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(54) **APPARATUS AND METHOD FOR MONITORING REGENERATION FREQUENCY OF A VEHICLE PARTICULATE FILTER**

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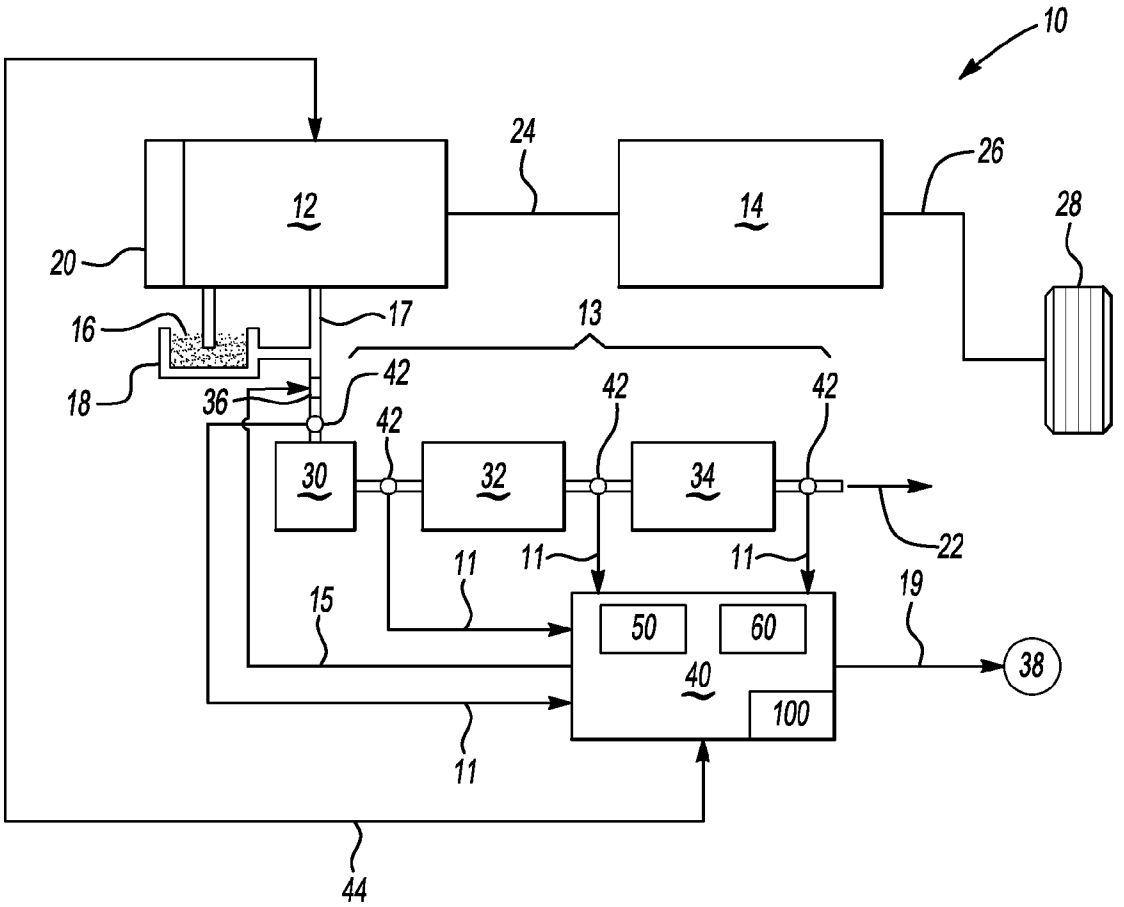
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(57) **ABSTRACT**

A vehicle includes an engine, a regenerable exhaust stream particulate filter, and a host machine. The host machine has a pair of soot models providing respective actual and modeled soot mass values for the soot contained in the particulate filter, calculates a ratio of a change in the actual and modeled soot masses, and executes a control action when the ratio exceeds a calibrated threshold. A diagnostic code and/or activation of an indicator device may be part of the control action. A system includes the particulate filter and host machine noted above. A method for use aboard the vehicle includes determining the actual and modeled soot mass values using first and second soot models, respectively, calculating a ratio of a change in the actual and modeled soot mass, comparing the ratio to a calibrated threshold, and executing a control action when the ratio exceeds the threshold.



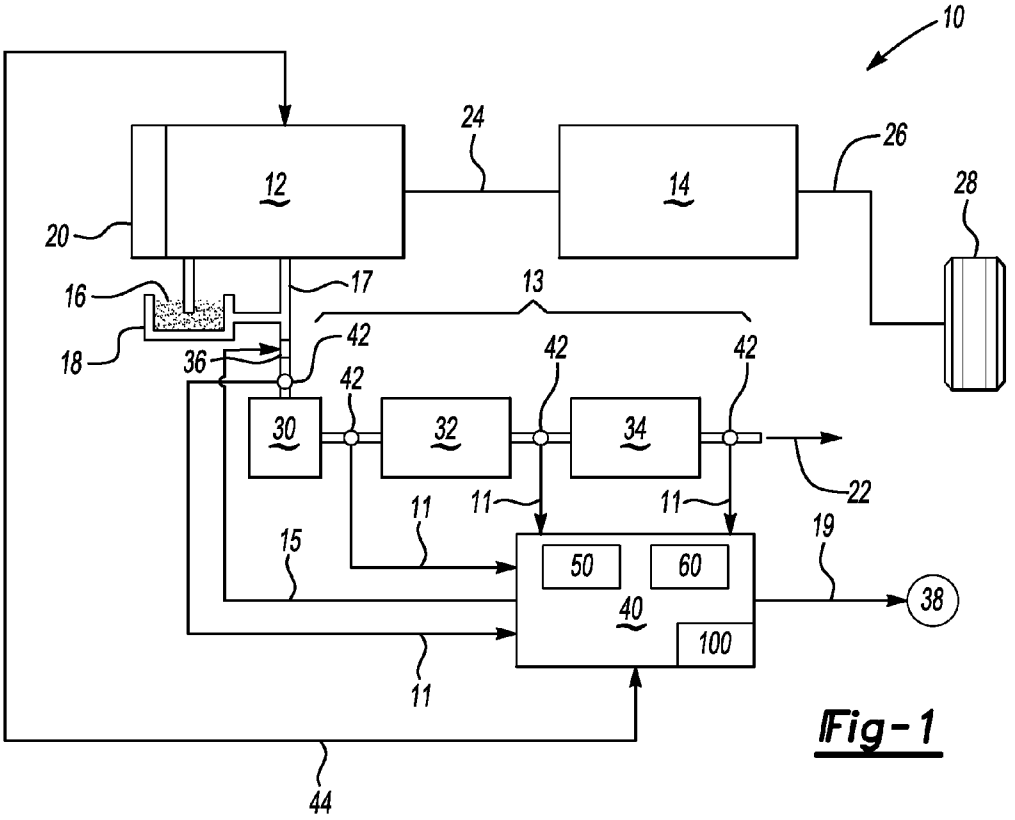

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Fig-1

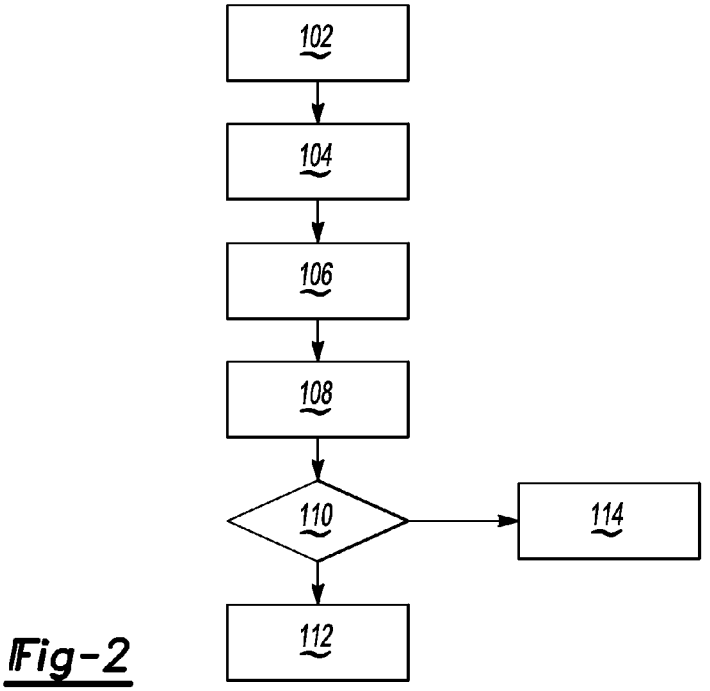

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Fig-2

APPARATUS AND METHOD FOR MONITORING REGENERATION FREQUENCY OF A VEHICLE PARTICULATE FILTER

TECHNICAL FIELD

[0001] The present invention relates to an apparatus and method for monitoring the regeneration frequency of a particulate filter adapted for removing soot from a vehicle exhaust stream.

BACKGROUND

[0002] Particulate filters are designed to remove microscopic particles of soot, ash, metal, and other suspended matter from an exhaust stream of a vehicle. Over time, the particulate matter accumulates on a substrate within the filter. In order to extend the life of the particulate filter and to further optimize engine functionality, some filters are designed to be selectively regenerated using heat.

[0003] Temperatures within the particulate filter can be temporarily increased to between approximately 450° C. to 600° C. by directly injecting and igniting fuel, either in the engine's cylinder chambers or in the exhaust stream upstream of the filter. The spike in exhaust gas temperature may be used in conjunction with a suitable catalyst, e.g., palladium or platinum, wherein the catalyst and heat act together to reduce the accumulated particulate matter to relatively inert carbon soot via a simple exothermic oxidation process.

SUMMARY

[0004] A vehicle as disclosed herein includes an engine, a particulate filter that is regenerable using heat, and a host machine. The host machine accesses a first soot model to determine an actual soot mass in the particulate filter, e.g., a lookup table indexed by a calculated or measured differential pressure across the filter, and a second soot model to determine a modeled soot mass in the filter. The second soot model provides the modeled soot mass relative to a set of current vehicle operating points or conditions. The host machine then calculates a ratio of a change in the actual soot mass to a change in the modeled soot mass. The host machine compares the calculated ratio to a calibrated threshold, and automatically executes a control action when the calculated ratio exceeds the calibrated threshold.

[0005] The method may be embodied as an algorithm executable by the host machine. By executing the algorithm as disclosed herein, the host machine can account for varying filter regeneration trigger points, i.e., sets of generated or related signals initiating a heat-based regeneration of the particulate filter. The host machine can also account for the varying soot masses remaining in the particulate filter subsequent to an immediately prior filter regeneration event.

[0006] Suitable control actions may include setting a first diagnostic code when the calculated ratio exceeds the calibrated threshold, activating an indicator device, transmitting a message, etc. As the actual and modeled soot values can vary with vehicle operating conditions, conventional monitoring methods that set an arbitrary threshold to cover a worst case scenario may be less than optimal. The present method may therefore improve the robustness of any regeneration frequency monitoring algorithm.

[0007] A system is also provided for use aboard the vehicle noted above. The system includes a host machine and a particulate filter, which is regenerable using heat. The host machine accesses a first soot model which provides an actual soot mass remaining in the particulate filter, and a second soot model which provides a modeled soot mass remaining in the filter using a set of current vehicle operating conditions. The host machine also calculates a ratio of a change in the measured soot mass to a change in the modeled soot mass. The host machine then compares the calculated ratio to a calibrated threshold, and executes a suitable control action when the ratio exceeds the threshold.

[0008] A method is also provided that may be embodied as an algorithm and used aboard the vehicle noted above. The method includes using a first soot model to determine an actual soot mass remaining in the particulate filter, and using a second soot model to determine a modeled soot mass remaining in the filter, with the second soot model using a set of current vehicle operating conditions. The method also includes calculating a ratio of a change in the actual soot mass to a change in the modeled soot mass, comparing the ratio to a calibrated threshold, and executing a control action when the ratio exceeds the calibrated threshold.

[0009] The above features and advantages and other features and advantages of the present invention are readily apparent from the following detailed description of the best modes for carrying out the invention when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a schematic illustration of a vehicle having an internal combustion engine and a regenerable particulate filter; and

[0011] FIG. **2** is a flow chart describing a method for monitoring filter regeneration frequency aboard the vehicle shown in FIG. **1**.

DESCRIPTION

[0012] Referring to the drawings, wherein like reference numbers correspond to like or similar components throughout the several figures, a vehicle **10** is shown schematically in FIG. **1**. The vehicle **10** includes a host machine **40** having an algorithm **100** adapted to monitor a frequency of regeneration of a heat-regenerable particulate filter **34** as explained below, and to execute a control action as needed depending on the frequency of regeneration. Algorithm **100** is explained in detail below with reference to FIG. **2**.

[0013] Vehicle **10** includes an internal combustion engine **12**, such as a diesel engine or a direct injection gasoline engine, an oxidation catalyst (OC) system **13** having the particulate filter **34**, and a transmission **14**. The engine **12** combusts fuel **16** drawn from a fuel tank **18**. In one possible embodiment, the fuel **16** is diesel fuel, the oxidation catalyst system **13** is a diesel oxidation catalyst (DOC) system, and the particulate filter **34** is a diesel particulate filter (DPF), although gasoline or other fuel types may be used depending on the design of engine **12**.

[0014] As noted above, algorithm **100** is executed by the host machine **40** in order to detect a condition in which a frequency of regeneration of the particulate filter **34** is higher than a threshold level required by design standards, doing so using first and second soot models **50** and **60**, respectively, as set forth herein. In particular, host machine **40** directly monitors regeneration frequency using a calculated ratio of the difference in a measured or actual soot level to a simulated or

modeled soot level from the first and second soot models **50** and **60**, respectively, with the two models determining soot levels remaining in the particulate filter **34** in different ways, and by comparing the calculated ratio to a calibrated threshold as explained below with reference to FIG. **2**.

[0015] Host machine **40** may be configured as a digital computer acting as a vehicle controller, and/or as a proportional-integral-derivative (PID) controller device having a microprocessor or central processing unit (CPU), read-only memory (ROM), random access memory (RAM), electrically erasable programmable read only memory (EEPROM), a high-speed clock, analog-to-digital (A/D) and/or digital-to-analog (D/A) circuitry, and any required input/output circuitry and associated devices, as well as any required signal conditioning and/or signal buffering circuitry. Algorithm **100** and any required reference calibrations are stored within or readily accessed by host machine **40** to provide the functions described below with reference to FIG. **2**.

[0016] Vehicle **10** also includes a throttle **20** which selectively admits a predetermined amount of the fuel **16** and air into engine **12** as needed. Combustion of fuel **16** by the engine **12** generates an exhaust stream **22**, which passes through the exhaust system of the vehicle before it is ultimately discharged into the surrounding atmosphere as shown. Energy released by the combustion of fuel **16** ultimately produces torque on an input member **24** of transmission **14**. The transmission **14** in turn transfers torque from the engine **12** to an output member **26** in order to propel the vehicle **10** via a set of wheels **28**, only one of which is shown in FIG. **1** for simplicity.

[0017] The OC system **13** as shown in FIG. **1** cleans and conditions the exhaust stream **22** as it passes from exhaust ports **17** of engine **12** through the vehicle's exhaust system. To this end, OC system **13** may include an oxidation catalyst **30**, a selective catalytic reduction (SCR) device **32**, and the particulate filter **34** noted above. SCR device **32** may be positioned between the oxidation catalyst **30** and the particulate filter **34**. As understood in the art, an SCR device converts nitrogen oxide (NOx) gasses into water and nitrogen as inert byproducts using an active catalyst. SCR device **32** may be configured as a ceramic brick or a ceramic honeycomb structure, a plate structure, or any other suitable design.

[0018] Regeneration of the particulate filter **34** may be active or passive. As understood in the art, passive regeneration requires no additional control action for regeneration. Instead, the particulate filter is installed in place of the muffler, and at idle or low power operations, particulate matter is collected on the filter. As the engine exhaust temperatures increase, the collected material is then burned or oxidized by the exhaust stream **22**. Active regeneration adds an external source of heat to complete the regeneration, along with additional control methodology.

[0019] However configured, the particulate filter **34** may be constructed of a suitable substrate constructed of, by way of example, ceramic, metal mesh, pelletized alumina, or any other temperature and application-suitable material(s). As the temperature of the exhaust stream **22** increases, particulate matter previously entrapped within the particulate filter **34** is burned or oxidized by the hot exhaust gas to form soot within the particulate filter.

[0020] Vehicle **10** may also include a fuel injection device **36** in electronic communication with the host machine **40** via control signals **15**, and in fluid communication with fuel tank **18**. Fuel injection device **36** selectively injects fuel **16** into the oxidation catalyst **30** or engine cylinders (not shown) when determined by the host machine **40**. The injected fuel **16** is then ignited and burned in a controlled manner to generate the increased levels of heat necessary for regenerating the particulate filter **34**.

[0021] Still referring got FIG. **1**, the respective first and second soot models **50**, **60** may be in the form of lookup tables and/or a series of calculations suitable for determining in different respective manners the remaining mass of soot in the particulate filter **34**. In one embodiment, the first soot model **50** provides a measured or actual soot mass value using the measured or calculated differential pressure across the particulate filter **34**, with the first soot model indexing a differential pressure across the particulate filter to the actual soot mass.

[0022] The second soot model **60** provides the modeled soot mass in a different manner, i.e., doing so using a set of current vehicle operating conditions and not using the differential pressure across the particulate filter **34**. Second soot model **60** uses feedback signals **44** describing the operating point of engine **12** and other suitable vehicle operating data points. Such points may include oxygen levels, throttle position, engine speed, accelerator pedal position, fueling quantity, requested engine torque, exhaust temperatures, elapsed time since the start of the last regeneration event, the particular driving mode such as highway driving, city driving, and/or other recognized modes or combinations of modes as determined by monitoring parameters such as engine speed, engine loading, braking, etc.

[0023] Host machine **40** also receives signals **11** from various sensors **42** positioned throughout the vehicle **10** describing various measured values, e.g., exhaust temperatures, pressure, oxygen levels, etc., at different locations within the OC system **13**, including directly upstream and downstream of the oxidation catalyst **30** and directly upstream and downstream of the particulate filter **34**. These signals **11** are each transmitted by or relayed to the host machine **40**. Host machine **40** is also in communication with the engine **12** to receive the feedback signals **44** indentifying the operating point of the engine, values which are used in particular by the second soot model **60** as described below.

[0024] Referring to FIG. **2**, the host machine **40** executes algorithm **100** aboard the vehicle **10** of FIG. **1** to monitor regeneration frequency of the particulate filter **34**. In general, the host machine **40** determines a measured or actual soot mass using the first soot model **50**, with the actual soot mass being based on a differential pressure across the particulate filter **34** according to one possible embodiment. The host machine **40** then determines a modeled soot mass in the particulate filter **34**, e.g., by referencing the second soot model **60** using vehicle operating data. Next, a ratio of a change in the actual soot mass is calculated and compared to a change in the modeled soot mass, with the ratio compared to a calibrated threshold. Host machine **40** can execute a control action when the ratio exceeds the threshold.

[0025] In particular, beginning at step **102** the host machine **40** first determines whether a set of initialization conditions

are present, i.e., whether a regeneration event is presently commanded. Step **102** may be satisfied by detecting a discrete on/off regeneration trigger signal generated internally by the host machine if the host machine is configured to control the regeneration process, or by another vehicle controller if configured otherwise. The algorithm **100** proceeds to step **104** after detection of the regeneration trigger signal or other initialization condition.

[0026] At step **104**, the host machine **40** determines the actual soot mass in the particulate filter **34**. In one possible embodiment, the host machine **40** directly reads or calculates the differential pressure across the particulate filter **34** using signals **11** from the sensors **42** positioned at the inlet and outlet sides of the particulate filter, in this case configured as temperature transducers or other suitable temperature sensors, and then references the first soot model **50** using the pressure drop to determine an actual soot mass value. This value is temporarily recorded in memory, and the algorithm **100** proceeds to step **106**.

[0027] At step **106**, the host machine **40** processes the feedback signals **44** and any other required signals **11** to calculate a change in the modeled soot mass, with the modeled soot mass determined with reference to the second soot model **60** described above. This change occurs over the time interval between the present regeneration trigger signal and the initiation of the immediately prior filter regeneration event. Host machine **40** also calculates the change in actual soot mass within the particulate filter **34** over the same time interval, this time with reference to first soot model **50**, and then proceeds to step **108** after temporarily recording the two change values in memory.

[0028] At step **108**, the host machine **40** calculates a ratio of the change values calculated at step **106**, i.e., the change in modeled soot mass and the change in actual soot mass in the elapsed interval since the last regeneration event, and temporarily records the value of this ratio in memory before proceeding to step **110**.

[0029] At step **110**, the host machine **40** compares the ratio from step **108** to a calibrated threshold. If the recorded ratio exceeds the calibrated threshold, the host machine **40** proceeds to step **112**, and otherwise proceeds to step **114**.

[0030] At step **112**, host machine **40** sets a first diagnostic code indicating that the ratio exceeds the calibrated threshold. Such a result could mean that there is more soot present within the particulate filter **34** than expected by the second soot model **60**, a result which may be caused by an air leak or an engine malfunction, and which therefore warrants further investigation. Additional control actions at step **112** may include activating an indicator device **38** to alert an operator, transmitting a message within vehicle **10**, transmitting a message outside of the vehicle using a vehicle telematics unit, and/or taking any other action suitable for signaling the need to inspect, maintain, or replace the particulate filter **34**.

[0031] At step **114**, the host machine **40** sets a second diagnostic code indicating that the calculated ratio does not exceed the calibrated threshold. Algorithm **100** may continue to execute in a suitable control loop to minimize variability, i.e., all regeneration events must maintain at least a minimum level of efficiency, thus making the algorithm robust for any given control system calibration, as well as a wider variety of control system calibrations.

[0032] While the best modes for carrying out the invention have been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention within the scope of the appended claims.

1. A vehicle comprising:
an engine;
a particulate filter which collects particulate matter from an exhaust stream of the engine, and which is selectively regenerable using heat; and
a host machine having a first soot model and a second soot model, with the first and the second soot models respectfully providing an actual soot mass and a modeled soot mass contained in the particulate filter;
wherein the host machine is operable for calculating a ratio of a change in the actual soot mass to a change in the modeled soot mass since an immediately prior regeneration event of the particulate filter, and for executing a control action when the ratio exceeds a calibrated threshold.

2. The vehicle of claim **1**, wherein the first soot model indexes a differential pressure across the particulate filter to the actual soot mass, and wherein the second soot model determines the modeled soot mass with respect to a set of current vehicle operating conditions not including the differential pressure across the particulate filter.

3. The vehicle of claim **1**, wherein the host machine generates a diagnostic code as at least part of the control action.

4. The vehicle of claim **3**, wherein the host machine activates an indicator device as an additional part of the control action.

5. The vehicle of claim **1**, wherein the engine is a diesel engine and the particulate filter is a diesel particulate filter.

6. A system for use aboard a vehicle having an internal combustion engine, the system comprising:
a particulate filter which collects particulate matter from an exhaust stream of the engine, and which is selectively regenerable using heat; and
a host machine having a first soot model and a second soot model, with the first and the second soot models respectfully providing an actual soot mass and a modeled soot mass contained in the particulate filter;
wherein the host machine is operable for calculating a ratio of a change in the actual soot mass to a change in the modeled soot mass since an immediately prior regeneration event of the particulate filter, and for executing a control action when the ratio exceeds a calibrated threshold.

7. The system of claim **6**, wherein the first soot model indexes differential pressure across the particulate filter to the actual soot mass, and wherein the second soot model determines the modeled soot mass with respect to a set of vehicle operating conditions not including the differential pressure across the particulate filter.

8. The vehicle of claim **6**, wherein the host machine generates a diagnostic code as at least part of the control action.

9. The vehicle of claim **8**, wherein the host machine activates an indicator device as an additional part of the control action.

10. The vehicle of claim **6**, wherein the engine is a diesel engine and the particulate filter is a diesel particulate filter.

11. A method for use aboard a vehicle having an internal combustion engine, a particulate filter which is regenerable using heat, and a host machine, the method comprising:
determining an actual soot mass value in the particulate filter using a first soot model;

determining a modeled soot mass value in the particulate filter using a second soot model, wherein the second soot model provides an estimated soot mass value contained in the particulate filter;

calculating a ratio of a change in the actual soot mass to a change in the modeled soot mass;

comparing the ratio to a calibrated threshold; and

executing a control action when the ratio exceeds a calibrated threshold.

12. The method of claim **11**, wherein the first soot model indexes differential pressure across the particulate filter to the actual soot mass value.

13. The method of claim **12**, further comprising determining a set of current vehicle operating conditions not including the differential pressure across the particulate filter, wherein the second soot model determines the modeled soot mass with respect to the set of current vehicle operating conditions.

14. The method of claim **11**, further comprising:

generating a diagnostic code as at least part of the control action.

15. The method of claim **14**, further comprising:

activating an indicator device as an additional part of the control action.

* * * * *