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(54) Method for operating an exhaust gas purification system

(57) The invention concerns a method for operating an exhaust gas purification system, said system comprising a controllable internal combustion engine adapted to predominantly operate under lean conditions, and a NO_x-adsorbing unit capable of storing NO_x during lean conditions and converting NO_x into N_2 during rich or stoichiometric conditions, said system having a capability of oxidizing HC and CO and reducing NO_x under stoichiometric conditions. The invention is characterized in that the method comprises the steps of determining a representation of a mass flow of NO_x in the exhaust gas and a current storage capacity of the NO_x-adsorbing unit, and switching engine operation mode between lean conditions and stoichiometric conditions depending on the representation of the NO_x mass flow in the exhaust gas and the current storage capacity of the NO_x-adsorbing unit.

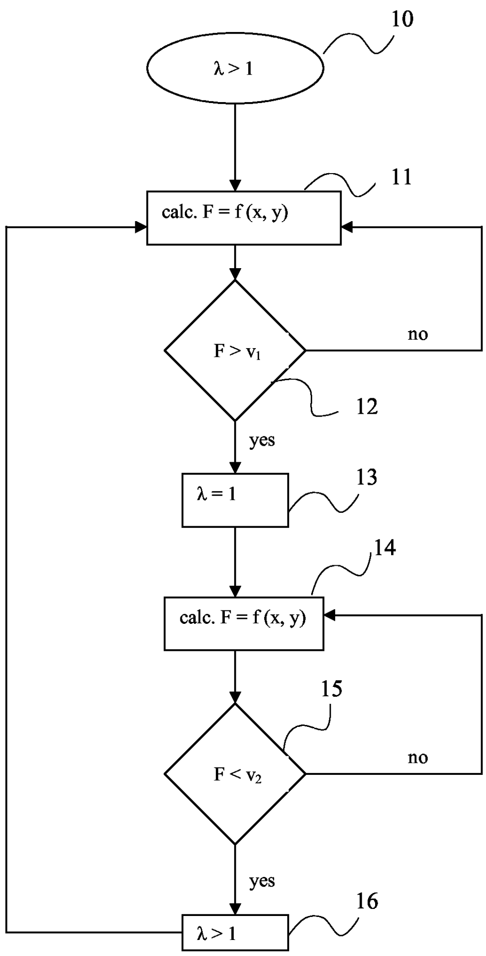

Fig. 2

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Description

TECHNICAL FIELD

[0001] The invention relates to a method for operating an exhaust gas purification system comprising an internal combustion engine, in particular, a diesel engine.

BACKGROUND ART

[0002] Purification of exhaust gas emanating from internal combustion engines is generally a matter of converting hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x) and/or particulate matter (PM) into less hazardous compounds. For engines operating at a stoichiometric air-to-fuel ratio (A) a conventional three-way catalyst is normally capable of converting HC, CO and NO_x in a sufficiently efficient way. For engines operating at a high air-to-fuel ratio (A) (i.e. under lean conditions) such as Diesel engines and lean-burn Otto engines the main problem is to reduce NO_x to nitrogen (N_2) since HC and CO are readily oxidized in the excess of oxygen. In addition, depending on the type of engine, there may also be a need for treatment of PM.

[0003] In order to convert NO_x in engines operating at a high air-to-fuel ratio (A) so-called NO_x-traps, or NO_x-adsorbents, have been developed. In principle, a NO_x-trap is a device comprising a catalytic material such as precious metals and a NO_x-storing compound such as barium which device is capable of storing NO_x during oxygen-rich, i.e. lean, conditions and reducing NO_x into N_2 during rich or stoichiometric conditions.

[0004] A NO_x-trap has a certain NO_x storage capacity which can be expressed in e.g. gram NO_x storable. When a NO_x-trap is full, i.e. when no more NO_x can be stored, it has to be regenerated. This is conventionally done by controlling the engine as to operate under rich conditions during a short, predetermined or sensor determined, time period, usually a number of seconds, during which time period the stored NO_x is converted. The storage capacity is mainly dependent on the temperature and decreases considerably above around 450°C.

[0005] Under normal conditions NO_x-traps generally work well and are efficiently regenerated. However, NO_x-traps, or exhaust gas purification systems including NO_x-traps, have not yet been optimized for more special conditions, such as high-load situations with a high NO_x mass flow and high exhaust temperatures.

DISCLOSURE OF INVENTION

[0006] An object of this invention is to provide a method for operating an exhaust gas purification system that reduces the emissions of hazardous compounds in situations where the temperature of the system is high, e.g. in situations where the engine load is high. This object is achieved by the technical features contained in claim 1. The dependent claims contain advantageous embodiments, further developments and variants of the invention.

[0007] The invention concerns a method for operating an exhaust gas purification system, said system comprising a controllable internal combustion engine adapted to predominantly operate under lean conditions, and a NO_x-adsorbing unit capable of storing NO_x during lean conditions and converting NO_x into N_2 during rich or stoichiometric conditions, said system having a capability of oxidizing HC and CO and reducing NO_x under stoichiometric conditions. The invention is characterized in that the method comprises the steps of: determining a representation of a mass flow of NO_x in the exhaust gas and a current storage capacity of the NO_x-adsorbing unit, and switching engine operation mode between lean conditions and stoichiometric conditions depending on the representation of the NO_x mass flow in the exhaust gas and the current storage capacity.

[0008] Thus, in the first step one determines a representation of two main parameters or of a relation between two main parameters, whereas in the second step one uses the determined value or values as a basis for a decision on whether to switch engine operation mode.

[0009] During lean operation of the engine a representation of the main parameter values, or their relation, form an indicator on whether the NO_x-emissions are, or will get, inadmissibly high in the tailpipe at the present conditions, i.e. with a certain mass flow of NO_x in the exhaust gas, and a certain current storage capacity of the NO_x-adsorbing unit. If, for example, a ratio between the two values reach a certain limit the engine operation mode can be switched to stoichiometric conditions so that the catalytic converter can work as a three-way catalyst and thereby continuously and simultaneously reduce the amounts of NO_x, HC and CO in the exhaust gas. Correspondingly, during stoichiometric operation of the engine a representation of the main parameter values, or their relation, form an indicator on whether the predicted NO_x-emissions are sufficiently low for switching to the normal lean operation mode.

[0010] An advantageous effect of the method according to the invention is that one can avoid a very frequent regeneration of the NO_x-adsorbing unit that conventionally is required when the NO_x mass flow is high and the temperature of the NO_x-adsorbing unit is close to a maximum storage temperature, i.e. when the current storage capacity is relatively small. Frequent regeneration events lead to increased fuel penalty and increased emissions of HC and CO which thus is avoided by the method according to the invention.

[0011] An example of a situation where the inventive method is very useful is when the engine is operated at high load which typically leads to both an increased total exhaust gas mass flow and an increased concentration of NO_x in the exhaust gas flow. It also leads to an increased exhaust gas temperature which heats up the NO_x-adsorbing unit and in turn reduces its NO_x storage capacity.

[0012] A diesel engine is conventionally operated in a lean combustion mode regardless of the load conditions; typically prior art diesel engines operate with an air-to-fuel ratio in the range 1.2 - 1.4 in high load situations. A diesel engine operated according to the inventive method is thus in clear contrast to such a prior art diesel engine.

[0013] A further advantageous effect of the inventive method is that one can avoid instantaneous NO_x breakthrough emissions, i.e. one can avoid that most or all of the NO_x flows straight through the NO_x-adsorbing unit, when the storage capacity of the NO_x-adsorbing unit is very small or zero.

[0014] It should be emphasized that the two main parameters, i.e. the mass flow of NO_x in the exhaust gas and the current storage capacity of the NO_x-adsorbing unit, do not need to be determined by direct means; they are preferably determined indirectly by calculations using a number of measured or calculated sub-parameters, such as engine data and exhaust gas temperatures and concentrations. Neither is it necessary to determine a "true" value of a certain main parameter; depending on how the method is realized it may be sufficient to determine a value that is proportional, or close to proportional, to a certain main parameter or to a function of the two parameters. Thus, it is sufficient to determine a representation of a "true" value. For instance, the current storage capacity of the NO_x-adsorbing unit may be determined by measuring the temperature of the unit and, using a predefined function that describes the dependency of the storage capacity on the temperature, calculating a value in terms of storage capacity in percentage of a nominal, low-temperature storage capacity. Such a calculated value is a "determination of a representation of the current storage capacity of the NO_x-adsorbing unit" with the interpretation that should be used here.

[0015] In a first preferred embodiment of the invention the method comprises the steps of determining a value of a function F, wherein F is a function of at least the mass flow of NO_x in the exhaust gas and the current storage capacity of the NO_x-adsorbing unit, and comparing the value with a predetermined threshold value. Preferably, the method also comprises the step of switching engine operation mode between lean conditions and stoichiometric conditions depending on the relationship between the value of the function F and the threshold value.

[0016] The function F may be calculated in different ways; the point is to use a function that depends on the two main parameters given above, which main parameters in turn may be determined from a number of measured or calculated sub-parameters, and let a calculated value of this function form a part of the input data used for controlling the engine.

BRIEF DESCRIPTION OF DRAWINGS

[0017] In the description of the invention given below reference is made to the following figure, in which:

Figure 1 shows, in a schematic view, an exhaust gas purification system to which the inventive method can be applied, and

Figure 2 shows a flow chart that schematically describes a first embodiment of the invention.

EMBODIMENT(S) OF THE INVENTION

[0018] Figure 1 shows, in a schematic view, an example of an exhaust gas purification system 1 to which the inventive method can be applied. The system comprises a controllable internal combustion engine 3 adapted to predominantly operate under lean conditions, such as a diesel engine; a combined NO_x-adsorbing unit/catalytic converter 5 capable of storing NO_x during lean conditions and converting NO_x into N2 during rich or stoichiometric conditions, and with a capability of oxidizing HC and CO and reducing NO_x under stoichiometric conditions; a particulate filter 7 and a control unit 8. An exhaust gas conduit 4 leads exhaust gas from the engine 3 downstream via the combined NO_x-adsorbing unit/catalytic converter 5 and the particulate filter 7 to the tailpipe 4'. The control unit 8 receives input data from the system, such as engine load, engine speed, status of exhaust gas recirculation (EGR) circuit, air intake, fuel consumption, and temperatures of the NO_x-adsorbing unit 5, the particulate filter 7 and at various positions along the exhaust conduit 4. The system may further comprise NO_x and/or lambda sensors located at various positions in the system. Signals from such sensors are preferably also transmitted to the control unit 8. The control unit 8 is further adapted to process selected input data, such as the air-to-fuel ratio (lambda) at a certain position in the system, and control the operation of the engine 3. This type of engine controlling is in principle well known to a person skilled in the art. It may be noted that all input data mentioned above is not required for applying the inventive method as will be further described below.

[0019] With the expression stoichiometric conditions is meant that the air-to-fuel ratio (lambda) is close to 1.0, i.e. the ratio may be a few hundredths below or above 1.

[0020] For the inventive method to be useful it is important that the exhaust aftertreatment system 1 has a three-way catalyst capability, i.e. that the system is capable of oxidizing HC and CO and reducing NO_x under stoichiometric conditions. This capability can be arranged in a separate catalytic converter but, preferably, the NO_x-adsorbing unit 5 is capable of operating as a catalytic converter as exemplified in figure 1. Most conventional NO_x-traps have this capability.

[0021] The inventive method can be advantageously applied in various situations. A first example is when the temperature of the NO_x-trap 5 is relatively close to a maximum storage temperature of the NO_x-trap. Typically, this example would refer to a temperature of approximately 400-450°C for conventional NO_x-traps. In this situation the NO_x storage capacity is reduced, i.e. the current storage capacity is low, which leads to frequent NO_x regeneration events, in particular if the NO_x mass flow is high. Each regeneration leads to a slip of a certain amount of NO_x, HC and CO which amount increases with increasing load. Frequent regeneration leads to increased fuel penalty and increased NO_x, HC and CO break-through. At some point on the regeneration frequency scale the tailpipe emissions, integrated over a certain time period, get so high that it is favourable to switch engine operation mode from the normal lean lambda (i.e. air-to-fuel ratio) strategy, which for a conventional diesel engine means that lambda is approximately 1.3, to a lambda-1 strategy, i.e. stoichiometric conditions. Since the regeneration frequency is a function of the mass flow of NO_x in the exhaust gas and the current storage capacity of the NO_x-adsorbing unit this point on the regeneration frequency scale can be determined from these two main parameters. By applying the inventive method to the conditions of this example the NO_x emissions can be decreased because of the three-way catalyst capability and HC/CO emissions can be decreased because of fewer NO_x regeneration events.

[0022] A second example is when the temperature of the NO_x-trap 5 rises above the maximum storage temperature of the NO_x-trap, i.e. approximately > 450-500°C for conventional NO_x-traps. In this situation most of the NO_x emissions will pass through the NO_x-trap. By switching over from a normal lean engine operation mode to a lambda-1 strategy a three-way catalyst function can be obtained. This has the effect that NO_x-emissions will decrease due to catalytic conversion.

[0023] A third example is when the system is equipped with a diesel particulate filter (DPF) 7 and the exhaust gas has such a high temperature that the DPF reaches its soot ignition temperature, which for conventional catalytic DPFs is approximately 580°C. Also in this situation the NO_x emissions will pass through the NO_x trap. Again, by switching over from the normal engine operation mode, e.g. a conventional lean diesel lambda strategy of around 1.3, to a lambda-1 strategy a three-way catalyst function can be obtained. This has again the effect that NO_x emissions will decrease due to catalytic conversion. In addition, the decreased content of oxygen will result in a well controlled regeneration of the DPF lowering the risk of damaging the DPF due to overheating. A further advantage of this third example is that the high temperature of the exhaust gas is utilized for regeneration of the DPF which means that the number of conventional regenerations of the DPF, i.e. regenerations where the exhaust gas temperature is actively increased by feeding additional fuel to the engine, is reduced. Thereby the fuel consumption is reduced.

[0024] The desired value of lambda used for controlling the engine may correspond to different positions in the exhaust gas purification system. In the third example given above the lambda value referred to is preferably a value measured or calculated downstream the DPF. By using a lambda value downstream the DPF it is possible to achieve a small excess of oxygen in the exhaust gas upstream the DPF, which excess is sufficient for an efficient, but still controlled, regeneration of the DPF. This efficient and controlled regeneration of the DPF can of course also be achieved by controlling the lambda upstream the DPF to a preferred value slightly above one.

[0025] Figure 2 shows a flow chart that schematically describes a first preferred embodiment of the invention. In a starting position 10 the engine is operated in a normal lean mode with $\lambda > 1$. In a first step 11 of the method a function F is calculated. F is a function of x and y, i.e. F depends on, at least, x and y, wherein x denotes the mass flow of NO_x in the exhaust gas and *y* denotes the current storage capacity of the NO_x-adsorbing unit. In a next step 12 the calculated value of F is compared with a first threshold value v_1. If F is less than v_1 step 11 is repeated; if F is greater than v_1 the engine operation mode is in step 13 switched from lean conditions to stoichiometric conditions, i.e. $\lambda = 1$. Step 14 is similar to step 11, i.e. the function F is calculated. In a next step 15 the calculated value of F is compared with a second threshold value v_2. If F is greater than v_2 step 14 is repeated; if F is less than v_2 the engine operation mode is in step 16 switched back to lean conditions, i.e. $\lambda > 1$ and step 11 can be run again.

[0026] The function F can be formulated and calculated in a number of ways. For instance, x, i.e. the mass flow of NO_x in the exhaust gas, can be calculated using various engine data, such as load, air intake, fuel consumption, air-to-fuel condition, engine speed, exhaust gas recirculation (EGR) status, and engine temperature. Further, if a NO_x-sensor is used the exhaust gas concentration of NO_x can be included in the calculations. For instance, a NO_x-sensor positioned upstream the NO_x-adsorbing unit together with an air intake sensor makes it possible to calculate the mass flow of NO_x, but an estimation from a mathematical model based on e.g. air and fuel can also be used.

[0027] The other main parameter y, i.e. the current storage capacity of the NO_x-adsorbing unit, can be calculated using various system data such as exhaust gas temperature, temperature of NO_x-adsorbing unit, degree of sulphur contamination of the NO_x-adsorbing unit, time elapsed since last regeneration of the NO_x-adsorbing unit, and regeneration frequency, which data may be combined with engine data in the calculations. Also the exhaust gas concentration of NO_x obtained from a NO_x-sensor may be used. To obtain the current storage capacity of the NO_x-adsorbing unit a calculated value may be related to a nominal, low-temperature storage capacity. In a refined controlling variant one may include the actual or remaining storage capacity of the NO_x-adsorbing unit in the calculations, i.e. one takes the amount of NO_x already stored into account.

[0028] One example on how to express the function F is to form a ratio between a first function corresponding to the mass flow of NO_x in the exhaust gas and a second function corresponding to the current storage capacity of the NO_x-adsorbing unit. In such a case the first and second functions could be calculated separately from each other. Another example on how to express F is to include a sub-parameter that itself depends on both the mass flow of NO_x in the exhaust gas and the current storage capacity of the NO_x-adsorbing unit. An example of such a sub-parameter is the regeneration frequency. Using the regeneration frequency as the controlling parameter it is not necessary to calculate x and *y* separately; instead one may provide the system with a NO_x-sensor located downstream the NO_x-adsorbing unit and use the signal from this sensor to control the regeneration frequency and, thus, a value of the function F.

[0029] The threshold values that should be used depends of course on how the function F is expressed, but also on the NO_x emissions, the fuel consumption trade-off and the emission legislation. Preferably, slightly different threshold values are used in steps 12 and 15 to create a hysteresis type function and avoid oscillations in the control system.

[0030] The invention has in principal the following effects on the fuel consumption: 1) a decreased air-to-fuel ratio (lambda) increases fuel consumption, 2) no additional storage of NO_x during engine operation at lambda = 1 decreases the need for regenerations which in turn decreases fuel consumption, 3) less need for conventional fuel-consuming DPF regeneration actions decreases fuel consumption and 4) altered trade-off between fuel consumption and engine out NO_x during engine operation at lambda = 1 decreases fuel consumption since NO_x does not have to be considered when optimizing injection timing. As an overall effect the inventive method is capable of decreasing the fuel consumption depending on driving conditions etc.

[0031] The general advantages of the invention may be summarized as: 1) less need for NO_x-trap and DPF regeneration actions, 2) smaller amounts of NO_x, CO and HC in tailpipe emissions and 3) possible decrease in fuel consumption.

[0032] A return to lean engine operation may be initiated when the predicted NO_x-emissions in a lean mode falls below a certain level.

[0033] The invention is not limited by the embodiments described above but a number of modifications are possible within the scope of the claims.

[0034] The method according to the invention may be applied to any internal combustion engine adapted to predominantly operate under lean conditions, such as diesel engines, running on diesel, natural gas, DME or other fuel, or Otto lean-burn engines.

Claims

1. Method for operating an exhaust gas purification system (1), said system comprising

   - a controllable internal combustion engine (3) adapted to predominantly operate under lean conditions, and
   - a NO_x-adsorbing unit (5) capable of storing NO_x during lean conditions and converting NO_x into N_2 during rich or stoichiometric conditions,

   said system having a capability of oxidizing HC and CO and reducing NO_x under stoichiometric conditions,

   characterized in
   that the method comprises the steps of:

   - determining a representation of a mass flow of NO_x in the exhaust gas and a current storage capacity of the NO_x-adsorbing unit (5), and
   - switching engine operation mode between lean conditions and stoichiometric conditions depending on the representation of the NO_x mass flow in the exhaust gas and the current storage capacity of the NO_x-adsorbing unit (5).

2. Method according to claim 1,
   characterized in
   that it further comprises the steps of:

   - determining a value of a function F, wherein F is a function of at least the mass flow of NO_x in the exhaust gas and the current storage capacity of the NO_x-adsorbing unit, and
   - comparing the value with a predetermined threshold value.

3. Method according to claim 2,
   characterized in
   that it further comprises the step of:

   - switching engine operation mode between lean conditions and stoichiometric conditions depending on the relationship between the value of the function F and the threshold value.

4. Method according to anyone of the above claims,
   characterized in
   that it further comprises the step of:

   - monitoring the exhaust gas concentration of NO_x using a NO_x-sensor.

5. Method according to anyone of the above claims,
   characterized in
   that the mass flow of NO_x in the exhaust gas is calculated using one or several of the following parameters: engine load, engine air-to-fuel condition, engine speed, exhaust gas recirculation (EGR) status, engine temperature and exhaust gas concentration of NO_x.

6. Method according to anyone of the above claims,

characterized in
that the current storage capacity of the NO_x-adsorbing is calculated using one or several of the following parameters: exhaust gas temperature upstream the NO_x-adsorbing unit, NO_x-adsorbing unit temperature, exhaust gas temperature downstream the NO_x-adsorbing unit, exhaust gas concentration of NO_x, degree of sulphur contamination of the NO_x-adsorbing unit, time elapsed since last regeneration of the NO_x-adsorbing unit, and regeneration frequency.

7. Method according to anyone of the above claims,
characterized in
that the NO_x-adsorbing unit is capable of oxidizing HC and CO and reducing NO_x under stoichiometric conditions.

8. Method according to anyone of the above claims,
characterized in
that it comprises the step of:

- controlling the engine such that the stoichiometric conditions are achieved downstream a particulate filter positioned downstream the NO_x-adsorbing unit or integrated with the NO_x-adsorbing unit into a single unit.

9. Method according to anyone of the above claims,
characterized in
that the engine is a diesel engine.

10. Exhaust gas purification system comprising

- a controllable internal combustion engine adapted to predominantly operate under lean conditions, and
- a NO_x-adsorbing unit capable of storing NO_x during lean conditions and converting NO_x into N_2 during rich or stoichiometric conditions,
said system having a capability of oxidizing HC and CO and reducing NO_x under stoichiometric conditions,

characterized in
that the system is configured to be run by a method according to anyone of claims 1 to 9.

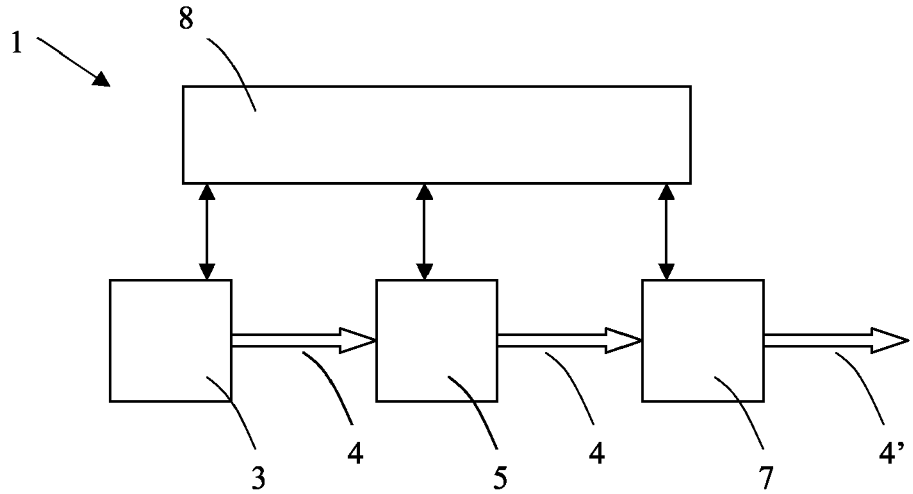

Fig. 1

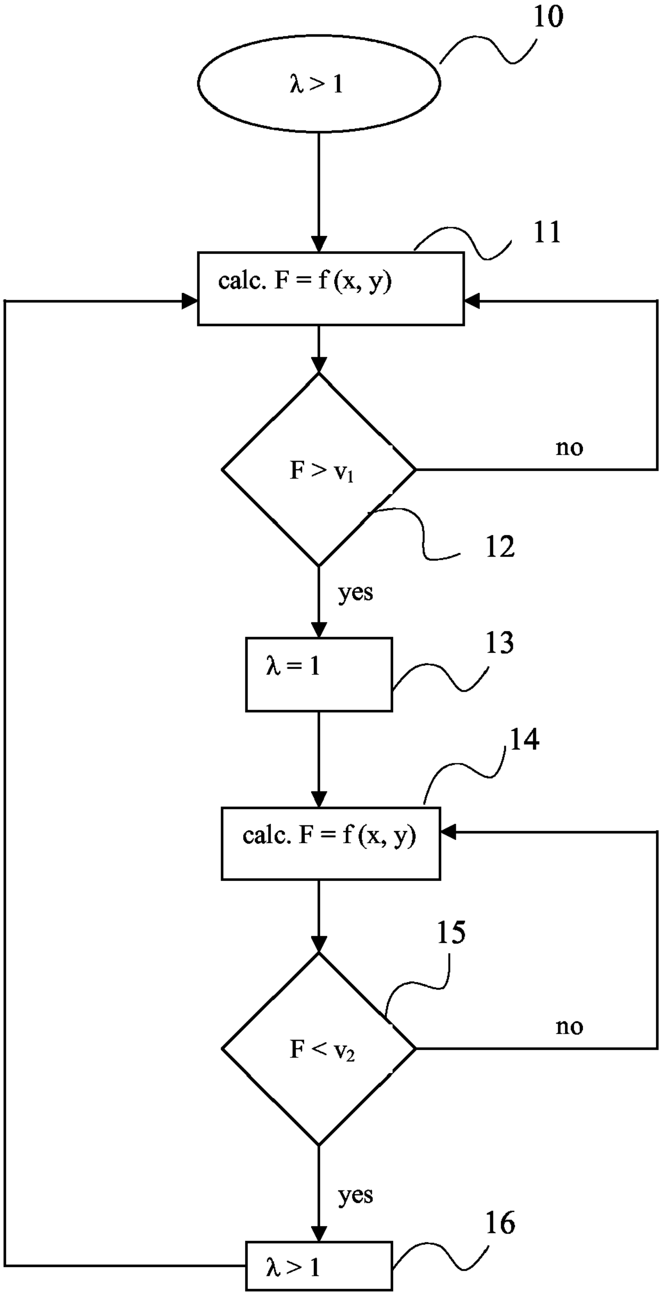
10
λ > 1
11
calc. F = f (x, y)
F > v1
no
12
yes
13
λ = 1
14
calc. F = f (x, y)
15
F < v2
no
yes
16
λ > 1

Fig. 2

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 05 10 5379

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 103 18 116 A1 (ROBERT BOSCH GMBH) 11 November 2004 (2004-11-11) * paragraph [0029] - paragraph [0036] * * figure 3 * -----	1-10	F02D41/02 F01N3/08
X	US 2004/031261 A1 (SUN JING ET AL) 19 February 2004 (2004-02-19) * paragraphs [0005] - [0009] * * paragraph [0030] - paragraph [0045] * * figures 3a,3b,4 * -----	1-10	
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A	US 2003/093988 A1 (SURNILLA GOPICHANDRA ET AL) 22 May 2003 (2003-05-22) * paragraph [0015] - paragraph [0038] * * figure 3 * -----	1-10	

TECHNICAL FIELDS SEARCHED (IPC)

F02D
F01N

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	25 November 2005	Calabrese, N

1

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25-11-2005

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