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(54) **METHOD AND MANAGEMENT SYSTEM FOR AN ENGINE BRAKE PROCEDURE IN A DIESEL CYCLED ENGINE**

(57) Method of managing an engine brake procedure in a diesel cycle engine (E), comprising a first process (CTRL1) arranged to control the variable geometry of the turbocharger to achieve a predetermined value of back pressure at the exhaust manifold and a second process (CTRL2) to control the throttling valve according to a function inversely proportional to an error given by the difference between the current speed value and the limit speed value of the turbocharger, according to a closed loop control.

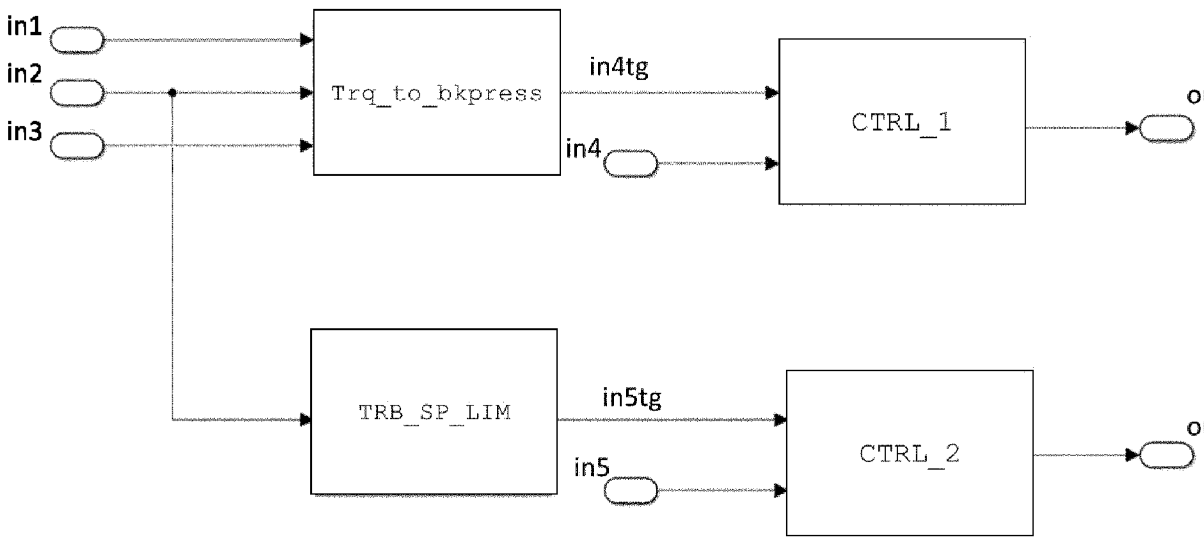

Fig.1

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Description

Field of the invention

[0001] The present invention relates to the field of methods and systems for managing the activation of an engine brake in a supercharged Diesel engine by means of a turbocharger equipped with a variable geometry turbine and a throttling valve arranged on the exhaust manifold.

[0002] More specifically, the invention concerns a diesel engine equipped with an engine brake operated by varying the opening times of the exhaust valves.

State of the art

[0003] In internal combustion engines intended for commercial and industrial vehicles, the functionality of the engine brake is foreseen, named with the English expression. In this operating condition, the engine is driven by the inertia of the vehicle, fuel injection is inhibited and at the same time a strategy is implemented that dissipates energy through the compression and expulsion of gas in the engine cylinders. Various strategies are known for operating engine brake.

[0004] In heavy road vehicles equipped with a Diesel engine, when the accelerator pedal is released while the vehicle is moving, the vehicle inertia continues to drive the engine crankshaft, so that a considerable mass of air is sucked in and compressed in the cylinders.

[0005] The compressed air during the compression stroke acts as an air spring, meaning that the energy accumulated during compression is at least partially returned to the crankshaft by pushing the pistons back.

[0006] When the engine brake function is activated, the profile of the cams that control the opening of the exhaust valves is varied to release the compressed air in the exhaust manifold before it can return the previously accumulated compression energy.

[0007] When used correctly, engine brake functionality can help a multi-ton vehicle to maintain or even reduce speed with minimal use of the service brakes. This fact is crucial especially on prolonged descents, where the vehicle brakes can be stressed to the point of losing efficiency due to overheating.

[0008] In the engine brake function, the braking power depends on the mass of fresh, and possibly exhausted, air, which is compressed and decompressed during engine brake activation. Supercharged engines can exploit the presence of the turbocharger to further increase the braking torque generated by the engine under engine brake conditions.

[0009] Indeed, the braking power of the engine brake depends both on the back pressure at the exhaust manifold and on the boost pressure at the intake manifold.

[0010] In particular, to increase braking power it is necessary to increase the boost pressure, and therefore the back pressure at the exhaust manifold. It is immediate to understand that the increase in supercharging pressure allows the introduction of a greater mass of air to be compressed into the cylinders.

[0011] The regulation of the back pressure at the exhaust manifold is carried out by means of a throttling valve located on the exhaust manifold, generally upstream of the turbine.

[0012] This throttling valve allows to indirectly regulate the mass of air circulating in the intake manifold and exhaust manifold.

[0013] In other words, braking power is a function of back pressure at the exhaust manifold.

[0014] The back paressure is influenced by the position of the turbine mobile blades and the position of the throttling valve.

[0015] The moving blades of the variable turbine geometry affect the mass of gas driving the turbine wheel, which, in turn, increases or decreases the boost pressure at the intake manifold.

[0016] The throttling valve, mostly used in Diesel engines, allows the pumping work of the engine to be increased, worsening its efficiency. When the engine is active, in the sense that it burns fuel, the throttling valve allows to adjust the enthalpy of the exhaust gases to regulate the temperature of the exhaust gas post-treatment system.

[0017] When the engine brake function is activated and a predetermined braking torque is requested, the variable geometry, commonly appealed as "VGT", and the throttling valve, commonly named "Exhaust Flap", assume predetermined positions in a look up table according to the amount of braking torque request.

[0018] However, while the position of the VGT is designed to meet the required braking power, the position of the flap is designed to prevent the turbocharger from exceeding a predetermined rotational speed value.

[0019] During engine brake operation, the Flap has the task of limiting the enthalpy of the gas flow that passes through the turbine and therefore the rotation speed of the turbocharger.

[0020] During the calibration process the operator has the task of determining which the positions of the VGT and the flap are to produce the required braking torque, maintaining a rotation speed of the turbocharger lower than a limit rotation speed.

[0021] Unfortunately, the rotation speed of the engine and the temperature of the gases at the exhaust manifold have a significant impact and therefore, the calibration of the operation of the VGT and flaps is very complex.

[0022] Due to this complexity, the VGT and flap control tables are conservative with a negative impact on engine brake response. In other words, stability conditions can be reached with a several seconds delay due to a calibration that aims at preserving the integrity of the components.

Summary of the invention

[0023] The purpose of the present invention is to indicate a method of managing the activation of the engine brake, in particular which includes the control of the VGT and the flap.

[0024] The basic idea of the present invention is to acquire a back pressure value at the exhaust manifold, when the engine brake function is activated, and to operate two controls in parallel, where

- a first process arranged to dynamically control the variable geometry as a function of a second error given by the difference between the objective backpressure value and the current backpressure value, according to a closed loop control,
- a second process arranged to control the throttling valve according to a function inversely proportional to an error given by the difference between the current rotation speed value and a limit rotation speed value of the turbine, according to a closed loop control.

[0025] Preferably, the first process controls the VGT as a function of an error between an acquired backpressure value and a measured backpressure value, thus realizing a closed loop control.

[0026] Advantageously, the first process tries to pursue, in the shortest possible time, the acquired back pressure value. Advantageously, the second process, being in closed loop and a function inversely proportional to the Rpm error, in the first instants of activation of the engine brake function, causes the flap to open completely, allowing the gases exiting the engine to flow towards the turbine without obstacles.

[0027] Thanks to the present invention, two benefits are obtained:

- Engine brake response is quicker,
- It is no longer necessary to calibrate the operation of the VGT and the flap, but it remains only necessary to calibrate the gains of the closed loop controls described above of the VGT and of the flap.

[0028] In particular, the controls are performed in closed loop and, therefore, insensitive to variations in the operating conditions of the internal combustion engine.

[0029] The invention includes the acquisition of the absolute pressure value at the exhaust manifold and the rotation speed of the turbocharger using a sensor, which is generally integrated into the VGT.

[0030] Preferably, the temperature of the gases at the exhaust manifold is also acquired as it is useful for increasing the precision of the braking torque/back pressure conversion during transients.

[0031] When the required braking torque is relatively low, the turbine wheel accelerates to a rotation speed far from the limit value. In this case, the flap can remain fully open. When the required braking torque is relatively high, the same first control adjusts the VGT so as not to exceed the required back pressure.

[0032] Preferably, the inverse function of the second control is non-linear. More preferably, the inverse function of the second control is parabolic, so as to obtain a flap closure relationship that is more rapid the closer the turbine wheel approaches the relative limit rotation speed.

[0033] When the flap intervenes to limit the rotation speed of the turbocharger wheel, the back pressure is given by the sum of the two contributions, i.e. the VGT and the flap.

[0034] This means that the first control, by regulating the VGT according to the error between the acquired backpressure value and the measured backpressure value, automatically tends to open the blades, so as to compensate for the backpressure contribution given by the flap.

[0035] To avoid triggering control instability phenomena in stationary conditions, it is preferable for the first control to be faster than the second control.

[0036] Preferably, the second control is supported by a third control arranged to control the closing of the flap when the flow rate of gas exiting the internal combustion engine is such as to trigger pumping phenomena (surge) in the turbocharger. Indeed, turbocharger manufacturers provide corresponding optimal operation tables with specified pumping areas. When the operating conditions are such as to trigger pumping phenomena, then the back pressure is completely entrusted to the closing of the flap rather than to the adjustment of the blades of the turbocharger turbine. The present solution allows the desired and acquired backpressure value to be obtained as quickly as possible without the risk that the turbocharger wheel may exceed the limit rotation speed.

[0037] The dependent claims describe preferred variants of the invention, forming an integral part of the present description.

Brief description of the figures

[0038] Further objects and advantages of the present invention will be clear from the following detailed description of an example of its implementation (and its variants) and from the attached drawings given purely for explanatory and non-limiting purposes, in which:

- Fig. 1 shows an example of a control scheme for implementing the method of the present invention;
- Fig. 2a shows a time diagram in which a comparison is represented between a trend of the objective braking torque (wide hatching), a trend of the braking torque obtained according to a control scheme of the known art (fine hatching) and a trend of the torque braking obtained through the control scheme (continuous section) of Fig. 1;
- Fig. 2b shows a time diagram in which a comparison

is represented between a trend of the objective back pressure (broad hatching), a trend of the back pressure obtained according to a control scheme of the known art (fine hatching) and a trend of the back pressure obtained by the control scheme (continuous line) of figure 1;

- Fig. 2c shows a time diagram in which a comparison is represented between a speed trend of the turbocharger wheel according to a control scheme of the prior art (fine hatching) according to the control scheme (continuous line) of figure 1;
- Fig. 2d shows a time diagram in which a comparison is represented between a trend in the temperature of the gases at the exhaust manifold according to a control scheme of the prior art (fine hatching) and according to the control scheme (continuous line) of the figure 1;
- Fig. 2e shows a time diagram in which a comparison is represented between a trend of the geometry of the movable blades of the turbine of the turbocharger according to a control scheme of the known art (fine hatching) and according to the control scheme (continuous line) of Figure 1,
- Fig. 2f shows a time diagram in which a comparison is represented between a trend of the position of the flap arranged on the exhaust manifold according to a control scheme of the known art (fine hatching) and according to the control scheme of (continuous line) Figure 1;
- Fig 3 shows an internal combustion engine equipped with means to perform the engine brake function, a variable geometry turbocharger and a flap arranged on the exhaust manifold, in which the engine is configured to implement the control scheme of the figure 1.

[0039] The same reference numbers and letters in the figures identify the same elements or components or functions.

[0040] It should also be noted that the terms "first", "second", "third", "higher", "lower" and the like may be used here to distinguish various elements. These terms do not imply a spatial, sequential, or hierarchical order for the modified elements unless specifically indicated or inferred from the text.

[0041] The elements and characteristics illustrated in the different preferred embodiments, including the drawings, can be combined with each other without departing from the scope of protection of the present application as described below.

Detailed descritpion

[0042] The present invention finds application in the field of internal combustion engines equipped with

- engine brake functionality via a system for varying the actuation profile VA of at least the exhaust valves V,
- a turbocharger TB with VGT variable geometry turbine,
- a throttling valve FP, hereinafter referred to as "flap", arranged on the exhaust line EM, preferably upstream of the turbocharger turbine according to the normal flow of gases expelled from the internal combustion engine.

[0043] Fig. 3 schematizes an internal combustion engine E, preferably diesel cycle, implementing the present invention. The exhaust manifold EM of the engine E comprises a pressure sensor PS and preferably also a temperature sensor TS.

[0044] The drive profile variation system VA, the flap and the VGT are controlled by a processing unit ECU, which receives various engine operating parameters as input, including the exhaust manifold pressure via the pressure sensor PS, the rotation speed of the turbocharger TB via a sensor integrated into the turbocharger itself and possibly the temperature via the temperature sensor TS.

[0045] Fig. 1 shows a control scheme according to the present invention.

[0046] The inputs identify

in1: braking torque request,
in2: rotation speed of the internal combustion engine,
in3: gas temperature measured at the exhaust manifold,
in4: back pressure measured at the exhaust manifold,
in5: rotation speed of the turbocharger wheel.

[0047] The outputs identify

out1: target position of the VGT mobile blades,
out2: flap target position.

[0048] The block *Torque_to_bkpress* indicates a model suitable for converting a target braking torque value into a target backpressure value *in4tg* at the exhaust manifold EM as a function of the rotation speed *in2* of the internal combustion engine and preferably also of the gas temperature measured at the exhaust manifold in3.

[0049] The block *TRB_SP_LIM* indicates a model suitable for identifying a target rotation speed value *in5tg* of the turbocharger turbine, at least as a function of the rotation speed of the internal combustion engine.

[0050] The block *CTRL1* represents a first control arranged to dynamically control the VGT in order to reach the target backpressure value acquired by the block *Trq_to_bkpress*. Preferably, the control CTRL1 is of the closed loop type arranged to operate on an error given by the difference between the target backpressure acquired by the block *Trq_to_bkpress* and the backpressure measured at the exhaust manifold by means, for example, the sensor PS.

[0051] It is worth highlighting that the backpressure at the exhaust manifold can also be estimated using a model that takes into account the rotation speed of the engine E, the position of the flap and the position of the VGT.

[0052] The block CTRL2 represents a second control, arranged to dynamically control the flap according to a function inversely proportional to an error given by the difference between the rotation speed of the turbocharger acquired through a speed sensor and a predetermined limit value of the rotation speed of the turbine, realizing therefore a closed loop control.

[0053] The second control acquires the limit value of the rotation speed of the turbocharger wheel from the block *TRB_SP_LIM* and the value of the current speed of the wheel. The more the two values differ, the more the flap is open. Conversely, the closer the two speed values are to each other, the more the flap is closed.

[0054] Therefore, the action of the flap control is an inverse function of the error between the two speed values. Preferably, the flap control action is achieved through an inversely proportional function, which can have a linear or parabolic trend.

[0055] Fig. 2a shows a braking torque request related to the activation of the engine brake through a curve with wide hatching indicating a negative step. A first curve with fine hatching is shown which represents the trend of the braking torque according to the flap and VGT control scheme according to the prior art. Furthermore, a second curve with a continuous line is shown, which represents the trend of the braking torque according to the present invention. It can be seen immediately that thanks to the present invention, the response of the system is much faster, guaranteeing the immediate delivery of the braking torque.

[0056] Fig. 2b shows the time trend of the back pressure, in particular the trend of the target back pressure (broad hatching), the trend of the back pressure according to the prior art scheme (fine hatching) and the trend of the back pressure thanks to the present invention (continuous line).

[0057] Figures 2c, 2d, 2e and 2f respectively show the comparison of time diagrams according to the known art (fine hatching) and according to the present invention (continuous line) respectively of the rotation speed of the wheel, of the temperature measured at the exhaust manifold, of the VGT position and the flap position.

[0058] According to a preferred variant of the invention, the system for varying the actuation profile VA of at least one of the exhaust valves V, during the activation of the engine brake function, provides four lifts, which identify:

- during the intake phase, lifting of an intake valve to suck-in fresh air from the intake manifold IM, and simultaneous lifting, at least partially, of an exhaust valve to also suck gas from the exhaust manifold EM;
- near the top dead center at the end of the compression phase, the exhaust valve is raised to prevent the energy accumulated inside the cylinder during the compression phase from being returned to the piston during the subsequent expansion phase,
- during the expansion phase, lifting of the exhaust valve to suck gas from the exhaust manifold EM,
- near the top dead center at the end of the exhaust phase, the exhaust valve is raised to prevent the energy accumulated inside the cylinder during the exhaust phase from being returned to the piston during the subsequent intake phase. The present invention can advantageously be carried out by means of a computer program, which includes coding means for carrying out one or more steps of the method, when this program is executed on a computer. It is therefore understood that the scope of protection extends to said computer program and further to computer readable means comprising a recorded message, said computer readable means comprising program coding means for carrying out one or more steps of the method, when said program is run on a computer. Constructive variations to the non-limiting example described are possible, without departing from the scope of protection of the present invention, including all the equivalent embodiments for a person skilled in the art, to the content of the claims.

[0059] From the above description, the person skilled in the art is able to realize the object of the invention without introducing further construction details.

Claims

1. Method of managing an engine brake procedure in a diesel cycle engine (E), comprising an exhaust manifold (EM) to which a throttling valve (FP), a variable geometry turbine (VGT) of a turbocharger (TB) and a pressure sensor (PS) are attached, the method comprising:

    - acquisition of

        + a first signal (*in4tg*) representing a target back pressure value at the exhaust manifold,
        + a second signal (*in4*) representing a current backpressure value at the exhaust manifold,
        + a third signal (*in5tg*) representing a limit rotation speed value of the turbine,
        + a quarter (*in5*) signal representing a current turbine rotation speed value,

    - a first process (*CTRL1*) arranged to dynamically control the variable geometry as a function of a second error given by the difference between the target backpressure value and the current backpressure value, according to a closed loop control,

- a second process (CTRL2) arranged to control the throttling valve according to a function inversely proportional to a first error given by the difference between the current speed value and the limit speed value, according to a closed loop control.

2. The method according to claim 1, further comprising

- acquisition of a fifth signal (in1) representing a target braking torque value e
- a procedure (*Trq_to_bkpress*) for converting said braking torque target value into said backpressure target value.

3. Method according to any one of claims 1 - 2, further comprising

- acquisition of a sixth signal (in2) representing a rotation speed of the internal combustion engine and a seventh signal (*in3*) representing a gas temperature measured at the exhaust manifold (EM) and
- a procedure (*TRB_SP_LIM*) for generating said third signal representing the limit rotation speed value of the turbine as a function of said sixth signal and said seventh signal.

4. Method according to any of the preceding claims, further comprising
a third control arranged to control the closure of the flap when the flow rate of gas exiting the internal combustion engine is such as to trigger pumping phenomena (surge) in the turbocharger.

5. Diesel cycle internal combustion (E) engine, comprising

- a system (VA) for varying an actuation profile of at least one exhaust valve (V) to carry out an engine brake procedure,
- an exhaust manifold (EM) on which are connected

  + a throttling valve (FP),
  + a variable geometry turbine (VGT) of a turbocharger (TB) and
  + a pressure sensor (PS),

- processing means (ECU) configured to control said throttling valve and said variable geometry turbine, configured to

  . acquire a signal representative of a braking torque and calculate a corresponding target value of back pressure at the exhaust manifold,
  . control the variable geometry to achieve said target backpressure value according to a closed loop control scheme,
  . control the throttling valve according to a function inversely proportional to a first error given by the difference between the current speed value and the limit speed value, according to a closed loop control scheme.

6. Engine according to claim 5, wherein said processing means (ECU) are configured to perform all the steps of any one of claims 1 - 4.

7. Industrial or commercial vehicle comprising a diesel cycle internal combustion (E) engine according to claim 5 or 6.

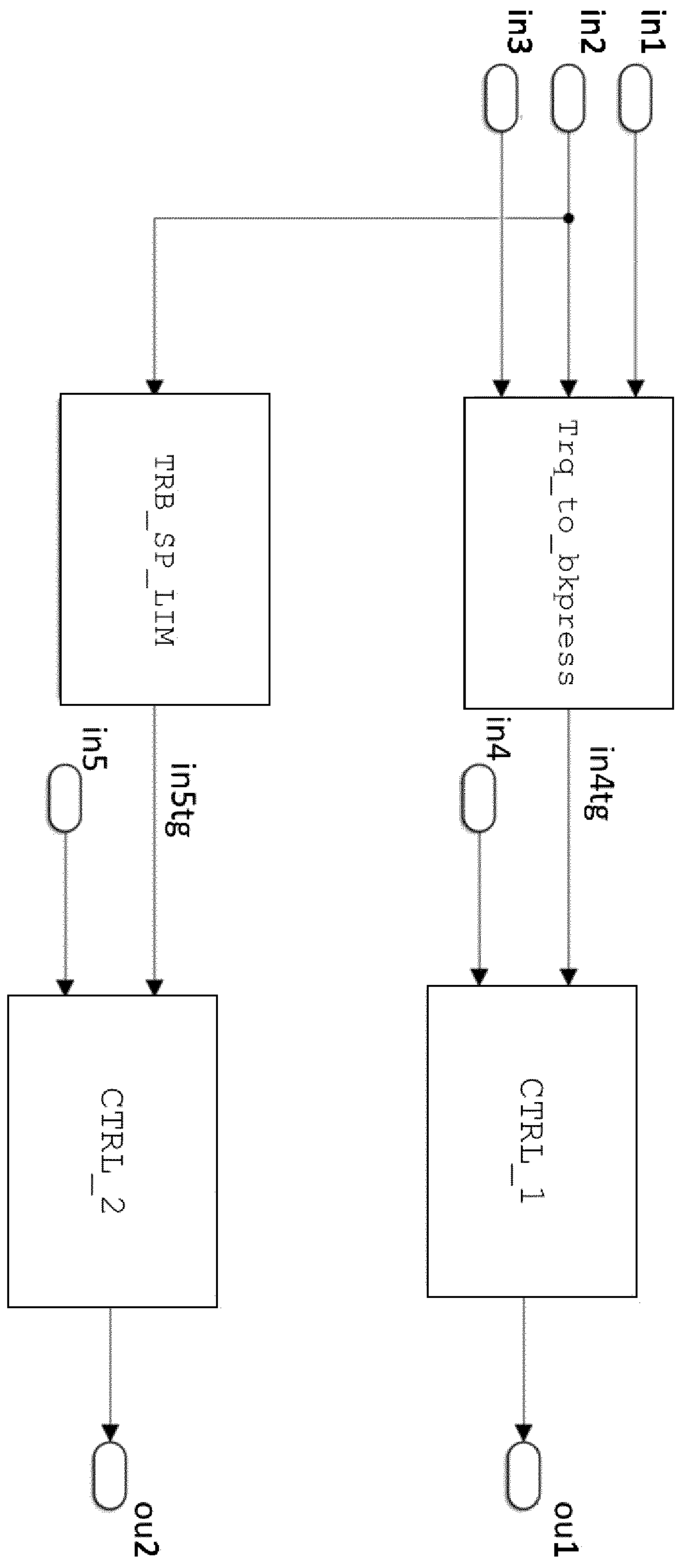
in1
in2
in3
Trq_to_bkpress
TRB_SP_LIM
in4
in4tg
in5
in5tg
CTRL_1
CTRL_2
ou1
ou2

Fig.1

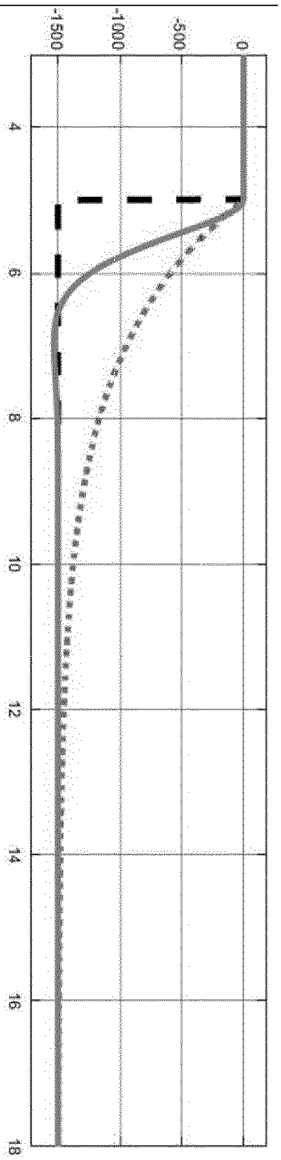

Fig.2a

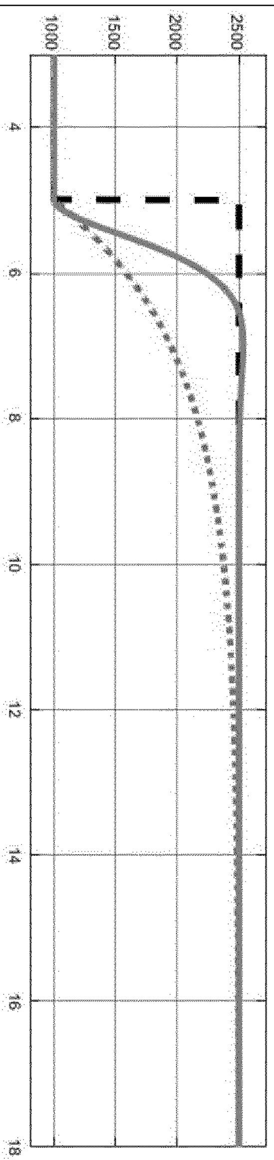

Fig.2b

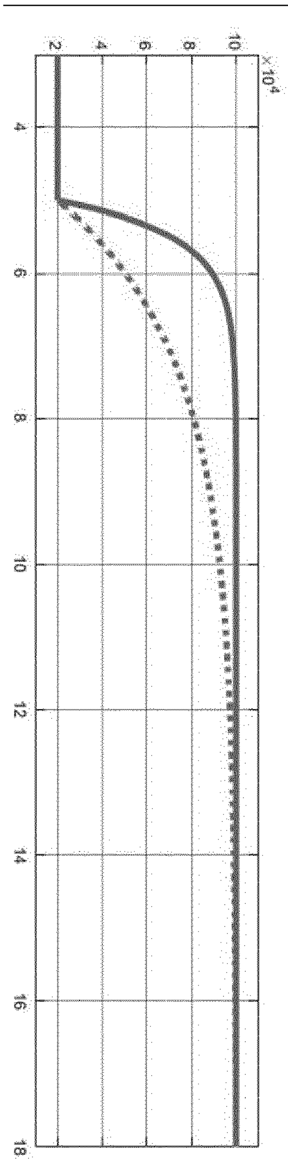

Fig.2c

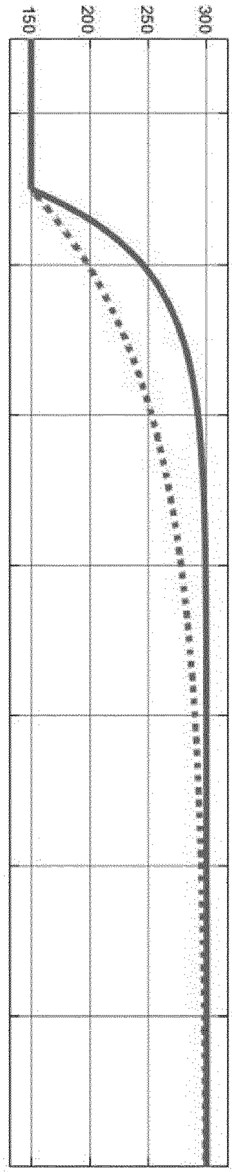

Fig.2d

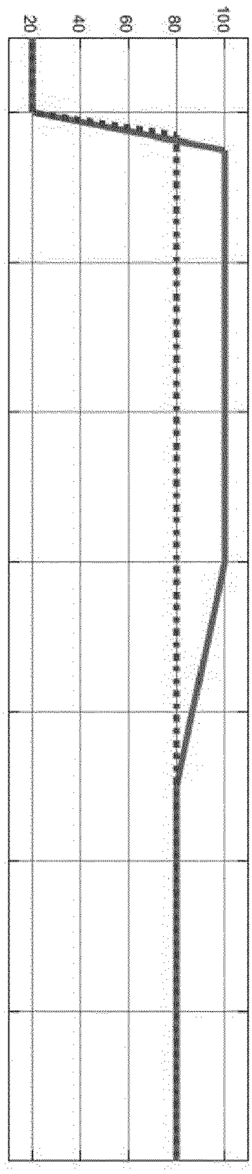

Fig.2e

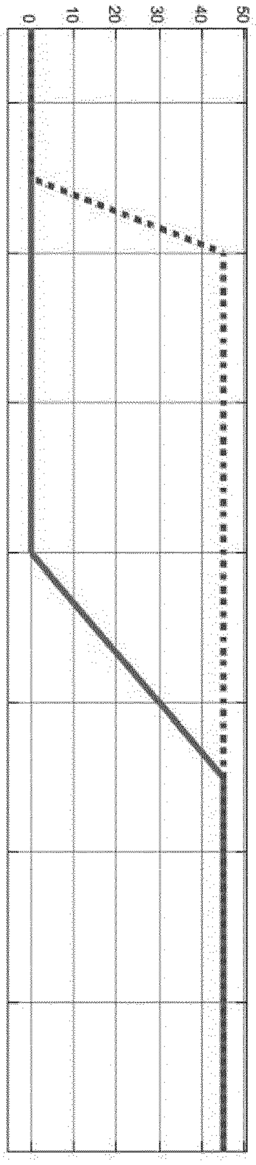

Fig.2f

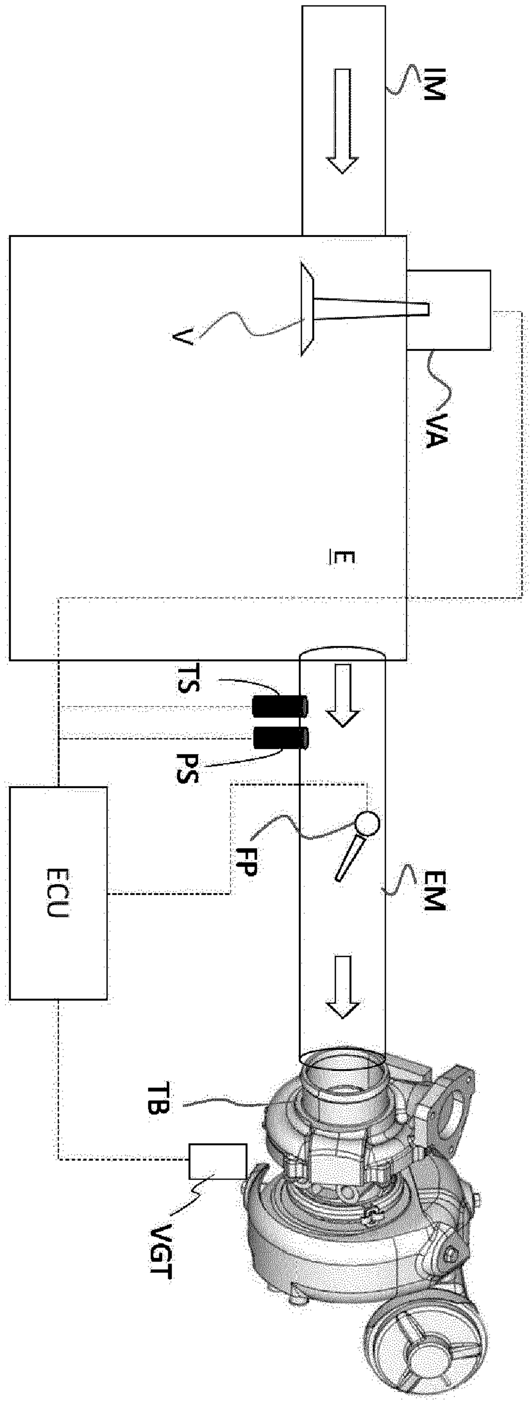

Fig.3

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EUROPEAN SEARCH REPORT

Application Number
EP 23 20 0205

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	EP 3 523 527 B1 (VOLVO TRUCK CORP [SE]) 4 November 2020 (2020-11-04) * paragraphs [0013], [0015], [0034], [0095], [0101], [0103]; figures 2,9 * -----	1-5	INV. F02B37/24 ADD. F02B37/22 F02D41/00
A	JP 2003 307151 A (KOMATSU MFG CO LTD) 31 October 2003 (2003-10-31) * paragraph [0029]; figure 6 * -----	3	
A	DE 10 2016 015357 A1 (DAIMLER AG [DE]) 29 June 2017 (2017-06-29) * paragraph [0044]; figure 8 * -----	4	
A	US 2015/089938 A1 (TANIMURA KENJI [JP] ET AL) 2 April 2015 (2015-04-02) * paragraph [0036]; figures 1,4-5 * -----	1-7	

TECHNICAL FIELDS SEARCHED (IPC)

F02B
F02D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	17 January 2024	Ulivieri, Enrico

CATEGORY OF CITED DOCUMENTS

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17-01-2024

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 3523527 B1	04-11-2020	CN 109790780 A	21-05-2019
		CN 109804151 A	24-05-2019
		EP 3523527 A1	14-08-2019
		EP 3535484 A1	11-09-2019
		EP 4212712 A1	19-07-2023
		US 2019249606 A1	15-08-2019
		US 2020200103 A1	25-06-2020
		WO 2018065053 A1	12-04-2018
		WO 2018065131 A1	12-04-2018
JP 2003307151 A	31-10-2003	NONE	
DE 102016015357 A1	29-06-2017	NONE	
US 2015089938 A1	02-04-2015	CN 104514648 A	15-04-2015
		DE 102014013675 A1	02-04-2015
		JP 6090088 B2	08-03-2017
		JP 2015068272 A	13-04-2015
		US 2015089938 A1	02-04-2015

EPO FORM P0459

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