the control signal comprises generating a regeneration signal indicative that regeneration of the diesel particle filter is required, whereby the regeneration signal is generated if the pressure difference signal exceeds a predetermined value.

31. A method according to claim 30 whereby the control means is configured to output the regeneration signal in dependence on the pressure difference signal and in further dependence at least in part on a mass flow rate signal indicative of the value of mass flow rate of exhaust gases through the aftertreatment system.

32. A carrier medium carrying computer readable code for controlling a vehicle to carry out the method of any one of claims 25 to 31.

33. A computer program product executable on a processor so as to implement the method of any one of claims 25 to 31.

34. A computer readable medium loaded with the computer program product of claim 33.

35. A processor arranged to implement the method of any one of claims 25 to 31, or the computer program product of claim 33.

36. A system, vehicle, method, computer program or carrier medium substantially as hereinbefore described with reference to FIG.'s 2 and 3.
Baseline Euro 6c After Treatment Layout and DPF sensors

1. Turbocharger
2. Diesel Oxidation Catalyst
3. Catalysed Diesel Particulate Filter
4. Selective Catalytic Reduction
5. Low Pressure Exhaust Gas Recirculation
6. Urea Tank
7. Urea Injector
8. Urea Mixer
9. DPF Differential Pressure Sensor
10. Powertrain Control Module
11. Particulate Matter Sensor

PRIOR ART

FIGURE 1(a)
New Smart DPF DP Sensor Transfer Curve

Differential Pressure [mbar] (X value) vs. DP Sensor Y Value

- Overloaded DPF and Maximum Peak Power
- Better signal to noise ratio (DPF diagnostics)

FIGURE 3(b)
**INTERNATIONAL SEARCH REPORT**

International application No
PCT/EP2016/061085

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01N11/00 F01N3/023 F01N9/00 F01N3/20
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
F01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>US 2014/366515 Al (KOWALKOWSKI JANEAN E [US] ET AL) 18 December 2014 (2014-12-18) the whole document claims 5,6</td>
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<td>EP 2 392 792 A2 (TOYOTA MOTOR CO LTD [JP]) 7 December 2011 (2011-12-07) the whole document claim 1</td>
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[ ] Further documents are listed in the continuation of Box C.  
[ ] See patent family annex.

* Special categories of cited documents:

- **A** document defining the general state of the art which is not considered to be of particular relevance
- **E** earlier application or patent but published on or after the international filing date
- **L** document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- **O** document referring to an oral disclosure, use, exhibition or other means
- **P** document published prior to the international filing date but later than the priority date claimed

**T** later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

- **X** document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- **Y** document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

- **Z** document member of the same patent family

Date of the actual completion of the international search
7 July 2016

Date of mailing of the international search report
20/07/2016

Name and mailing address of the ISA/Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2380 HV Rijswijk Tel.: (+31-70) 340-2040, Fax: (+31-70) 340-3016

Wagner, A

Form PCT/ISA/210 (second sheet) (April 2009)
**INTERNATIONAL SEARCH REPORT**

**Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. 
   - **Claims Nos.:**
   - because they relate to subject matter not required to be searched by this Authority, namely:

2. **X**
   - **Claims Nos.:**
   - because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
     - see **FURTHER INFORMATION sheet** PCT/ISA/210

3. 
   - **Claims Nos.:**
   - because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1. 
   - **As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.**

2. 
   - **As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.**

3. 
   - **As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:**

4. 
   - **No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:**

**Remark on Protest**

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.
Continuation of Box 11.2

Claims Nos.: 36

Claim 36 refers to the figures without defining any concrete technical features. Therefore no search can be carried out for this claim.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.
## INTERNATIONAL SEARCH REPORT

### Information on patent family members

**International application No**

**PCT/EP2016/061085**

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<td>20-10-2005</td>
<td>DE 102005015432 Al</td>
<td>20-10-2005</td>
</tr>
<tr>
<td>JP 4424040 B2</td>
<td>03-03-2010</td>
<td>JP 2005291169 A</td>
<td>20-10-2005</td>
</tr>
<tr>
<td>US 2005217250 Al</td>
<td>06-10-2005</td>
<td></td>
<td></td>
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<tr>
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<td>18-12-2014</td>
<td>DE 102014108104 Al</td>
<td>18-12-2014</td>
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<tr>
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<td></td>
<td>US 2014366515 Al</td>
<td>18-12-2014</td>
</tr>
<tr>
<td>EP 2392792 A2</td>
<td>07-12-2011</td>
<td>EP 2392792 A2</td>
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<tr>
<td>JP 2011252423 A</td>
<td>15-12-2011</td>
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