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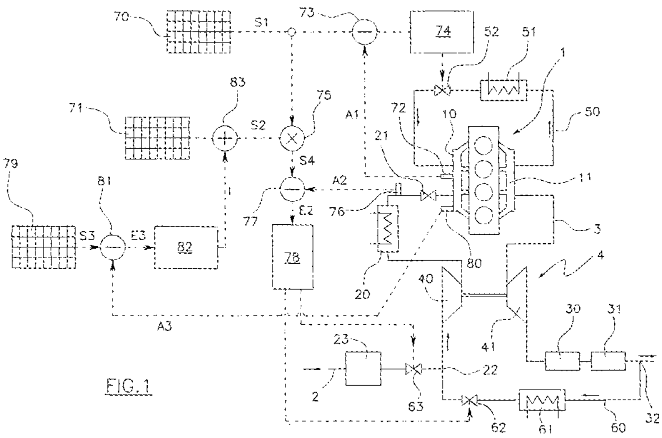
(54) Title of the Invention: **Method for operating an internal combustion engine**
Abstract Title: **Method of regulating the flow rate of EGR gas through short and long EGR routes of a turbocharged i.c. engine**

(57) The flow rate of EGR gas through short and long EGR routes 50, 60 of a turbocharged i.c. engine is regulated by a method comprising (a) determining a first setpoint value S1 for the total amount of exhaust gas requested into the intake manifold 10; (b) determining a second setpoint value S2 for a parameter representative of the relationship between the total amount of exhaust gas requested into the intake manifold and the amounts from the short and long EGR routes 50, 60; (c) applying the set-point values S1, S2 to a control routine for adjusting the means 52, 62, 63 which regulate the flow rate through the EGR routes 50, 60; (d) determining a third setpoint value S3 for the temperature in the intake manifold 10; (e) determining the actual intake manifold temperature A3; (f) calculating the error E3 between the actual temperature A3 and the third setpoint value S3; and (g) using the error E3 for generating a correction index I to apply to the second setpoint value S2 in order to minimize the error E3.

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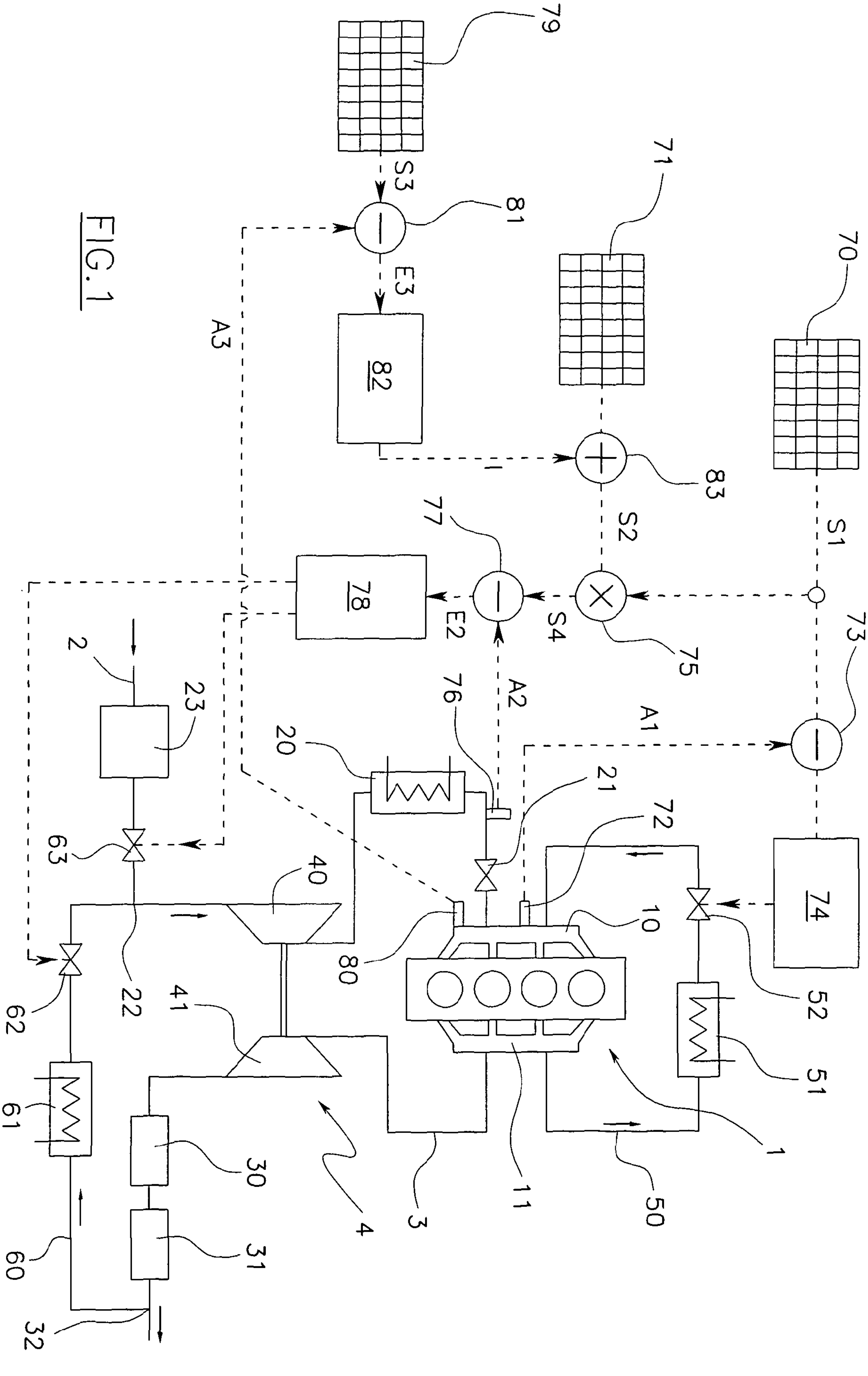
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FIG. 1

# METHOD FOR OPERATING AN INTERNAL COMBUSTION ENGINE SYSTEM

**TECHNICAL FIELD**

The present invention relates to a method for operating an internal combustion engine system, in particular a turbocharged Diesel engine system.

**BACKGROUND**

A turbocharged Diesel engine system generally comprises a Diesel engine having an intake manifold and an exhaust manifold, an intake line for conveying fresh air from the environment in the intake manifold, an exhaust line for conveying the exhaust gas from the exhaust manifold to the environment, and a turbocharger which comprises a compressor located in the intake line for compressing the air stream flowing therein, and a turbine located in the exhaust line for driving said compressor.

The turbocharged Diesel engine system further comprises an intercooler located in the intake line downstream the compressor, for cooling the air stream before it reaches the intake manifold, and a diesel oxidation catalyst (DOC) located in the exhaust line downstream the turbine, for degrading residual hydrocarbons and carbon oxides contained in the exhaust gas.

The turbocharged Diesel engine systems can also be equipped with a diesel particulate filter (DPF) located in the exhaust line downstream the DOC, for capturing and removing diesel particulate matter (soot) from the exhaust gas.

In order to reduce the polluting emission, most turbocharged Diesel engine system actually comprises an exhaust gas recirculation (EGR) system, for selectively routing back exhaust gas from the exhaust manifold into the intake manifold.

The exhaust gas mixed with the fresh induction air is aspired into the engine cylinders, in order to reduce the production of unburned hydrocarbon (HC), carbon monoxide (CO), soot, and oxides of nitrogen ($NO_x$) during the combustion process.

Conventional EGR systems comprise an EGR conduit for fluidly connecting the exhaust manifold with the intake manifold, an EGR cooler for cooling the exhaust gas before mixing it with the induction air, valve means for regulating the flow rate of exhaust gas through the EGR conduit, and a microprocessor based controller (ECU) for determining the required amount of exhaust gas and for controlling said valve means accordingly.

The required amount of exhaust gas is generally determined by the ECU using an empirically determined data set or map, which correlates the amount of exhaust gas to a plurality of engine operating parameters, such as for example engine speed, engine load and engine coolant temperature.

Since the EGR conduit directly connect the exhaust manifold with the intake manifold, the exhaust gas routed back by these conventional EGR systems is at high temperature and cause a relevant temperature increase of the induction air in the intake manifold, typically up to 80°C-90°C in normal engine operating conditions.

While an high temperature of the induction air is useful for reducing HC and CO emissions, it promote the production $NO_x$, whose emission cannot be maintained below the threshold provided for by the strictest standards, such as for example by Euro 6.

In order to further reduce the $NO_x$ emission, have been considered improved EGR systems comprising an additional EGR conduit, which fluidly connects the exhaust line downstream the DPF with the intake line upstream the compressor of turbocharger, an additional EGR cooler located in the additional EGR conduit, and additional valve means for regulating the flow rate of exhaust gas through the additional EGR conduit.

In these improved systems, while the conventional EGR conduit defines a short route for the exhaust gas recirculation, the additional EGR conduit defines a long route for the exhaust gas recirculation, which comprises also a relevant portion of the exhaust line and a relevant portion of the intake line.

Flowing along the long route, the exhaust gas is then obliged to pass through the turbine of turbocharger, the DOP, the DPF, the additional EGR cooler, the compressor of turbocharger and the intercooler, so that it become considerably colder than the exhaust gas which flows through the short route, to thereby reaching the intake manifold at a lower temperature.

As a matter of fact, routing back the exhaust gas through the long route only, it would be possible, in normal engine operating conditions, to obtain an induction air temperature in the intake manifold around 40°C-50°C.

However a so low temperature of the induction air is not admissible, because it is suitable for reducing $NO_x$ emission but increases the HC and Co emissions.

Therefore, these improved EGR systems are generally configured for routing back the exhaust gas partially through the short route and partially through the long route, in order to maintain the temperature of the induction air in the intake manifold at an optimal intermediate value in any engine operating condition.

Such optimal intermediate value is determined during engine project activity, with the purpose of obtaining a satisfactory compromise between the reduction of $NO_x$ emission and the increasing of HC and Co emissions.

In production, these improved EGR systems are then provided with a microprocessor base controller (ECU) which is configured for determining the total amount of exhaust gas required, for determining the long route exhaust gas rate which is necessary for obtaining the desired optimal temperature, and for controlling the valve means of both EGR conduits accordingly.

The total amount of exhaust gas and the long route exhaust gas rate are determined by the ECU using empirically determined data sets or maps, which respectively correlates the total amount of exhaust gas and the long route exhaust gas rate to a plurality of engine operating parameters, such as for example engine speed, engine load and engine coolant temperature.

One drawback of these improved EGR systems is that such data sets or maps are determined during a calibration activity, using an engine system perfectly efficient which is operated under standard environmental conditions, i.e. standard environmental temperature, pressure and moisture.

Therefore, the value contained in the data sets or maps are valid only for engine systems which are operated in the same environmental conditions of that used in calibration phase, and completely ignore the reduction in efficiency of the engine system components due to their aging.

For example, it has been observed that cooler devices, such as for example intercooler and EGR coolers, shows a progressive reduction in performance.

Such reduction in performance implies that the temperature of exhaust gas to be mixed with the fresh engine induction air increases, due to the reduction of heat transfer between the exhaust gas and the coolant of the coolers.

In this case, the long route EGR rate, provided by the empirical data sets or maps, does not permit to obtain the predetermined optimal temperature value for the engine induction air in the intake manifold, but realizes an higher temperature which increase $NO_x$ emission with respect to that expected.

More generally, it has been observed that any variation in environmental conditions or components efficiency with respect to the reference ones considered during calibration activity, leads to a variation of exhaust gas temperature which results in emission spread compared with the desired one.

**DISCLOSURE**

An object of the present invention is to solve, or at least to positively reduce, the above mentioned drawbacks with a simple, rational and inexpensive solution.

An object of an embodiment of the invention is attained by the characteristics of the invention as reported in independent claims. The dependent claims recite preferred and/or especially advantageous features of the invention.

The invention provides a method for operating an internal combustion engine system, wherein said internal combustion engine system comprises at least:

a combustion engine having an intake manifold and an exhaust manifold,

a first EGR route for conveying exhaust gas from the exhaust manifold into intake manifold,

a second EGR route for conveying exhaust gas from the exhaust manifold into intake manifold, wherein the second EGR route is configured for conveying into the intake manifold exhaust gas having lower temperature than that conveyed through the first EGR route, and regulating means for regulating the flow rate of exhaust gas through the first EGR route and the flow rate of exhaust gas through the second EGR route.

The method comprises the step of:

determining a first setpoint value for the total amount of exhaust gas requested into the intake manifold,

determining a second setpoint value for a parameter representative of the relationship between the total amount of exhaust gas requested into the intake manifold, the amount of exhaust gas from the first EGR route, and the amount of exhaust gas from the second EGR route,

applying said first and second setpoint values to a control routine for adjusting the regulating means accordingly.

According to the invention, the method further comprises the step of:

determining a third setpoint value for the temperature within the intake manifold;

determining the actual temperature within the intake manifold;

calculating the error between said actual temperature and the third setpoint value, and

using said error for generating a correction index to be applied to the second setpoint value, in order to minimize said error.

As a matter of fact, the method according to the invention performs an external control loop of the induction air temperature in the intake manifold, which is able to continuously correct the rate of exhaust gas coming from the first and second EGR route, in order to compensate eventual variations in environmental conditions and/or in engine component efficiency, to thereby obtaining a desired temperature value in any engine operating conditions.

According to an aspect of the invention, the parameter expressed by the second setpoint value is the rate of exhaust gas from the second EGR route on the total amount of exhaust gas requested into the intake manifold. Alternatively, such parameter would be the rate of exhaust gas from the first EGR route, or the rate between the exhaust gas from the first EGR route and the exhaust gas from the second EGR route.

According to another aspect of the invention, the actual temperature within the intake manifold is determined by measuring temperature therein, for example through a temperature sensor set inside the intake manifold. However, the intake manifold temperature would eventually be estimated.

According to an embodiment of the invention, the correction index is added to the second setpoint value.

According to another embodiment of the invention, the second setpoint value and the third setpoint value are both determined from empirically determined data sets or maps, which respectively correlates the "parameter" and the intake manifold temperature to a plurality of engine operating parameters, such as for example engine speed, engine load and engine coolant temperature.

The method according to the invention can be realized in the form of a computer program comprising a program-code to carry out all the steps of the method of the invention, and in the form of a computer program product comprising means for executing the computer program.

The computer program product comprises, according to a preferred embodiment of the invention, a microprocessor based control apparatus for an IC engine, for example the ECU of the engine, in which the program is stored so that the control apparatus defines the invention in the same way as the method. In this case, when the control apparatus execute the computer program all the steps of the method according to the invention are carried out.

The method according to the invention can be also realized in the form of an electromagnetic signal, said signal being modulated to carry a sequence of data bits which represent a computer program to carry out all steps of the method of the invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described, by way of example, with reference to the accompanying drawing, in which:

Figure 1 is a schematic illustration of a turbocharged Diesel engine system allowing the method according to the invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention is hereinafter disclosed with reference to a turbocharged Diesel engine system. However, the invention would theoretically be applied to different Diesel engine system and even to spark-ignition engine systems.

The turbocharged Diesel engine system comprises a Diesel engine 1 having an intake manifold 10 and an exhaust manifold 11, an intake line 2 for conveying fresh air from the environment in the intake manifold 10, an exhaust line 3 for conveying the exhaust gas from the exhaust manifold 11 to the environment, and a turbocharger 4 which comprises a compressor 40 located in the intake line 2 for compressing the air stream flowing therein, and a turbine 41 located in the exhaust line 3 for driving said compressor 40.

The turbocharged Diesel engine system further comprises an intercooler 20 located in the intake line 2 downstream the compressor 40 of turbocharger 4, for cooling the air stream before it reaches the intake manifold 10, and a valve 21 located in the intake line between the intercooler 20 and the intake manifold 10.

The turbocharged Diesel engine system further comprises a diesel oxidation catalyst (DOC) 30 located in the exhaust line 3 downstream the turbine 41 of turbocharger 4, for degrading residual hydrocarbons and carbon oxides contained in the exhaust gas, and a diesel particulate filter (DPF) 31 located in the exhaust line 3 downstream the DOC 30, for capturing and removing diesel particulate matter (soot) from the exhaust gas.

In order to reduce the polluting emission, the turbocharged Diesel engine system comprises an exhaust gas recirculation (EGR) system, for selectively routing back exhaust gas from the exhaust manifold into the intake manifold.

The EGR system comprise a first EGR conduit 50 for directly fluidly connecting the exhaust manifold 11 with the intake manifold 12, a first EGR cooler 51 for cooling the exhaust gas, and a first electrically controlled valve 52 for determining the flow rate of exhaust gas through the first EGR conduit 51.

The first EGR conduit 51 defines a short route for the exhaust gas recirculation cooler, so that the exhaust gas routed back by this EGR conduit 51 is quite hot.

The EGR system further comprise a second EGR conduit 60, which fluidly connects a branching point 32 of the exhaust line 3 downstream the DPF 32 with a leading point 22 of the intake line 2 upstream the compressor 40 of turbocharger 4, and a second EGR cooler 61 located in the additional EGR conduit 60.

The flow rate of exhaust gas through the second EGR conduit 60 is determined by two second electrically controlled valves 62 and 63, wherein the valve 62 is located in the second EGR conduit 60 downstream the second EGR cooler 61, and the valve 63 is located in the intake line 2 downstream an air filter 23 and upstream the leading point 22.

The second EGR conduit 60 defines a long route for the exhaust gas recirculation, which comprises also the portion of the exhaust line 3 comprised between the exhaust manifold 11 and the branching point 32, and the portion of the intake line 2 comprised between the leading point 22 to the intake manifold 10.

Flowing along the long route, the exhaust gas is obliged to pass through the turbine 41 of turbocharger 4, the DOP 30, the DPF 31, the second EGR cooler 61, the compressor 40 of turbocharger 4 and the intercooler 20, so that it become considerably colder than the exhaust gas which flows through the first EGR conduit 50, to thereby reaching the intake manifold at a lower temperature.

The turbocharged Diesel engine system is operated by a microprocessor (ECU) based control circuit, which is provided for generating and applying control signals to the valves 52, 62 and 63, to thereby adjusting the flow rate of exhaust has through the first EGR conduit 50 and the second EGR conduit 60.

The control circuit is that represented with dotted lines in figure 1.

The control circuit determine a setpoint value S1 for the total amount of exhaust gas which is requested into the exhaust manifold 10, and a setpoint value S2 for the requested rate of long route exhaust gas on said total amount, that is the percentage of exhaust gas on the total which must come from the second EGR conduit 60.

Obviously the remaining percentage of exhaust gas must come from the first EGR conduit 50.

The setpoint value S1 is determined by the ECU from an empirical determined map 70 which correlates the requested total amount of exhaust gas to a plurality of engine operating parameters, such as engine speed, engine load and engine coolant temperature.

The setpoint value S2 is determined by the ECU from another empirical determined map 71 which correlates the long route exhaust rate to a plurality of engine operating parameters, such as engine speed, engine load and engine coolant temperature.

The maps 70 and 71 are stored in a memory module (not shown) of the control circuit.

The control circuit determine the actual amount A1 of exhaust gas which are present into the intake manifold 10.

The determination of the amount A1 is provided through an estimation which is performed by ECU using a physical model of turbocharger the Diesel engine system, and which is illustrated as a virtual sensor 72 in figure 1.

The determination of the amount A1 would eventually be performed through the determination of another physical parameter, which is directly related with the amount of exhaust gas, such as for example the oxygen ($O_2$) concentration.

The determination of the amount A1 would also be provided by measuring the amount of exhaust gas, or another physical parameter related with the amount of exhaust gas, through a sensor set into the intake manifold 11

The determined value A1 of the amount of exhaust gas into the intake manifold 10 is sent to an adder 73, which calculates the difference E1 between the setpoint value S1 and said determined value A1:

$$E1=S1-A1.$$

The difference E1 is supplied to a controller 74, for instance a PI controller, which in function of the above named difference, generates a correction which is applied to the control signal of the valve 52, in order adjust the flow rate of exhaust gas through the first EGR conduit 50 for minimizing said difference E1.

Contemporaneously the setpoint value S1 and the setpoint value S2 are sent to a multiplier 75, which calculates another setpoint value S4 for the amount of exhaust gas which is requested coming from the second EGR conduit 60:

$$S4=S1*S2.$$

Contemporaneously, the control circuit determine the actual amount A2 of exhaust gas into the intake line 2 upstream the valve 21 and downstream the intercooler 20, that is the actual amount of exhaust gas supplied by the second EGR conduit 60.

The determination of the amount A2 is provided through an estimation which is performed by ECU using a physical model of turbocharger the Diesel engine system, and which is illustrated as a virtual sensor 76 in figure 1.

The determination of the amount A2 would eventually be performed through the determination of another physical parameter, which is directly related with the amount of exhaust gas, such as for example the oxygen ($O_2$) concentration.

The determination of the amount A2 would also be provided by measuring the amount of exhaust gas, or another physical parameter related with the amount of exhaust gas, through a sensor set into the intake line 2 between intercooler 20 and valve 21.

The determined value A2 is sent to an adder 77, which calculates the difference E2 between the setpoint value S4 and said determined value A2:

$$E2=S4-A2.$$

The difference E2 is supplied to a controller 78, for instance a PI controller, which in function of the above named difference, generates a correction which is applied to the control signal of the valve 62 and or 63, in order adjust the flow rate of exhaust gas through the second EGR conduit 60 for minimizing said difference E2.
As a matter of fact, the control circuit performs a control loop of the total amount of exhaust gas in the intake manifold, and a control loop of the amount of exhaust gas supplied by the second EGR conduit 60 on the total amount, which are able to continuously correct the flow rate of exhaust gas through the first and the second EGR conduit, 50 and 60, in order to actually reaching the setpoint values S1 and S2 (S4).
According to the invention, contemporaneously with the preceding steps, the control circuit further determine a setpoint value S3 for the temperature within the intake manifold 10.
The setpoint value S3 is determined by the ECU from an empirical determined map 79 which correlates the intake manifold temperature to a plurality of engine operating parameters, such as engine speed, engine load and engine coolant temperature.
The maps 79 is stored in a memory module (not shown) of the control circuit.
The control circuit determine the actual temperature A3 within the intake manifold 10.
The actual temperature A3 is determined by measuring temperature within the intake manifold through a temperature sensor 80.

Alternatively, the intake manifold temperature A3 would eventually be estimated.

The determined temperature value A3 is sent to an adder 81, which calculates the difference E3 between the setpoint value S3 and said determined value A3:

$$E3=S3-A3.$$

The difference E3 is supplied to a controller 82, for instance a PI controller, which in function of the above named difference, generates a correction index I to be applied to the setpoint value S2, in order to modify the setpoint value S2 upstream the multiplier 75, in order to minimize said error E3.

As a matter of fact, the correction index I is sent to an adder 83, which adds the correction index I to the setpoint S2, before the latter is sent to the multiplier 75.

Obviously, the correction index I can be also a negative number.

In this way, the control circuit performs an external control loop of the induction air temperature in the intake manifold 10, which is able to continuously correct the rate of exhaust gas coming from the first and the second EGR conduit, 50 and 60, in order to compensate eventual variations in environmental conditions and/or in engine component efficiency, to thereby obtaining a desired temperature value S3 in any engine operating conditions.

While the present invention has been described with respect to certain preferred embodiments and particular applications, it is understood that the description set forth herein above is to be taken by way of example and not of limitation. Those skilled in the art will recognize various modifications to the particular embodiments are within the scope of the appended claims. Therefore, it is intended that the invention not be limited to the disclosed embodiments, but that it has the full scope permitted by the language of the following claims.

**CLAIMS**

**1.** Method for operating an internal combustion engine system, said internal combustion engine system comprising at least:

a combustion engine (1) having an intake manifold (10) and an exhaust manifold (11),

a first EGR route (50) for conveying exhaust gas from the exhaust manifold (11) into intake manifold (10),

a second EGR route (60) for conveying exhaust gas from the exhaust manifold (11) into intake manifold (10), wherein said second EGR route (60) is configured for conveying into the intake manifold (10) exhaust gas having lower temperature than that conveyed through the first EGR route (50), and

regulating means (52, 62, 63) for regulating the flow rate of exhaust gas through the first EGR route (50) and the flow rate of exhaust gas through the second EGR route (60),

the method comprising the step of:

determining a first setpoint value (S1) for the total amount of exhaust gas requested into the intake manifold (10),

determining a second setpoint value (S2) for a parameter representative of the relationship between the total amount of exhaust gas requested into the intake manifold (10), the amount of exhaust gas from the first EGR route (50), and the amount of exhaust gas from the second EGR route (60),

applying said first and second setpoint values (S1, S2) to a control routine for adjusting the regulating means (52, 62, 63) accordingly,

characterized in that the method further comprises the step of:

determining a third setpoint value (S3) for the temperature within the intake manifold (10),

determining the actual temperature (A3) within the intake manifold (10),

calculating the error (E3) between said actual temperature (A3) and the third setpoint value (S3), and

using said error (E3) for generating a correction index (I) to be applied to the second setpoint value (S2), in order to minimize said error (E3).

**2.** Method according to claim 1, wherein the parameter expressed by the second setpoint value (S2) is the rate of exhaust gas from the second EGR route (60) on the total amount of exhaust gas requested into the intake manifold (10).

**3.** Method according to claim 1, wherein the actual temperature (A3) within the intake manifold (10) is determined by measuring temperature therein.

**4.** Method according to claim 1, characterized in that said correction index (I) is added to the second setpoint value (S2).

**5.** Method according to claim 1, characterized in that said second setpoint value (S2) is determined from an empirically determined data set or map (71) correlating said parameter to a plurality of engine operating parameters.

**6.** Method according to claim 1, characterized in that said third setpoint value (S3) is determined from an empirically determined data set or map (79) correlating the temperature within the intake manifold (10) to a plurality of engine operating parameters.

**7.** Method according to claim 5 or 6, characterized in that said engine operating parameters are chosen in the group of: engine speed, engine load and engine coolant temperature.

**8.** Method according to claim 1, wherein the internal combustion engine system further comprises:

an intake line (2) for conveying air from the environment into the intake manifold (10), and

an exhaust line (3) for conveying exhaust gas from the exhaust manifold (11) to the environment,

and wherein

the first EGR route comprises a first EGR conduit (50) which fluidly connects the exhaust manifold (11) with the intake manifold (10),

the second EGR route comprises a second EGR conduit (60) which fluidly connects a point (32) of the exhaust line (3) downstream the exhaust manifold (11) with a point (22) of the intake line (2) upstream the intake manifold (10), and

the regulation means comprises first valve means (52) for regulating the flow rate of exhaust gas through the first EGR conduit (50), and second valve means (62, 63) for regulating the flow rate of exhaust gas through the second EGR conduit (60),

and wherein the control routine comprises the steps of:

determining the actual amount (A1) of exhaust gas into the intake manifold (10),

calculating the error (E1) between said actual amount (A1) of exhaust gas and the first setpoint value (S1),

using said error (E1) for generating a correction to be applied to a control signal of the first valve means (52), in order to adjust the flow rate of exhaust gas for minimizing said error (E1),

using first and second setpoint values (S1, S2) for calculating a fourth setpoint value (S4) for the amount of exhaust gas requested from the second EGR route (60),

determining the actual amount (A2) of exhaust gas into the intake line (2) upstream the intake manifold (10) and downstream the second EGR conduit (60),

calculating the error (E2) between said actual amount (A2) of exhaust gas in the intake line (2) and the fourth setpoint value (S4),

using said error (E2) for generating a correction to be applied to a control signal of the second valve means (62, 63), in order adjust the flow rate of exhaust gas for minimizing said error (E2).

**9.** Method according to claim 8, wherein the internal combustion engine system further comprises:

a turbocharger (4) having a compressor (40) located in the intake line (2) and a turbine (41) located in the exhaust line (41) for driving the compressor (40),

and wherein

the second EGR conduit (60) fluidly connects a point (32) of the exhaust line (3) downstream the turbine (41) and a point (22) of the intake line (2) upstream the compressor (40), and

wherein the determination of the actual amount (A2) of exhaust gas into the intake line (2) provides for determining such actual amount (A2) downstream the compressor (40).

**10.** Method according to claim 8, wherein the internal combustion engine system further comprises:

a first EGR cooler (51) located in the first EGR conduit (50),

a second EGR cooler (61) located in the second EGR conduit (60), and

an intercooler (21) located in the intake line (2) upstream the intake manifold (10) and downstream the second EGR conduit (60),

and wherein the determination of the actual amount (A2) of exhaust gas into the intake line (2) provides for determining such actual amount (A2) downstream the intercooler (21).

**11.** Method according to claim 8, wherein the determination of the actual amount (A1) of exhaust gas into the intake manifold (10), and the determination of the actual amount (A2) of exhaust gas into the intake line (2), are provided by means of respective model-based estimations.

**12.** Computer program comprising a computer-code for carrying out a method according to anyone of the preceding claims.

**13.** Computer program product comprising a computer program according to claim 12.

**14.** Computer program product as in claim 13, comprising a control apparatus wherein the computer program is stored.

**15.** An electromagnetic signal modulated as a carrier for a sequence of data bits representing the computer program according to claim 12.

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|---|---|---|---|
| **Application No:** | GB0918275.9 | **Examiner:** | John Twin |
| **Claims searched:** | 1 to 15 | **Date of search:** | 10 February 2010 |

## Patents Act 1977: Search Report under Section 17

**Documents considered to be relevant:**

| Category | Relevant to claims | Identity of document and passage or figure of particular relevance |
|---|---|---|
| A | - | US 2009/0249783 A1 (General Electric) |
| A | - | WO 2007/107865 A2 (Toyota) |

Categories:

| | | | |
|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category. | P | Document published on or after the declared priority date but before the filing date of this invention. |
| & | Member of the same patent family | E | Patent document published on or after, but with priority date earlier than, the filing date of this application. |

**Field of Search:**

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC$^{X}$ :

Worldwide search of patent documents classified in the following areas of the IPC

F02D; F02M

The following online and other databases have been used in the preparation of this search report

EPODOC, TXTE, WPI

**International Classification:**

| Subclass | Subgroup | Valid From |
|---|---|---|
| F02M | 0025/07 | 01/01/2006 |
| F02D | 0041/00 | 01/01/2006 |