PROCESS FOR THE REMOVAL OF PARTICULATES FROM THE EXHAUST GAS OF AN INTERNAL COMBUSTION ENGINE

The process comprises the operations of: arranging a particulate filter (PT) in the exhaust duct (EP), generating, by indicator devices (S1-S5), electrical signals indicative of the values of parameters (NQ) of the operation of the engine (ICE); performing filter regeneration phases of the filter (PT) by controlling the injectors (II-I4) of the engine (ICE) in such a way as to cause a controlled increase in the temperature of the exhaust gas so as to cause combustion of the particulates accumulated in the filter (PT), identifying on the basis of signals provided by at least some of the indicator devices (S1-S5) the type of journey or trip (MP) currently being made by the motor vehicle from among a plurality of predefined types of journey or trip (MP1-MP4); calculating, according to a predefined estimation function, and in dependence on the instantaneous type of journey or trip (MP), the quantity (Q) of particulates gradually accumulated in the filter (PT); and starting a filter regeneration phase of the filter (PT) when the calculated quantity (Q) of particulates accumulated in the filter (PT) exceeds a predetermined threshold.

[Continued on next page]
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— of inventorship (Rule 4.17(iv)) for US only
Process for the removal of particulates from the exhaust gas of an internal combustion engine

The present invention relates to the process for the removal of particulates from the exhaust gas of an internal combustion engine, in particular a diesel engine of a motor vehicle, provided with a plurality of fuel injectors.

More specifically, the subject of the present invention is a process comprising the operations of:

arranging a filter in the exhaust pipe of the engine, operable to retain the particulates contained in the exhaust gas;

...generating, by means of indicators, electrical signals indicative of the values of engine operating parameters; and

...performing filter regeneration phases, by means of processor and control means, by controlling the fuel injectors of the engine in a predetermined manner as a function of the signals provided from the said indicator means, in such a way as to cause a controlled increase in the temperature of the exhaust gas sufficient to cause combustion of the particulates accumulated in the filter.

Processes or methods of this type are known which make it possible to control regeneration of the filtration device (the so called "trap" for the particulates) utilising strategies based essentially on only the distance travelled by the motor vehicle and on a counter pressure signal provided by a sensor in the exhaust pipe.

These prior art methods do not make it possible to take into account the various different driving conditions which significantly influence the regeneration processes of the
particulates accumulated in the "trap" with consequent of
deterioration in the reliability of the motor vehicle and its
fuel consumption.

One object of the present invention is to provide a process
which makes it possible to overcome the disadvantages of the
prior art arrangements described above.

This object is achieved according to the invention with a
process the characteristics of which are defined in the
annexed Claim 1.

Further characteristics and advantages of the invention will
become apparent from the following detailed description,
given purely by way of non-limitative example, with reference
to the attached drawings, in which:

Figure 1 is a systematic representation of a system
operating according to the invention;

Figure 2 is a graph which qualitatively demonstrates, as
a function of the speed of rotation of the engine \( n \) plotted
on the abscissa, the quantity \( q \) of fuel injected into the
engine, for the various types of journey or trip of a motor
vehicle;

Figure 3 is a block diagram which illustrates one
control mode for controlling the quantity of fuel injected
into the cylinders of the engine in a post-injection phase,
in a process according to the invention; and

Figure 4 is a further diagram which shows, as a function
of the type \( t' \) of regeneration used, plotted on abscissa, the
variation of a function which represents concentration of
particulates in the filter during a regeneration phase.
With reference to the drawings, in Figure 1 the reference number ICE generally indicates an internal combustion engine, for example a diesel cycle engine. In the illustrated example this engine has four cylinders C1-C4 disposed in line, but the invention is not limited to this configuration.

Each of the cylinders of the engine ICE is associated with a respective injector I1-I4, controlled by an electronic unit ECU.

The engine ICE is associated with an exhaust manifold EP, in which, in the illustrated example, and in a manner known per se, are fitted first and second catalytic converters CC1 and CC2. Associated with the second, which is disposed downstream of the first, is a particulate filtration device indicated PT. An electric temperature sensor TS is associated with the input of the filter PT to provide, in operation, electrical signals indicative of the temperature of the exhaust gas at the inlet of this filter.

The sensor TS is connected to an electronic processor and control unit PCU. In the exemplary embodiment illustrated in Figure 1 this unit PCU is shown as a separate and distinct element from the unit ECU which controls the engine injectors. It will be apparent to those skilled in the art, however, that in place of two physically separate interconnected units, it is possible to make use of a single electronic unit arranged to perform the functions of both the units ECU and PCU.

To the unit PCU are further connected devices S1-S5 which provide it with electrical signals indicative of the speed of rotation n (number of revolutions per unit of time) of the
engine ICE, the quantity \( q \) of fuel injected into the cylinders of the engine ICE, the temperature \( T_c \) of the coolant liquid of the engine ICE, the atmospheric pressure \( P \) and the temperature \( T_A \) of the aspirated air.

Memory devices \( M \) are also associated with the unit PCU. Although in Figure 1 these memory devices are illustrated as separate from the unit PCU it will be apparent to the man skilled in the art that such memory devices could be integrated in the PCU memory or even in the unit ECU.

The processing and control unit PCU is arranged to perform, in cooperation with unit ECU, filter regeneration phases of the filter PT by controlling the fuel injectors II-I4 in a predetermined manner as a function of the signals provided by the devices S1-S5 and TS in such a way to cause a controlled increase in the temperature of the exhaust gas so as to cause combustion of the particulates accumulated in the said filter.

In the above-described system the processing and control unit PCU is, for this purpose, arranged to identify in operation the type of journey or trip in which the motor vehicle is engaged at any instant from among a plurality of predetermined types of journey or trip. The identification of the type of journey or trip is performed on the basis of the signals provided from the devices S1 and S2, that is to say as a function of the instantaneous speed of rotation \( n \) of the engine ICE and of the quantity of fuel \( q \) injected into the said engine.

The type of journey or trip which the motor vehicle is making is determined on the basis of the results of a statistical
analysis, and on the basis of a diagram of the type qualitatively illustrated in Figure 2. In this figure the quantity $q$ of fuel injected is plotted on the ordinate as a function of the speed of rotation $n$ of the engine. In this figure the curve indicated $A$ is the curve corresponding to operating condition of the engine with the accelerator pressed 100%, that is to say the curve corresponding to the maximum delivery of power by the engine ICE.

The region underlying the curve $A$ is divided, (on the basis of experimental detections) into a plurality of ranges of values each corresponding to the profile of a particular type of journey or trip of the motor vehicle. In the illustrated example there are indicated substantially four ranges indicated MP1-MP4 corresponding, in order, a type of journey or trip in the city ("urban driving"), a mountain journey, motorway driving and, finally the so-called mixed journeys.

A diagram of the type illustrated by way of example in Figure 2 is memorised in the system, for example in the memory devices $M$ associated with the unit PCU, for example in the form of the table or map. In operation the unit PCU is arranged to acquire the signals indicative of the speed of rotation $n$ and of the injected quantity $q$ of fuel, and to average the corresponding values, acquired for example each 20 ms within the ambit of a movable time window, for example of 5 minutes. On the basis of the averaged values thus obtained the unit PCU determines the type of trip or current journey profile $M_{Pi}$ (with $i=1,\ldots,4$ in the example of Figure 2).

The processing and control unit PCU is, moreover, set up to calculate, as a function of a predefined estimate, and in
dependence on the type of journey or trip \( M_{\text{pi}} \), the quantity \( q \) of particulate material gradually accumulated in the filter \( PT \), and to start the regeneration phase of this filter when the quantity of particulates accumulated in the filter, as calculated, exceeds the predetermined threshold.

The unit PCU in particular is arranged to calculate the quantity of particulates \( Q \) accumulated in the filter \( PT \) on the basis of a predetermined function \( I \) indicative of the rate of accumulation (for example in g/h) of particulates in the filter \( PT \), predetermined and memorised for the said type of journey or trip \( M_{\text{pi}} \) of the motor vehicle. It has been found in this way that the accumulation of particulates in the filter is an essentially linear process over time, depending on the various conditions of use of the engine of the motor vehicle, that is to say to the profile of the various types of journey or trip which the motor vehicle is making. The function \( I = I(t; M_{\text{pi}}) \) is conveniently determined in a statistical manner and is memorised in the system as a function of the various types of journey the vehicle may make.

In operation, the quantity \( Q \) of particulates accumulated at each instant is then calculated by the unit PCU as an integral over time of the various accumulation rates upon variation of the journey or trip profile of the vehicle, essentially according to a relation of the type:

\[
Q = \int_{0}^{t} I(t; M_{\text{pi}}) \, dt + Q_{0}
\]  

(1)

where \( t \) is time, and \( Q_{0} \) represents the so-called initial condition determined by the quantity of particulates
remaining in the filter PT at the end of the preceding regeneration phase.

When the quantity Q of accumulated particulates exceeds the predetermined threshold the unit PCU causes commencement of a new regeneration phase.

Conveniently the comparison threshold is predetermined with prefixed values according to the type of journey or trip which the motor vehicle is making at the time.

In the regeneration phase a spontaneous combustion of the particulates takes place as soon as and as long as the exhaust gas of the engine, at the inlet of the filter itself, reaches temperatures greater than a predetermined value, for example 650°C, in the presence of a sufficient percentage of oxygen.

The processing and control unit PCU is arranged to control the temperature in the filter itself during a filter regeneration phase of the filter PT, causing a controlled increase of the exhaust gas temperature resulting in combustion of the particulates accumulated in the filter.

Control of the temperature during the regeneration process of the filter PT can conveniently take place according to the diagram of Figure 3. In conformity with this diagram the unit PCU is arranged to make an open loop determination of the partial quantity of fuel PIQ to be introduced into the cylinders C1-C4 of the engine ICE in a post-injection phase, in dependence on the speed of rotation n of the engine and the overall quantity q of fuel to be injected into the cylinders at each injection. The determination of the partial
quantity PIQ of fuel to be injected in the post injection phase is determined for example by means of a map (map PIQ) stored in the memory devices M.

The unit PCU is moreover arranged to modify the said partial quantity of fuel PIQ to be injected into the engine in the post injection phase, by adding/subtracting a first correction quantity \( \Delta PIQ_1 \) determined according to a mapped function of the speed of rotation \( n \) of the engine and the quantity \( q \) of fuel injected into the cylinders "weighted" as a function of the values assumed by some ambient quantities (such as the air temperature \( T_a \) and the atmospheric pressure \( P \)) and engine quantities (such as temperature \( T_c \) of the engine coolant), via a factor \( W_1 \) obtained by means of a suitable pre-memorised weighting map. The quantity PIQ is further modified by adding/subtracting from it a second correction quantity \( \Delta PIQ_2 \), generated in an open loop determination as a function of the difference between the effective temperature \( T \) of the exhaust gas at the inlet of the filter PT (detected by means of the sensor TS) and a predetermined reference temperature \( T_{sp} \). The correction quantity \( \Delta PIQ_2 \) can conveniently be determined by means of a PID governor (Proportional-Integral-Derivative).

Subsequently, following a further conditioning through a factor \( W_2 \) obtained from a suitable map as a function of the value of the temperature \( T \) of the exhaust gas, the effective partial quantity of fuel \( \Delta PIQ \) to be injected into the engine in the post-injection phase during the regeneration process of the filter is obtained.

The process and control unit PCU is arranged to end a regeneration phase of the filter PT after a predetermined
working time $t^*$ has passed since the beginning of this regeneration, which is conveniently variable in a predetermined manner as a function of the type of journey or trip MPI made by the motor vehicle during the regeneration. The working time $t^*$ is defined as the percentage of time for which the temperature in the filter PT is effectively above the predetermined value (for example $650^\circ$).

The unit PCU is further arranged to calculate the residual quantity $Q_0$ of unburnt particulates in the filter, at the end of a filter regeneration phase, according to a further predetermined estimation function, and to assume this residual quantity as the initial value for the calculation of the quantity of particulates accumulated in the filter starting from the end of this regeneration phase.

The residual particulates at the completion of regeneration is conveniently calculated in a variable manner as a function of the type of journey or trip made during regeneration.

If a regeneration phase is interrupted the residual particulates can be calculated on the basis of an estimation function such as that (essentially a decreasing exponential) which is qualitatively shown in Figure 4.

In this Figure, along the ordinate is plotted the rate of percentage decrease $I^*$ of the particulates in the filter during regeneration upon variation of the regeneration working time $t^*$ which is plotted along the abscissa.

This function can also be utilised in particular to estimate the residual quantity of unburnt particulates in the filter
PT when, during a filter regeneration phase, the motor ICE is switched off before completion of this regeneration phase.

Naturally, the principle of the invention remaining the same, the embodiments and details of construction can be widely varied with respect to what has be described and illustrated purely by way of non-limitative example, without by this departing from the ambit of the invention as defined in the annexed claims.
CLAIMS

1. A process for the removal of particulates from the exhaust gas of an internal combustion engine, in particular a diesel engine (ICE) of a motor vehicle provided with a plurality of fuel injectors (I1-I4) the process comprising the operations of:

   arranging a filter (PT) in the exhaust duct (EP) of the engine (ICE) operable to retain the particulates contained in the exhaust gas;

   generating, by indicator means (S1-S5), electrical signals indicative of the values of operating parameters (NQ) of the engine (ICE);

   performing, by processor and control means (PCU, ECU) filter regeneration phases of the filter (PT) by controlling the injectors (I1-I4) of the engine (ICE) in a predetermined manner as a function of the signals provided by the said indicator means (S1-S5) in such a way as to cause an increase in the temperature of the exhaust gas so as to cause a combustion of the particulates accumulated in the filter (PT);

   the process being characterised by the operations of:

   identifying, by means of the said processor and control means, (PCU, ECU) and on the basis of signals provided by at least some of the said indicator means (S1-S5) the type of journey or trip (MPi) currently being made by the motor vehicle from among a plurality of predefined types of journey or trip (MP1-MP4);

   calculating by means of the said processor and control means (PCU, ECU) and according to a predefined estimation function in dependence on the instantaneous type of journey or trip (MPi) the quantity of particulates (Q) gradually accumulated in the filter (PT); and
starting a filter regeneration phase of the filter (PT) when the calculated quantity (Q) of particulates accumulated in the filter (PT) exceeds a predetermined threshold.

2. A process according to Claim 1, in which the said threshold is determined by predetermined values according to the instantaneous type of journey or trip (MPi) of the motor vehicle.

3. A process according to Claim 1 or Claim 2, in which the said indicator means (S1-S5) are operable to provide to the processor and control means (PCU) and (ECU) electrical signals indicative of the instantaneous values of the speed of rotation \((n)\) of the engine (ICE) and the quantity \((q)\) of fuel injected into the engine (ICE); and the processor and control means (PCU, ECU) are arranged to recognise the type of journey or trip (MPi) of the motor vehicle on the basis of instantaneous values of the speed of rotation \((n)\) of the engine (ICE) and the quantity \((q)\) of fuel injected.

4. A process according to any of Claims from 1 to 3, in which the said processor and control means (PCU, ECU) are arranged to calculate the quantity \((Q)\) of particulates accumulated in the filter (PT) on the basis of a predetermined function \((I)\) indicative of the rate of accumulation of the particulates (PT) memorised for the said types of journey or trip (MPi) of the motor vehicle.

5. A process according to Claim 4, in which the said function \((I)\) indicative of the rate of accumulation is a linear function in time which is different for each type of journey or trip (MPi) of the motor vehicle.
6. A process according to any of Claims 1 to 5, in which the said processor and control means (PCU, ECU) are arranged to terminate a filter regeneration phase of the filter (PT) after a predetermined working time (t') has elapsed since commencement, which time is variable in a predetermined manner as a function of the types of journey or trip (MPi) made by the motor vehicle during regeneration.

7. A process according to Claims 4 and 6, in which the said processor and control means (PCU, ECU) are arranged to calculate, at the end of a filter regeneration phase of the filter (PT) the residual quantity of unburnt particulates in the filter (PT) as a function of the type of journey or trip made during regeneration, and to assume this residual quantity as the initial value (Q₀) for the calculation of the quantity (Q) of particulates accumulated in the filter starting from the end of this regeneration phase.

8. A process according to Claim 7, in which the said processor and control means (PCU, ECU) are arranged to be able to calculate, by means of a predetermined estimation function, the residual quantity of unburnt particulates (Q₀) in the filter (PT) in the case of interruption of a filter regeneration phase (PT) or when the engine (ICE) is switched off during a filter regeneration phase (PT).
FIG. 2

- URBAN DRIVING
- MOUNTAIN DRIVING
- MOTORWAY DRIVING
- MIXED JOURNEYS

q

p
A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F02D41/02 F01N3/023 F01N9/00

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)
IPC 7 F02D F01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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