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(54) **SYSTEM AND METHOD FOR MONITORING A FILTER**

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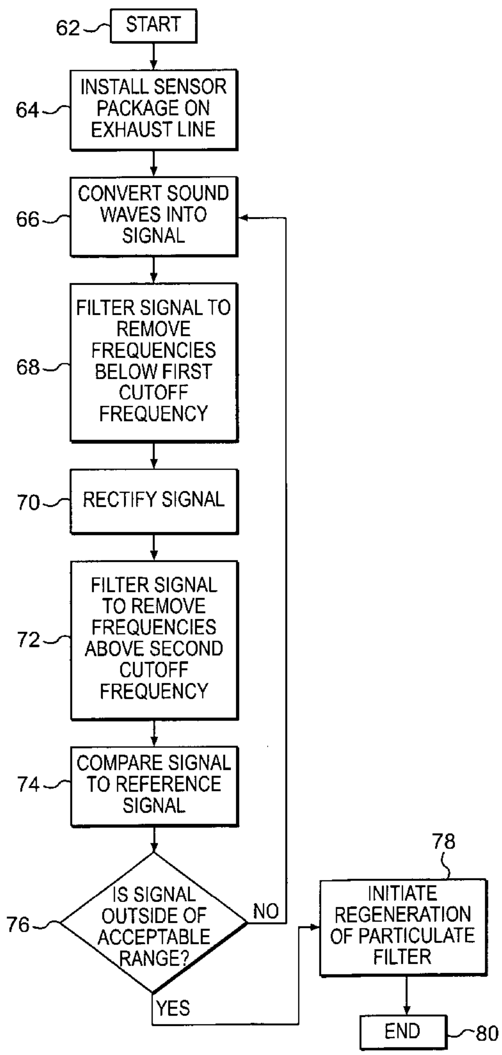
(57) **ABSTRACT**

An engine assembly may include an internal combustion engine configured to combust fuel. The combustion of fuel may produce exhaust and sound waves that may be directed into an exhaust line. A particulate filter may be operatively coupled to the exhaust line, and the particulate filter may be configured to filter the exhaust. The engine assembly may also include a sensor package operatively coupled to the exhaust line. At least a portion of the sensor package may extend into the exhaust line at a location downstream from the particulate filter. The sensor package may be configured to monitor the sound waves passing through the particulate filter and to produce an electrical signal indicative of the intensity of the sound waves.



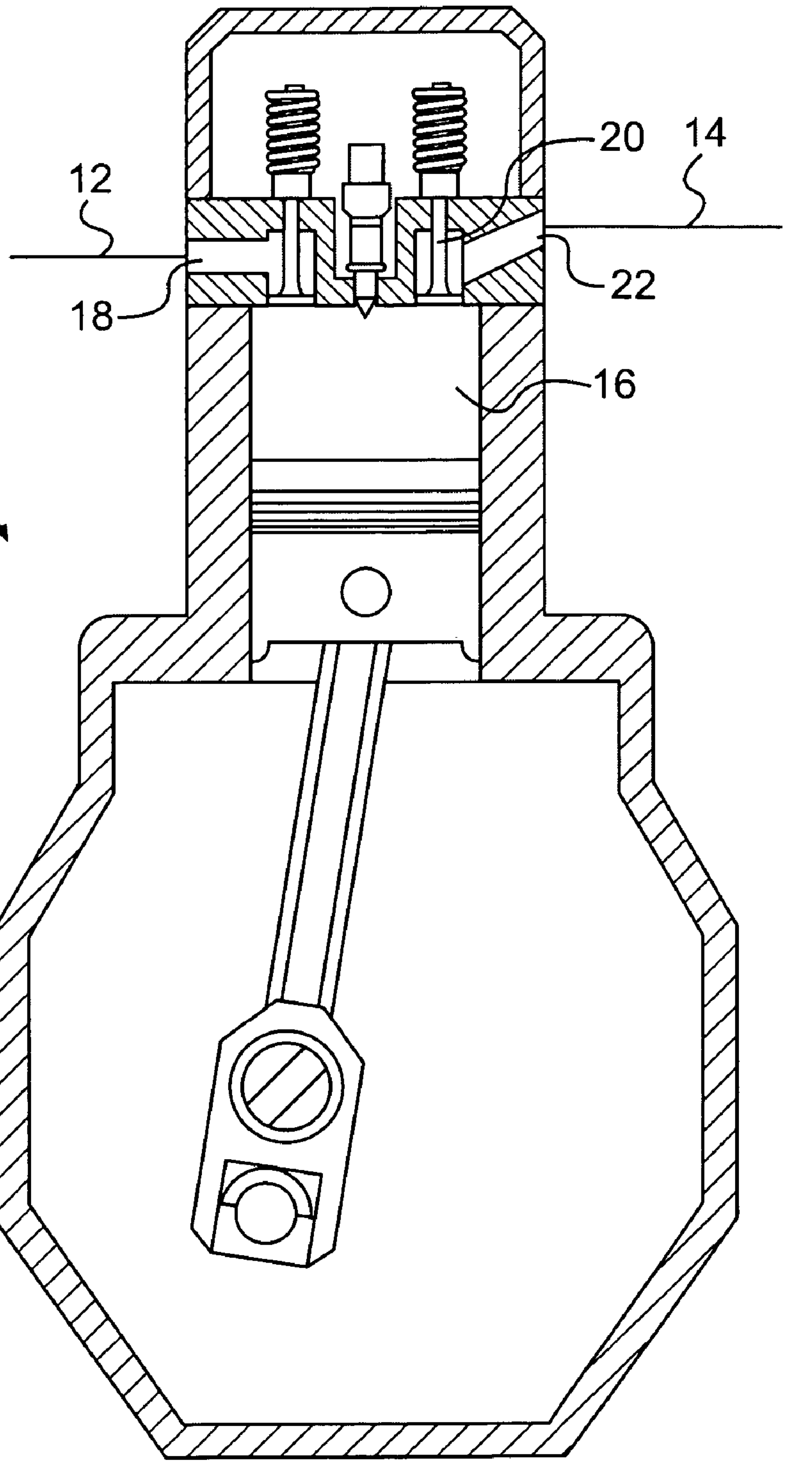


FIG. 1

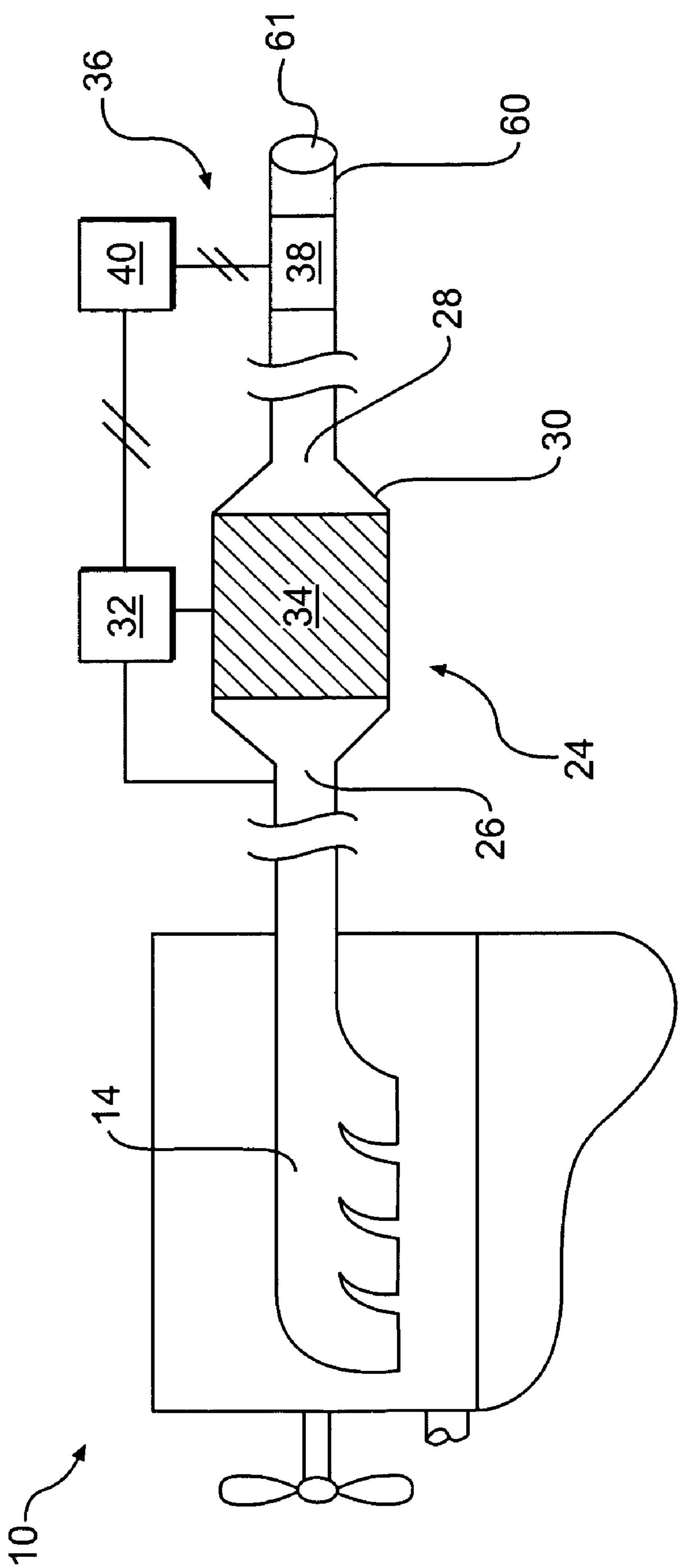


FIG. 2

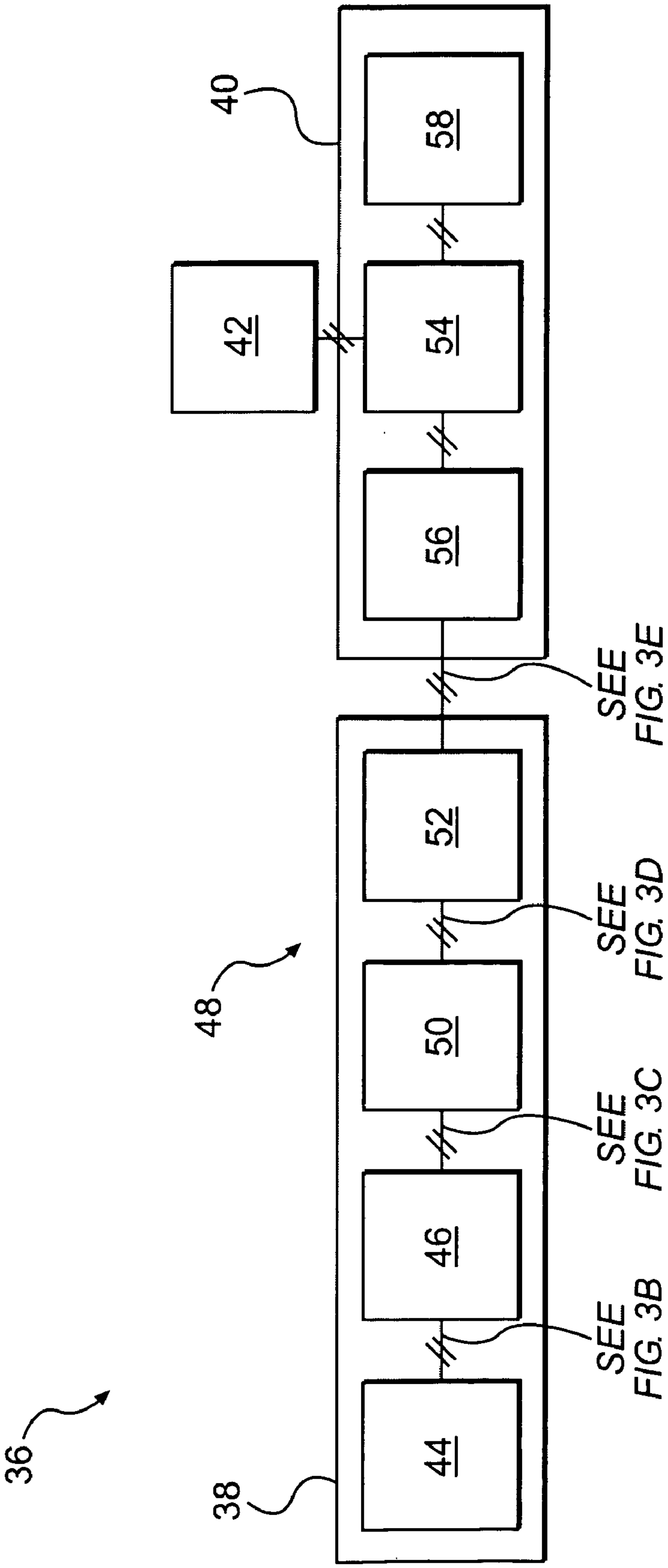

40
58
42
54
56
SEE FIG. 3E
52
SEE FIG. 3D
48
50
SEE FIG. 3C
46
SEE FIG. 3B
36
44
38

FIG. 3A

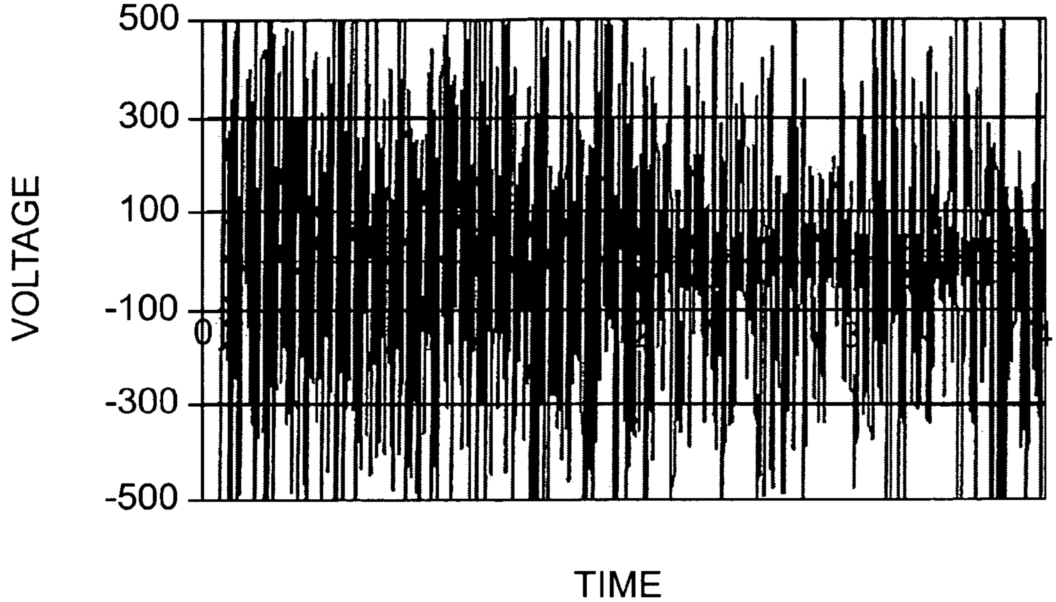
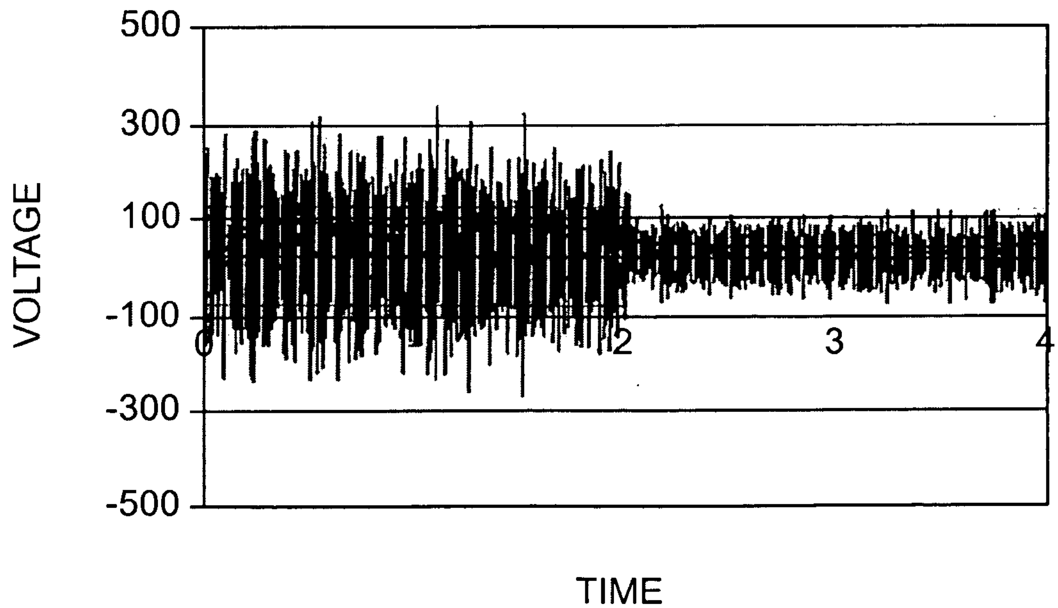

500
300
100
-100
-300
-500
VOLTAGE
0
2
3
4
TIME

FIG. 3B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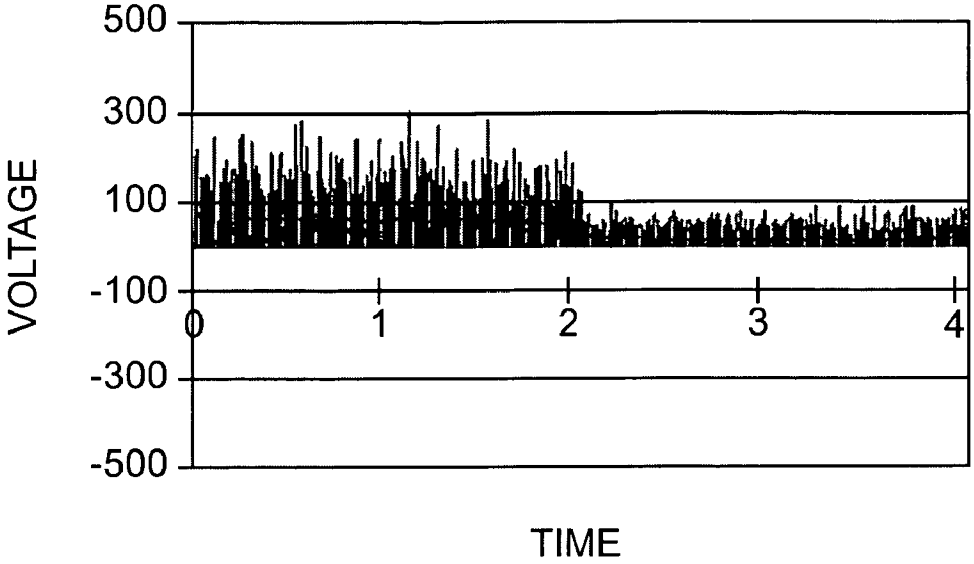
300
100
-100
-300
-500
VOLTAGE
0
2
3
4
TIME

FIG. 3C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-300
-500
VOLTAGE
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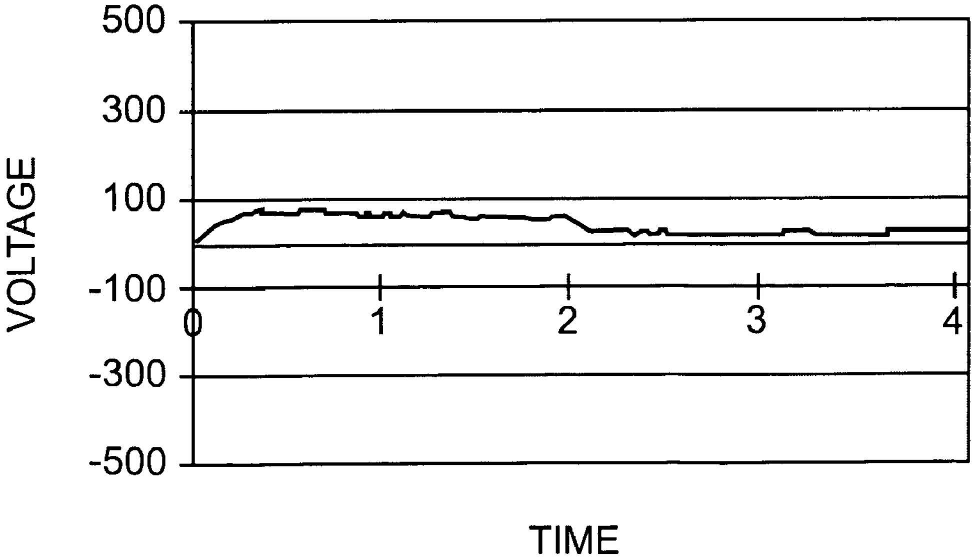
1
2
3
4
TIME

FIG. 3D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300
100
-100
-300
-500
VOLTAGE
0
1
2
3
4
TIME

FIG. 3E

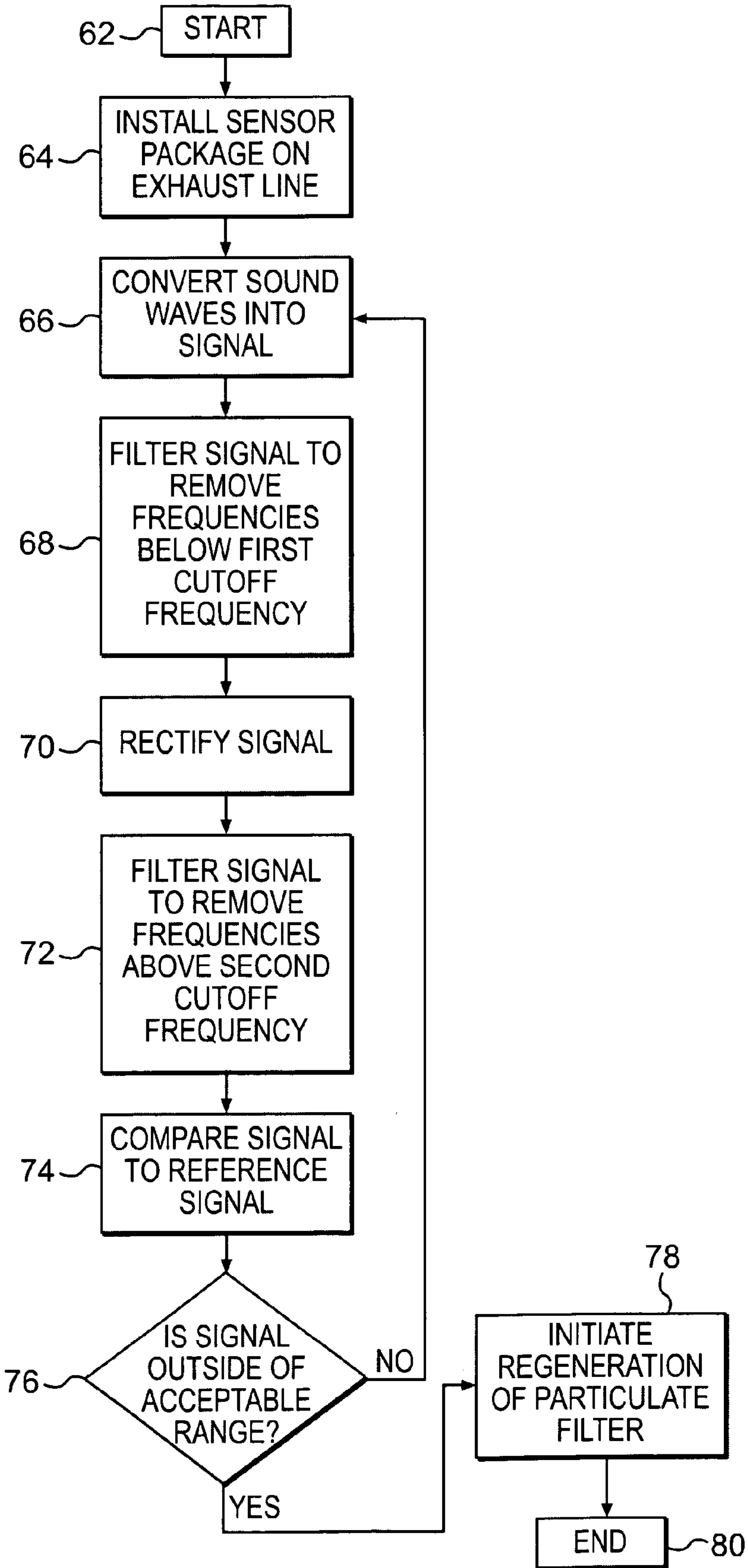
62
START
64
INSTALL SENSOR PACKAGE ON EXHAUST LINE
66
CONVERT SOUND WAVES INTO SIGNAL
68
FILTER SIGNAL TO REMOVE FREQUENCIES BELOW FIRST CUTOFF FREQUENCY
70
RECTIFY SIGNAL
72
FILTER SIGNAL TO REMOVE FREQUENCIES ABOVE SECOND CUTOFF FREQUENCY
74
COMPARE SIGNAL TO REFERENCE SIGNAL
76
IS SIGNAL OUTSIDE OF ACCEPTABLE RANGE?
NO
YES
78
INITIATE REGENERATION OF PARTICULATE FILTER
END
80

FIG. 4

SYSTEM AND METHOD FOR MONITORING A FILTER

TECHNICAL FIELD

[0001] The present disclosure relates generally to filter monitoring, and more particularly to a system and method for monitoring the state of a filter.

BACKGROUND

[0002] 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.

[0003] 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 may be 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 build up 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.

[0004] At least one system has been developed for diesel particulate filter monitoring. For example, U.S. Pat. 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. For example, 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, in Rauchfuss, the proximity of the acoustic sensors to the upstream and downstream sides of the filter may present problems. For example, the relatively high temperature of the exhaust at the upstream and downstream sides of the filter may damage the acoustic sensors. Furthermore, Rauchfuss does not disclose an efficient way to focus on specific frequencies that are most relevant with respect to determining the filter state.

[0005] The disclosed system is directed to overcoming one or more of the problems set forth above.

SUMMARY OF THE INVENTION

[0006] In one aspect, the present disclosure is directed to an engine assembly. The engine assembly may include an internal combustion engine configured to combust fuel. The combustion of fuel may produce exhaust and sound waves that may be directed into an exhaust line. The engine assembly may also include a particulate filter operatively coupled to the exhaust line, the particulate filter being configured to filter the exhaust. The engine assembly may further include a sensor package operatively coupled to the exhaust line, wherein at least a portion of the sensor package extends into the exhaust line at a location downstream from the particulate filter. The sensor package may be configured to monitor the sound waves passing through the particulate filter and to produce an electrical signal indicative of the intensity of the sound waves.

[0007] In another aspect, the present disclosure is directed to a method of monitoring a particulate filter. The method may include producing exhaust and sound waves by combusting fuel with an internal combustion engine. The method may also include directing the exhaust and sound waves through the particulate filter. The method may further include converting the sound waves into an electrical signal with a sensor package. The sensor package may be operatively coupled to an exhaust line of the internal combustion engine at a location downstream from the particulate filter, and at least a portion of the sensor package may extend into the exhaust line. The method may further include regenerating the particulate filter if the electrical signal falls outside a predetermined range.

[0008] In yet another aspect, the present disclosure is directed to a machine including an internal combustion engine configured to combust fuel. The combustion of fuel may produce exhaust and sound waves that may be directed into an exhaust line. The machine may also include a particulate filter operatively coupled to the exhaust line. The particulate filter may be configured to filter the exhaust. The machine may further include a sensor package operatively coupled to the exhaust line. At least a portion of the sensor package may extend into the exhaust line at a location downstream from the particulate filter. The sensor package may be configured to convert the sound waves passing through the particulate filter into a voltage signal indicative of the intensity of the sound waves.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a diagrammatic illustration of a combustion chamber of an engine according to an exemplary disclosed embodiment of the present disclosure.

[0010] FIG. 2 is a diagrammatic illustration of an engine having a particulate filter assembly according to an exemplary embodiment of the present disclosure.

[0011] FIG. 3A is a block diagram of a monitoring assembly according to an exemplary disclosed embodiment of the present disclosure.

[0012] FIGS. 3B-3E are graphs of signals from the monitoring assembly of FIG. 3A, according to an exemplary disclosed embodiment of the present disclosure.

[0013] FIG. 4 is a flow diagram of a method for monitoring the state of a particulate filter according to an exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION

[0014] 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.

[0015] FIG. 1 shows a combustion chamber **16** from an internal combustion engine **10** of a machine (not shown), including an intake line **12** and an exhaust line **14**. Intake line **12** may provide an intake path for air, fuel, recirculated exhaust gases, or any suitable combination thereof. The air, fuel, and/or gases from intake line **12** may be directed into combustion chamber **16** through an intake port **18**. The air, fuel, and/or gases may be combusted within combustion chamber **16**, which may produce heat, sound energy, and exhaust. In order to evacuate the exhaust from within combustion chamber **16**, an exhaust valve **20** may be opened to place combustion chamber **16** into fluid communication with exhaust line **14** via an exhaust port **22**. When exhaust valve **20** is opened, the sound energy produced by combustion, in the form of sound waves, may also escape from combustion chamber **16** into exhaust line **14**.

[0016] In the embodiment shown in FIG. 2, exhaust line **14** is shown as being coupled to four separate combustion chambers (not shown). However, any number of combustion chambers may be used. Furthermore, internal combustion engine **10** may include diesel engines, gasoline engines, natural gas engines, and other engines known in the art.

[0017] Exhaust line **14** may be operatively connected to a particulate filter assembly **24**. The exhaust and sound waves exiting from combustion chamber **16** may flow downstream through exhaust line **14** into particulate filter assembly **24**. Particulate filter assembly **24** may be configured to filter or trap particulate matter in the exhaust. Particulate filter assembly **24** may include, for example, an inlet **26** for receiving the exhaust stream, an outlet **28** allowing filtered exhaust to exit from particulate filter assembly **24**, a filter element **34** located between inlet **26** and outlet **28**, and a particulate filter regeneration device **32**.

[0018] In one embodiment, filter element **34** may be located within a filter housing **30**. Filter element **34** 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 **34** 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 **34** may be situated horizontally, vertically, radially, or helically. Additionally or alternatively, filter element **34** may be arranged in a honeycomb, mesh, or any other suitable configuration so as to maximize the available surface area for filtration.

[0019] Particulate filter regeneration device **32** 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 filter element **34**. As the temperature of the exhaust stream increases, the temperature of the trapped particulate matter in filter element **34** may also increase. When the trapped particulate matter reaches the predetermined temperature, it may burn away, and thus, filter element **34** may be regenerated. In one embodiment, particulate filter regeneration device **32** may be operatively coupled to exhaust line **14** at a location upstream from filter element **34**. It is also contemplated that particulate filter regeneration device **32** may be operatively coupled to filter housing **30** and/or filter element **34**. Particulate filter regeneration device **32** 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 by convection, combustion, and/or other methods of heat transfer.

[0020] A filter monitoring assembly **36** may be operatively connected to internal combustion engine **10**. Filter monitoring assembly **36** may be configured to determine the state of filter element **34**, and in particular, the degree of loading (amount of trapped particulate matter) in filter element **34**. Upon making a determination about the state of filter element **34**, filter monitoring assembly **36** may selectively help trigger the activation of particulate filter regeneration device **32** to regenerate filter element **34** when such action is deemed appropriate. Filter monitoring assembly **36** is shown in FIG. 3A, and may include, for example, a sensor package **38**, a control box **40**, and/or an alert assembly **42**, and may be mounted near, on, or in exhaust line **14**. In one embodiment, at least a portion of filter monitoring assembly **36** may be inserted into exhaust line **14**, and may rest therein at any suitable location downstream from filter element **34**. In another embodiment, where the portion of filter monitoring assembly **36** is inserted into a tailpipe section **60** of exhaust line **14**, it should be understood that the portion may be configured to create little to no backpressure in exhaust line **14** and allow the free flow of exhaust therethrough.

[0021] Sensor package **38** may be configured to receive an input, such as, for example, sound waves that have traveled out of combustion chamber **16**, through filter element **34**, and into exhaust line **14**. Sensor package **38** may convert the sound waves into an electrical (e.g. voltage) signal, and may include a microphone **44**, a high-pass filter **46**, and an envelope detector **48**. It is understood that sensor package **38** may include fewer or additional components and may, in certain embodiments, constitute a single component. Filter monitoring assembly **36** may also include another sensor package (not shown) located upstream of filter element **34**, which may be used for comparing and contrasting the upstream and downstream sound waves.

[0022] Microphone **44** may include a piezoelectric microphone having ceramic or quartz crystals linked with a diaphragm exposed to the sound waves in exhaust line **14**. Additionally or alternatively, the ceramic or quartz crystals may be directly exposed to the sound waves. The impact of the sound waves may cause stress in the ceramic or quartz crystals, causing them to generate a microphone signal proportional to the acoustic pressure of the sound waves.

FIG. 3B is an exemplary illustration of the microphone signal in the form of a microphone voltage waveform.

[0023] The microphone signal may be directed into high-pass filter **46**. High-pass filter **46** may include a resistor-capacitor circuit configured to block or filter out frequencies that are lower than a predetermined cutoff frequency, while allowing frequencies higher than the cutoff frequency to pass. Additionally or alternatively, high-pass filter **46** may include components in place of or in addition to the resistor-capacitor circuit, and it should be understood that suitable high-pass filter constructions known in the art may be employed. In one embodiment, high-pass filter **46** may be set to block frequencies below 2,000 Hz, because generally, sound waves having such frequencies may pass through filter element **34** relatively unattenuated regardless of the loading of filter element **34**, and thus, provide little information about the state of filter element **34**. It should be understood that the cutoff frequency may be selectively adjusted to suit a particular application. FIG. **3**C is an exemplary illustration of a high-pass filter signal, generated after the microphone signal has passed through high-pass filter **46**. With the low frequencies having been removed, the remaining frequencies may form a high-pass filter voltage waveform having a lesser amplitude than the microphone voltage waveform.

[0024] The high-pass filter signal may enter envelope detector **48**, which may be configured to convert the high-pass filter signal into the voltage signal, an example of a voltage signal waveform being shown in FIG. **3**E. Envelope detector **48** may include a rectifier **50** and a low-pass filter **52**. Rectifier **50** may include a full wave rectifier, configured to convert an alternating current waveform, such as, for example, high-pass filter voltage waveform, into a direct current waveform by reversing the negative (or positive) portions of the alternating current waveform. Accordingly, an entirely positive (or negative) direct current waveform, such as the full wave rectifier waveform shown in FIG. **3**D, may be produced. The full wave rectifier waveform may then be passed through low-pass filter **52**. Low-pass filter **52** may include a resistor-capacitor circuit configured to block or filter out frequencies higher than a predetermined cutoff frequency, while allowing frequencies lower than the predetermined cutoff frequency to pass. As the full wave rectifier waveform passes through low-pass filter **52**, it may be converted into the voltage signal waveform.

[0025] A signal detector, such as, for example, a voltage detector **54**, may be operatively connected to sensor package **38** in order to receive the electrical signal. A low signal (e.g. voltage) level may be set for voltage detector **54**. The low voltage level may be indicative of a point at which filter element **34** is clogged and should be regenerated. When the voltage signal approaches or falls below the low voltage level, voltage detector **54** may send out an output signal to initiate a function. In one embodiment, voltage detector **54** may send the output signal to a regeneration signal device **58** and/or regeneration device **32** to trigger regeneration of filter element **34**. Additionally or alternatively, voltage detector **54** may activate an alert assembly **42**, such as, for example, a light in a cab of the machine, thus telling the operator that regeneration of filter element **34** may be required. It is also contemplated that the voltage signal from low-pass filter **52** may be directly connected to the light in the cab, and the light may turn off when the voltage signal becomes too low or weak to continue powering the light.

[0026] Control box **40** may be provided to monitor and maintain engine firing sequences and events associated therewith, such as, for example, when to inject fuel, when to open valves, and other variables to ensure that internal combustion engine **10** is running efficiently. In one embodiment, voltage detector **54** may be included in control box **40**. Sensor package **38** may be operatively connected to control box **40** using an analog-to-digital converter **56**. Analog-to-digital converter **56** may be configured to convert the voltage signal into a discrete digital number that may be relatively easily analyzed and/or monitored by voltage detector **54**.

[0027] Sensor package **38** and/or control box **40** may be calibrated when filter element **34** is clean by taking a reading of the sound waves passing through filter element **34** when it is clean to provide a reference or baseline voltage signal. As filter element **34** becomes increasingly loaded with particulate matter, the actual voltage signal from sensor package **38** may decrease with respect to the baseline voltage signal, due to the attenuating effect of the particulate matter in filter element **34**. When the actual voltage signal falls below the low voltage level, it may indicate that regeneration of filter element **34** is required. It is contemplated that the low voltage level may be set by, for example, using design data, historical performance data, and/or taking a reading of sound waves passing through a clogged filter element with sensor package **38** and control box **40** to produce another reference voltage signal, such as the low voltage level.

[0028] As long as internal combustion engine **10** continually operates in the same condition under which the reference voltage signals were taken, then the reference voltage signals may accurately reflect the state of filter element **34**. However, internal combustion engine **10** may not always operate in the same condition, but rather, may operate differently as the load on internal combustion engine **10** changes. For example, when internal combustion engine **10** is subjected to a low load condition, internal combustion engine **10** may produce a first level of horsepower that has associated with it a particular level of sound energy. If the reference voltage signals are taken during the low load condition, then the reference voltage signals may accurately indicate the state of filter element **34** as long as the internal combustion engine **10** continues to operate in the same low load condition. However, machines may often be used in dynamic environments, where they may not operate under the exact same load conditions at all times, but rather, may be subject to changing load conditions as the machine travels up and down inclines, or when the machine lifts and lowers objects. If internal combustion engine **10** is subjected to a high load condition, it may respond by producing an increase in horsepower and may generate a level of sound energy greater than that generated during the low load condition. The increase in the level of sound energy may produce a corresponding increase in the value of the actual voltage signal produced by sensor package **38**. If voltage detector **54** compares the actual voltage signal produced in the high load condition to the reference voltage signals produced when internal combustion engine **10** is operating under the low load condition, then an inaccuracy may result. For example, suppose that the baseline voltage signal is taken during the low load condition. If internal combustion engine **10** is then subsequently subjected to the high load condition, the increased level of sound energy may produce an actual voltage signal greater than the baseline voltage signal. As internal combustion engine **10** continues to operate in the high load condition, filter element **34** may become clogged. However, the actual voltage signal may not fall far enough below the baseline voltage signal to trigger regeneration, because the level of sound energy in the high load condition may compensate for the attenuation caused by clogging of filter element **34**. Thus, regeneration of filter element **34** may not be performed although it may be necessary.

[**0029**] A solution to the problem may include providing control box **40** with a mechanism configured to associate the reference voltage signals with engine horsepower, thus allowing control box **40** to adjust these signals as the engine horsepower changes. For example, control box **40** may include one or more electronic databases (not shown) configured to store one or more engine maps. An engine map may include, for example, a table associating particular reference voltage signals, such as, for example, baseline voltage signals and low voltage levels, with engine horsepower values. Control box **40** may monitor engine horsepower, and, based at least in part on the table in the engine map, may selectively adjust the reference voltage signals for voltage detector **54** to reflect changes in the sound energy that may occur as a result of changes in engine horsepower. This adjustment may serve to ensure that the state of filter element **34** may be accurately determined regardless of the changing sound energy levels created by internal combustion engine **10**. It should be understood that the one or more databases may include a plurality of engine maps accessible by control box **40**. Each engine map may apply to a particular machine, specific engine model, and/or work site environment. The engine maps may be created by using design data, historical performance data, experimental data, and/or any other information that may be suitable for associating engine horsepower with sound energy levels.

[**0030**] An exemplary method of monitoring filter element **34** will now be described in greater detail. To start (step **62**), sensor package **38** may be installed on exhaust line **14** (step **64**). In one embodiment, sensor package **38** may be attached to the outside wall of exhaust line **14** at any suitable location downstream from filter element **34**. In another embodiment, at least microphone **44** may extend into exhaust line **14** at any suitable location downstream from filter element **34**. In yet another embodiment, sensor package **38** may be inserted into exhaust line **14** through an opening **61** at or near tailpipe section **60** proximate the furthermost downstream end of exhaust line **14**. These installation locations are exemplary only, and it should be understood that sensor package **38** may be installed on, in, or near exhaust line **14** at any location suitable for receiving sound waves from combustion chamber **16** after they have passed through filter element **34** and into exhaust line **14**

[**0031**] The process of converting the sound waves into the voltage signal may begin when the sound waves reach microphone **44**. Microphone **44** may convert the sound waves into a microphone signal (step **66**). The microphone signal may enter high-pass filter **46** to filter out frequencies of the microphone signal lower than a first predetermined cutoff frequency to create the high-pass filter signal (step **68**). The high-pass filter signal may enter full wave rectifier **50**, and full wave rectifier **50** may convert the high-pass filter signal into the rectified voltage signal, having a direct current waveform, by reversing the negative portions of the high-pass filter signal waveform (step **70**). The rectified voltage signal may then be passed through low-pass filter **52**. Low-pass filter **52** may block or filter out frequencies of the direct current waveform higher than a second predetermined cutoff frequency, while allowing frequencies lower than the second predetermined cutoff frequency to pass (step **72**). The voltage signal may emerge from low-pass filter **52** and enter voltage detector **54**. The reference voltage signal may be pre-set in voltage detector **54** using the engine map as a guide. The voltage signal may be compared to the reference voltage signal to determine the degree of loading of filter element **34** (step **74**). The voltage detector may continually monitor the voltage signal. If the voltage signal falls outside of a predetermined acceptable range (step **76**: YES), such as the range of values between the baseline voltage signal and the low voltage level, then regeneration of filter element **34** may be initiated (step **78**). If the voltage signal falls within a predetermined acceptable range (step **76**: NO), then the process returns to step **66**. The process may end (step **80**) when internal combustion engine **10** is shut off.

[**0032**] In the mode of operation described above, the sound waves received by sensor package **38** may be converted by sensor package **38** into the voltage signal indicative of the state of filter element **34**. The voltage signal may be received by control box **40**. Control box **40** may signal for the activation of particulate filter regeneration device **32** based on the strength or value of the voltage signal. In another mode of operation, the voltage signal may directly control a light in the cab of the machine, to inform the machine operator when regeneration of filter element **34** is required.

INDUSTRIAL APPLICABILITY

[**0033**] The disclosed monitoring assembly may have applicability in internal combustion engines, such as diesel engine assemblies. Monitoring assembly **36** may have particular applicability in monitoring the state of a filter element **34** of a diesel engine.

[**0034**] Monitoring assembly **36** may assist filter element **34** by controlling the timing, number, and/or duration of regenerations performed on filter element **34**. By using monitoring assembly **36** to determine the state of filter element **34**, clogging of filter element **34** 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 filter element **34**. Using the analysis performed by monitoring assembly **36** as the basis for triggering regeneration can help to ensure that regeneration may take place when necessary, which may result in increased filter efficiency, cleaner exhaust, and improved engine efficiency. Also, unnecessary regenerations may be avoided, which may help to extend the working life of filter element **34**, because repeated regeneration of filter element **34** may cause cracking and/or other forms of damage.

[**0035**] Further, monitoring assembly **36** may be properly characterized as a passive monitoring system. In contrast, an active monitoring system may inject sound energy into one side of filter element **34** and may read the sound energy as it emerges from the other side. Accordingly, active monitoring systems may include sound wave generation devices and other components for broadcasting signals. These device and components may be costly, and may be too delicate for harsh engine environments. In contrast, monitoring assembly **36** may operate using the sound energy from an internal combustion engine **10**, and may not require the use of sound wave generation devices. Thus, monitoring assembly **36** may monitor filter element **34** using fewer components than active monitoring systems. As long as internal combustion engine **10** is running, monitoring assembly **36** may monitor filter element **34**, and may automatically initiate regeneration of filter element **34** or alert a machine operator that regeneration may be required.

[**0036**] Furthermore, monitoring assembly **36** may be configured to monitor and analyze types of sound energy that may be more helpful for determining the state of filter element **34** than other types of sound energy. For example, low frequency sound waves, such as, for example, those under 2,000 Hz, may pass through a clogged particulate filter relatively unattenuated. Thus, monitoring low frequency sound waves may provide little assistance in determining the state of filter element **34**. A high-pass filter **46** in monitoring assembly **36** may filter or block out the low frequency sound waves. High frequency sound waves may experience greater attenuation than low frequency sound waves when they pass through a clogged particulate filter. For example, sound waves having frequencies between 2,000 Hz and 7,000 Hz may experience a 5 dB or higher drop in intensity when passing through a clogged particulate filter. Thus, high-pass filter **46** may allow monitoring assembly **36** to focus on the high frequency sound waves that may convey more information about the state of filter element **34**. Monitoring assembly **36** may also include a full wave rectifier **50** and a low-pass filter. Full wave rectifier **50** may create an easily filtered output for filtering by low-pass filter **52**, allowing low-pass filter **52** to output a relatively steady signal to a low voltage detector **54**. This configuration may help to improve the accuracy and precision of monitoring assembly **36**.

[**0037**] 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.

What is claimed is:

1. An engine assembly, comprising:

an internal combustion engine configured to combust fuel, wherein the combustion of fuel produces exhaust and sound waves that are directed into an exhaust line;

a particulate filter operatively coupled to the exhaust line, the particulate filter being configured to filter the exhaust; and

a sensor package operatively coupled to the exhaust line, wherein at least a portion of the sensor package extends into the exhaust line at a location downstream from the particulate filter, the sensor package being configured to monitor the sound waves passing through the particulate filter and to produce an electrical signal indicative of the intensity of the sound waves.

2. The engine assembly of claim 1, wherein the exhaust line further includes an opening at a downstream end, and wherein the portion of the sensor package is configured to be inserted into the exhaust line through the opening.

3. The engine assembly of claim 1, wherein the sensor package further includes:

a microphone configured to receive the sound waves and convert the sound waves into a signal;

a first filter configured to receive the signal and reduce frequencies of the signal that are below a first cutoff frequency, while allowing frequencies above the first cutoff frequency to pass, to produce a filtered signal; and

an envelope detector configured to receive the filtered signal and convert the filtered signal into the electrical signal.

4. The engine assembly of claim 3, wherein the envelope detector further includes:

a rectifier configured to receive the filtered signal and convert the filtered signal into one of an entirely positive waveform and an entirely negative waveform, to produce a rectified signal; and

a second filter configured to receive the rectified signal and reduce frequencies of the rectified signal that are above a second cutoff frequency, while allowing frequencies below the second cutoff frequency to pass, to produce the electrical signal.

5. The engine assembly of claim 1, wherein the electrical signal is received by a signal detector operatively coupled to the sensor package, and the signal detector is set with at least one of a high signal level, indicative of the particulate filter being clean, and a low signal level, indicative of the particulate filter being loaded.

6. The engine assembly of claim 5, wherein the signal detector is configured to automatically trigger regeneration of the particulate filter when the electrical signal falls below the low signal level.

7. The engine assembly of claim 5, wherein at least one of the high signal level and the low signal level is selectively adjusted based at least in part on the intensity of the sound waves produced by the internal combustion engine.

8. A method of monitoring a particulate filter, comprising:

producing exhaust and sound waves by combusting fuel with an internal combustion engine;

directing the exhaust and sound waves through the particulate filter;

converting the sound waves into an electrical signal with a sensor package, the sensor package being operatively coupled to an exhaust line of the internal combustion engine at a location downstream from the particulate filter, and wherein at least a portion of the sensor package extends into the exhaust line; and

regenerating the particulate filter if the electrical signal falls outside a predetermined range.

9. The method of claim 8, further including receiving the sound waves with a microphone of the sensor package, wherein the microphone produces a signal.

10. The method of claim 9, further including reducing frequencies of the signal that are below a first cutoff frequency, while allowing frequencies above the first cutoff frequency to pass, to produce a filtered signal.

11. The method of claim 10, further including converting the filtered signal into one of an entirely positive waveform and an entirely negative waveform, to produce a rectified signal.

12. The method of claim 11, further including reducing frequencies of the rectified signal that are above a second cutoff frequency, while allowing frequencies below the second cutoff frequency to pass, to produce the electrical signal.

13. The method of claim 8, further including selectively adjusting the predetermined range based at least in part on the intensity of the sound waves produced by the internal combustion engine.

14. A machine comprising:

an internal combustion engine configured to combust fuel, wherein the combustion of fuel produces exhaust and sound waves that are directed into an exhaust line;

a particulate filter operatively coupled to the exhaust line, the particulate filter being configured to filter the exhaust; and

a sensor package operatively coupled to the exhaust line, wherein at least a portion of the sensor package extends into the exhaust line at a location downstream from the particulate filter, the sensor package being configured to convert the sound waves passing through the particulate filter into a voltage signal indicative of the intensity of the sound waves.

15. The machine of claim 14, wherein the exhaust line further includes an opening at a downstream end, and wherein the portion of the sensor package is configured to be inserted into the exhaust line through the opening.

16. The machine of claim 14, wherein the sensor package further includes:

a piezoelectric microphone configured to receive the sound waves and convert the sound waves into a signal;

a high-pass filter configured to receive the signal and reduce frequencies of the signal that are below a first cutoff frequency, while allowing frequencies above the first cutoff frequency to pass, to produce a filtered signal; and

an envelope detector configured to receive the filtered signal and convert the filtered signal into the voltage signal.

17. The machine of claim 16, wherein the envelope detector further includes:

a full wave rectifier configured to receive the filtered signal and convert the filtered signal into one of an entirely positive waveform and an entirely negative waveform, to produce a rectified signal; and

a low-pass filter configured to receive the rectified signal and reduce frequencies of the rectified signal that are above a second cutoff frequency, while allowing frequencies below the second cutoff frequency to pass, to produce the voltage signal.

18. The machine of claim 14, wherein the voltage signal is received by a voltage detector operatively coupled to the sensor package, and the voltage detector is set with at least one of a high voltage level, indicative of the particulate filter being clean, and a low voltage level, indicative of the particulate filter being loaded.

19. The machine of claim 18, wherein the voltage detector is configured to automatically trigger regeneration of the particulate filter when the voltage signal falls below the low voltage level.

20. The machine of claim 18, wherein at least one of the high voltage level and the low voltage level is selectively adjusted based at least in part on the intensity of the sound waves produced by the internal combustion engine.

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