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(54) Title: METHOD AND ARRANGEMENT FOR MAINTAINING A DIESEL PARTICULATE FILTER IN A DIESEL ENGINE EXHAUST SYSTEM

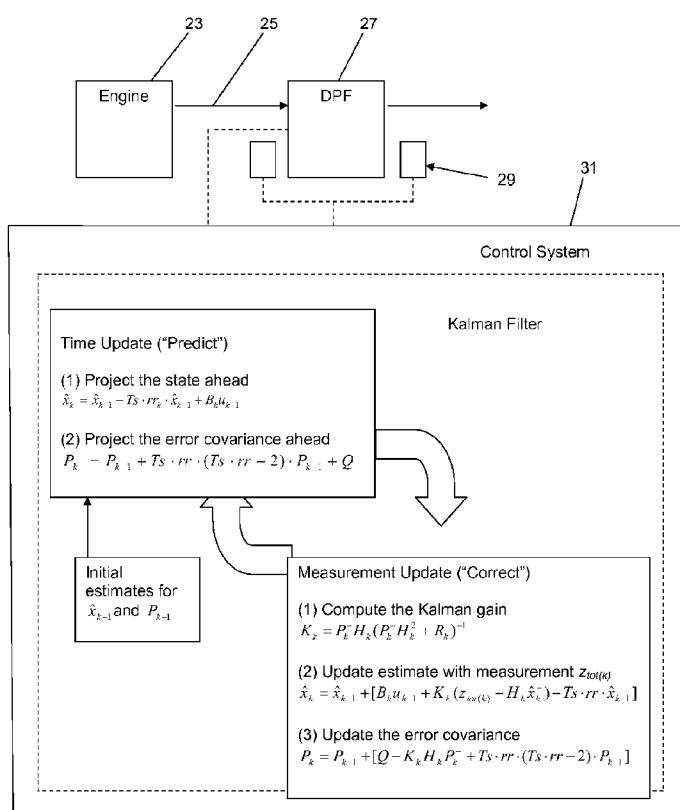


FIG. 1

(57) Abstract: A method and apparatus for maintaining a diesel particulate filter (DPF) is provided. A pressure drop across the DPF is measured and an initial estimate of soot loading in the DPF is provided to a recursive filter. Using the recursive filter, the initial estimate of soot loading is updated in view of the measured pressure drop to provide an updated estimate of soot loading in the DPF. Active regeneration of the DPF is triggered when an earliest one of at least one triggering condition occurs, the updated estimate of soot loading reaching a predetermined value being one of the at least one triggering condition.



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METHOD AND ARRANGEMENT FOR MAINTAINING A DIESEL PARTICULATE FILTER IN A DIESEL ENGINE EXHAUST SYSTEM

BACKGROUND AND SUMMARY

[0001] The present invention relates generally to diesel engines with exhaust systems comprising diesel particulate filters (DPF) and, more particularly, to methods and arrangements for triggering and stopping active regeneration in DPFs.

[0002] In diesel engines, it is now typical to use a DPF downstream of the engine to filter particulate from the engine exhaust. If too much soot collects in the DPF, the soot can burn in an uncontrolled manner and may crack or melt the DPF. This phenomenon is sometimes referred to as a “runaway” or uncontrolled regeneration. Other problems can result from excessive soot accumulation in the DPF as well, such as an increase in engine backpressure, which can have an adverse effect on engine operation and affect fuel consumption.

[0003] To avoid aforementioned problems such as runaway regenerations, it is common to periodically clean the DPF by burning off the soot, through a so-called active regeneration by O₂ oxidation, in a controlled manner that does not damage the DPF. Ordinarily, exhaust systems are configured to perform an active regeneration when soot loading in the DPF filter reaches a level of about 5 g/l (grams per liter). This active regeneration cycle could be triggered by a sensor that measures a particular pressure drop across the DPF that, given a particular soot model for the filter, corresponds to a particular soot loading level. Other events may trigger active regenerations, as well, such as operation for a predetermined length of time.

[0004] In the present application, references to “models” of aspects of engine operation are understood to generally refer to simulation software that calculates those operation aspects in real-time or offline based on known engine parameters and/or sensor measurements. The

development of such models is well-known in the field of diesel engines; many models relate only to the particular engine for which they were developed, and the development of such models is not intended to form part of the present invention, except as otherwise described herein. Variables or parameters associated with such engine operation models are ordinarily determined through extensive testing of engine operation and the process by which they are determined is also known in the field of diesel engines.

[0005] While, in the ideal case, soot should collect uniformly in the DPF, in practice, it does not always do so. Two main causes for non-uniform soot distribution are high flow velocity through the DPF, such as often occurs during highway driving, and so-called passive regeneration, which occurs when NO₂ in the exhaust gas oxidizes the soot. Passive regeneration typically occurs at temperatures of about 250 °C to 450 °C, which falls at least partially within normal operating temperatures of the DPF. Active regeneration typically occurs at temperatures greater than 550 °C.

[0006] Triggering of the active regeneration cycle as a function of pressure drop across the DPF assumes a uniform soot distribution. When soot is not uniformly distributed then it is possible that, although the pressure drop across the DPF has not reached a trigger point, some portions of the DPF may have soot loading at or above the level where runaway regeneration can occur, and other portions of the DPF may have soot loading below that level. In other words, in certain conditions, the pressure drop measurements may tend to underestimate actual soot loading on parts of the DPF, which can lead to damage to the DPF.

[0007] Once an active regeneration begins, regeneration proceeds according to a regeneration schedule for the filter for a predetermined length of time such that it will be completely or substantially burnt off.

[0008] It is desirable to provide a system and method for triggering active regenerations in a DPF where soot loading may be non-uniform. It is also desirable to provide a system and method for triggering the end of active regeneration in a DPF where soot loading may be non-uniform.

[0009] In accordance with an aspect of the present invention, a method for maintaining a DPF is provided. According to the method, a pressure drop across the DPF is measured. An initial estimate of soot loading in the DPF is provided to a recursive filter in the preferred embodiment. In another embodiment of the invention, a cost function or a weight function could be used instead. Using the recursive filter, the initial estimate of soot loading is updated in view of the measured pressure drop to provide an updated estimate of soot loading in the DPF. Active regeneration of the DPF is triggered when the earliest one of at least one triggering condition occurs, the updated estimate of soot loading reaching a predetermined value being one of the at least one triggering condition.

[0010] In accordance with another aspect of the present invention, a method for estimating soot loading in a DPF is provided. According to the method, a pressure drop across the DPF is measured. An initial estimate of soot loading in the DPF is provided to a recursive filter. Using the recursive filter, the initial estimate of soot loading is updated in view of the measured pressure drop to provide an updated estimate of soot loading in the DPF.

[0011] In accordance with another aspect of the present invention, a diesel engine system comprises a diesel engine, a DPF downstream of the engine, a pressure sensor arrangement for measuring pressure drop across the DPF, and a control system. The control system comprises a recursive filter arranged so that, upon provision of a soot loading estimate in the DPF and a measurement by the pressure sensor arrangement of pressure drop across the DPF, an updated

soot loading estimate in the DPF is provided, and so that active regeneration of the DPF is triggered in response to at least one triggering condition, the at least one triggering condition including the updated estimate of soot loading.

BRIEF DESCRIPTION OF THE DRAWING

[0012] The features and advantages of the present invention are well understood by reading the following detailed description in conjunction with the drawing in which like numerals indicate similar elements and in which:

[0013] FIG. 1 schematically shows an engine exhaust system including a DPF according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0014] A diesel engine system 21 according to an embodiment of the present invention shown in FIG. 1 and comprises a diesel engine 23 and an exhaust line 25 including a DPF 27 downstream of the engine cylinders. A sensor arrangement 29 that ordinarily includes differential pressure (delta-P) sensor measures pressure at an inlet and an outlet of the DPF 27. A heating element or device (not shown) is disposed in or upstream of the DPF 27 to raise the temperature of the exhaust gas flow during active regeneration. The sensor arrangement 29 also typically comprises monitors for monitoring temperature of the exhaust gas flow, typically at least in the DPF, often upstream and downstream of the DPF, as well.

[0015] A controller 31 is provided. The controller 31 receives signals from the delta-P sensor and the temperature monitors, processes the signals, and, in response to the signals, determines whether active regeneration should be triggered or, if triggered, whether it should be stopped. If

the controller 31 determines that active regeneration should be triggered, it sends a signal to the heating element to heat the exhaust gas flow. If the controller 31 determines that active regeneration should be stopped, it sends a signal to the heating element to stop heating of the exhaust gas flow.

[0016] The controller 31 can trigger and stop active regeneration as a function of an estimated soot loading in the DPF 25. The soot load estimate can be obtained through a recursive filtering procedure performed by the controller 31 using inputs from the delta-P sensor and the temperature monitors. It is presently preferred to obtain the estimate using a discrete Kalman filter.

[0017] Soot loading in a DPF can be estimated according to an aspect of the present invention using a recursive filtering approach, preferably such as a Kalman filter. Starting and stopping of active regeneration of the DPF can be affected as a function of the soot loading estimate. The following describes the process for estimating accumulated soot mass and non-uniform soot distribution using a recursive Kalman filter.

Estimate/Model Prediction of Soot Loading - x

[0018] Using a Kalman equation analysis, an estimate of soot loading in a DPF resulting from a soot loading process of the DPF is governed by the linear stochastic difference equation:

$$(1) \quad x_k = A_k x_{k-1} + B_k u_{k-1} + w_{k-1}$$

where:

x_k is estimated soot loading at time k ;

A is an $n \times n$ matrix that relates the state of soot loading x_{k-1} at the previous time step $k-1$ to the state x_k at the current time step k in the absence of either a driving function or process noise, and is determined by a DPF regeneration model;

u is a control input value for the engine soot generation rate that is determined by an engine soot generation model;

B is an $n \times 1$ matrix determined by filter effectiveness that relates the value u at the previous time step $k-1$ to the state of soot loading x_k at time k ; and

w is uncertainty (noise) of the process model.

Measurement - z

[0019] A measurement, in particular, the pressure drop across the DPF is represented by the equation:

$$(2) \quad z_k = H_k x_k + v_k$$

z_k is a measurement of pressure drop (hereinafter delta-P) across the DPF from the delta-P sensor at time step k ;

H is an $m \times n$ matrix that relates the state of soot loading, i.e., x , to the measurement z_k of delta-P across the DPF; and

v is uncertainty (noise) of the measurement.

[0020] Random variables for process noise or uncertainty w and measurement noise or uncertainty v are assumed to be independent of each other and, with normal probability distribution:

$$(3) \quad p(w) \sim N(0, Q)$$

$$(4) \quad p(v) \sim N(0, R)$$

Where:

Q is the process noise covariance; and

R is the measurement noise covariance.

Values for Q and R are calibrated in test cells. Q is calibrated by measuring the prediction error of the internal model $x_k = A_k x_{k-1} + B_k u_{k-1} + w_{k-1}$ and R is calibrated by measuring the prediction error of the sensor-based model $z_k = H_k x_k + v_k$. The uncertainties of the model prediction and measurement are independent, and are described as a normal distribution with zero mean.

Soot Generation Rate - u

[0021] The engine soot generation rate, u , can be estimated by the engine soot generation model. A transient-cycle indicator I_t can be introduced to adjust the soot prediction for an improved estimate and is defined as:

$$(5) \quad I_t = C_1 + \frac{C_2}{T_s} \cdot \left(\frac{AFR_{k-1}}{AFR_k} - 1 \right)$$

Where:

AFR is the air/fuel ratio;

T_s is a sampling time interval;

C_1 is a parameter equal to “1” when the engine soot generation model is properly calibrated; and

C_2 is a calibration parameter for the particular soot generation model.

[0022] The transient-cycle indicator I_t is always greater than or equal to C_1 , i.e., when

$AFR_{k-1} < AFR_k$, the algorithm automatically sets I_t equal to C_1 .

Soot Regeneration Factor - A

[0023] The DPF is regenerated by burning off soot, as the result of a reaction with NO_2 at lower exhaust temperatures during normal operation and with O_2 during a regeneration process. NO_2 and O_2 react with soot in the DPF in the following temperature ranges: approx. 250-450 °C and >550 °C respectively. The soot regeneration model is defined as:

$$(6) \quad A_k = 1 - Ts \cdot rr_k$$

Where:

Ts is the sampling time of the control system

rr is the soot reaction rate, which can be estimated as:

$$(7) \quad rr_k = C_3 \cdot [O_2]_k \cdot \exp[-E_{o_2} / (R_g T_k)] + C_4 \cdot [NO_2]_k \cdot \exp[-E_{no_2} / R_g T_k]$$

$$(8) \quad [O_2]_k = \frac{(AFR_k - AFR_s) \times 0.21}{AFR_k + 0.065 \times AFR_s}$$

Where:

$[O_2]$ is oxygen concentration in the exhaust stream;

$[NO_2]$ is NO_2 concentration in the exhaust stream;

R_g is the gas constant;

AFR_k is the air/fuel ratio at time k ;

AFR_s is the stoichiometric air/fuel ratio for diesel;

C_3 , C_4 , E_o , and E_{no} are calibration parameters determined through testing.

Non-Uniform Soot Distribution Adjustment x_{nud} for Soot Loading Estimate x Based on Delta-P Sensor Measurement z

[0024] If the soot loading distribution is uniform across the DPF, the following equation describes a soot loading estimator based on the delta-P measurement:

$$(9) \quad x_{p(k)} = z_k / H_k$$

Where $x_{p(k)}$ is the delta-P sensor predicted soot loading where uniform distribution is assumed; z_k is the delta-P sensor measurement; and

H_k is the gain of the delta-P sensor based soot loading estimator, which is calculated based on the volume flow of the exhaust gas and the temperature of the exhaust gas.

[0025] Soot distribution in an actual DPF will often be non-uniform, however, in which case the soot-loading predicted by the delta-P sensor based soot model will likely be lower than the actual soot loading inside the DPF, at least in local areas. Accordingly, a Non-Uniform Distribution model, $x_{nud(k)}$, is introduced to estimate the difference. If:

$$x_{tot(k-1)} \geq x_{nud(k-1)}$$

(where x_{tot} = estimated total soot loading)

and

$$v_{k-1} > v_0$$

then the non-uniform distribution model can be represented as:

$$(10) \quad x_{nud(k)} = x_{nud(k-1)} + [k_1 \cdot rr_{(k-1)} + k_2 \cdot (v_{(k-1)} - v_0)^2][x_{tot(k-1)} - x_{nud(k-1)}]$$

Where:

$x_{nud(k)}$ is the non-uniformly distributed soot mass estimate at time k ;

$x_{nud(k-1)}$ is the non-uniformly distributed soot mass estimate at time $k-1$;

$vel_{(k-1)}$ is the exhaust gas flow velocity at time $k-1$;

v_o is the the minimum exhaust gas flow velocity that can cause non-uniform soot distribution;

k_1, k_2 are calibration parameters; and

$rr_{(k-1)}$ is the soot reaction rate at time $k-1$.

The model in equation (10) is based on the expectation that soot is non-uniformly distributed because of soot regeneration and high exhaust gas velocity. In equation (10), if $rr > 0$, then it generates some x_{nud} ; or if the velocity of the exhaust gas exceeds a threshold value then it generates some x_{nud} . The more x_{nud} that currently exists, the less likely that more x_{nud} will be generated. Once $x_{nud} = x_{tot}$ then no more x_{nud} can be generated.

If :

$$x_{tot(k-1)} \geq x_{nud(k-1)}$$

and

$$v_{k-1} \leq v_o$$

then the non-uniform distribution model can be represented as:

$$(11) \quad x_{nud(k)} = x_{nud(k-1)} + k_1 \cdot rr_{(k-1)} \cdot [x_{tot(k-1)} - x_{nud(k-1)}]$$

when $v_{k-1} = v_o$, i.e. $v_{k-1} - v_o = 0$ so part of equation (10) cancels out.

If $x_{tot(k-1)} < x_{nud(k-1)}$:

$$(12) \quad x_{nud(k)} = x_{nud(k-1)} - rr_{(k-1)} \cdot x_{tot(k-1)}$$

when $v_{k-1} < v_o$, at which time it is understood that all soot is x_{nud} soot, and the total soot loading is decreasing. Therefore, x_{nud} should decrease and the rate for it to decrease is $rr \cdot x_{tot}$.

[0026] Using the foregoing adjustments for non-uniform soot distribution, the delta-P sensor-based soot loading model looks like:

$$(13) \quad z_{tot(k)} = H_k (x_{p(k)} + x_{nud(k)})$$

where $z_{tot(k)}$ is the calculated pressure drop assuming that $x_{p(k)} + x_{nud(k)}$ are correct.

The variance of the model estimate, i.e., measurement noise covariance, is adjusted according to the following equation:

$$(14) \quad R_k = R0 \cdot \exp(k_3 \cdot x_{nud(k)})$$

Where:

$R0$ is the variance of the model estimate when soot is uniformly distributed; and

k_3 is a calibration parameter.

[0027] Formulating a discrete-time Kalman Filter using *a priori* soot loading estimates and delta-P sensor measurements it is possible to arrive at an *a posteriori* estimate of the soot load in the DPF. The discrete-time Kalman filter time update or prediction equations are represented by the *a priori* state estimate at time k (in the following equations, it will be understood that $x_k = x_{p(k)} + x_{nud(k)}$ and that $x_{k-1} = x_{p(k-1)} + x_{nud(k-1)}$):

$$(15) \quad \hat{x}_k^- = A_k \hat{x}_{k-1} + B_k u_{k-1} = \hat{x}_{k-1} - Ts \cdot rr_k \cdot \hat{x}_{k-1} + B_k u_{k-1}$$

and by the *a priori* estimate error covariance:

$$(16) \quad P_k^- = P_{k-1} A_k^2 + Q = P_{k-1} + Ts \cdot rr \cdot (Ts \cdot rr - 2) \cdot P_{k-1} + Q$$

The Kalman filter measurement update or correction equations are represented by the Kalman gain equation:

$$(17) \quad K_k = P_k^- H_k (P_k^- H_k^2 + R_k)^{-1}$$

by the *a posteriori* state estimate at time k given measurement $z_{tot(k)}$

$$(18) \quad \hat{x}_k = \hat{x}_{k-1} + [B_k u_{k-1} + K_k (z_{tot(k)} - H_k \hat{x}_k^-) - Ts \cdot rr \cdot \hat{x}_{k-1}]$$

(where the residual $(z_{tot(k)} - H_k \hat{x}_k^-)$ is the difference between the actual delta-P measurement and the estimate of the delta-P measurement across the DPF) and by the *a posteriori* estimate error covariance equation:

$$(19) \quad P_k = P_{k-1} + [Q - K_k H_k P_{k-1} + Ts \cdot rr \cdot (Ts \cdot rr - 2) \cdot P_{k-1}]$$

[0028] Successive *a priori* estimates of soot loading are made based on preceding *a posteriori* soot loading estimates and updated using measurement data to provide new *a posteriori* soot loading estimates. The *a posteriori* soot loading estimates can be used to trigger starting and stopping of active regeneration.

Trigger for Start of Active Regeneration

[0029] Active regeneration is triggered when the *a posteriori* estimated soot loading x_k plus the standard deviation of the *a posteriori* estimated soot loading E_k reaches or exceeds a pre-determined value, i.e., $x_k + E_k \geq \text{trigger value}$.

Trigger for Stop of Active Regeneration

[0030] Active regeneration stops when the estimated soot loading is less than a pre-determined value, or the total duration of active regeneration reaches a pre-determined time limit, or the difference between the soot generation rate and the soot oxidation rate is less than a pre-determined value while the DPF temperature is above a pre-determined threshold, whichever is reached first.

[0031] Operation of the diesel engine system 21 with a control system 31 comprising a recursive filter, ordinarily a Kalman filter, proceeds so that, upon provision of an initial estimate $\hat{x}_{k-1}$ of

soot loading in the DPF 25 and error covariance P_{k-1} and a measurement $z_{tot(k)}$ by the sensor arrangement 29 of pressure drop across the DPF, an updated estimate $\hat{x}_k$ of soot loading in the DPF is provided. The Kalman filter will typically be part of a computer program on some computer-readable medium.

[0032] Active regeneration of the DPF 25 is triggered, i.e., the control system 31 initiates a regeneration process, in response to at least one triggering condition, the at least one triggering condition including the updated estimate $\hat{x}_k$ of soot loading.

[0033] The sensor arrangement 29 ordinarily at least periodically measures the pressure drop across the DPF 25 and includes pressure sensors proximate an inlet and an outlet of the DPF. In addition, the sensor arrangement 29 will ordinarily also measure gas temperature in the DPF.

The control system 31 is ordinarily adapted to periodically update the updated estimate $\hat{x}_k$ of soot loading in view of respective ones of the at least periodic pressure drop measurements $z_{tot(k)}$ to generate a plurality of updated estimates $\hat{x}_k$ of soot loading and to periodically calculate a standard deviation E_k of the plurality of updated estimates of soot loading. The control system 31 is ordinarily adapted to trigger regeneration when a sum of the updated estimate $\hat{x}_k$ of soot loading plus the standard deviation E_k of the plurality of updated estimates of soot loading exceeds a predetermined value. Regeneration can be stopped when another earliest one of at least one stopping condition occurs, the updated estimate of soot loading $\hat{x}_k$ reaching another predetermined value being one of the at least one stopping condition. Another stopping condition can be a predetermined lapse of time following commencement of regeneration.

[0034] A measurement noise covariance in the Kalman filter R_k can be a function of a non-uniformly distributed soot mass estimate $x_{nud(k)}$ according to the relationship previously identified

in equation (14), and where the non-uniformly distributed soot mass estimate $x_{nud(k)}$ is a function of exhaust gas flow velocity $v_{(k-1)}$ in the DPF 25 and soot reaction rate $rr_{(k-1)}$ according to the relationships previously identified in equations (10), (11), and (12).

[0035] In the present application, the use of terms such as “including” is open-ended and is intended to have the same meaning as terms such as “comprising” and not preclude the presence of other structure, material, or acts. Similarly, though the use of terms such as “can” or “may” is intended to be open-ended and to reflect that structure, material, or acts are not necessary, the failure to use such terms is not intended to reflect that structure, material, or acts are essential. To the extent that structure, material, or acts are presently considered to be essential, they are identified as such.

[0036] While this invention has been illustrated and described in accordance with a preferred embodiment, it is recognized that variations and changes may be made therein without departing from the invention as set forth in the claims.

WHAT IS CLAIMED IS:

1. A method for maintaining a DPF, comprising:

measuring a pressure drop across the DPF;
providing an initial estimate of soot loading in the DPF to a recursive filter;
using the recursive filter, updating the initial estimate of soot loading in view of the measured pressure drop to provide an updated estimate of soot loading in the DPF;
triggering active regeneration of the DPF when an earliest one of at least one triggering condition occurs, the updated estimate of soot loading reaching a predetermined value being one of the at least one triggering condition.

2. The method for maintaining a DPF as set forth in claim 1, wherein the recursive filter is a Kalman filter.

3. The method for maintaining a DPF as set forth in claim 1, comprising at least periodically measuring the pressure drop across the DPF, and at least periodically updating the updated estimate of soot loading in view of respective ones of the at least periodic pressure drop measurements to generate a plurality of updated estimates of soot loading and calculating a standard deviation of the plurality of updated estimates of soot loading, comprising triggering regeneration when the updated estimate of soot loading plus the standard deviation, or a function of the estimated error, of the plurality of updated estimates of soot loading exceeds a predetermined value.

4. The method for maintaining a DPF as set forth in claim 3, wherein the recursive filter is a Kalman filter.
5. The method for maintaining a DPF as set forth in claim 4, wherein a measurement noise covariance in the Kalman filter is a function of a non-uniformly distributed soot mass estimate.
6. The method for maintaining a DPF as set forth in claim 5, wherein the non-uniformly distributed soot mass estimate is a function of exhaust gas flow velocity in the DPF and soot reaction rate.
7. The method for maintaining a DPF as set forth in claim 1, comprising, after triggering active regeneration of the DPF, stopping active regeneration of the DPF when another earliest one of at least one stopping condition occurs, the updated estimate of soot loading reaching another predetermined value being one of the at least one stopping condition.
8. The method for maintaining a DPF as set forth in claim 7, wherein the recursive filter is a Kalman filter.
9. The method for maintaining a DPF as set forth in claim 8, wherein a measurement noise covariance in the Kalman filter is a function of a non-uniformly distributed soot mass estimate.

10. The method for maintaining a DPF as set forth in claim 9, wherein the non-uniformly distributed soot mass estimate is a function of exhaust gas flow velocity in the DPF and soot reaction rate.

11. The method for maintaining a DPF as set forth in claim 7, wherein another one of the at least one stopping condition comprises lapsing of a predetermined period of time.

12. The method for maintaining a DPF as set forth in claim 1, comprising calculating exhaust gas flow velocity through the DPF and adjusting the initial estimate for soot distribution as a function of the exhaust gas flow velocity.

13. A computer program stored on a computer-readable medium for performing the method of claim 1.

14. A method for estimating soot loading in a DPF, comprising:

- measuring a pressure drop across the DPF;
- providing an initial estimate of soot loading in the DPF to a recursive filter; and
- using the recursive filter, updating the initial estimate of soot loading in view of the measured pressure drop to provide an updated estimate of soot loading in the DPF.

15. The method for estimating soot loading in a DPF as set forth in claim 14, wherein the filter is a Kalman filter.

16. The method for estimating soot loading in a DPF as set forth in claim 15, wherein a measurement noise covariance in the Kalman filter is a function of a non-uniformly distributed soot mass estimate.

17. The method for estimating soot loading in a DPF as set forth in claim 16, wherein the non-uniformly distributed soot mass estimate is a function of exhaust gas flow velocity in the DPF and soot reaction rate.

18. A computer program stored on a computer-readable medium for performing the method of claim 14.

19. A diesel engine system, comprising:

- a diesel engine;
- a DPF downstream of the engine;
- a pressure sensor arrangement for measuring pressure drop across the DPF; and
- a control system comprising a recursive filter arranged so that, upon provision of an estimate of soot loading in the DPF and a measurement by the pressure sensor arrangement of pressure drop across the DPF, an updated estimate of soot loading in the DPF is provided, and so that active regeneration of the DPF is triggered in response to at least one triggering condition, the at least one triggering condition including the updated estimate of soot loading.

20. The diesel engine system as set forth in claim 19, wherein the pressure sensor arrangement at least periodically measures the pressure drop across the DPF, and the control system is

adapted to periodically update the updated estimate of soot loading in view of respective ones of the at least periodic pressure drop measurements to generate a plurality of updated estimates of soot loading and to periodically calculate a standard deviation of the plurality of updated estimates of soot loading, the control system being adapted to trigger regeneration when the updated estimate of soot loading plus the standard deviation, or a function of the estimated error, of the plurality of updated estimates of soot loading exceeds a predetermined value.

21. The diesel engine system as set forth in claim 19, wherein the recursive filter is a Kalman filter.

22. The diesel engine system as set forth in claim 21, wherein a measurement noise covariance in the Kalman filter is a function of a non-uniformly distributed soot mass estimate.

23. The diesel engine system as set forth in claim 22, wherein the non-uniformly distributed soot mass estimate is a function of exhaust gas flow velocity in the DPF and soot reaction rate.

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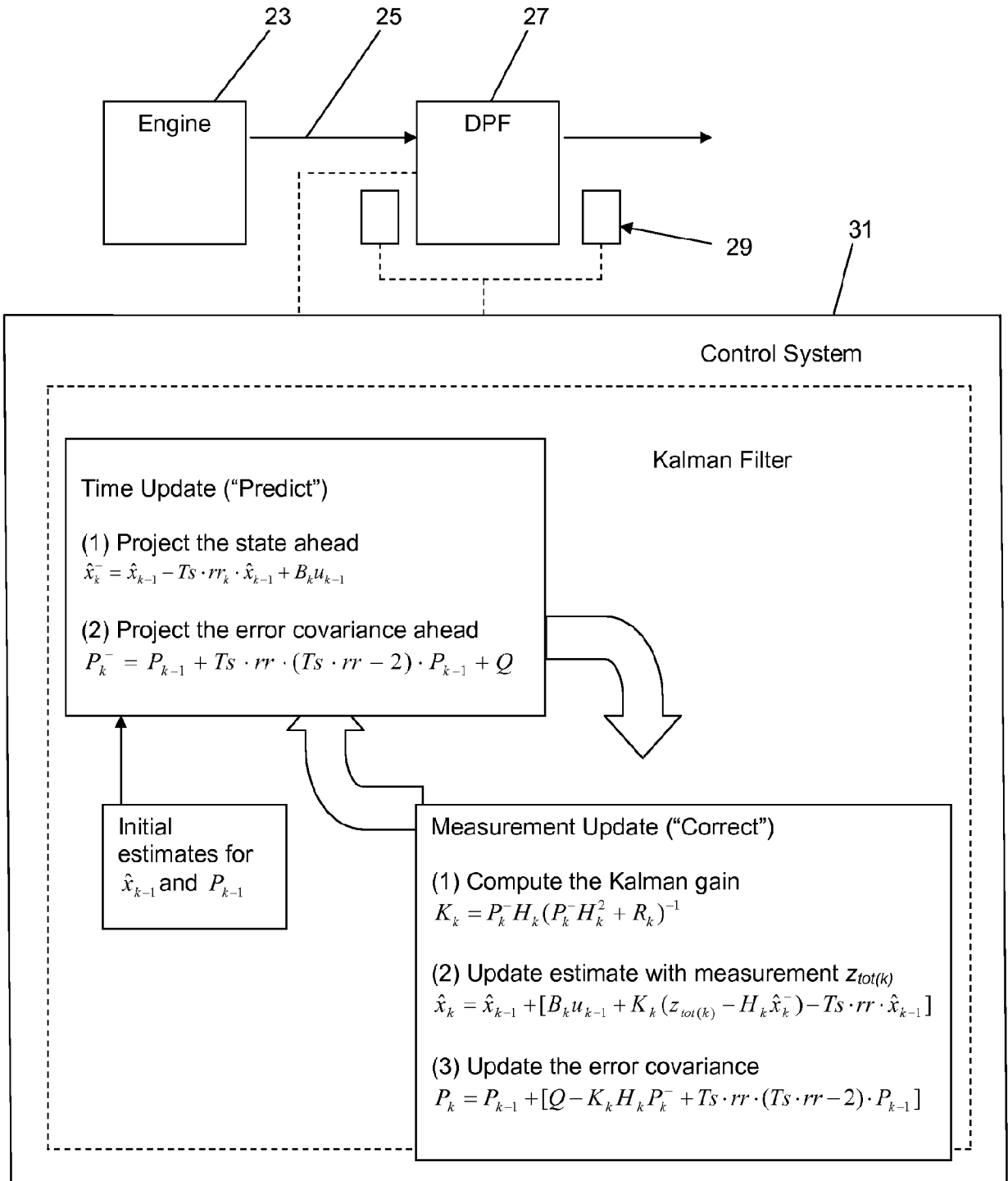


FIG. 1

CORRECTED VERSION
INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 07/67888

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F01N 3/00 (2008.01)

USPC - 60/295

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)

USPC: 60/295

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 055/283; 060/295, 297; 701/101, 103, 108 (see text below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Electronic Databases Searched: PubWEST (USPT,PGPB,EPAB,JPAB); USPTO, Google, Answers.com, Google Patents

Search terms: Gas, flow, velocity, control, uniform, distribution, standard deviation, time, reaction rate, error, regeneration, adjust, periodic, kalman, recursive, exhaust, computer, estimate, soot, loading, pressure dr

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/0056272 A1 (DOLLMEYER et al.) 15 March 2007 (15.03.2007) para [0009], [0012]-[0014], [0016]-[0017], [0021], [0025]-[0026], [0036], [0041], [0046], [0049], [0057], [0061], [0066], [0076], [0112], [0114]-[0115]	1, 3, 12-14, and 18-20
Y		2, 4-11, 15-17 and 21-23
Y	US 2006/0137340 A1 (STEWART) 29 June 2006 (29.06.2006) para [0073]	2, 4-6, 8-10, 15-17, and 21-23
Y	US 2006/0191258 A1 (OPRIS) 31 August 2006 (31.08.2006) para [0006]-[0007], [0009]-[0010], [0024]-[0025], [0028]-[0031]	6-11, 17 and 23

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search

27 December 2007 (27.12.2007)

Date of mailing of the international search report

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