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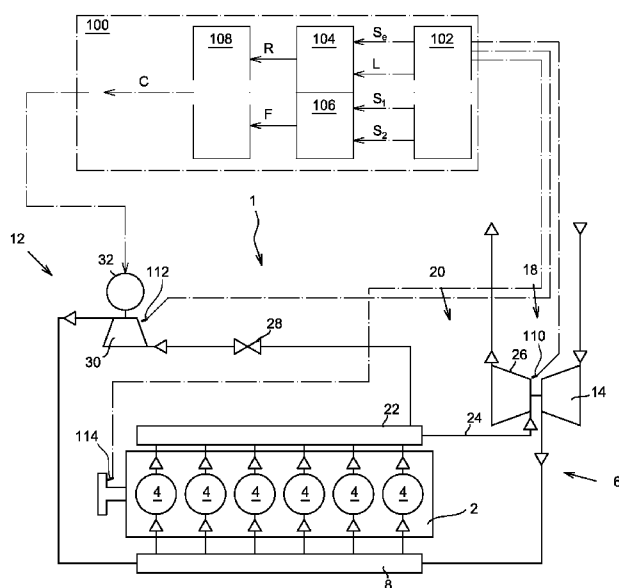
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Declarations under Rule 4.17:

— as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

[Continued on next page]

(54) **Title:** METHOD OF CONTROLLING THE OPERATING AN INTERNAL COMBUSTION ENGINE, AND A CONTROL SYSTEM FOR CONTROLLING THE OPERATION OF AN INTERNAL COMBUSTION ENGINE

**FIG. 1**

(57) **Abstract:** Invention relates to method of controlling the operating an internal combustion engine (1), in which method combustion gas is pressurized by a first compressor (18) and introduced into the engine; fuel is combusted in the engine making use of the pressurized combustion gas thus forming exhaust gas; exhaust gas is removed from the engine; a portion of the exhaust gas is recirculated by including the portion into the combustion gas prior to its introduction into the engine; the portion of the exhaust gas is pressurized by a controllable second compressor (30) and introduced into the combustion gas; further a first signal (S₁) indicative to the rotational speed of the first compressor (14) is acquired; a second signal (S₂) indicative to the rotational speed of the second compressor (30) is acquired; feedback signal (F) is acquired as a function of the first signal and the second signal; and the feedback signal is used in process of providing a control signal (C) used for controlling the operation of the second compressor.



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- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*
- Published:**
- *with international search report (Art. 21(3))*

**Method of controlling the operating an internal combustion engine,
and a control system for controlling the operation of an internal combustion engine**

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Technical field

[001] The invention relates to internal combustion piston engines and exhaust gas recycling therein.

[002] Invention relates to method of controlling the operating an internal combustion engine, in which method combustion gas is pressurized by a first compressor and introduced into the engine, fuel is combusted in the engine making use of the pressurized combustion gas thus forming exhaust gas, exhaust gas is removed from the engine, a portion of the exhaust gas is recirculated by including the portion into the combustion gas prior to its introduction into the engine, and the portion of the exhaust gas is pressurized by a controllable second compressor and introduced into the combustion gas.

[003] Invention relates also to control system for controlling the operation of an internal combustion engine comprising a first compressor for pressurizing the combustion gas to be introduced into the engine, an exhaust gas recycling conduit system in which a second compressor is arranged for pressurizing recycled exhaust gas to be introduced into the engine.

Background art

[004] Turbochargers are well-known for supplying air to the intake of an internal combustion engine at pressures above ambient pressure.

[005] Generally, a turbocharger comprises an exhaust gas driven turbine wheel mounted on a rotatable shaft within a turbine housing. Rotation of the turbine wheel rotates a compressor wheel mounted on the other end of the shaft within a compressor housing. In order to facilitate control of the operation of the turbo charger, the turbine may be of a fixed or variable geometry type. Variable geometry turbines differ from fixed geometry turbines in that the size or function of the inlet passageway can be varied to control the gas introduction into the turbine so that the power output of the turbine can be varied to suite varying engine demands.

10 [006] During the operation of an internal combustion engine nitrogen oxides (NO_x) are formed. NO_x is produced during the combustion process in an engine due to high temperature in the presence of oxygen and nitrogen. In order to meet the requirements of exhaust emissions exhaust gas recirculation (EGR) systems may be used, in which a portion of the engine's exhaust gas is recirculated back to the combustion chambers of the engine. This is typically achieved by directing an amount of the exhaust gas from the exhaust manifold to the inlet manifold of the engine. This is commonly called as external recirculation. The recirculated exhaust gas lowers the peak temperature produced during combustion. As NO_x production increases with increased peak temperature, recirculation of exhaust gas reduces the amount of undesirable NO_x formed. Turbochargers may form part of the EGR system.

[007] In engines with high inlet manifold pressure, it is necessary to increase the pressure of the recirculated exhaust-gases e.g. by means of a compressor electrically or turbine driven. There are a number of publications disclosing the use of compressor for the purpose.

[008] For example in publication US 2010/122530A1 there is disclosed such a system. The EGR system for an engine with a turbocharger comprises a second turbocharger which operates in parallel with the main turbocharger. The second turbocharger, herein referred to as the EGR turbo-

charger, has a turbine part, which is powered by a portion of the engine exhaust. The compressor part of the turbocharger is arranged to feed a portion of the engine exhaust gas, after pressurizing the exhaust gas, to the inlet manifold of the engine. As such, the turbine part of the EGR turbo-
5 charger drives the EGR turbocharger's compressor part so that the EGR turbocharger feeds a portion of engine exhaust gas to the engine intake.

[009] US 6216461 B1 discloses an exhaust gas recirculation and control system for an internal combustion engine. The recirculated exhaust gas is pumped through the EGR duct by an EGR compressor driven by a dedicat-
10 ed EGR drive that is independently controllable. This way the EGR flow rate capacity of the system is not dictated by, or limited, by factors such as engine exhaust flow rate. A controller modulates power delivery to the drive means in response to at least one operating condition parameter in order to achieve a desired EGR flow rate. The system comprises also a controller
15 operably connected with the EGR drive to modulate power delivery to the EGR drive and thereby control an EGR flow rate. The controller modulates the EGR output of the compressor in response to various input parameters from sensors, each of which provides a signal to indicate a particular operating parameter.

20 [0010] For closed-loop operation, the signal may also include an appropriate feedback signal corresponding to the operation of the EGR drive or EGR compressor, such as a signal indicating drive speed of the drive or compressor, position of the EGR drive or EGR compressor, EGR flow rate, or another suitable signal indicating the output of the EGR system.

25 [0011] A problem relating to exhaust gas recirculation by means of an EGR compressor is to arrange proper EGR operation and control for various operational conditions of the engine.

Disclosure of the Invention

[0012] The above mention problem of the prior art is solved by method of
5 controlling the operating an internal combustion engine, in which method
combustion gas is pressurized by a first compressor and introduced into the
engine; fuel is combusted in the engine making use of the pressurized
combustion gas thus forming exhaust gas; exhaust gas is removed from the
engine; a portion of the exhaust gas is recirculated by including the portion
10 into the combustion gas prior to its introduction into the engine; the portion
of the exhaust gas is pressurized by a controllable second compressor and
introduced into the combustion gas. It is characteristic to the invention that
in the method a first signal indicative to the rotational speed of the first
compressor is acquired; a second signal indicative to the rotational speed
15 of the second compressor is acquired; feedback signal is acquired as a
function of the first signal and the second signal; and the feedback signal is
used in process of providing a control signal used for controlling the opera-
tion of the second compressor.

[0013] According to an embodiment of the invention the feedback signal is
20 acquired as speed ratio defined as a ratio of the second signal to the first
signal.

[0014] According to an embodiment of the invention the first signal indica-
tive to the rotational speed is the actual rotational speed of the first com-
pressor.

25 [0015] According to an embodiment of the invention the second signal in-
dicative to the rotational speed is the actual rotational speed of the second
compressor.

[0016] According to an embodiment of the invention the process of provid-
ing a control signal comprises acquiring a reference signal of the operation

of the engine and establishing the control signal by comparing the feedback signal to the reference signal.

[0017] According to an embodiment of the invention that the reference signal is a function of engine load and engine's rotational speed.

- 5 [0018] According to an embodiment of the invention the reference signal is acquired based on predefined map of reference signal values stored in or made readable to the reference signal processing unit.

[0019] The above mention problem of the prior art is solved by a control system for controlling the operation of an internal combustion engine comprising a first compressor for pressurizing the combustion gas to be introduced into the engine, and an exhaust gas recycling conduit system in which a second compressor is arranged for pressurizing recycled exhaust gas to be introduced into the engine. The control system is comprised of an input unit, arranged to receive measurement data indicating the operational status of the engine, including the rotational speed of the first compressor, the rotational speed of the second compressor, engine speed, and engine load; a reference signal processing unit arranged to acquire a reference signal based on at least the engine speed and engine load; a feedback signal processing unit arranged to acquire a feedback signal as a function of the rotational speed of the second compressor and the rotational speed of the first compressor; a controller unit arranged to acquire a control signal by comparing the feedback signal to the reference signal.

[0020] According to an embodiment of the invention the controller unit is arranged to decrease the control signal value in case difference between the feedback signal and the reference signal is higher than predetermined set value.

[0021] According to an embodiment of the invention the controller unit is arranged to increase the control signal value in case difference between the

feedback signal and the reference signal is lower than predetermined set value.

[0022] According to an embodiment of the invention that the reference signal processing unit is arranged to acquire a reference signal based on pre-defined map of reference signal values stored in or made readable to the reference signal processing unit.

Brief Description of Drawings

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[0023] In the following, the invention will be described with reference to the accompanying exemplary, schematic drawings, in which

Figure 1 illustrates an internal combustion engine according to an embodiment of the invention; and

15 Figure 2 illustrates other embodiments of the invention.

Detailed Description of Drawing

20 [0024] Figure 1 depicts schematically an internal combustion engine 1. The engine comprises a body 2 in which several cylinders 4 are arranged with in-line arrangement. The engine further comprises an inlet gas conduit system 6 leading through an inlet manifold 8 to each cylinder 4 of the engine 1. The inlet gas conduit system is arranged for conveying inlet gas, typically
25 air, to the combustion chambers of the engine. The engine comprises also an exhaust gas system 20 and an exhaust gas recirculation conduit 12 system connecting the exhaust gas conduit system 20 with the inlet gas conduit system 6.

[0025] The inlet manifold 8 is connected to an outlet of a compressor part 14 of a turbocharger unit 18. The compressor part of the turbocharger unit 18 is called here as the first compressor. The exhaust gas conduit system 20 comprises an exhaust manifold 22 from which an exhaust conduit 24 extends to an inlet of a turbine part 26 of the turbocharger unit 18. The turbine part 26 and the compressor part 18 of the turbocharger are coupled with each other in a manner known as such. The compressor is thus operated by means of the turbine part. The turbine part may be provided with a waste-gate or other control system (not shown).

[0026] The exhaust gas recirculation conduit system 12 connects the exhaust gas conduit system 20 with the inlet gas conduit system 6 so that a portion of the exhaust gas flow of the engine may be recirculated back to the engine. The actual location at which the exhaust gas recirculation conduit system 12 joins to the exhaust gas system 20 may vary according to specific installation and such possible locations are apparent to those skilled in the art.

[0027] The exhaust gas recirculation conduit system 12 comprises in this embodiment an on/off valve 28 in order to permit or allow the recirculation by opening or closing the valve when so desired.

[0028] The exhaust gas recirculation conduit system 12 in the engine comprises a second compressor 30 in order to pressurize recirculated portion of the exhaust gas to desired level. The second compressor 30 is controllable so that the amount of the recirculated exhaust gas flow may be efficiently controlled at all operational situations of the engine. In the embodiment of figure 1 the second compressor 30 is provided with a motor 32 which may be driven by electric energy. The inlet side of the second compressor 30 is connected to the exhaust manifold 22 of the engine to receive exhaust gas of the engine. An outlet of the compressor 30 is connected to the inlet gas conduit system 6 by means of the exhaust gas recirculation conduit system

12. The inlet side of the second compressor 30 may be in some installations connected to a location downstream the turbine part 26 in the exhaust gas conduit system 20.

5 [0029] In the operation of the engine combustion air is introduced to the engine through an inlet gas conduit and the air is supercharged by the first compressor by making use of energy of the exhaust gases of the engine arranged to flow in and exhaust gas system. And, a controllable amount of exhaust gas is recirculated to the inlet gas conduit system and back to the
10 combustion process of the engine.

[0030] Even if not shown here the exhaust gas recirculation conduit system 12 may comprise a gas cleaning device, such as hot gas particulate material filter, and a gas cooler unit.

15 [0031] According to an embodiment of the invention the internal combustion engine and its operation is controlled so that while running the engine combustion gas is pressurized by the first compressor 26 and pressurized combustion gas is introduced into the engine, in which fuel is combusted making use of the pressurized combustion gas. Combustion gas is oxygen containing gas, preferably air. Combustion of the fuel form exhaust gas which
20 is removed from the engine via the exhaust gas system 20. A controllable portion of the exhaust gas is recirculated back to the engine and the combustion process by including the portion into the combustion gas prior to its
25 introduction into the engine.

[0032] Next, the portion of the exhaust gas is pressurized by the second compressor 30 and is introduced into the combustion gas. The second compressor is controlled to provide work in relation to the operation of the
30 first compressor. More specifically, the second compressor is controlled based on a feedback signal which is defined in relation to the rotational speed of the first compressor.

[0033] According to an embodiment of the invention this practised so that at least a first signal indicative to the rotational speed of the first compressor is acquired and a second signal indicative to the rotational speed of the second compressor is acquired. The first signal and the second signal are used to generate the feedback signal representing the operational status of the second compressor in respect to the first compressor i.e. the feedback signal is acquired as a function of the first signal and the second signal. In its simplest form the first signal indicative to the rotational speed is the actual rotational speed of the first compressor and second signal indicative to the rotational speed is the actual rotational speed of the second compressor.

[0034] According to an advantageous embodiment of the invention the feedback signal is generated as a speed ratio defined as a ratio of the second signal to the first signal and feedback signal is used in a process of providing a control signal to the second compressor.

[0035] In the method the process of providing a control signal comprises acquiring a reference signal and establishing the control signal by comparing the feedback signal to the reference signal. The reference signal is a function of engine load and engine's rotational speed.

[0036] According to an embodiment of the invention the reference signal is acquired based on predefined and/or interpolated map of reference signal values stored in or made readable to the reference signal processing unit. An example of such a map is shown in the table below for a specific engine the maximum rotational speed of which is 1100 rpm. It is clear that the invention is applicable to engines capable of rotating at other speeds also.

<i>Reference signal (%)</i>											
	Engine load (%)										
	0	20	40	60	70	80	90	100	80	90	100
0	0	0	0	0	10	10	10	10	20	30	40
200	0	0	10	10	30	30	30	30	40	50	60
400	0	20	30	30	50	50	50	50	60	70	80
600	20	40	50	50	70	70	70	70	80	90	100
800	40	60	70	70	90	90	90	90	90	100	100
900	60	80	90	90	100	100	100	100	100	100	100
1000	80	100	100	100	100	100	100	100	100	100	100
1100	100	100	100	100	100	100	100	100	100	100	100

[0037] According to an embodiment of the invention a speed difference is defined as a difference between the feedback signal and the reference signal, and the speed difference is used to generate a control signal to the second compressor. According to an embodiment of the invention the control signal value is decreased in case the difference between the feedback signal and the reference signal is higher than predetermined set value. Respectively, the control signal value is increased in case the difference between the feedback signal and the reference signal is lower than predetermined set value.

[0038] Further, the engine is provided with a control system 100 for controlling the operation of the engine according to the invention. The control system 100 comprises an input unit 102, which is arranged to receive measurement data indicating the operational status of the engine. The input unit 102 is in data transmission connection with numerous senders positioned at certain surveillance targets of the engine, particularly such as the first compressor with a speed sensor 110 measuring the rotational speed of the first compressor, the second compressor with a speed sensor 112 measuring

the rotational speed of the second compressor, engine speed sensor, and engine load sensor or calculated load information, which in figure 1 is illustrated as a combined sensor 114.

5 [0039] Further the control system comprises a reference signal processing unit 104. The reference signal processing unit is arranged to acquire a reference signal based on at least the engine speed S_e and engine load L , which are read or acquired by the input unit 102 and thereafter made available to the reference signal processing unit 104. The reference signal processing unit has access to a predefined map of reference signal values
10 stored in or made readable to the reference signal processing unit.

[0040] Additionally the control system comprises a feedback signal processing unit 106 arranged to acquire a feedback signal F . According to an
15 embodiment of the invention the feedback signal F is a ratio of the rotational speed of the second compressor S_2 and the rotational speed S_1 of the first compressor. The control system further comprises a controller unit 108 which is arranged to acquire a control signal C by comparing the feedback signal acquired by the feedback signal processing unit to the reference signal
20 acquired by reference signal processing unit 104.

[0041] The controller unit is arranged to perform a comparison between the feedback signal and the reference signal. It is arranged to decrease the control signal value in case difference between the feedback signal and the
25 reference signal is higher than predetermined set value. Respectively, the controller unit is arranged to increase the control signal value in case difference between the feedback signal to the reference signal is lower than predetermined set value.

30 [0042] In figure 1 the controlling of the second compressor 30 is accomplished by controlling the motor 32 operating the compressor. In figure 2 there is shown another embodiment of the invention in which the second

compressor is operated by a second turbine 32' through which exhaust gas of the engine is arranged to flow performing work in the turbine. In this case the controlling of the second compressor 30 may be accomplished by a control valve 40 in the exhaust gas recirculation conduit system 12 and/or a control valve 42 in the exhaust gas recirculation conduit 12 system. In other respect the embodiment of figure 2 corresponds to that in figure 1.

[0043] In figure 2 there is shown also another embodiment of the invention in which in addition to the first compressor unit 14 there is a second compressor unit 14' i.e. two turbo chargers are connected in series. Thus, it is clear that the turbocharger unit i.e. the turbine part and/or the compressor part, may comprise more than two stages as well. In such an embodiment the rotational speed of the first compressor means preferably the rotation speed of the compressor operating at a higher pressure level.

[0044] While the invention has been described herein by way of examples in connection with what are, at present, considered to be the most preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments, but is intended to cover various combinations or modifications of its features, and several other applications included within the scope of the invention, as defined in the appended claims. For example the invention may be well applied to two stroke or four stroke engines operating with various cycles, such as the otto- or diesel cycle. The engine configuration may also vary from in-line engine to e.g. V engine. The details mentioned in connection with any embodiment above may be used in connection with another embodiment when such combination is technically feasible.

Claims

1. Method of controlling the operating an internal combustion engine (1), in which method
- 5 - combustion gas is pressurized by a first compressor (18) and introduced into the engine;
- fuel is combusted in the engine making use of the pressurized combustion gas thus forming exhaust gas;
- exhaust gas is removed from the engine;
- 10 - a portion of the exhaust gas is recirculated by including the portion into the combustion gas prior to its introduction into the engine;
- the portion of the exhaust gas is pressurized by a controllable second compressor and introduced into the combustion gas;
- characterized** in that in the method:
- 15 - a first signal indicative to the rotational speed of the first compressor is acquired;
- a second signal indicative to the rotational speed of the second compressor is acquired;
- feedback signal is acquired as a function of the first signal and the second
- 20 signal; and
- the feedback signal is used in process of providing a control signal used for controlling the operation of the second compressor.
2. Method of operating an internal combustion engine according to
- 25 claim 1, **characterized** in that the feedback signal is acquired as speed ratio defined as a ratio of the second signal to the first signal.
3. Method of operating an internal combustion engine according to claim 1, **characterized** in that the first signal indicative to the rotational speed is the actual rotational speed of the first compressor.

4. Method of operating an internal combustion engine according to claim 1, **characterized** in that the second signal indicative to the rotational speed is the actual rotational speed of the second compressor.
5. Method of operating an internal combustion engine according to claim 1, **characterized** in that the process of providing a control signal comprises acquiring a reference signal of the operation of the engine and establishing the control signal by comparing the feedback signal to the reference signal.
6. Method of operating an internal combustion engine according to claim 5, **characterized** in that the reference signal is a function of engine load and engine's rotational speed.
7. Method of operating an internal combustion engine according to claim 6, **characterized** in that the reference signal is acquired based on predefined map of reference signal values stored in or made readable to the reference signal processing unit.
8. Control system for controlling the operation of an internal combustion engine (1) comprising a first compressor (30) for pressurizing the combustion gas to be introduced into the engine (1); an exhaust gas recycling conduit system (12) in which a second compressor is arranged for pressurizing recycled exhaust gas to be introduced into the engine;
which control system is comprised of:
- input unit (102), arranged to receive measurement data indicating the operational status of the engine, including the rotational speed of the first compressor, the rotational speed of the second compressor, engine speed, and engine load;
- reference signal processing unit (104) arranged to acquire a reference signal based on at least the engine speed (S_e) and engine load (L);

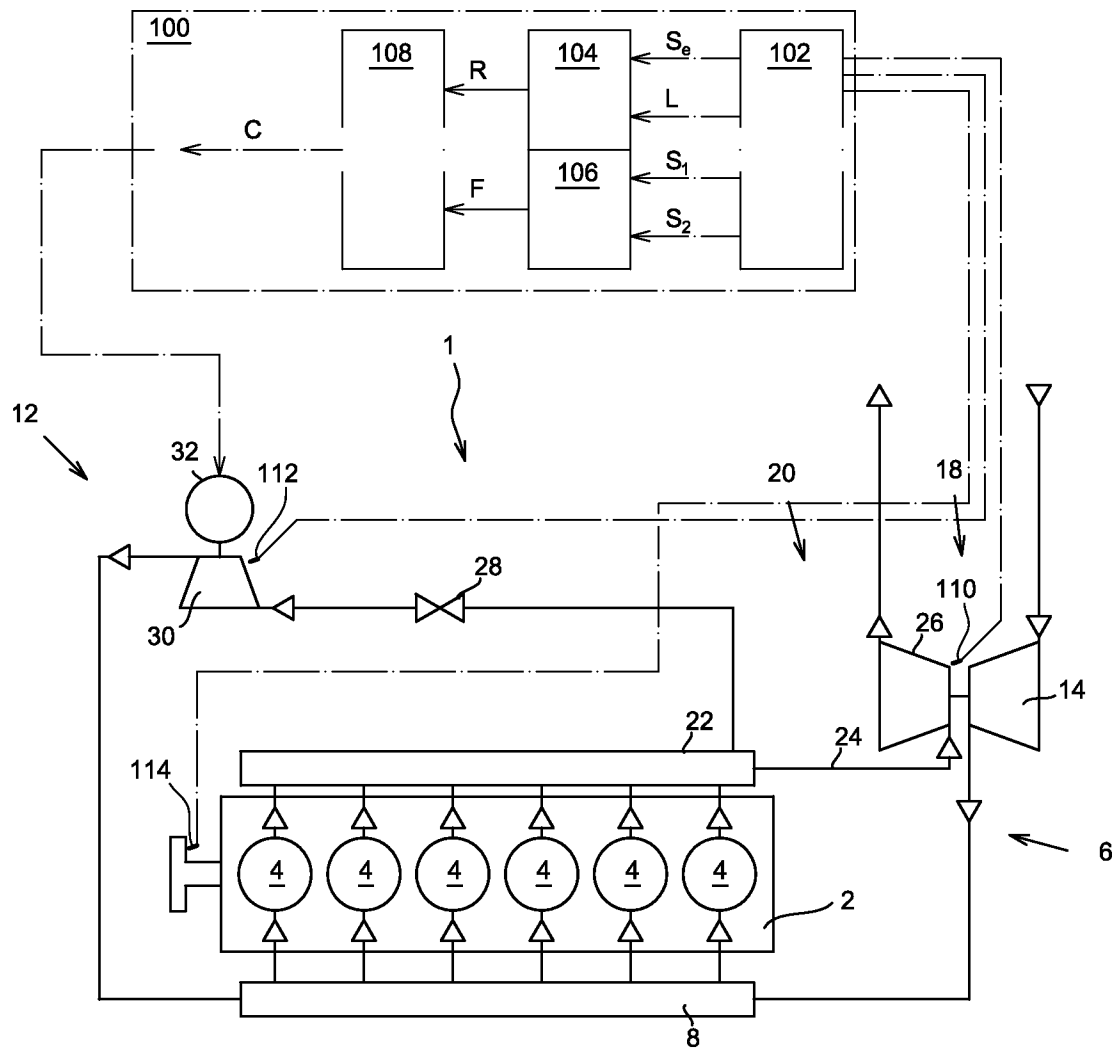
- feedback signal processing unit (106) arranged to acquire a feedback signal as a function of the rotational speed (S_2) of the second compressor and the rotational speed (S_1) of the first compressor;
- controller unit (108) arranged to acquire a control signal (C) by comparing the feedback signal to the reference signal.

9. Control system according to claim 8, **characterized** in that the controller unit is arranged to decrease the control signal value in case difference between the feedback signal and the reference signal is higher than predetermined set value.

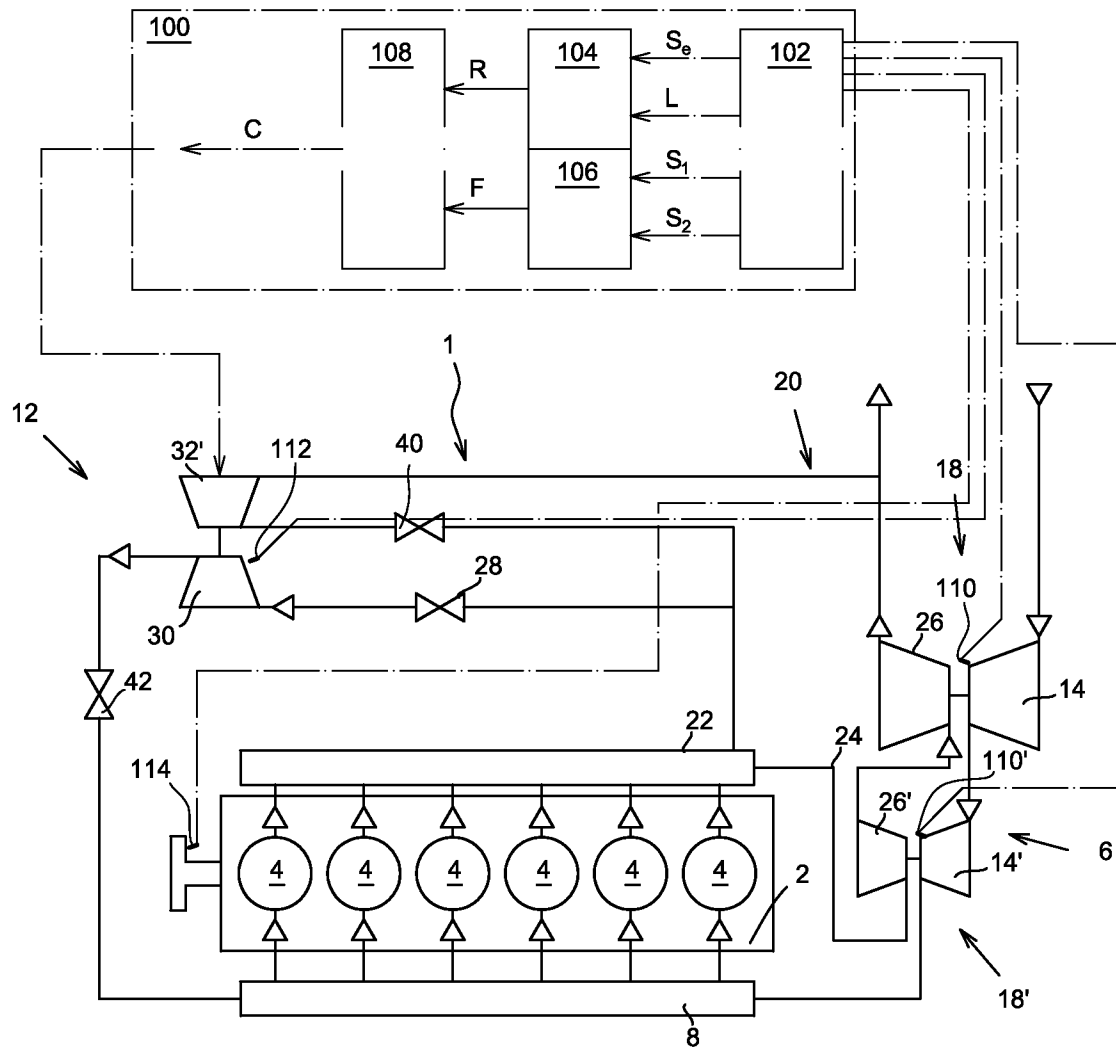
10. Control system according to claim 8, **characterized** in that the controller unit is arranged to increase the control signal value in case difference between the feedback signal and the reference signal is lower than predetermined set value.

11. Control system according to claim 8, **characterized** in that the reference signal processing unit is arranged to acquire a reference signal based on predefined map of reference signal values stored in or made readable to the reference signal processing unit.

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**FIG. 1**

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**FIG. 2**

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2013/050844

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02M25/07 F02D41/00
ADD.

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)
F02M F02D

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)

EP0-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	US 2011/094224 A1 (SHEIDLER ALAN D [US] ET AL) 28 April 2011 (2011-04-28) abstract figure 1 paragraphs [0006], [0017], [0019] -----	1-11
X	US 6 216 461 B1 (SHAO JOSH S [US] ET AL) 17 April 2001 (2001-04-17) cited in the application abstract figures 1,4 column 4, line 25 - line 56 column 6, line 3 - line 6 ----- -/--	1-11



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

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

26 November 2013

Date of mailing of the international search report

05/12/2013

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer

Payr, Matthias

INTERNATIONAL SEARCH REPORT

International application No

PCT/FI2013/050844

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 5 791 146 A (DUNGNER STEFAN [SE]) 11 August 1998 (1998-08-11) abstract figure 1 column 3, line 26 - line 32 column 5, line 66 - column 6, line 10 column 6, line 35 - line 43 -----	1-11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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