(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
7 September 2007 (07.09.2007)

PCT

(10) International Publication Number
WO 2007/100472 A1

(51) International Patent Classification:
B01D 46/46 (2006.01)

(21) International Application Number:
PCT/US2007/003532

(22) International Filing Date: 8 February 2007 (08.02.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11/362,863 28 February 2006 (28.02.2006) US
11/495,751 31 July 2006 (31.07.2006) US

(71) Applicant *(for all designated States except US)*: **CATERPILLAR INC.** [US/US]; 100 N.E. Adams Street, Peoria, IL 61629-6490 (US).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **DAOUD, Mohamed, I.** [EG/US]; 11032 N. Serene Boulevard, Dunlap, IL 61525 (US).

(74) Agents: **BARNES, D., James** et al.; 100 N.E. Adams Street, Peoria, IL 61629-6490 (US).

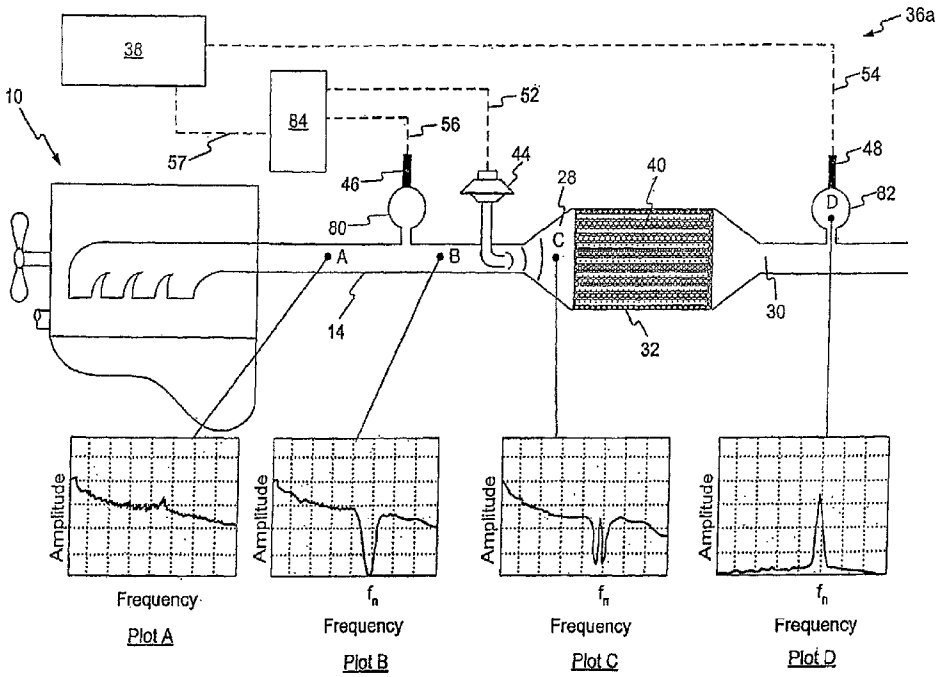
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: SYSTEM AND METHOD FOR MONITORING A FILTER



(57) Abstract: A monitoring assembly for a filter (32) includes an acoustic apparatus (36, 36a). The acoustic apparatus (36, 36a) includes a first receiver (46), a second receiver (48), a resonator (80, 82), and a transmitter (44). The transmitter (44) is configured to emit sound waves receivable by at least one of the first receiver (46), the second receiver (48), and the resonator (80, 82). The monitoring assembly (36, 36a) also includes an electronic control module (38) configured to receive signals from at least one of the first and second receivers (46, 48).

WO 2007/100472 A1

Description

SYSTEM AND METHOD FOR MONITORING A FILTER

Technical Field

The present disclosure relates generally to filter monitoring, and more particularly to a system and method for monitoring the state of a particulate filter.

Background

Engines, including diesel engines, gasoline engines, natural gas engines, and other engines known in the art, may exhaust a complex mixture of air pollutants. The air pollutants may be composed of gaseous and solid materials, including, for example, particulate matter. Particulate matter may include unburned carbon particles, such as soot. Particulate matter may be generated during operation of an engine, as fuel is supplied to the engine and is combusted in one or more combustion chambers within the engine. The engine may expel this particulate matter along with other engine exhaust from the one or more combustion chambers through an exhaust line. If this particulate matter is not filtered or otherwise removed from the engine exhaust, these particulates may be vented to the environment. Due to increased attention on the environment, exhaust emission standards have become more stringent. The amount of particulates emitted from an engine may be regulated depending on the type of engine, size of engine, and/or class of engine.

In order to remove particulate matter from engine exhaust, an exhaust filtration system may be disposed within the exhaust line. The exhaust filtration system may include a particulate filter or trap that may remove particulate matter from the engine exhaust. Particulate filters may typically

include a wire mesh medium through which the engine exhaust is passed. The wire mesh medium may filter or trap particulate matter from the engine exhaust. Use of the particulate filter for extended periods of time may cause particulate matter to buildup in the wire mesh medium, thereby causing the functionality of the filter and engine performance to decrease. To avoid this decrease, a heating element may be used to increase the temperature of the trapped particulate matter above the combustion temperature of the trapped particulate matter, thereby burning away the trapped particulate matter and regenerating the filter system. Although regeneration may reduce the buildup of particulate matter in the filter, repeated regeneration of the filter may result in a buildup of ash in the components of the filter over time, or may cause damage to the filter, possibly resulting in a deterioration of filter performance.

At least one system has been developed for diesel particulate filter monitoring. For example, U.S. Patent No. 6,964,694 to Rauchfuss et al. ("Rauchfuss") discloses incorporating one or more acoustic sensors into an exhaust system of an engine for detecting one or more frequencies passing through a filter. The one or more acoustic sensors may be fluidly or mechanically coupled to portions of the exhaust system to determine the frequency caused by the exhaust flow through the filter. The acoustic emissions from the filter may be compared to a known filter state to determine the present filter state. However, if the engine in Rauchfuss is not in operation, and no exhaust flow is being produced, then there are no frequencies or sounds for the one or more acoustic sensors to detect. When there are no frequencies or sounds to detect, the system in Rauchfuss cannot readily determine the state and/or loading of the filter.

The present invention is directed to overcoming one or more of the problems set forth above.

Summary of the Invention

In an exemplary embodiment of the present disclosure, a monitoring assembly for a filter includes an acoustic apparatus. The acoustic apparatus includes a first receiver, a second receiver, a resonator, and a transmitter. The transmitter is configured to emit sound waves receivable by at least one of the first receiver, the second receiver, and the resonator. The monitoring assembly also includes an electronic control module configured to receive signals from at least one of the first and second receivers.

In another exemplary embodiment of the present disclosure, a monitoring assembly for a filter includes a first resonator fluidly connected to the filter. The monitoring assembly also includes a transmitter connected proximate an inlet of the filter and a second resonator fluidly connected to an outlet of the filter.

In still another exemplary embodiment of the present disclosure, a method of monitoring a filter of an internal combustion engine includes attenuating sound energy produced by the engine at a resonance frequency and sensing the resonance frequency. The method also includes emitting a sound wave at the resonance frequency, the sound wave having a first amplitude. The method further includes sensing a second amplitude of the sound wave downstream of an outlet of the filter.

Brief Description of the Drawings

FIG. 1 is a diagrammatic illustration of an engine having a particulate filter assembly according to an exemplary embodiment of the present disclosure;

FIG. 2 is a diagrammatic illustration of the particulate filter assembly from FIG. 1;

FIGS. 3A-3C are graphs illustrating exemplary trend curves related to the particulate filter assembly; and

FIG. 4 is a flow diagram of a method for monitoring the state of a diesel particulate filter according to an exemplary embodiment of the present disclosure.

FIG. 5 is a diagrammatic illustration of an engine having a particulate filter assembly according to another exemplary embodiment of the present disclosure.

FIG. 6 is a graph illustrating exemplary relationships between transmission loss, frequency, and soot loading.

Detailed Description

Exemplary embodiments of the present disclosure are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

FIG. 1 illustrates a schematic representation of an internal combustion engine 10 including an intake line 12, an exhaust line 14, and an engine block 16. Intake line 12 may provide an intake path for air, recirculated exhaust gases, or a combination thereof. Gases from intake line 12 may be directed into one or more combustion chambers (not shown) housed in engine block 16. Exhaust line 14 may provide a path for exhaust gases to exit from the combustion chambers. An upstream portion of exhaust line 14 may split into one or more exhaust passages 18, 20, 22, and 24, each being operatively connected to one of the combustion chambers.

During operation of internal combustion engine 10, intake air may enter into the combustion chambers through intake line 12. The intake air and fuel may be combusted within the combustion chambers, and the exhaust generated by combustion may be evacuated from within the combustion chambers through exhaust passages 18, 20, 22, and 24. In one embodiment, exhaust line 14 may be coupled to four combustion chambers by four exhaust passages 18, 20, 22, and 24. However, any number of combustion chambers and exhaust passages may be used. Internal combustion engine 10 may include diesel

engines, gasoline engines, natural gas engines, and other engines known in the art.

Exhaust line 14 may be operatively connected to a particulate filter assembly 26. A stream of exhaust exiting from the combustion chambers through exhaust passages 18, 20, 22, and 24 may flow downstream through exhaust line 14 into particulate filter assembly 26. Particulate filter assembly 26 may be configured to filter or trap particulate matter in the exhaust stream as the exhaust stream passes therethrough. Particulate filter assembly 26 may include, for example, an inlet 28 for receiving the exhaust stream, an outlet 30 allowing filtered exhaust to exit from particulate filter assembly 26, a particulate filter 32 located between inlet 28 and outlet 30, a particulate filter regeneration device 34, an acoustic apparatus 36, and a controller, such as an electronic control module 38. Particulate filter assembly 26 is shown in greater detail in FIG. 2.

Particulate filter 32 may include any type of filter known in the art. In one embodiment, particulate filter 32 may include a filter element 40 located within a filter housing 42. Filter element 40 may be constructed of any material useful in removing pollutants and/or particulates from the exhaust stream, such as, for example, foam cordierite, sintered metal, ceramic, or silicon carbide. It is contemplated that filter element 40 may also include catalyst materials capable of collecting soot, NOx, sulfur compounds, particulate matter, and/or other pollutants known in the art. Such catalyst materials may include, for example, alumina, platinum, rhodium, barium, cerium, and/or alkali metals, alkaline-earth metals, rare-earth metals or combinations thereof. Filter element 40 may be situated horizontally, vertically, radially, or helically. Additionally or alternatively, filter element 40 may be arranged in a honeycomb, mesh, or any other suitable configuration so as to maximize the available surface area for filtration.

Particulate filter regeneration device 34 may be configured to increase the temperature of the exhaust stream produced by internal combustion

engine 10 to a predetermined temperature. The predetermined temperature may include, for example, a regeneration temperature of particulate filter 32. In one embodiment, particulate filter regeneration device 34 may be operatively coupled to exhaust line 14 at a location upstream of particulate filter 32. It is also contemplated that particulate filter regeneration device 34 may be operatively coupled to filter housing 42 and/or filter element 40. Particulate filter regeneration device 34 may include, for example, a fuel injector and an igniter, heat coils, electrical conductors, and/or other heat sources known in the art. Such heat sources may be configured to assist in increasing the temperature of the exhaust stream through convection, combustion, and/or other methods of heat transfer. As the temperature of the exhaust stream increases, the temperature of the trapped particulate matter in particulate filter 32 may also increase. When the trapped particulate matter reaches the predetermined temperature, it may burn away, and thus, particulate filter 32 may be regenerated.

Acoustic apparatus 36 may include, for example, a transmitter 44 and one or more receivers 46 and 48. Transmitter 44 may be positioned at a location upstream of particulate filter 32, and may be configured to send sound waves towards and/or through particulate filter 32. The transmitter 44 may include, for example, a speaker, a tweeter, and/or any other device configured to emit and/or direct sound energy over a range of desired frequencies and amplitudes. It is contemplated that the sound waves transmitted by transmitter 44 may include ultrasounds and/or any other high or low frequency sonic emissions. In order to produce these emissions, transmitter 44 may include a transducer for converting electrical signals into sound waves. It is also contemplated that receivers 46 and 48 may also include transducers that may be similar or identical to the transducer of transmitter 44. The transducers of receiver 46 and 48 may be configured receive sound waves from transmitter 44, and may convert those sound waves into electrical signals. The receivers 46, 48 include, for example, audio sensors, microphones, and/or any other conventional devices configured to

detect and/or transmit sound energy. The transducers, on the other hand, may include piezoelectric transducers, or any other suitable transducers known in the art capable of converting electrical signals/pulses to mechanical vibrations, and vice versa. The type of transducer chosen may depend on a host of factors, including, for example, its working frequency, size and weight, cost, corrosion resistance, and ability to withstand high temperature environments.

The transducers may be either permanently or removably coupled to exhaust line 14 or particulate filter 32 by one or more attachment devices (not shown), such as, for example, brackets, clips, welds, adhesives, and/or any other suitable attachment devices known in the art. In one embodiment, at least one of the transducers may be indirectly coupled so that a space may exist between the at least one transducer and exhaust line 14 or particulate filter 32. In another embodiment, at least one of the transducers may be directly mounted onto a surface of exhaust line 14 or particulate filter 32. In yet another embodiment, at least one of the transducers may be mounted so as to extend into exhaust line 14 or particulate filter 32.

Receiver 46 may be located on the same side of particulate filter 32 as transmitter 44, and thus, may receive sound waves directly from transmitter 44. Receiver 48 may be located on a side of particulate filter 32 opposite that of transmitter 44. By positioning receiver 48 on the opposite side, receiver 48 may receive sound waves from transmitter 44 after they have passed through particulate filter 32. By comparing the properties of the sound waves received by receiver 46 to the sound waves received by receiver 48, the type, kind, and/or magnitude of variation between the sound waves received by receivers 46 and 48 may be determined. The variation may be influenced by the physical properties of particulate filter 32, including, for example, the type of material used to make particulate filter 32, the shape and size of particulate filter 32, and/or the amount of particulate matter trapped in particulate filter 32. It is also contemplated that the variation may be indicative of damage to particulate filter 32, including, for

example, melting and/or cracking. This process of analyzing the sound waves will be explained in further detail below.

In one embodiment of the present disclosure, acoustic apparatus 36 may be integrated and/or permanently coupled to exhaust line 14 and/or particulate filter assembly 26. Additionally or alternatively, acoustic apparatus 36 may include a portable diagnostic tool selectively coupled to exhaust line 14 and/or particulate filter assembly 26. In either case, acoustic apparatus 36 may be located proximate exhaust line 14 and/or particulate filter assembly 26, and thus, may be exposed to heat. Accordingly, acoustic apparatus 36 may include insulation (not shown) and/or a cooling system (not shown) to protect its components from being damaged by the heat.

Electronic control module 38 may include an electronic controller in the form of one or more microprocessors and one or more memory components. The microprocessors and memory components may include software code instruction sets that may be executed to perform various control and information functions, such as, for example, assisting in the operation of internal combustion engine 10, acoustic apparatus 36, and/or particulate filter regeneration device 34.

In one embodiment, electronic control module 38 may be configured to supply electrical signals/pulses to transmitter 44, and receive electrical signals/pulses from receivers 46 and 48 through electrical connections 52, 54, and 56. The transducer of transmitter 44 may convert the electrical signals/pulses into sound waves, such as, for example, ultrasounds. The type and kind of sound waves transmitted by transmitter 44 may be selectively adjusted by electronic control module 38 in terms of its frequency, intensity, wavelength, amplitude, and other properties, based upon the characteristics of internal combustion engine 10, particulate filter 32, particulate matter, and/or the working environment.

Receivers 46 and 48 may be configured to receive sound waves from transmitter 44. The transducers of receivers 46 and 48 may convert those sound waves into electrical signals/pulses that may be sent back to electronic control module 38 for recording and/or analysis. The electrical signals/pulses sent by receivers 46 and 48 may contain information indicative of the sound spectrum and characteristics of the sound waves received by receivers 46 and 48. It is also contemplated that receivers 46 and 48 may be configured to focus on one or more specific sound wave characteristics, such as, for example, frequency, intensity, wavelength, amplitude, and/or loudness. As such, receivers 46 and 48 may filter out extraneous data before sending electrical signals/pulses to electronic control module 38. Additionally or alternatively, electronic control module 38 may be configured to filter out extraneous data after receiving electrical signals/pulses from receivers 46 and 48.

Electronic control module 38 may operate transmitter 44 and receivers 46 and 48 continuously during operation of internal combustion engine 10 to constantly monitor the state of particulate filter 32. Additionally or alternatively, electronic control module 38 may operate transmitter 44 and receivers 46 and 48 intermittently. For example, in one embodiment, electronic control module 38 may not monitor particulate filter 32 during the initial operation of internal combustion engine 10. In such a state, electronic control module 38 may not supply electric signals/pulses to transmitter 44 or receive electronic signals/pulses from receivers 46 and 48, effectively turning acoustic apparatus 36 off. One or more sensors may be operatively connected to electronic control module 38 to supply electronic control module 38 with sensed values from internal combustion engine 10, particulate filter assembly 26, and/or exhaust line 14. If the sensed values fall outside of a predetermined range, electronic control module 38 may recognize the out-of-range condition as being related to loading of and/or damage to particulate filter 32. As such, electronic control module 38 may turn on acoustic apparatus 36 by sending electronic

signals/pulses to transmitter 44, and receiving electronic signals/pulses from receivers 46 and 48.

It is also contemplated that electronic control module 38 may reverse the relationship between the various transducers. For example, in one mode of operation, the transducer of transmitter 44 may transmit sound waves, while transducers of receivers 46 and 48 may receive sound waves. However, by switching the direction of the electronic signals/pulses, one or both of the transducers of receivers 46 and 48 may be converted into transmitters (effectively converting one or both of receivers 46 and 48 into transmitters), while the transducer of transmitter 44 may be converted into a receiver (effectively converting transmitter 44 into a receiver).

During servicing, where internal combustion engine 10 may not be running and/or electronic control module 38 may not receive power, a service technician may attach a portable version of acoustic apparatus 36 on or near particulate filter assembly 26. The service technician may connect acoustic apparatus 36 to an external power source (not shown) to turn on transmitter 44 and receivers 46 and 48 to monitor particulate filter 32 and determine whether particulate filter 32 should be cleaned, repaired, or replaced. The external power source may include one or more batteries, a power outlet, and/or any other suitable power supply device. Thus, acoustic apparatus 36 may operate without having to run internal combustion engine 10.

When transmitter 44 and receivers 46 and 48 are turned on, sound waves may propagate from transmitter 44 towards receivers 46 and 48. The specific sound spectrum patterns and characteristics of the sound waves received by receiver 46 (upstream sound waves) may be recorded and analyzed by electronic control module 38. Similarly, the specific sound spectrum patterns and characteristics of the sound waves received by receiver 48 (downstream sound waves) may also be recorded and analyzed by electronic control module 38. Using its microprocessors and memory components, electronic control module 38

may conduct an analysis of the sound spectrum patterns and characteristics of the upstream and downstream sound waves. For example, electronic control module 38 may perform an analysis in the time and frequency domains of the upstream and downstream sound waves.

During the analysis, values, charts, and/or graphs representing the sound spectrum pattern and characteristics of the upstream and downstream sound waves may be determined. The values, charts, and/or graphs for the upstream and downstream sound waves may be compared and contrasted to detect any variations between the wave characteristics of the upstream and downstream sound waves.

In one embodiment, levels of variation may correspond to the load level (amount of particulate matter) in particulate filter 32. For example, if receivers 46 and 48 detect a low level of variation between the upstream and downstream sound waves, electronic control module 38 may interpret the low level as indicating that particulate filter 32 is relatively clean. If the level of variation is lower than it should be for a clean particulate filter, electronic control module 38 may interpret the lower level as indicating that particulate filter 32 is damaged. For example, electronic control module 38 may recognize, based on the lower level of variation, that a gap that may be allowing unaffected sound waves to pass through particulate filter 32. On the other hand, a higher level of variation may indicate that particulate filter 32 is loaded, or has become clogged.

It is also contemplated that the level of variation of the sound waves may be plotted over time to form one or more trend curves, such as, for example, trend curves 58, 62, and 66. Trend curves 58, 62, and 66 may be analyzed by electronic control module 38, and/or may be displayed to a user or service technician on a visual display assembly (not shown), such as, for example, a computer screen, video monitor, or any other suitable device. In FIG. 3A, trend curve 58 may be representative of the level of variation between the upstream and downstream sound waves over time during the operation of internal

combustion engine 10. The increase in the level of variation over time in trend curve 58 may indicate that particulate filter 32 is becoming increasingly loaded with particulate matter. A limit line 60 may indicate the level of variation where regeneration of particulate filter 32 becomes desirable. When trend curve 58 reaches limit line 60, regeneration or cleaning of particulate filter 32 may be initiated by electronic control module 38, the user, and/or the service technician.

Trend curve 62 in FIG. 3B may be representative of the level of variation between the upstream and downstream sound waves before, during, and after regeneration of particulate filter 32. For example, trend curve 62 may include a rising portion and a falling portion. The rising portion may be similar to trend curve 58 in that both may indicate that particulate filter 32 is being loaded with particulate matter. The falling portion, on the other hand, may be indicative of a decrease in the level of variation over time that may occur as a result of regenerating particulate filter 32 to burn off, and thereby decrease, the amount of particulate matter in particulate filter 32. A lower limit line 64 may represent a level of variation where regeneration may cease. Thus, once the level of variation decreases to the limit line, regeneration device 34 may shut off, and particulate filter 32 may once again begin loading. In contrast, trend curve 66 in FIG. 3C shows an example of a curve that may be generated when particulate filter 32 is damaged. In trend curve 66, rising portions may be typical of the level of variation over time during loading of particulate filter 32. A sharply falling portion between the rising portions may indicate that the level of variation decreased over a short interval of time. This relatively sharp decrease may be the result of damage to particulate filter 32, such as, for example, formation of a gap or hole in particulate filter 32 that may allow sound waves to travel from transmitter 44 to receiver 48 without being filtered by filter element 40.

Electronic control module 38 may be calibrated so as to link a particular level or type of variation with a particular state of particulate filter 32, including, for example, clean, loading, loaded, and/or damaged. Associated with

the particular level or type of variation may be a treatment or action that should be performed on particulate filter 32, such as, maintaining, cleaning, regenerating, or replacing, one or more parts of particulate filter 32.

It is contemplated that an analyzer (not shown) separate from electronic control module 38 may be used to perform the analysis on the upstream and downstream sound waves, and/or may trigger operation of particulate filter regeneration device 34. The analyzer may include, for example, one or more microprocessors and one or more memory components, similar to those used in electronic control module 38. Using an analyzer that is separate from electronic control module 38 may allow acoustic apparatus 36 to be portable, while providing acoustic apparatus 36 with the ability to operate independently from internal combustion engine 10 and/or electronic control module 38.

Electronic control module 38 may be operatively connected to particulate filter regeneration device 34 by a suitable electrical connection 50. Electronic control module 38 may send an electronic signal/pulse to particulate filter regeneration device 34 to initiate regeneration of particulate filter 32. Electronic control module 38 may determine the appropriate time to initiate regeneration based at least in part upon a time/maintenance schedule, historical performance data, and/or when the analysis of particulate filter 32 using acoustic apparatus 36 indicates that the amount of particulate matter trapped in particulate filter 32 has exceeded a predetermined value.

As shown in FIG. 5, in another exemplary embodiment of the present disclosure, an acoustic apparatus 36a may include a resonator 80 connected upstream of the inlet 28, and a resonator 82 connected downstream of the outlet 30. The resonators 80, 82 may be connected to the exhaust line 14 such that, for example, sound energy from the internal combustion engine 10 may enter the resonators 80, 82. The resonators 80, 82 may be any type of conventional resonator known in the art and in an exemplary embodiment, the

resonators 80, 82 may be substantially identical in size, shape, and/or design. The resonators 80, 82 may include a body configured to contain a volume of air, an orifice fluidly connected to the exhaust line 14, a neck configured to allow for the vibration of a volume of air, and a nipple configured to be connected to, for example, one of the receivers 46, 48 discussed above. A volume of air enclosed within the resonators 80, 82 may, for example, act as a spring connected to the volume of air within the neck, and may vibrate in an adiabatic fashion at a resonance frequency f_n of the particular resonator 80, 82. The resonance frequency f_n of each particular resonators 80, 82 may be a function of the temperature, density, and/or volume of the air in the resonator 80, 82, its molecular composition, and the mass of the air within the neck.

In an exemplary embodiment, the resonators 80, 82 may be Helmholtz resonators. Such resonators may make it possible to detect individual frequency components of complex acoustic wave shapes, such as, those produced by the internal combustion engine 10. For example, the resonator 80 may act as a band stop filter at its resonance frequency f_n. In such an embodiment, the resonator 80 may be configured to attenuate the amplitude of sound energy transmitted by the exhaust line 14 (from, for example, the internal combustion engine 10) at its resonance frequency f_n. As shown in Plot A of FIG. 5, the exhaust line 14 may assist in transmitting sound energy from the internal combustion engine 10 across a range of frequencies. In such an exemplary embodiment, the resonator 80 may absorb sound energy at its resonance frequency f_n, and, as shown in Plot B, sound energy transmitted at the resonance frequency f_n of the resonator 80 may be attenuated downstream of the resonator 80. Thus, only sound energy transmitted at the resonance frequency f_n may be audible within the resonator 80 and substantially no sound energy may be audible downstream of the resonator 80 at that frequency. It is understood that in an exemplary embodiment of the present disclosure, the first and second resonators

80, 82 may be sized, shaped, designed and/or otherwise configured to attenuate sound energy at the same resonance frequency f_n.

The receivers 46, 48 may be connected to the resonators 80, 82, respectively, and may be configured to sense and/or otherwise detect sound energy within the body of the corresponding resonators 80, 82. As discussed above, the receivers 46, 48 may be, for example, audio sensors, microphones, and/or any other conventional devices configured to sense, detect and/or transmit sound energy. The receiver 46 may be connected to an amplifier 84 via the electrical connection 56, and the amplifier 84 may be connected to the electronic control module 38 via an electrical connection 57. The receiver 46 may contain one or more components configured to transmit signals containing information indicative of the sensed amplitude of sound energy in the resonator 80 to the electronic control module 38. As discussed above, such components may include, for example, a conventional transducer.

The amplifier 84 may be configured to receive electrical signals from the receiver 46 representative of the sound energy attenuated by the resonator 80. The amplifier 84 may also be configured drive the transmitter 44, at the detected frequency of the sound energy attenuated by the resonator 80, at any desired amplitude. As shown in Plot C of FIG. 5, the amplifier 84 may assist the transmitter 44 in emitting sound energy at the resonance frequency f_n upstream of the inlet 28. It is understood that the electrical connection 57 between the amplifier 84 and the electronic control module 38 may enable the electronic control module 38 to store, analyze, and/or otherwise process data contained in the electronic signals sent from the receiver 46, and the electronic control module 38 may also assist in controlling one or more aspects of the amplifier 84. It is further understood that, in an exemplary embodiment, the receiver 46 may share a direct electrical connection with the electronic control module 38.

As shown in FIG. 5, the receiver 48 may be connected to the electronic control module 38 via the electrical connection 54. As illustrated in Plot D of FIG. 5, the resonator 82 may be configured to attenuate the amplitude of sound energy being transmitted at its resonance frequency f_n, and the receiver 48 may be configured to detect, for example, the amplitude of the sound energy attenuated by the resonator 82. The receiver 48 may also contain one or more components, such as, for example, a conventional transducer, configured to transmit signals containing information indicative of the sensed amplitude to the electronic control module 38. As will be discussed below, the difference between the amplitude of the sound energy detected downstream of the outlet 30 and upstream of the inlet 28 may correspond to the soot loading of the particulate filter 32.

Industrial Applicability

The exemplary acoustic apparatuses 36, 36a disclosed herein may have applicability in diesel engine assemblies. Acoustic apparatuses 36, 36a may have particular applicability in monitoring the state of a particulate filter 32 of a diesel engine 10.

In the embodiment described in FIG. 4, acoustic apparatus 36 may include a transmitter 44, arranged on a first side of particulate filter 32, that starts (step 68) the monitoring process by transmitting sound waves, such as, for example, ultrasounds (step 70). The transmitted ultrasounds may be received (step 72) by a receiver 46, located on the same side of particulate filter 32 as transmitter 44, and a receiver 48, located on the opposite side of particulate filter 32. Receiver 46 may receive relatively unmodified ultrasounds that may be substantially identical to the ultrasounds transmitted by transmitter 44, and may convert these unmodified ultrasounds into electrical signals/pulses that may also be sent to an electronic control module 38. Receiver 48 may receive modified ultrasounds that have traveled through particulate filter 32, and may convert these modified ultrasounds into electrical signals/pulses that may also be sent to

electronic control module 38. Electronic control module 38 may function as an analysis tool for analyzing (comparing and contrasting) the sound spectrum patterns and characteristics of the unmodified and modified ultrasounds (step 74) to determine the types and/or magnitudes of any variations between the unmodified and modified ultrasounds. Electronic control module 38 may maintain, clean, regenerate, or replace, particulate filter 32 (step 76) based at least in part on the types and/or magnitudes of the variations. This process may end (step 78) after treating particulate filter 32. Additionally or alternatively, the process may repeat continuously.

It is also understood that as the soot loading of the particulate filter 32 increases, the transmission loss of a sound wave directed across the filter element 40 of the particulate filter 32 may also increase. This direct relationship is graphically illustrated by the inset plot of transmission loss versus soot loading (at an exemplary resonance frequency f_n of the resonators 80, 82) shown in FIG. 6. This known relationship may be preprogrammed into the electronic control module 38, and the exemplary acoustic apparatus 36a shown in FIG. 5 may be used to detect the soot loading of the particulate filter 32. As discussed above, while the internal combustion engine 10 is operating, the resonator 80 may attenuate the amplitude of the sound energy passing through the exhaust line 14 at its resonance frequency f_n. It is understood, however, that the resonance frequency f_n may be a function of, among other things, the temperature of the medium (i.e., the exhaust gas) carrying the sound energy and that the resonance frequency f_n may change as the temperature of the medium changes. The acoustic apparatus 36a may, thus, be configured to automatically adjust the account for these variations.

For example, the receiver 46 may sense the frequency at which the sound energy has been attenuated by the resonator 80. One or more components of the receiver 46 may then send a signal containing information representing this sensed frequency to the amplifier 84. The amplifier 84 may communicate this

information to the electronic control module 38 for storage and/or processing. The amplifier 84 may also drive the transmitter 44 to produce a sound wave having a desired amplitude at the sensed frequency, and the amplifier 84 may also communicate the amplitude of the emitted sound wave to the control module 38. The emitted sound wave may pass from the inlet 28 to the outlet 30, and may experience a transmission loss (i.e., a reduction in amplitude) based on the amount of soot trapped within the filter element 40.

The receiver 48 may sense, among other things, the amplitude of the sound wave exiting the outlet 30 of the particulate filter 32, and may send a signal containing information representing this sensed amplitude to the electronic control module 38. The electronic control module 38 may compare the amplitude of the sound wave produced by the transmitter 44 to the amplitude of the sound wave sensed by the receiver 48 to determine the magnitude of the transmission loss caused by the trapped soot. This transmission loss value may be, for example, entered into one or more preset algorithms and/or plotted on the inset plot shown in FIG. 6 to determine the amount of soot loading in the particulate filter 32. It is understood that this process may be repeated during operation of the internal combustion engine 10 to adjust for increases or decreases in the exhaust temperature and/or increases in the level of soot loading. The detected level of soot loading may assist an operator in, for example, developing a cleaning and/or regeneration schedule for the particulate filter 32.

For ease of discussion, the acoustic apparatuses 36, 36a disclosed herein will be referred to as acoustic apparatus 36 for the duration of this disclosure. Using acoustic apparatus 36 to perform the analysis may be beneficial for many reasons. Acoustic apparatus 36 may produce sound waves that may allow acoustic apparatus 36 to perform relatively non-invasive analyses, meaning that neither particulate filter 32, exhaust line 14, nor their components need be removed to determine the state of particulate filter 32. This may help to minimize the amount of downtime associated with scheduling and performing

maintenance on a work machine (not shown) of which particulate filter 32 may be a part. The use of acoustical analysis may also allow monitoring of particulate filter 32 in real-time while internal combustion engine 10 is in operation. The sound waves, such as, for example, ultrasounds, transmitted/received by acoustic apparatus 36 may be relatively unaffected by variations in fuel characteristics, engine load, and/or engine back pressure, that may occur during actual operation of internal combustion engine 10. Thus, acoustic apparatus 36 may maintain its accuracy even in a dynamic engine environment. Additionally or alternatively, acoustic apparatus 36 may include a separate analyzer and/or power source, such that acoustic apparatus 36 may be portable, and capable of analyzing particulate filter 32 while internal combustion engine 10 is turned off. Because acoustic apparatus 36 may be removably attached to particulate filter 32 for testing, and may be subsequently removed and used on another particulate filter immediately thereafter, it may be particularly useful as an on-site diagnosis and/or preventative maintenance tool.

Acoustic apparatus 36 may also extend the working life of particulate filter 32, conserve fuel/energy, and help to maintain filtration capability, by controlling the timing, number, and/or duration of regenerations performed on particulate filter 32. For example, by using acoustic apparatus 36 to determine the state of particulate filter 32, damage to and/or clogging of particulate filter 32 may be directly measured without relying on back pressure sensor readings and similar devices that may not provide accurate indications of the actual state of particulate filter 32. Using the analysis performed by acoustic apparatus 36 as the basis for triggering regeneration can help to ensure that regeneration may take place when necessary, which may lead to increased filter efficiency and cleaner exhaust. Also, unnecessary regenerations may be avoided, which may help to preserve fuel/energy, while extending the working life of particulate filter 32.

It will be apparent to those skilled in the art that various modifications and variations can be made in the disclosed system and method without departing from the scope of the disclosure. Additionally, other embodiments of the disclosed system and method will be apparent to those skilled in the art from consideration of the specification. It is intended that the specification and examples be considered as exemplary only, with a true scope of the disclosure being indicated by the following claims and their equivalents.

Claims

1. A monitoring assembly for a filter, comprising:

a first resonator (80) fluidly connected to the filter (32);

a transmitter (44) connected proximate an inlet (28) of the filter (32); and

a second resonator (82) fluidly connected to an outlet (30) of the filter (32).

2. The assembly of claim 1, further including a first receiver (46) connected to the first resonator (80) and a second receiver (48) connected to the second resonator (82).

3. The assembly of claim 2, further including an amplifier (84) connected to at least one of the first and second receivers (46, 48).

4. The assembly of claim 3, wherein the amplifier (84) is configured to drive the transmitter (44) at a desired frequency and amplitude.

5. The assembly of claim 3, wherein the amplifier (84) is connected to an electronic control module (38).

6. The assembly of claim 5, wherein the electronic control module (38) is connected to at least one of the first and second receivers (46, 48).

7. The assembly of claim 3, wherein the first and second resonators (80, 82) are configured to attenuate sound energy at the same resonance frequency.

8. A method of monitoring a filter (32) of an internal combustion engine (10), comprising:

attenuating sound energy produced by the engine (10) at a resonance frequency;

sensing the resonance frequency;

emitting a sound wave at the resonance frequency, the sound wave having a first amplitude; and

sensing a second amplitude of the sound wave downstream of an outlet (30) of the filter (32).

9. The method of claim 8, further including comparing the first amplitude and the second amplitude to determine a transmission loss.

10. The method of claim 9, further including determining a soot loading of the filter (32) based on the transmission loss.

11. A monitoring assembly for a filter (32), comprising:

a transmitter (44), arranged on a first side of the filter, configured to emit sound waves;

a first receiver (46), arranged on the first side of the filter, configured to receive the sound waves; and

a second receiver (48), arranged on a second side of the filter, configured to receive the sound waves.

12. The assembly of claim 11, wherein the first side is an upstream side, from which engine exhaust enters the filter (32).

13. The assembly of claim 11, wherein the second side is a downstream side, from which engine exhaust exits the filter (32).

14. The assembly of claim 11, wherein the second receiver (48) receives sound waves that have passed through the filter (32).

15. The assembly of claim 11, wherein the first and second receivers (46, 48) are configured to convert the sound waves into signals.

16. An engine assembly including the monitoring assembly of any of claims 11-15.

17. A method of monitoring a particulate filter (32), comprising:

transmitting sound waves from a first side of the filter (32) with a transmitter (44);

receiving the sound waves on the first side of the filter (32) with a first receiver (46);

receiving the sound waves on a second side of the filter (32) with a second receiver (48); and

determining at least one value indicative of a variation between the sound waves received on the first side and the sound waves received on the second side.

18. The method of claim 17, further including regenerating the filter (32) if the magnitude of the at least one value is outside of a predetermined range.

19. The method of claim 17, further including replacing the filter (32) if the magnitude of the at least one value is outside of a predetermined range.

20. The method of claim 17, wherein the sound waves are ultrasounds.

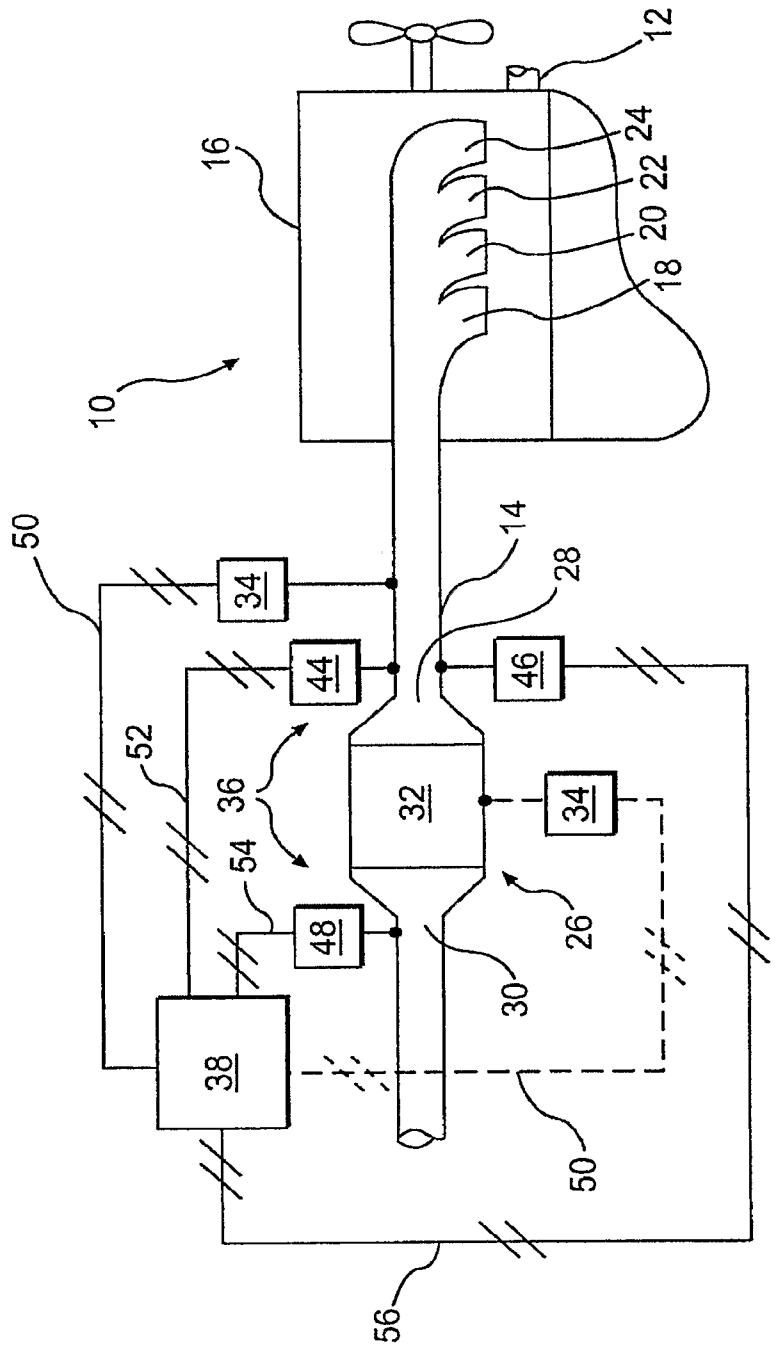


FIG. 1

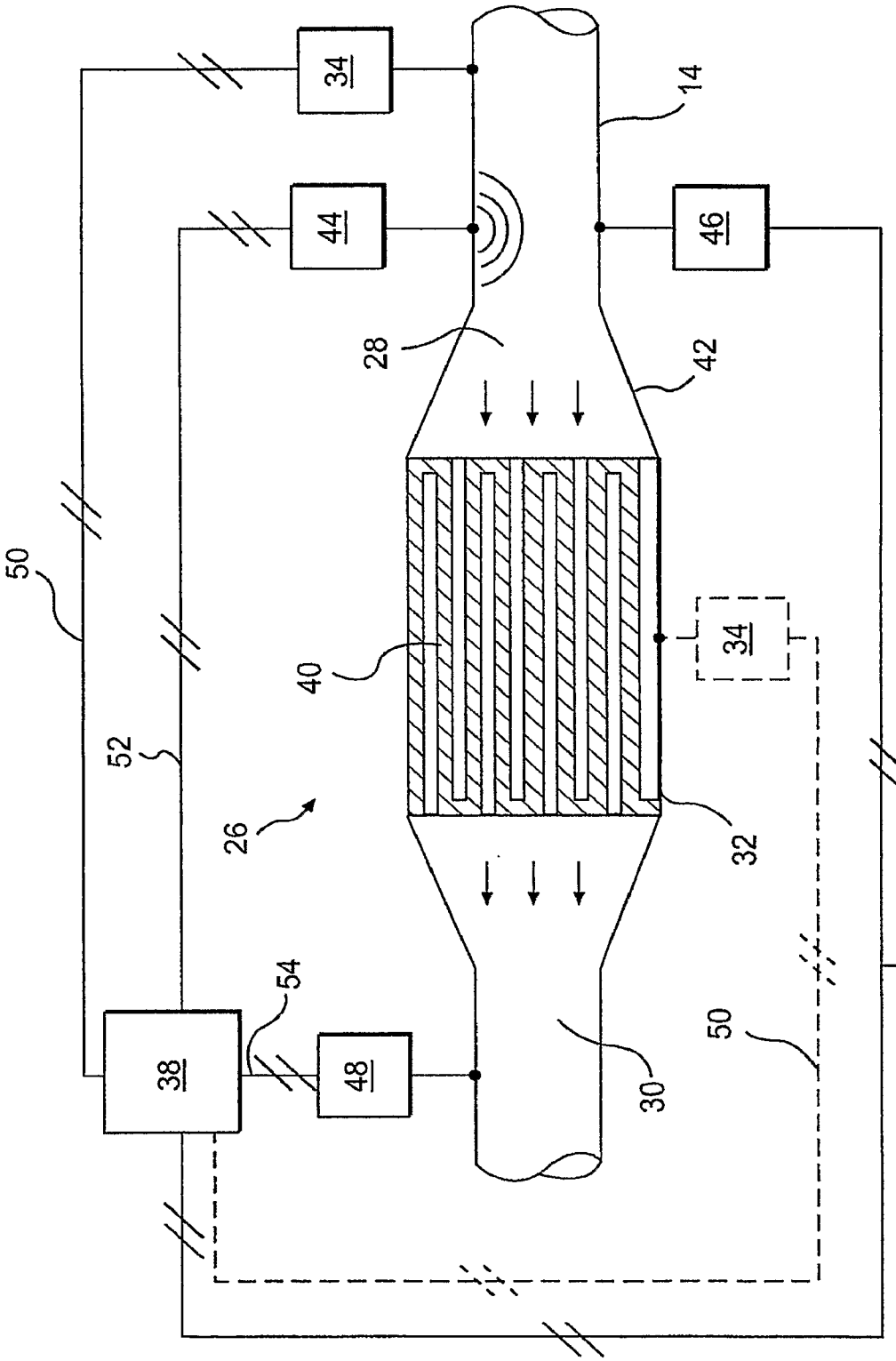


FIG. 2

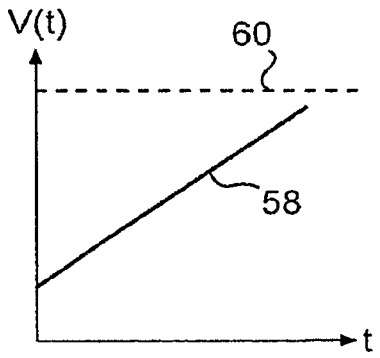


FIG. 3A

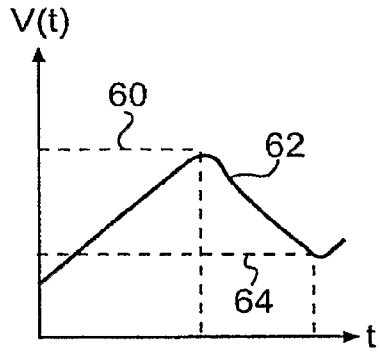


FIG. 3B

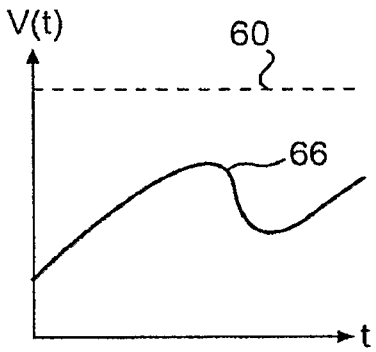


FIG. 3C

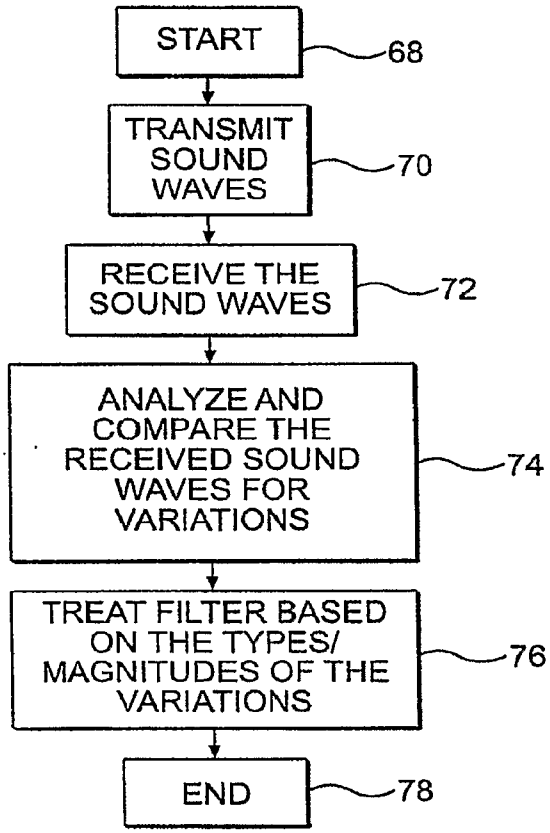

START
68
TRANSMIT SOUND WAVES
70
RECEIVE THE SOUND WAVES
72
ANALYZE AND COMPARE THE RECEIVED SOUND WAVES FOR VARIATIONS
74
TREAT FILTER BASED ON THE TYPES/ MAGNITUDES OF THE VARIATIONS
76
END
78

FIG. 4

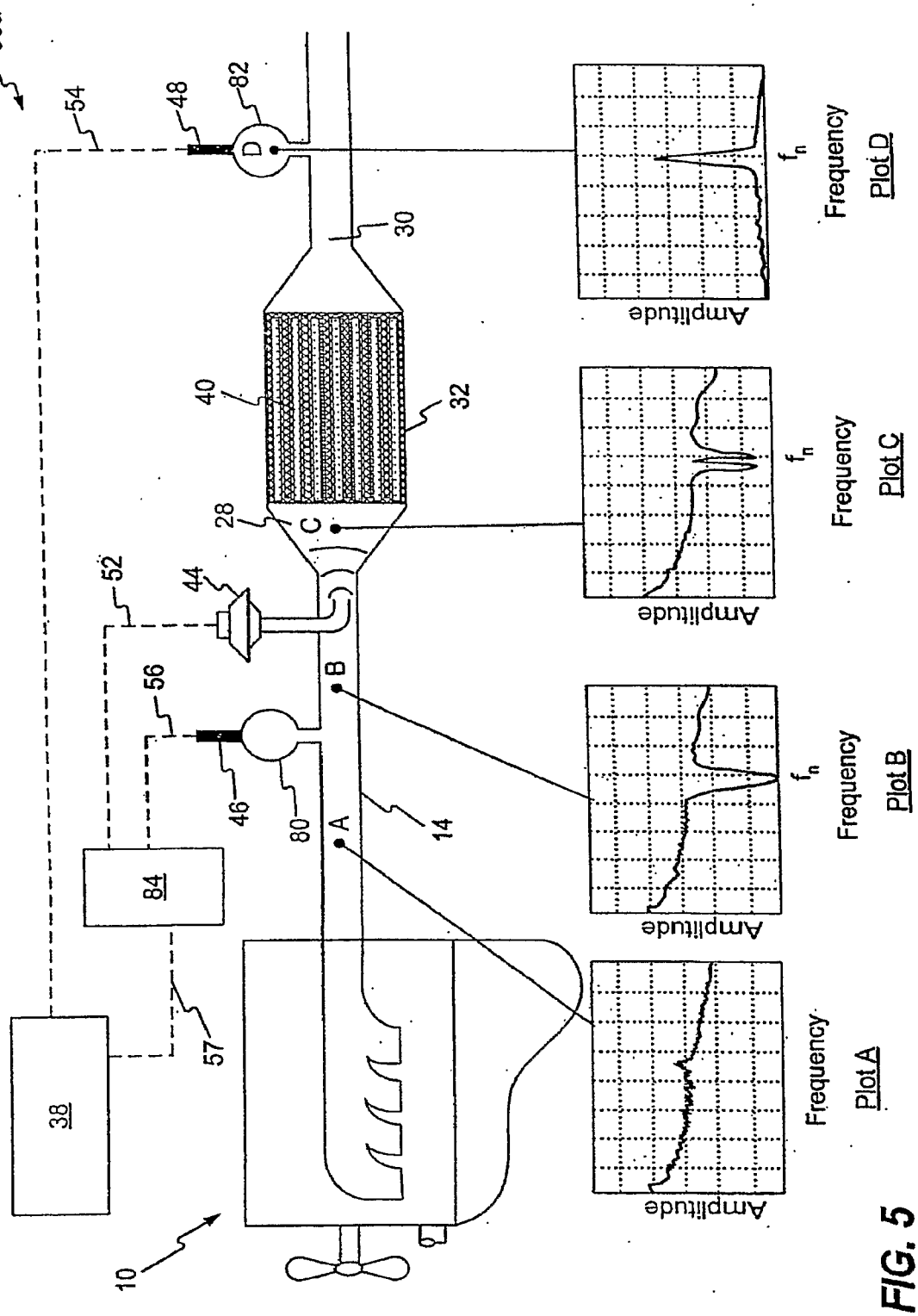

36a
54
48
82
D
30
40
32
28
C
52
44
56
B
46
80
A
14
84
57
38
10
Amplitude
Frequency
f_n
Plot D
Plot C
Plot B
Plot A

FIG. 5

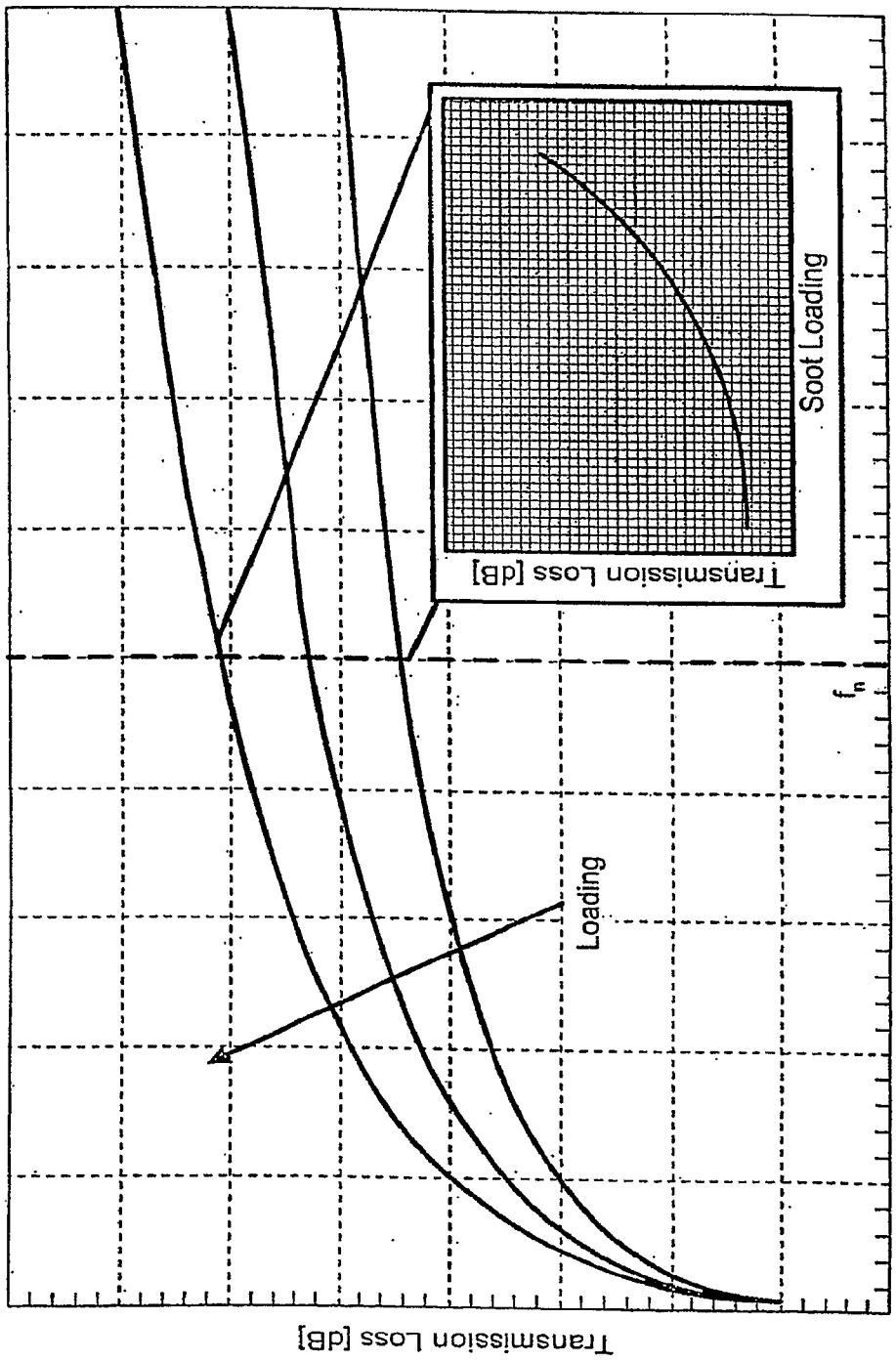

Transmission Loss [dB]
Soot Loading
Transmission Loss [dB]
Loading
f_n
Frequency [Hz]

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/003532

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01D46/46

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)
B01D

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 practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 102 42 300 A1 (BOSCH GMBH ROBERT [DE]) 18 March 2004 (2004-03-18) paragraphs [0014] - [0021], [0034] - [0037], [0043] - [0051]; claims 1,7,9	11-16, 18-20
X	US 2004/031386 A1 (RAUCHFUSS MARK S [US] ET AL) 19 February 2004 (2004-02-19) cited in the application paragraphs [0017], [0018], [0021]; figures 1,2	11-17
X	DE 103 19 368 A1 (AVL LIST GMBH [AT]) 20 November 2003 (2003-11-20) paragraphs [0006] - [0017]; figures 1,2a,2b,2c	11-17

-/--

[X] Further documents are listed in the continuation of Box C.

[X] 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 document 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.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 July 2007	26/07/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hoffmann, Alexander

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/003532

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 653 327 A (VARTERASIAN JOHN H [US] ET AL) 31 March 1987 (1987-03-31) abstract; figure 3	11-15
X	FR 2 828 116 A1 (ONDEO DEGREMONT [FR]) 7 February 2003 (2003-02-07) claim 1	11
A	JP 08 121150 A (ISUZU CERAMICS RES INST) 14 May 1996 (1996-05-14) abstract	11
A	WO 01/43847 A (GNEUSS KUNSSTTOFFTECHNIK GMBH [DE]; GNEUSS DETLEF [DE]) 21 June 2001 (2001-06-21) claims 1,6,8	11
A	JP 07 310525 A (MATSUSHITA ELECTRIC IND CO LTD) 28 November 1995 (1995-11-28) abstract	11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/003532

Box II 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. ☐ 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:

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).

Box III 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:

see additional sheet

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 fee, this Authority did not invite payment of any additional fee.

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.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-10

The first invention, claims 1-10, concerns a monitoring assembly for a filter. The core of the invention is concentrated on the idea to attenuate sound energy produced by the engine/exhaust system at a resonance frequency upstream of said fuilter, to emit upstream of said filter a sound wave at said resonance frequency having a first amplitude and to sense the said sound wave downstream of said filter having a second amplitude and determining a soot loading and/or damage of said filter by comparing the first and second amplitude.
The invention eliminates other noises of the engine/exhaust system for a more precise monitoring of a filter. Thus it was the problem to be solved to improve the precision of monitoring a filter during running of the engine. The first invention is applicable only during running of the engine.

---

2. claims: 11-20

The second invention, claims 11-20, concerns a monitoring assembly for a filter. The core of the invention is concentrated on the idea to emit sound waves on the upstream side of a filter with a separate transmitter, to receive sound waves - from the transmitter - on the upstream and the downstream side of said filter with a respective first and second receiver and to determine at least one value indicative of a variation between the sound waves received by said first and second receiver to determine a soot loading and/or damage of said filter.
The advantage of the second invention is that the monitoring can carried out during running of the motor and during standstill of the motor and/or that by providing a separate sound source the monitoring is more precise, since the monitoring is not influenced by changing noises of the engine during changing of operational status (see D6, paragraph 0025) and/or that the monitoring of the filter can be carried out during the full range of operational status of the engine (not only under predefined operational conditions (see D6, paragraph 0020)
The problem to be solved was to monitor the filter not only during running of the engine but also during standstill of the engine and/or to improve the precision of the monitoring during running of the engine.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2007/003532

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 10242300 A1	18-03-2004	WO 2004026434 A1	01-04-2004
		EP 1542781 A1	22-06-2005
		JP 2005538304 T	15-12-2005
		US 2005247131 A1	10-11-2005
US 2004031386 A1	19-02-2004	NONE	
DE 10319368 A1	20-11-2003	NONE	
US 4653327 A	31-03-1987	DE 3764845 D1	18-10-1990
		EP 0242060 A2	21-10-1987
FR 2828116 A1	07-02-2003	CA 2456064 A1	20-02-2003
		CN 1538872 A	20-10-2004
		EP 1414555 A1	06-05-2004
		WO 03013707 A1	20-02-2003
		JP 2005525211 T	25-08-2005
		US 2004237654 A1	02-12-2004
JP 8121150 A	14-05-1996	NONE	
WO 0143847 A	21-06-2001	AT 260698 T	15-03-2004
		CA 2394407 A1	21-06-2001
		DE 19961426 A1	05-07-2001
		EP 1239936 A2	18-09-2002
		JP 2003516847 T	20-05-2003
		US 2003132146 A1	17-07-2003
JP 7310525 A	28-11-1995	JP 2780638 B2	30-07-1998