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 <i>F02D 41/10</i> (2006.01) <i>F02B 37/24</i> (2006.01)</p> | <p>(81) Designated States (<i>unless otherwise indicated, for every kind of national protection available</i>): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.</p> |
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(54) Title: IMPROVED METHOD OF CONTROLLING A TURBOCHARGED ENGINE

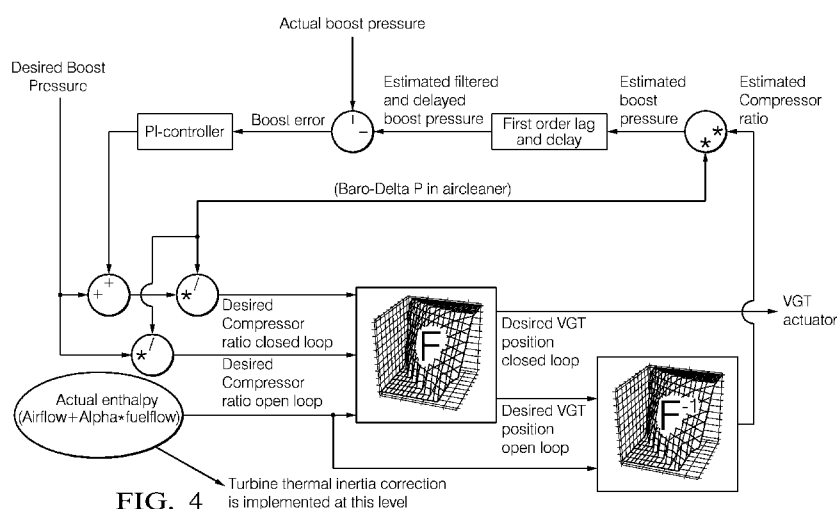


FIG. 4 Turbine thermal inertia correction is implemented at this level

(57) Abstract: A method to control an engine system which includes a turbocharger, said method comprising: i) determining an open loop demand compressor ratio from a demand boost pressure and inlet pressure; ii) inputting the output of i) into a model/map F to provide as an output a VGT or waste gate position, wherein an input to said map is additionally a parameter indicative of the enthalpy of the exhaust gases; where the enthalpy parameter is a function of $\text{airflow} + \beta \cdot \text{fuel flow}$, characterised wherein β is a function of the measured or estimated temperature of exhaust gases T3.

Improved method of Controlling a Turbocharged Engine

Field of the Invention

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This disclosure relates to an improved method of controlling a turbocharged engine. It has application to boost control for engine systems which use variable geometry turbocharger VGT or with systems that use wastegates. It can also be used in systems with or without Exhaust Gas Recirculation (EGR) or High pressure EGR only, or High pressure and Low pressure EGR. The invention can be applied to engine systems with a single turbocharger (single stage) or in a system with two turbo chargers in series, or in systems where there is a combination of a supercharger and a turbocharger.

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Background to the Invention

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In turbocharged engines, pressure from exhaust gases exiting the cylinders is used to drive a turbine, which in turn drives a compressor. This boosts the pressure of inlet air to the cylinders. In automotive applications, boost refers to the amount by which intake manifold pressure exceeds atmospheric pressure.

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Diversion of exhaust gases regulates the turbine speed, which in turn regulates the rotating speed of the compressor. The primary function of systems which include a wastegate is to regulate the maximum boost pressure in turbocharger systems, to protect the engine and the turbocharger. An alternative is to use variable geometry turbocharger VGT.

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The state of art boost control for turbocharged engines typically uses a model-based approach to enhance the control performance especially in combination with the usage of high and low pressure Exhaust Gas Recirculation EGR and to cope with many different boost demand values for the same engine speed and load points but different combustion modes; e.g. normal operation, DPF regeneration, NOx trap regeneration, and such like.

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The feed-forward control part of this model based approach is used to limit the necessary correction of the closed loop part and to have the fastest possible boost response without overshoots or instabilities

A problem is that the effects of the thermal inertia of the exhaust manifold and turbine housing are not considered in these models and hence, during transients, errors introduced by this deficiency cause problems. It is one object of the invention to overcome such problems.

5 Statement of the Invention

In one aspect is provides a method to control an engine system which includes a turbocharger, said method comprising: i) determining an open loop demand compressor ratio from a demand boost pressure and inlet pressure; ii) inputting the output of i) into a model/map F to provide as an output a VGT or
10 wastegate position, wherein an input to said map is additionally a parameter indicative of the enthalpy of the exhaust gases; where the enthalpy parameter is a function of $\text{airflow} + \beta \cdot \text{fuel flow}$, characterised wherein β is a function of the measured or estimated temperature of exhaust gases T3.

T3 can be the temperature at the inlet to the turbine or in the exhaust manifold temperature.
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B can be $= [1 + F2 \cdot (\text{Filt}(T3) - T3) / T3]$ where F2 is a calibration value between 0 and 1, where Filt is a first order time lag filter of time constant τ .

T3 is preferably calculated in Kelvin.
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F2 may be variable and dependent on the value of T3.

The time constant τ may be dependent on measured or estimated gas flow through the turbine.

25 A method as claimed in claims including the additional steps of:

- iii) using the output of ii) in a feedback control loop, to provide a value for the estimated compressor ratio;
- iv) from iii) and from actual/estimated input pressure, estimating the boost pressure;
- v) comparing the estimated boost pressure with actual boost pressure to provide a boost error which is
30 feedback with the demanded boost pressure to provide a corrected desired boost pressure for the closed loop.

Said corrected desired boost pressure for the closed loop may be input to a first model, F, to provide a desired VGT or wastegate position for the closed loop which is used to control the wastegate/VGT.

The demand VGT/wastegate position in the open loop may be fed to a further map F^{-1} which determines an estimated actual VGT or wastegate position.

5 Said second map F^{-1} may be generally an inverse of said first map F .

Said enthalpy parameter may be also fed into said second map F^{-1} .

10 Brief Description of the Drawings

The invention will now be described by way of example and with reference to the following figures of which:

15 Figure 1 shows a simplified control system of feed forward boost control;

Figure 2 shows a method of closed loop boost pressure control typically used which includes an open loop portion similar to that of figure 1 but which also includes a closed loop portion;

20 Figures 3a, b, and c, show plots of the compressor ratio for two different VGT positions (50% and 100%) against parameters of air mass flow and fuel flow mass.

Figure 4 is similar to figure 2 but shows an input is a refined and variable value of enthalpy;

25 Figure 5 shows boost control response without and with turbine thermal correction as in one example

Figure 6a and b shows boost control response without and with turbine thermal correction as in one example under identical conditions in high definition

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Background

As mentioned, the prior art systems of boost control are often model-based which rely on stored maps which are typically established/calibrated under steady state conditions. Since the maps and physical

relations are established under steady state operating conditions, the effect of the thermal inertia of the exhaust manifold and turbine housing are not captured in these models and hence during transients, errors introduced by this deficiency cause problems. In one aspect of the invention these errors are corrected. This is done in one aspect with the closed loop part and as they could be wrongly interpreted as an error in the open loop model.

Figure 1 shows a simplified control system of feed forward boost control for controlling a VGT actuator of a turbocharged system which includes EGR. A similar control can be used to control wastegate position and is applicable also to non-EGR systems. An engine ECU provides a demand or “desired” boost pressure value, that is to say the pressure desired at the outlet of the turbo compressor/pressure at the inlet manifold. In the open loop, the pressure inlet to the compressor, which may be measured or assumed to be a nominal atmospheric pressure, optionally minus any losses due to filter losses, is used with the desired boost pressure to provide a desired compressor ratio (e.g. in the open loop). This parameter is then used in a look-up map F (e.g. along with the parameter of air mass flow and estimated enthalpy) to determine the opening position of the VGT or wastegate (e.g. as a percentage of fully closed position). So the look at map can be considered as a table with the entries 1) desired compressor pressure ratio and 2) the actual “enthalpy” or model of “enthalpy” and the output is the VGT / Waste Gate position demand. The general input to the system is the desired boost pressure (typically provided by the ECU) and the ultimate output is the VGT actuator/wastegate position

Figure 2 shows a method of closed loop boost pressure control typically used which includes an open loop portion similar to that of figure 1 but which also includes a closed loop portion.

With reference to the closed loop portion, the desired boost pressure is modified using a feedback control loop by the addition of a correction factor which is effectively mitigating the effect of a boost error. The resulting output of this (modified/corrected desired boost pressure) is then used along with the assumed/measured/estimated input pressure to provide a desired compressor ratio with respect to the closed loop portion. Similarly the desired boost pressure (without any correction applied from any feedback input) is used along with the inlet pressure to provide a desired compressor ratio in the open loop, which is input to the map F. It is to be noted that the open loop and closed loop portions are used at the same time. A further input to the map F is the enthalpy.

The output of the map F provides for the desired VGT position for both the closed loop portion which is used for the VGT actuator itself. In order to provide feedback control, the desired open loop value of the

VGT is input to a map F^{-1} which is effectively the inverse of the map F to provide the estimated actual compressor ratio. In theory this estimated compressor ratio output from F^{-1} should be the same as the desired compressor ratio (open loop input to F) i.e. same as the estimated demand compressor ratio for the open loop. However there may be circumstances where the demanded value is too high for the VGT to cope and therefore there are boundaries; the VGT actuator cannot open more than 100%. Thus the output to the inverse map gives a value the system is actually capable of producing.

The estimated compressor ratio is then used to determine the estimated boost pressure in a feedback loop (from the assumed/estimated/measured input pressure at X , and then passed through a first order lag/delay filter to mimic the time lag/delay of the system. This gives an estimated filtered and delayed boost pressure which is then compared to the actual boost pressure to give a boost (pressure) error at Y . This is passed through a proportional and integral (PI) control unit before used to compensate the desired boost pressure.

Enthalpy

As mentioned a further input to the control system is the enthalpy. The energy going to the turbine (enthalpy) can be represented in a model (i.e. is a function) by the sum of the airflow (g/s) going to the turbine and the fuel flow (g/s) injected into the engine multiplied by a factor α or $\alpha..$ This fuel flow multiplied by the factor is a representation of the thermal energy going into the exhaust manifold.

Enthalpy parameter = airflow + α *fuelflow

The above formula will now be explained. If we consider a more or less constant efficiency of the engine to transform fuel into indicated torque, then it can be seen that the rest of the fuel energy that is not used for creating torque is energy that is released under the form of heat (heat going into the coolant and heat going into the exhaust). It is this heat and the airflow going into the exhaust that is driving the turbine of the turbocharger.

Exhaust Enthalpy available for the turbine

$$\dot{H}_{exh} = (\dot{m}_{air} + \dot{m}_{fuel}) c p_{exh} T_{exh} = (\dot{m}_{air} + \dot{m}_{fuel}) c p_{air} T_{air} + (1 - \eta_{engine}) \dot{m}_{fuel} Q_{fuel}$$

$$\dot{H}_{exh} = c p_{air} T_{air} \left[\dot{m}_{air} + \dot{m}_{fuel} \frac{(1 - \eta_{engine}) Q_{fuel} + c p_{air} T_{air}}{5 c p_{air} T_{air}} \right]$$

$$\dot{H}_{exh} = k[\dot{m}_{air} + \dot{m}_{fuel}\alpha]$$

5

Where If no turbine-in temperature/model is available, enthalpy flow can be simplified by $\dot{m}_{air} + \alpha \dot{m}_{fuel}$

Where “cp” of air = “specific heat” of air; Q_{fuel}= lower heating value of fuel; η_{engine} = efficiency of the engine; $\dot{m}$ (dot) = mass flow ; T_{exh} = temperature of exhaust (K); T_{air} = temperature of air (K)

10

Figures 3a, b, and c, show plots of the compressor ratio for two different VGT positions (50% and 100%) against parameters of air mass flow and fuel flow mass as shown. Figure c shows how the enthalpy varies with compressor ratio for the two positions and shows there is a defined relationship between these two parameters for a particular VGT position. As can be seen from figure 3 b if the fuel mass flow is

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multiplied by a factor α then a similar defined relationship can be obtained with the expression $\dot{m}_{air} + \alpha * \dot{m}_{fuel}$. Thus in the prior art the enthalpy input to the figures is determined from this expression.

Description of Example

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During boost transients e.g. during torque steps, the energy that is going to the turbine is unfortunately not going directly to the turbine wheel, but some of this energy is consumed or released for heating up (or cooling down) the exhaust manifold and turbine housing until the system reaches its steady state temperature level.

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The existing boost control model does not take into account this effect. According to one example, the control methodology takes into account this thermal inertia of the exhaust header and turbine housing(s) to calculate more accurately the instantaneous energy really going to the turbine wheel and hence to improve the control performance, such that the closed loop part of the controller needs to apply less

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corrections.

In aspects of the invention, the enthalpy input to the control system is modified to take into account thermal time effects.

Example

In one example the model is corrected for thermal transient effects as follows:

- 5 In a first step the measured or estimated turbine-in/exhaust manifold temperature is determined, T3 This is measured in Kelvin.

In the next step a first order lag filter (having a time constant τ) is applied to this T3 temperature.

- 10 The first order lag filter time constant τ is preferably variable and may depend on on turbine flow; this could be achieved by using a look-up in a table with τ versus turbine flow. Thus the output of the filter may be stated as $Filt(T3)$ where T3 is in Kelvin.

- The higher the turbine flow the lower the time constant for heating up or cooling down the exhaust manifold and turbine housing.
- 15

In the next step the correction factor F1 is calculated as : $F1 = [1 + F2 * (Filt(T3) - T3) / T3]$
where F2 is a calibration value between 0 and 1, (typically 0.85)

- 20 The values of F2 may can be calibrated differently for increasing and decreasing T3 temperatures.

With this F2, the amplitude effect of the thermal inertia correction can be calibrated to get the best match of the turbocharger model during temperature transients.

- 25 In the next step the the final enthalpy representation (which is input to the map F) is modified :

New enthalpy parameter = $airflow + F1 * \alpha * fuelflow$

or in other words

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New enthalpy parameter = $airflow + \beta * fuelflow = airflow + \beta * fuelflow$

This (revised) value of enthalpy is input into the control methodology (map F) as shown in figure 4 which is essentially the same as figure 2 except it shows the input of the new parameter.

The advantage of this method is the improved boost control performance/response especially in situations where large T3 temperatures variations can be observed or with systems with high thermal inertia like in dual stage turbocharger applications. Typical difficult situations for the boost control when no thermal inertia correction is applied are a long, zero or low engine load or coasting situation followed by a high load step-in.

Figure 5 shows the turbine thermal inertia correction effect implemented by one example of the invention with respect to a vehicle with a turbocharged engine. The top chart shows various parameters as indicated. The bottom chart shows the value of the actual boost pressure as well as the value of alpha.

In the first half of the chart the conventional control is implemented without the correction according to implementations of the invention. In the second half of the chart one example of the invention is implemented. The demand boost is increased. As can be seen in the lower chart, the value of "ACM Vgt boost int term" is the integrator term of the closed loop PI feedback controller (Proportional-Integral controller) fluctuates relatively wildly in relation to when the thermal correction is implemented, when the invention is not applied.

Likewise figure 6a and b shows boost control response improvement without and with turbine thermal correction under identical conditions in higher definition. As well as smoother control, the demand and actual boost pressure follow each other much more accurately.

The open loop models are sometimes on-line corrected to adapt for differences between turbochargers from car to car (production spread). This invention can also be implemented to "learn" wrong corrections if the differences between the boost model (in the case that it is not corrected for the turbine thermal inertia) and the real boost are not coming from the part to part variation, but are differences introduced by the thermal inertia phenomenon. There is a risk of on-line adaptation in the case where the turbine inertia is not taken into account. If the difference between the model and the real boost is due to the thermal inertia effect this is preferably not integrated in the adapted model.

Thus by applying thermal inertia corrections, the on-line adaptation of the turbocharger model is less prone to learn “wrong” corrections.

Claims

1. A method to control an engine system which includes a turbocharger, said method comprising:
 - 5 i) determining an open loop demand compressor ratio from a demand boost pressure and inlet pressure;
 - ii) inputting the output of i) into a model/map F to provide as an output a VGT or wastegate position, wherein an input to said map is additionally a parameter indicative of the enthalpy of the exhaust gases; where the enthalpy parameter is a function of $\text{airflow} + \beta * \text{fuel flow}$, characterised wherein β is a function of the measured or estimated temperature of exhaust gases T3.
- 10 2. A method as claimed in claim 1 wherein T3 is the temperature at the inlet to the turbine or in the exhaust manifold temperature.
3. A method as claimed in claims 1 or 2 where $\beta = [1 + F2 * (\text{Filt}(T3) - T3) / T3]$
- 15 where F2 is a calibration value between 0 and 1, where Filt is a first order time lag filter of time constant τ .
4. A method as claimed in claim 3 where T3 is calculated in Kelvin.
- 20 5. A method as claimed in claims 3 or 4 wherein F2 is variable and dependent on the value of T3.
6. A method as claimed in claims 1 to 5 wherein the time constant τ is dependent on measured or estimated gas flow through the turbine.
- 25 7. A method as claimed in claims 1 to 6 including the additional steps of:
 - iii) using the output of ii) in a feedback control loop, to provide a value for the estimated compressor ratio;
 - iv) from iii) and from actual/estimated input pressure, estimating the boost pressure;
 - 30 v) comparing the estimated boost pressure with actual boost pressure to provide a boost error which is feedback with the demanded boost pressure to provide a corrected desired boost pressure for the closed loop.
8. A method as claimed in claim 7 wherein said corrected desired boost pressure for the closed loop

is input to a first model, F , to provide a desired VGT or wastegate position for the closed loop which is used to control the wastegate/VGT.

9. A method as claimed in claim 8 wherein the demand VGT/wastegate position in the open loop is fed
5 to a further map F^{-1} which determines an estimated actual VGT or wastegate position.

10. A method as claimed in claim 9 wherein said second map F^{-1} is generally an inverse of said first map F .

10 11. A method as claimed in claim 9 or 10 wherein said enthalpy parameter is also fed into said second map F^{-1} .

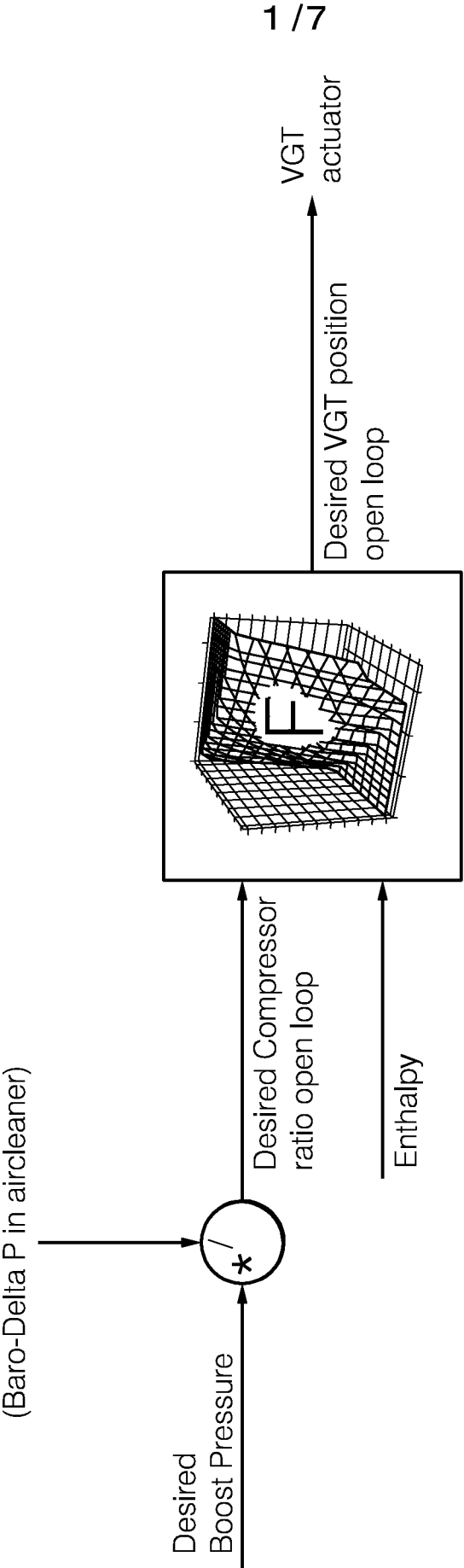


FIG. 1

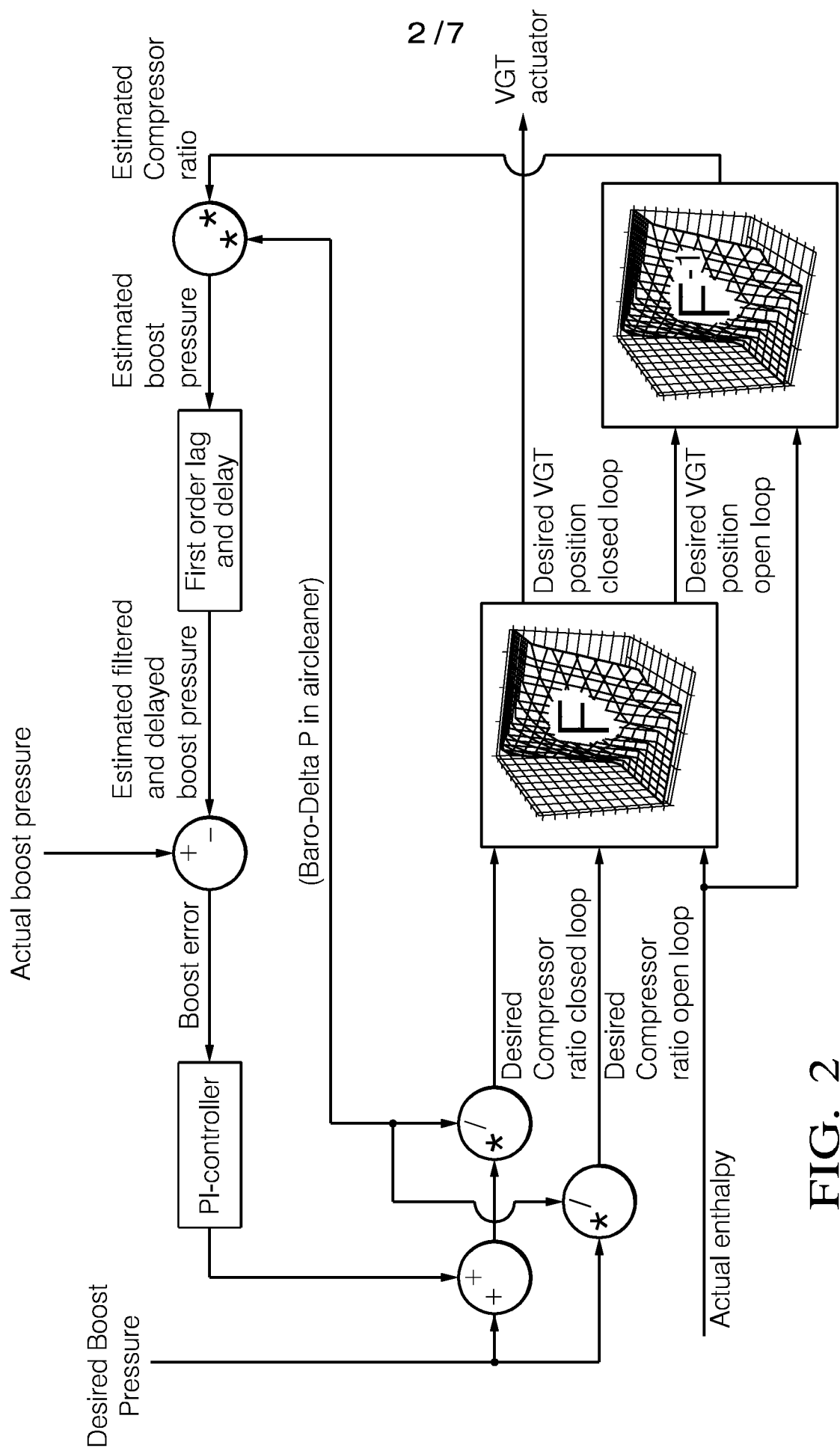


FIG. 2

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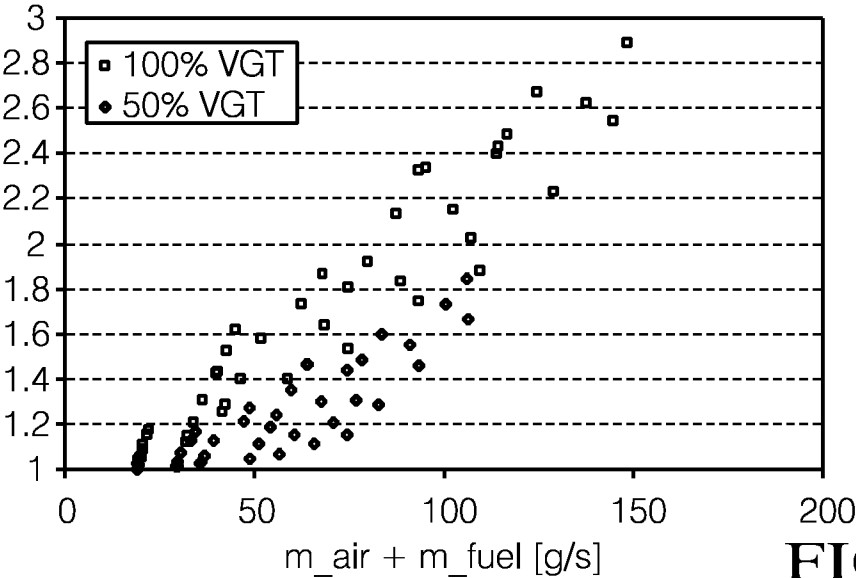


FIG. 3a

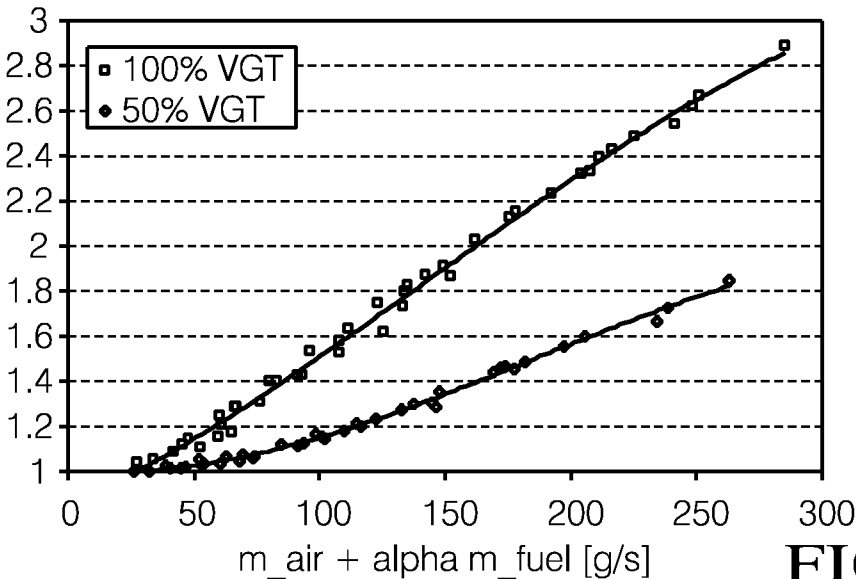


FIG. 3b

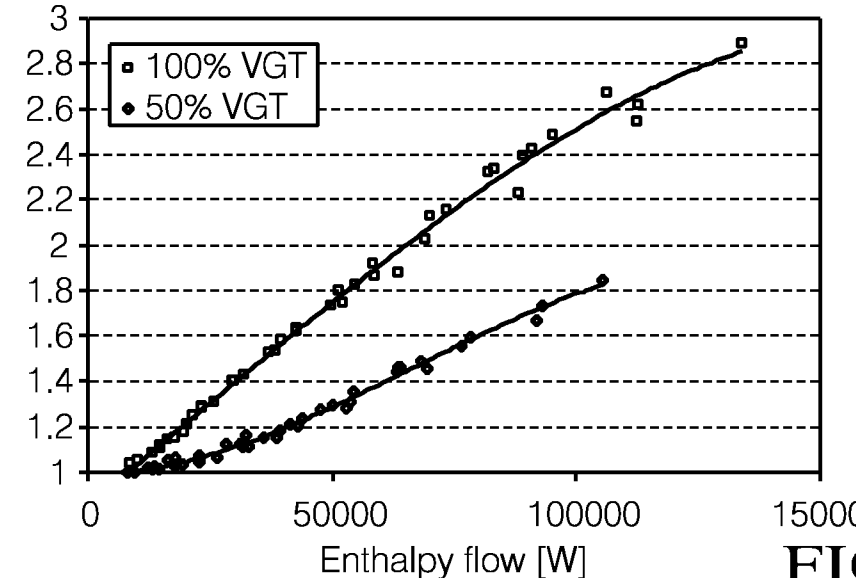


FIG. 3c

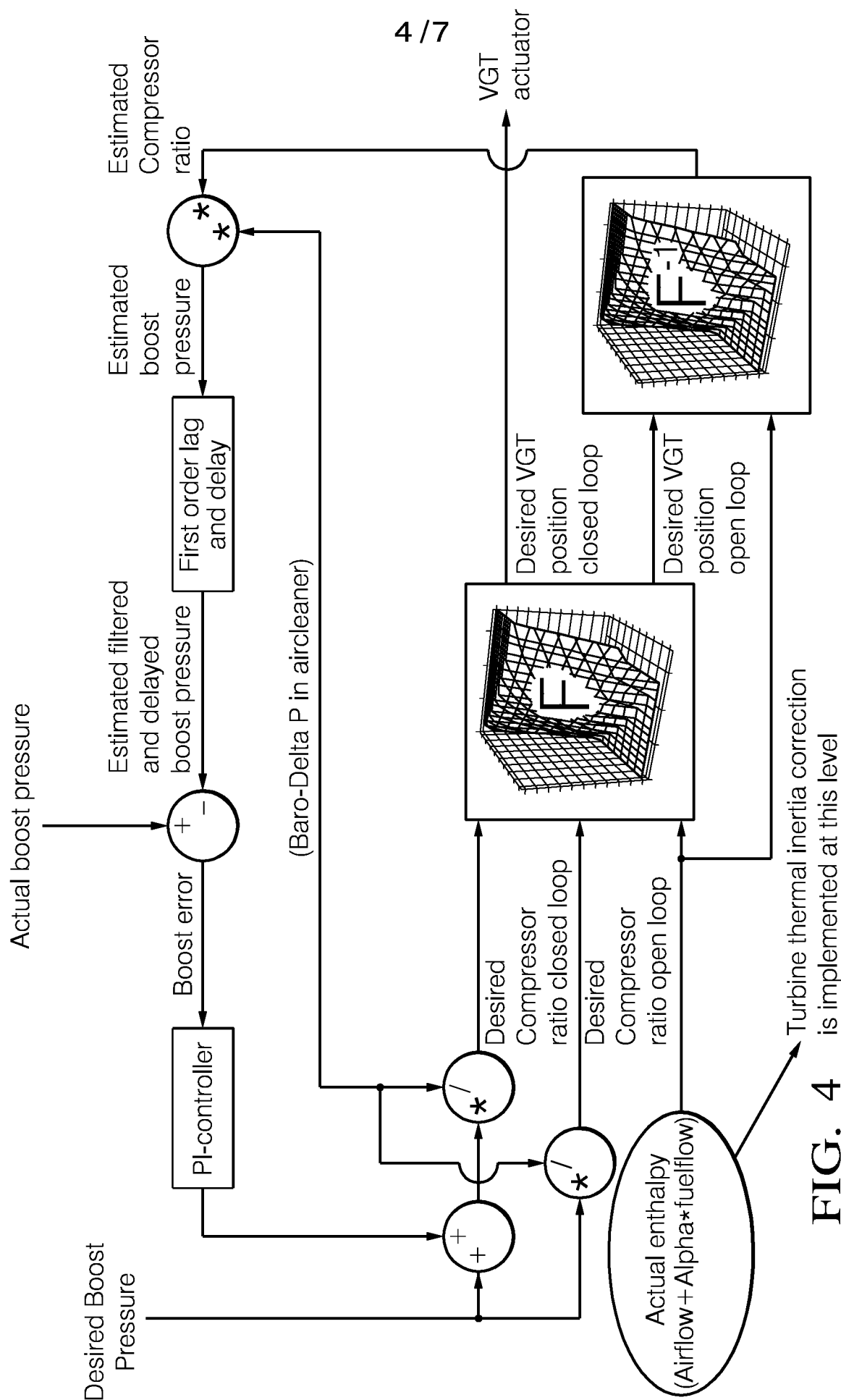


FIG. 4 is implemented at this level

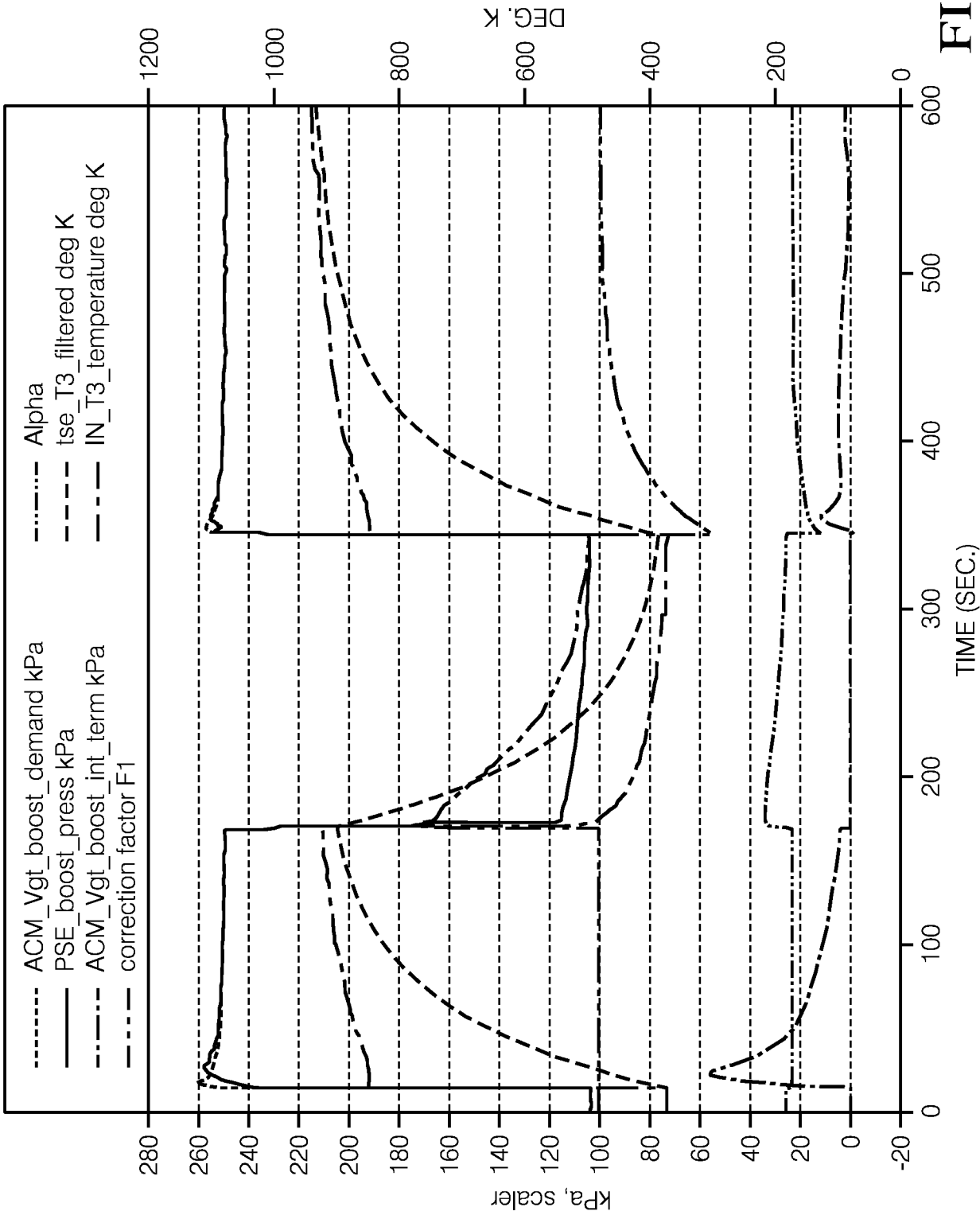


FIG. 5

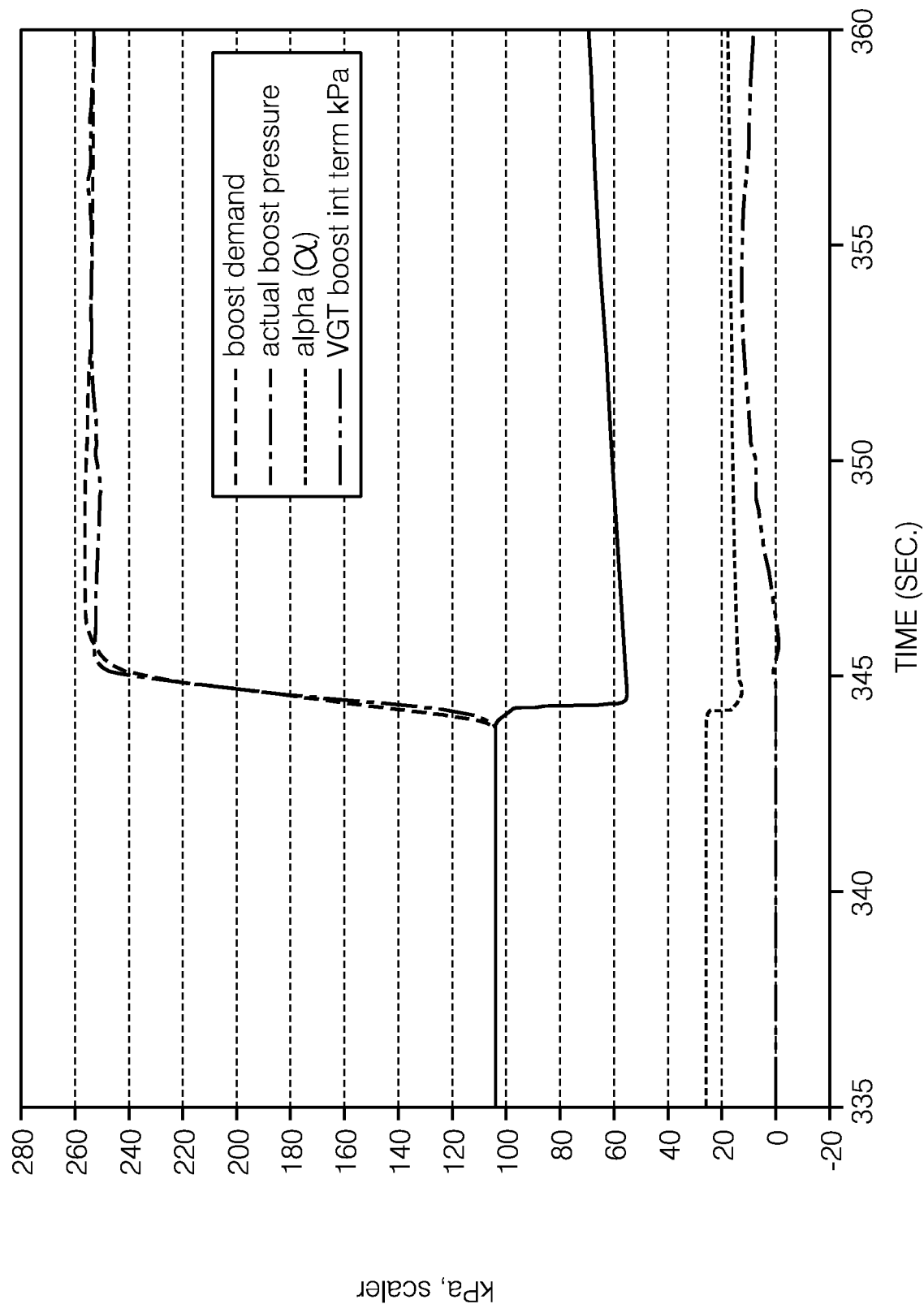


FIG. 6a

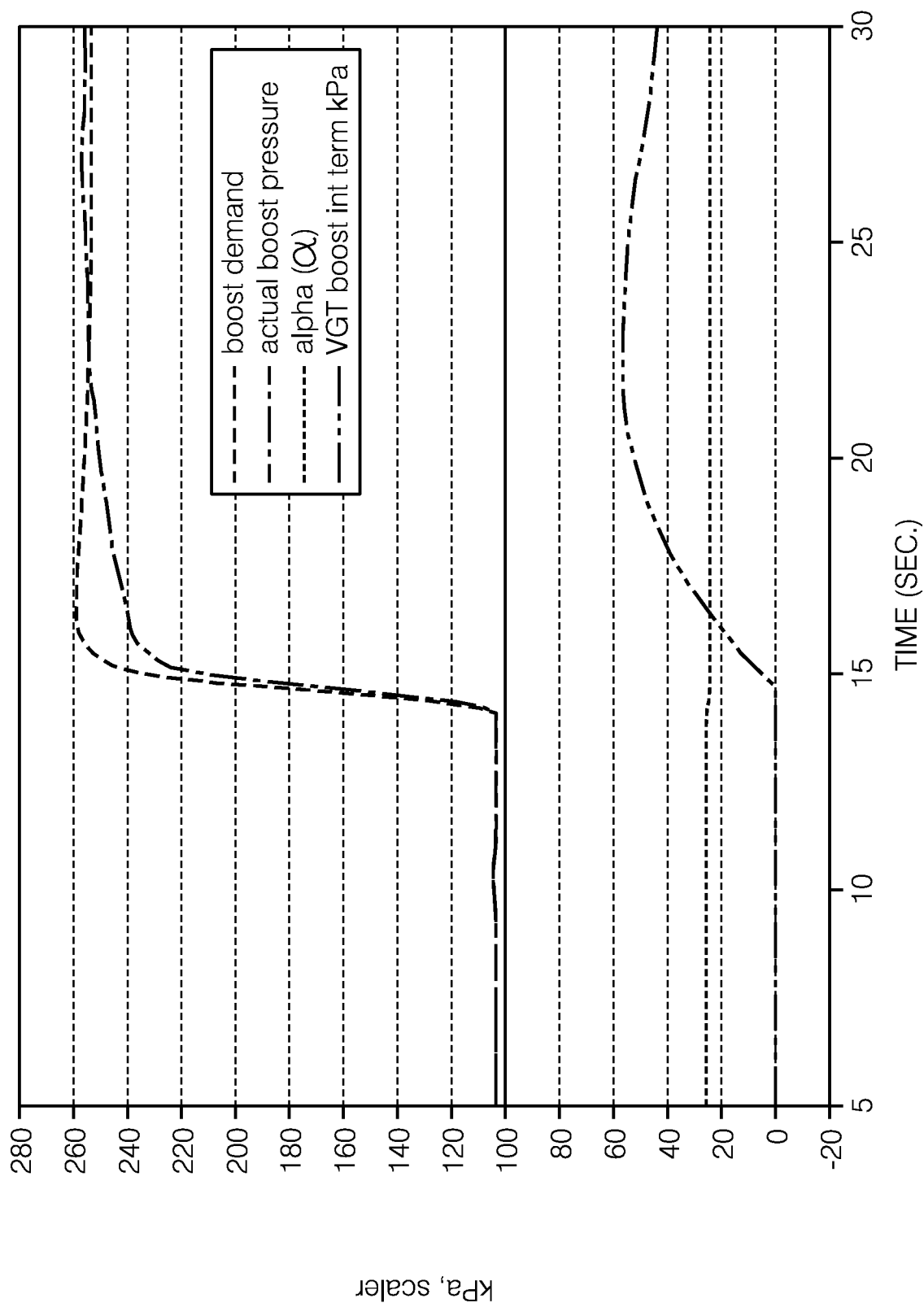


FIG. 6b

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/074210

A. CLASSIFICATION OF SUBJECT MATTER

INV. F02D41/14 F02D41/00
ADD. F02D41/10 F02D41/18 F02B37/18 F02B37/24

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)

F02D F02B

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2011/041493 A1 (DOERING JEFFREY ALLEN [US] ET AL) 24 February 2011 (2011-02-24) paragraph [0003]; claims 2,10; figure 3 paragraph [0006] paragraph [0015] - paragraph [0017] paragraph [0026] paragraph [0031] paragraph [0036] - paragraph [0042] paragraph [0045] - paragraph [0049] paragraph [0056] - paragraph [0061] ----- -/-	1-5,7,8 6,9-11



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search

5 February 2016

Date of mailing of the international search report

12/02/2016

Name and mailing address of the ISA/

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Rocabruna Vilardell

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/074210

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/227109 A1 (WANG YUE-YUN [US] ET AL) 14 August 2014 (2014-08-14)	1-8
A	abstract; claims 1-3,6,10,11; figure 3 paragraph [0003] paragraph [0015] paragraph [0021] - paragraph [0028] paragraph [0032] - paragraph [0061] paragraph [0077] - paragraph [0085] -----	9-11
X	JP 2010 203303 A (NISSAN MOTOR) 16 September 2010 (2010-09-16)	1-8
A	abstract; claims 1-6; figures 4-7 paragraph [0002] - paragraph [0007] paragraph [0014] - paragraph [0033] -----	9-11
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/074210

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