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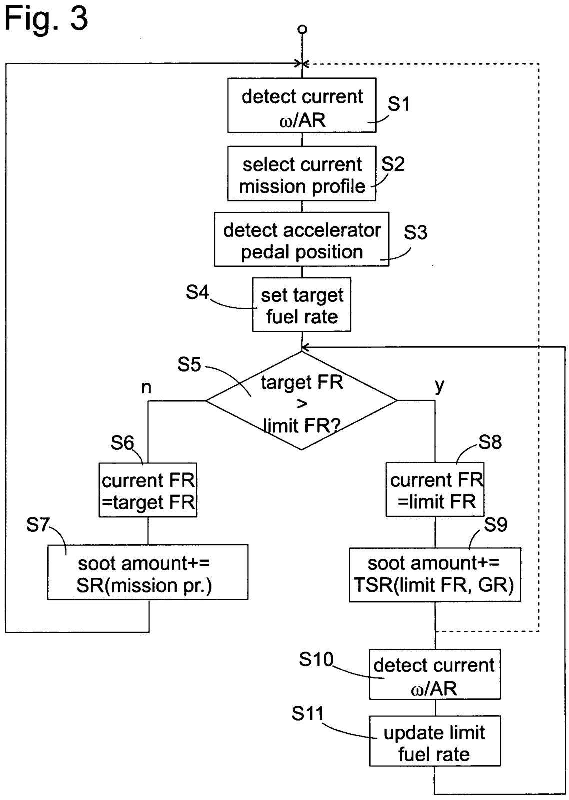
(54) **Estimation of the soot load of a particulate filter**

(57) The soot load of a particulate filter (12) in the exhaust system of a motor vehicle is estimated by
a) selecting (S2) a mission profile of the motor vehicle based on the history of one or more of its operation parameters (ω, AR);
b) increasing (S7) the estimated soot load at a rate (SR) associated to the currently selected mission profile;
c) determining (S4) a target fuel injection rate (TFR) of an engine of the motor vehicle based on input from a driver (S3) ;
d) determining a limit fuel injection rate (LFR) based on a set of operation parameters comprising at least one of the engine speed (ω) and the engine airflow (AR);
e) in a time interval in which the target fuel injection rate (TFR) exceeds the limit fuel injection rate (LFR), increasing the estimated soot load (S9) at a rate (TSR) associated to an instantaneous value of at least one of said operation parameters.

Fig. 3



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Description

[0001] The present invention relates to a method and an apparatus for estimating the soot load of a particulate filter in the exhaust system of a motor vehicle.

[0002] It is known that the rate of soot generation in the engine of a motor vehicle, in particular a diesel engine, is related to operating regimes also referred to as mission profiles. Mission profiles can be defined associated to typical driving situations such as e.g. urban stop and go traffic, in which a vehicle typically runs intermittently at low engine speed and torque, highway driving, where speed and torque are high, etc.

[0003] A problem of this soot estimation strategy originates from the fact that for judging the current mission profile of a vehicle, data that describe the operating conditions of the vehicle at different times have to be averaged or otherwise combined. However, the actual soot generation rate can be strongly influenced by transient variations of the driving conditions. For example, a vehicle which stops repeatedly and, in between, moves at a moderate velocity will be judged to be in an urban driving mission profile, regardless of whether the driver accelerates slowly when the traffic light turns green, and allows the vehicle to coast when he sees a red traffic light in front, or whether he accelerates abruptly at a green light and approaches a red traffic light at full speed, braking only in a short distance from the traffic light. The rates of soot generation, however, can be substantially different for these driving styles.

[0004] It is dangerous to underestimate the soot load of a particulate filter, because this might cause a filter to be regenerated too late, when its soot load is so high that heat from combustion of the soot can damage the filter. Current methods for estimating the soot load therefore tend to overestimate it, in order to allow for a safe regeneration in case of a "sportive" or "nervous" driving style. If a vehicle is driven economically, the soot load in the filter therefore tends to be overestimated, so that the filter will be regenerated more often than necessary. This may penalize the driver who has an economical style of driving, since if the soot load in the filter at the time of regeneration is too small, extra fuel is needed for the filter to reach an optimal regeneration temperature, or, if a regeneration is carried out at a sub-optimal temperature, it may be incomplete.

[0005] The object of the present invention is therefore to provide a method and an apparatus for estimating the soot load of a particulate filter in the exhaust system of a motor vehicle which allow to take account of a driver's personal driving style.

[0006] This object is achieved by a method comprising the steps of

a) selecting a mission profile of the motor vehicle based on the history of one or more operation parameters of the vehicle;

b) increasing the estimated soot load at a rate associated to the currently selected mission profile;

c) determining a target fuel injection rate of an engine of the motor based on input from a driver;

d) determining a limit fuel injection rate based on a set of operation parameters comprising at least one of the engine speed and the engine airflow;

e) in a time interval in which the target fuel injection rate exceeds the limit fuel injection rate, increasing the estimated soot load at a rate associated to an instantaneous value of at least one of said operation parameters.

[0007] While soot load estimation based on the mission profile may be perfectly adequate for most of the time, abrupt acceleration may contribute significantly to the soot load, although the duration of such accelerations may only be a small fraction of the total operating time of the engine. The contribution of these accelerations may be taken account of according to the invention by using different increase rates of the estimated soot load in above steps b) and e).

[0008] If the accelerator pedal is pressed abruptly while the engine is running slowly, the target fuel injection rate corresponding to the accelerated pedal position may be out of proportion to the airflow rate of the engine, so that soot is generated at a very high rate for a short time due to insufficient fresh air supply. Preferably, this fact is taken account of by setting the rate of fuel actually injected into the engine equal to the limit fuel injection rate, if the latter is less than the target fuel injection rate.

[0009] Different strategies may be used for defining the limit fuel injection rate, as will be explained in more detail below.

[0010] The above mentioned set of operation parameters of the vehicle preferably further comprises a gear ratio, since the latter is found to be correlated to the soot output of the engine at a given engine speed or engine airflow.

[0011] If the vehicle comprises a turbocharger, correlation between engine speed and engine airflow is rather loose, since the speed of the turbocharger tends to follow that of the engine with a delay. Therefore, if the engine is accelerating, airflow at a given engine speed tends to be lower than in a steady state, whereas in case of deceleration of the engine, it tends to be higher. If there is a turbocharger, it is appropriate if the set of operation parameters comprises at least both of the engine speed and the engine airflow. In case of a simple engine without a turbocharger, the method may be simplified by using only one of these two parameters.

[0012] The limit fuel injection rate may be predefined as a function of said set of operation parameters such that at when the engine is operating at the limit fuel injection rate the rate of soot generation is constant and independent from the operation parameters of said set. In other words, the rate of soot generation will be the same whenever the fuel injection rate is limited. This allows for a particularly simple and precise estimation of the soot generated in the time interval of method step e) by multiplying the rate of soot generation by the duration of the time interval.

[0013] The amount of soot generated in the time interval of step e) may be calculated by multiplying the estimated soot generation rate by the duration of said time interval even if the actual rate of soot generation in this time interval is not constant.

[0014] In particular, if the limit fuel injection rate is predefined as a function of the set of operation parameters such that for any practical combination of values of said operating parameters the rate of soot generation does not exceed a predetermined constant rate, said constant rate may be taken as the rate at which the estimated soot load is increased in step e). This will still cause the estimated amount of soot to be slightly higher than the actual one, but the error is much smaller than that of a method which is based on mission profiles alone, and the error can be made very small for an economical style of driving.

[0015] Another simple approach is to determine the rate at which the estimated soot load is increased based on the instantaneous value of said at least one operation parameter of step e) at the beginning of the time interval of step e).

[0016] Of course, the rate at which the estimated soot load is increased may also be updated one or more times in the time interval of step e).

[0017] Preferably, the above-defined method for estimating the soot load is used in a method for controlling the regeneration of a particulate filter in the exhaust system of a motor vehicle, in which a decision to regenerate the filter is then taken based on the thus estimated accumulated soot load.

[0018] A further object of the invention is a data processor program product comprising a data carrier in which program instructions for enabling a data processor to carry out the above soot estimation or regeneration control method are recorded in machine-readable form.

[0019] Further, the object of the invention is achieved by an apparatus for estimating the soot load of a particulate filter in the exhaust system of a motor vehicle, comprising

a) means for selecting a mission profile of the motor vehicle based on the history of one or more operation parameters of the vehicle;

b) means for increasing the estimated soot load at a rate associated to the currently selected mission profiles;

c) means for determining a target fuel injection rate of an engine of the motor vehicle based on input from a driver;

d) means for determining a limit fuel injection rate based on a set of operation parameters comprising at least one of the engine speed and the engine airflow; and

e) means for increasing, in a time interval in which the target fuel injection load exceeds the limit fuel injection rate, the estimated soot load at a rate associated to an instantaneous value of at least one of said operation parameters.

[0020] Further features and advantages of the invention will become apparent from the subsequent description of embodiments thereof referring to the appended drawings.

Fig. 1 is a diagram of a combustion engine system in which the present invention is implemented;

Fig. 2 is a block diagram of part of the logical structure of the electronic control unit shown in Fig. 1; and

Fig. 3 is a flowchart of a control method carried out by the electronic control unit.

[0021] Fig. 1 schematically illustrates a Diesel engine and its exhaust system, to which the present invention is applicable. The engine has a plurality of combustion chambers 1 in which pistons 2 reciprocate, and to which fresh air is supplied by an intake manifold 3. Along the intake manifold 3, there is located an airflow meter 4, a throttle valve 5 and an exhaust gas recirculation (EGR) valve 6. A fuel injection valve 7 is connected to a common rail, not shown.

[0022] An exhaust duct 8 extends from the combustion chambers 1 to an exhaust catalyst 9. An exhaust recirculation line 10 extends from exhaust duct 8 to EGR valve 6. A turbine 11 for driving an intake air compressor, not shown, may be located in exhaust duct 8.

[0023] In the schematic representation of Fig. 1, the exhaust catalyst 9 is represented as a single block. In practice, it may be divided into two separate units, a pre-catalyst which is small-sized and located physically close to the engine in order to reach operating temperature quickly after engine start-up, and a main catalyst located further downstream, of larger size and capable of processing the exhaust gas from the engine without overheating even at high engine loads.

[0024] Catalyst 9 degrades residual hydrocarbons, nitric oxides and carbon monoxide contained in the exhaust stream. Particles such as soot contained in the exhaust stream pass catalyst 9 essentially unaffected.

[0025] A particulate filter 12 is located downstream of catalyst 9 for collecting these particles from the exhaust stream. Particulate filter 12 is placed in a common casing together with the main catalyst, in order to enable efficient heating of particulate filter 12 by heat from catalytic reactions occurring in catalyst 9.

[0026] A sensor 13 may be provided at an upstream side of particulate filter 12 for monitoring the temperature of filter 12 and/or catalyst 9, of for monitoring the exhaust gas pressure at the upstream side of filter 12.

[0027] As an alternative or subsidiary means for heating the particulate filter 12, ECU 14 might be designed to control fuel injection into combustion chambers 1 after the top dead centre position of their respective pistons 2. Even if it is burnt in the cylinder 1, fuel injected in such a so-called post-injection does not contribute substantially to the mechanical power of the engine, but causes a significant increase in the temperature of exhaust gas from the engine, by which the filter 12 is heated.

[0028] Particulate filter 12 comprises a body of porous material into which dead-end holes extend from upstream and downstream sides thereof, respectively. When the engine is running, soot particles are at first collected within the pores of filter material, and, in a later stage, a layer of collected particles begins to build up on the walls of the upstream holes.

[0029] The ECU 14 controls fuel injection into the combustion chamber 1 by injection valve 7, throttle valve 5 position and the amount of exhaust gas recirculation at EGR valve 6 based on an airflow rate detected at airflow meter 4, engine speed, accelerator pedal position, etc. Since these functions of the ECU 14 are known to the man of the art, they need not be described further here.

[0030] The ECU 14 further has the task of estimating the amount of soot accumulated in particulate filter 12 and to decide, based on this estimated quantity, whether it is necessary to regenerate particulate filter 12 or not.

[0031] Fig. 2 is a block diagram of sub-units of ECU 14 for estimating the amount of soot. A skilled person will readily recognize that these sub-units can be implemented by circuitry or by software.

[0032] A mission profile diagnostic unit 15 of ECU 14 has inputs for various operation parameters of the engine, such as engine speed ω, airflow rate AR, engine temperature T, a gear ratio GR of a transmission, not shown, driven by the engine of fig. 1. Other parameters, such as engine temperature, vehicle speed, etc. may also be input into diagnostic unit 15.

[0033] For selecting a current mission profile of the vehicle, diagnostic unit 15 mainly uses the engine speed ω and engine torque M, as indicated by a diagram drawn into the square of diagnostic unit 15 in fig. 2. Typically, there may be an area 16a characterized by very low engine speeds and torques, corresponding e.g. to parking manoeuvres, an area 16b at high engine speeds and low torque, corresponding to downhill driving, an area 16c at low engine speed and low to intermediate torque corresponding to slow urban traffic, an area 16d of intermediate engine speed and torque corresponding to fast urban traffic, an area 16e at low to intermediate engine speed and high torque corresponding to uphill driving or hauling and high speed areas 16f, 16g corresponding to highway driving. In order to judge the mission profile correctly, not only current engine speed and torque values are taken into account, but also past ones, e.g. by averaging or any other appropriate type of temporal filtering, so that short-time variations of engine speed and torque will not cause the diagnostic unit 15 to switch to another mission profile. The other parameters not shown in the diagram may be used for distinguishing between the other types of mission profiles or for carrying out plausibility check of a mission profile selected based on engine speed and torque.

[0034] A typical soot generation rate associated to each mission profile and specified e.g. as soot mass per unit of time is stored in diagnostic unit 15. The soot generation rate SR associated to the currently selected mission profile is output from diagnostic unit 15 to a multiplexer 17.

[0035] A fuel limiting unit 18 receives at least some of the operating parameters that are input into diagnostic unit 15. The fuel limiting unit 18 stores a characteristic also referred to as a soot map which defines, as a function of said operating parameters, an upper limit of the fuel rate that may be injected into cylinders 1. The soot map is determined experimentally by the engine manufacturer based on measurements of the soot generation rate of the engine under various operating conditions.

[0036] If the set of operating parameters input into the fuel limiting unit is "complete", i.e. if the soot generation rate of the engine is uniquely determined by these operating parameters, the soot map may specify for any combination of values of these operating parameters a limit fuel supply rate LFR yielding a predetermined maximum admissible soot rate.

[0037] In most practical cases, the set of input operating parameters is not complete, i.e. the soot generation rate depends also on operation parameters which are not input into fuel limiting unit 18. In that case the soot map will specify, for any combination of values of the input parameters, a limit fuel rate LFR at which the maximum admissible soot generation rate is not exceeded regardless of values the parameters not input into fuel limiting unit 18 may have.

[0038] The position of the accelerator pedal is not regarded as an operating parameter of the engine. A signal AC representative of this position is received by a fuel metering unit 19 which calculates from it a target fuel rate TFR.

[0039] A minimum detection unit 20 receives fuel rate signals LFR and TFR and outputs the smaller one of these as a fuel rate control signal FR to injection valve 7, so that the rate of fuel which is actually supplied to the engine is the smaller one of the rates specified by LFR and TFR.

[0040] Fuel rate signals LFR and TFR are also supplied to a comparator 21. The output of the comparator 21 controls a soot rate calculator 22 to calculate a transient soot rate TSR based on the operating parameters whenever LFR is less than TFR. A multiplexer 17 supplies this transient soot rate TSR instead of the stationary soot rate SR from diagnostic unit 15 to an integrator 23. The output of the integrator 23 corresponds to the estimation of the amount of soot accumulated in particulate filter 12. If the output of integrator 12 exceeds a predetermined constant, ECU 14 regenerates particulate filter 12, calculates a residual amount of soot that will be left over in filter 12 after the regeneration based on regeneration conditions and the mission profile at the time of regeneration, and sets the the integrator 23 to the calculated amount when the regeneration is finished.

[0041] The predetermined constant can be the same for all mission profiles; preferably, different values are used for the threshold depending on the currently selected mission profile. As a rule, high speed mission profiles are more suitable for regeneration than low speed ones, so that a lower threshold may be set for the former than for the latter.

[0042] Fig. 3 is an example of a flowchart of the operation of ECU14. In step s1, current engine speed ω or airflow rate AR are detected. In case of a motor vehicle without a turbocharger, it will generally be sufficient to detect one of these two operating parameters; in case of a vehicle with a turbocharger as shown in fig. 1, both parameters may be detected, and if the airflow rate is different from what would be expected based on the engine speed under steady state conditions, it can be judged that the engine is accelerating or decelerating, and that the detected values should therefore not be used in subsequent step s2.

[0043] Step s2 selects or updates a current mission profile based on present and past values of ω and/or AR.

[0044] Based on an accelerator pedal position AC detected in step s3, a target fuel rate TFR is set in step s4. Step s5 decides whether this target fuel rate TFR exceeds a limit fuel rate LFR which is calculated based on the current engine speed ω and/or airflow rate AR.

[0045] If the target fuel rate TFR is lower, it is set as the current fuel rate FR to be injected into the cylinders 1 in step s6, and the estimated soot amount is incremented by the soot rate SR, which is a function of the current mission profile. The method then returns to step s1.

[0046] If the target fuel rate TFR is higher than the limit fuel rate LFR, the limit fuel rate LFR is set as the fuel rate to be injected FR in step s8. The soot amount is then incremented in step s9 by the transient soot rate TSR, which is a function of the limit fuel rate LFR associated to the present gear ratio.

[0047] The method may then repeat the detection of the current engine speed ω or air flow rate AR in step s10. The values detected in step s10 will generally be higher than those of previous step s1, i.e. there is more air available for burning the fuel. The limit fuel rate LFR is therefore recalculated in step s11, and then the method returns to step s5. Steps s8 to s11 are thus repeated in a loop until the engine has accelerated so much that fuel may be injected at the target fuel rate TFR set in step s4. A new steady state has then been reached, in which soot generation is moderate and is modelled with appropriate precision based on the mission profile. In between, in every iteration of step s9, the estimated soot amount has been incremented by the same value determined at the beginning of the transition.

[0048] As an alternative, the method might return directly to step s1 after executing step s9. In this way, the target fuel rate TFR is adapted if the driver changes the position AC of the accelerator pedal during the acceleration, and also the transient soot rate TSR by which the estimated soot amount is incremented in step s9 is continuously updated during the acceleration based on current operating parameters.

List of reference signs

combustion chamber	1
piston	2
intake manifold	3
airflow meter	4
throttle valve	5
EGR valve	6
fuel injection valve	7
exhaust duct	8
exhaust catalyst	9
exhaust recirculation line	10
turbine	11
particulate filter	12
temperature/pressure sensor	13
ECU	14
diagnostic unit	15
area	16a-16g
multiplexer	17
fuel limiting unit	18
fuel metering unit	19
minimum detection unit	20
comparator	21
soot rate calculator	22
integrator	23

Claims

1. A method for estimating the soot load of a particulate filter (12) in the exhaust system of a motor vehicle, wherein

a) a mission profile of the motor vehicle is selected (S2) based on the history of one or more operation parameters (ω, AR) of the vehicle;
b) the estimated soot load is increased (S7) at a rate (SR) associated to the currently selected mission profile;
c) a target fuel injection rate (TFR) of an engine of the motor vehicle is determined (S4) based on input from a driver (S3);
characterized in that
d) a limit fuel injection rate (LFR) is determined based on a set of operation parameters comprising at least one of the engine speed and the engine airflow;
e) in a time interval in which the target fuel injection rate (TFR) exceeds the limit fuel injection rate (LFR), the estimated soot load is increased (S9) at a rate (TSR) associated to an instantaneous value of at least one of said operation

parameters.

2. The method of claim 1, wherein while the target fuel injection rate (TFR) exceeds the limit fuel injection rate (LFR), the rate (FR) of fuel actually injected into the engine is set (S8) equal to the limit fuel injection rate (TFR).

3. The method of claim 1 or 2, wherein said set of operation parameters further comprises a gear ratio (GR) .

4. The method of any of the preceding claims, wherein the motor vehicle comprises a turbocharger and the set of operation parameters comprises at least both of the engine speed (ω) and the engine airflow (AR).

5. The method of any of the preceding claims, wherein the limit fuel injection rate (LFR) is pre-defined as a function of said set of operation parameters such that at the limit fuel injection rate the rate of soot generation is constant and independent from the operation parameters of said set.

6. The method of any of claims 1 to 4, wherein the rate at which the estimated soot load is increased in step e) is constant while step e) lasts.

7. The method of claim 6, wherein the limit fuel injection rate (LFR) is pre-defined as a function of said set of operation parameters such that for any practical combination of values of said operating parameters the rate of soot generation does not exceed a predetermined constant rate, and said constant rate is taken as the rate (TSR) at which the estimated soot load is increased (S9) in step e) .

8. The method of claim 6, wherein throughout the time interval of step e) the rate (TSR) at which the estimated soot load is increased (S9) is determined based on the instantaneous value of said at least one operation parameter at the beginning of said time interval.

9. The method of any of claims 1 to 4, wherein in the time interval of step e) the rate (TSR) at which the estimated soot load is increased (S9) is updated.

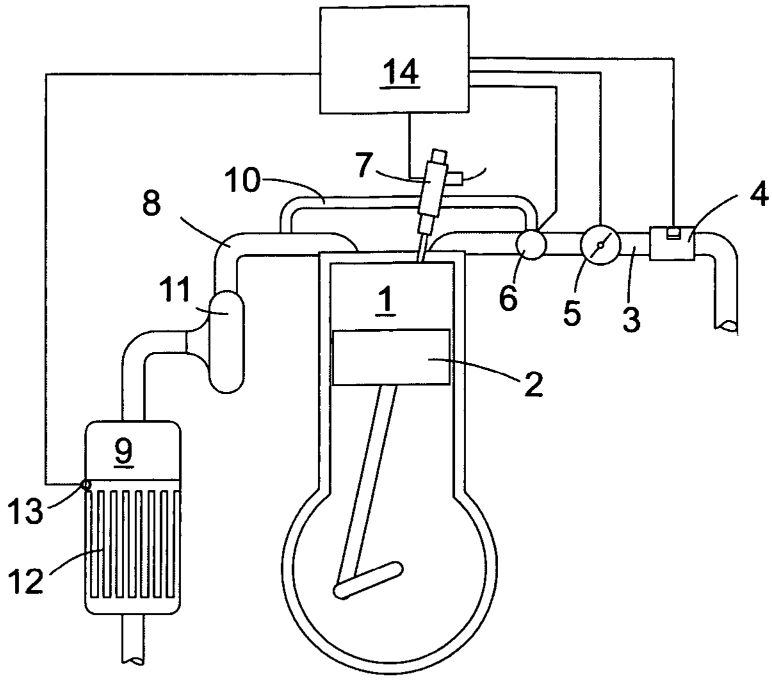
10. A method for controlling regeneration of a particulate filter (12) in the exhaust system of a motor vehicle, wherein the soot load accumulated in the filter (12) is estimated by a method according to one of the preceding claims and a decision to regenerate the filter is taken based on the thus estimated accumulated soot load.

11. A data processor program product comprising a data carrier in which program instructions for enabling a data processor to carry out the method of one of claims 1 to 10 are recorded in machine-readable form.

12. An apparatus for estimating the soot load of a particulate filter (12) in the exhaust system of a motor vehicle, comprising

a) means (15) for selecting a mission profile of the motor vehicle based on the history of one or more operation parameters of the vehicle;
b) means (23) for increasing the estimated soot load at a rate (SR) associated to the currently selected mission profile;
c) means (14, 7) for determining a target fuel injection rate (TFR) of an engine of the motor vehicle based on input from a driver;
characterized by
d) means (18) for determining a limit fuel injection rate (LFR) based on a set of operation parameters comprising at least one of the engine speed (ω) and the engine airflow (AR);
e) means (15, 23) for increasing, in a time interval in which the target fuel injection rate (TFR) exceeds the limit fuel injection rate (LFR), the estimated soot load at a rate associated to an instantaneous value of at least one of said operation parameters.

Fig. 1


14
7
10
8
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11
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6
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3
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13
12

Fig. 2

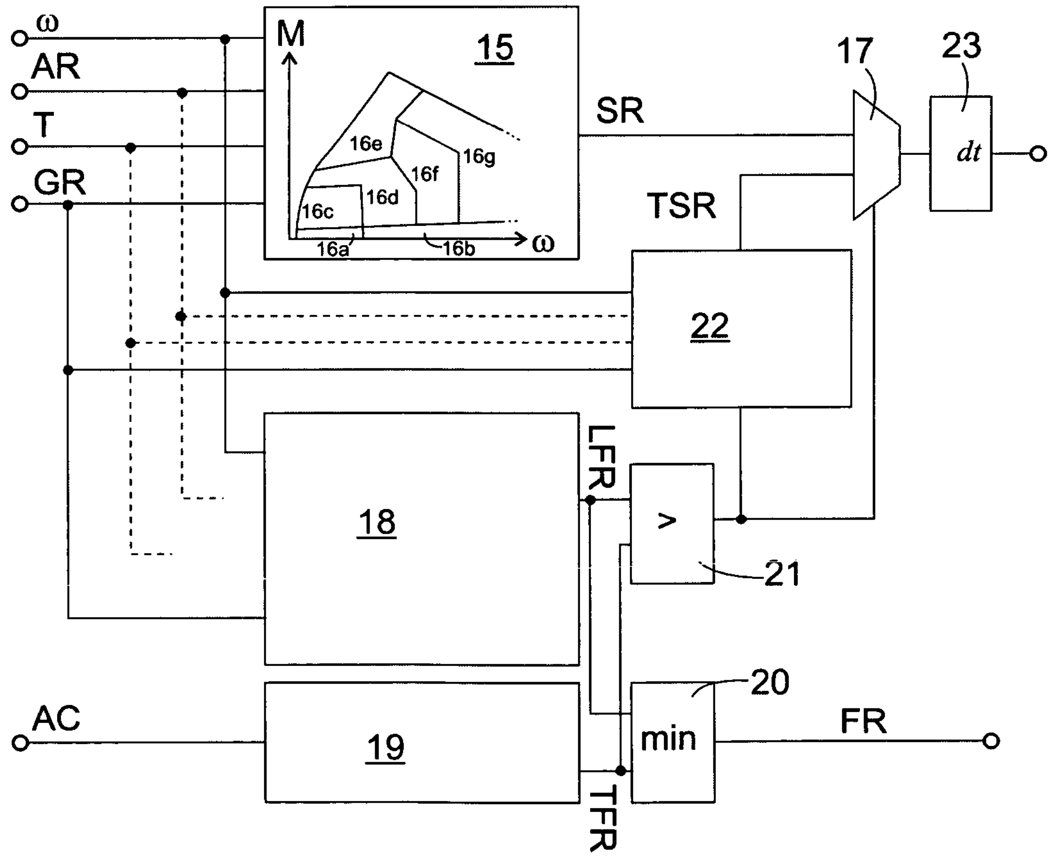
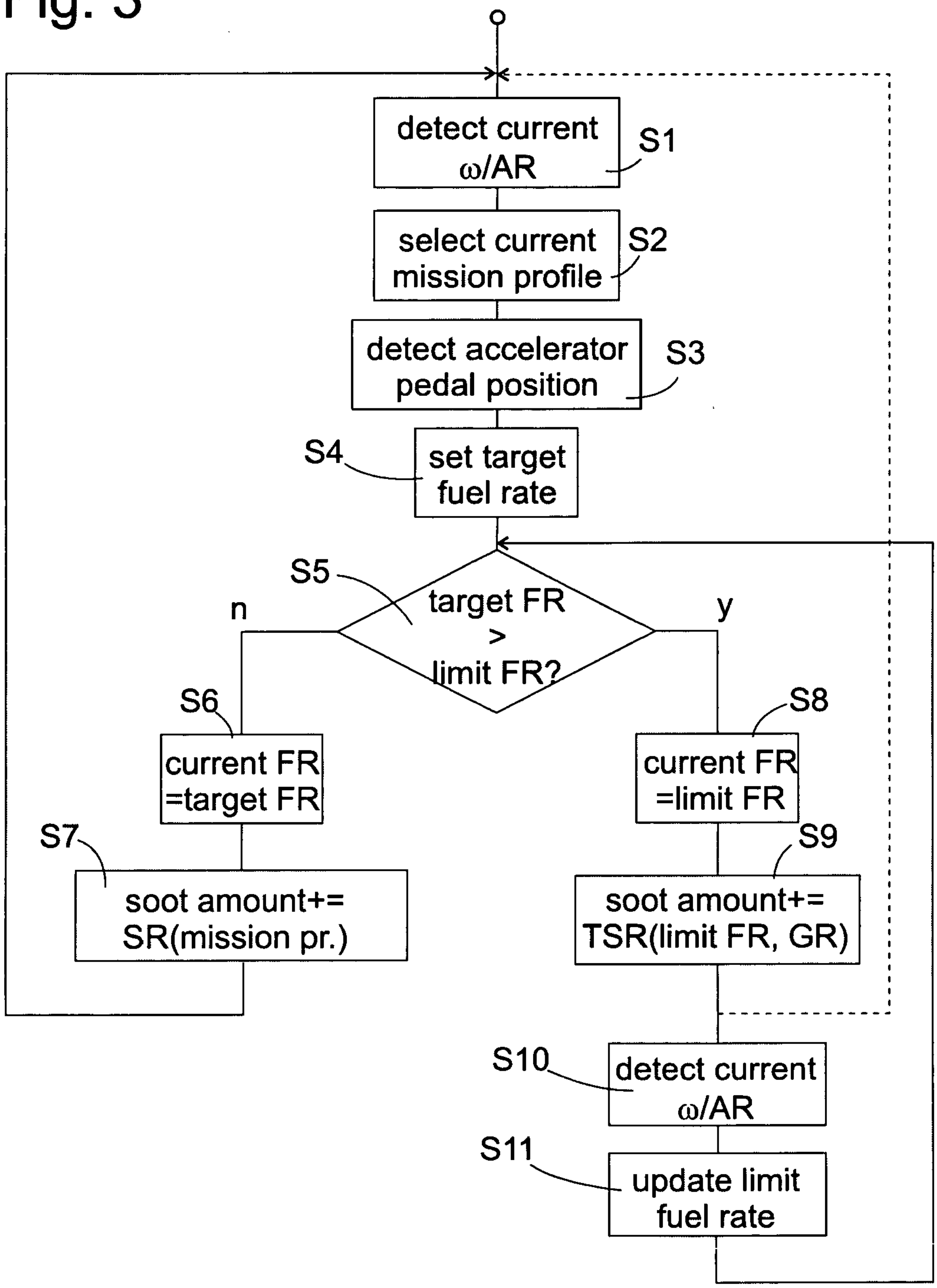

ω
AR
T
GR
M
15
16e
16g
16f
16d
16c
16a
16b
ω
SR
17
23
dt
TSR
22
LFR
18
>
21
20
AC
19
min
FR
TFR

Fig. 3


detect current ω/AR
S1
select current mission profile
S2
detect accelerator pedal position
S3
S4
set target fuel rate
S5
target FR > limit FR?
n
y
S6
current FR =target FR
S7
soot amount+= SR(mission pr.)
S8
current FR =limit FR
S9
soot amount+= TSR(limit FR, GR)
S10
detect current ω/AR
S11
update limit fuel rate

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 08 00 2631

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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TECHNICAL FIELDS SEARCHED (IPC)
F02D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	29 July 2008	Jackson, Stephen

CATEGORY OF CITED DOCUMENTS

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