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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
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(54) **Title**: PROTECTION SYSTEM FOR WHR SYSTEM AND ENGINE SYSTEM

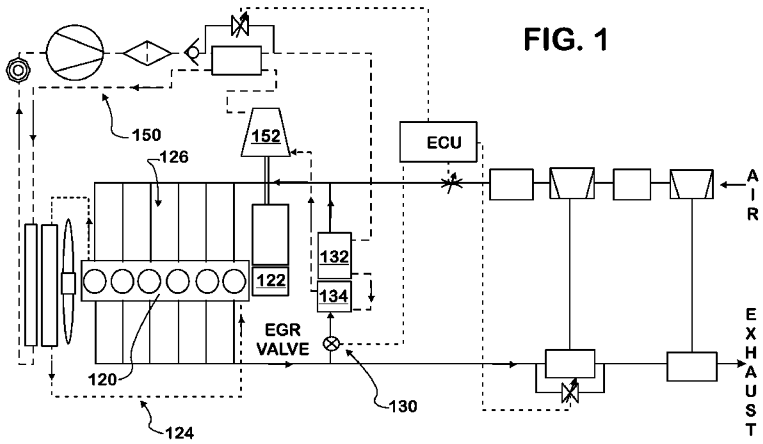

FIG. 1

(57) **Abstract**: A first exhaust gas recirculation (EGR) valve is positioned within a first EGR passage fluidly connecting an engine exhaust stream and an engine intake stream, while a waste heat recovery (WHR) system is used to recover heat from the EGR stream. When the working fluid of the WHR system approaches a critical breakdown temperature, an engine control unit (ECU) closes the first EGR valve in response to a sensor reading and opens a second EGR valve positioned with a second EGR passage fluidly connecting the engine exhaust stream and the engine intake stream. The second EGR flow is cooled by an engine coolant loop before being routed into the engine intake system. The ECU also operates to divert the cooling working fluid flow away from a turbine when sensors indicate characteristics of the working fluid may be damaging to the turbine.

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PROTECTION SYSTEM FOR WHR SYSTEM AND ENGINE SYSTEM

TECHNICAL FIELD

[0001] The present device relates to system and methods which protect the working fluid of a waste heat recovery system and the engine turbo charger from the possible damages of overheating. Particularly, the system and methods relate to diverting potentially harmful high-temperature exhaust fluids to prevent the breakdown of working fluid and exposure of high- and low-pressure turbo chargers.

BACKGROUND

[0002] In internal combustion engines, when the combustion temperatures exceed about 2500 °F (about 1371 °C), atmospheric nitrogen begins to react with intake oxygen to form compounds called nitrogen oxides (NOx). These compounds play a major role in air pollution, particularly in high traffic areas such as cities. To reduce the formation of NOx, combustion temperatures must be kept below the 2500 °F threshold. One way this is achieved is by re-circulating a small amount of engine exhaust back into the engine intake through an exhaust gas recirculation (EGR) valve.

[0003] The EGR valve controls a passageway between the intake and exhaust manifolds. Sensors and a control unit are used to open the valve to allow the intake vacuum to draw a portion of the exhaust stream through the valve and into the intake stream. The exhaust gas flow dilutes the incoming air/fuel mixture and has a quenching effect on combustion temperatures, which keeps NOx production within acceptable limits. As an added benefit, it also reduces the engine's octane requirements which lessens the occurrence of detonation (spark knock).

[0004] However, when a waste heat recovery (WHR) system is also used to recover energy from the EGR exhaust flow before it enters the engine intake system, the working fluid of the WHR can be exposed to very high temperatures. In fact, if uncontrolled, the refrigerant can reach breakdown temperatures in the EGR cooler components—i.e., the boiler and the super heater. To avoid this scenario, the EGR valve may be closed, allowing the high-temperature exhaust gas to run directly to the turbo charger. Unfortunately, the turbo chargers may also be damaged from exposure to the high-temperature exhaust.

[0005] The disclosed system and methods address these problems in the prior art by providing a protection system for both the WHR working fluid and the engine turbo chargers.

The system provides means for protecting against exposing either component to the potentially damaging temperatures of the exhaust stream. Likewise, the methods provide for protecting an engine and a WHR system from damage due to extreme high-temperature exhaust flow.

SUMMARY

[0006] An engine system for protecting the waste heat recovery system and engine components by diverting high-temperature EGR flow is disclosed. In basic form, the system comprises a first exhaust gas recirculation (EGR) valve positioned within an EGR passage fluidly connecting an engine exhaust stream and an engine intake stream, a second EGR valve positioned within a second EGR passage fluidly connecting the exhaust stream and intake stream, a waste heat recovery (WHR) system having a working fluid loop for recovering heat from the first EGR stream, a sensor for determining a characteristic of the WHR working fluid and an engine control unit (ECU).

[0007] In an embodiment of the system, the ECU diverts exhaust gas from the first EGR into the second EGR by closing the first EGR valve and opening the second EGR valve. An engine coolant loop provides heat exchange relationship with the high- and low-temperature coolers of the second EGR to facilitate cooling of the EGR flow before adding to the engine intake system.

[0008] A method of protecting engine components from condensation damage is also disclosed. Generally speaking, the method comprises the steps of opening a first EGR valve to divert an exhaust flow from a portion of an engine exhaust stream through a first EGR passage, directing the exhaust flow through a super heater and a boiler coupled to the first EGR passage, pumping a working fluid through a waste heat recovery (WHR) system fluid loop thermally coupled to the first EGR passage, exchanging heat between the exhaust flow and the working fluid as the two pass through the boiler and the super heater to cool the exhaust flow, introducing the cooled exhaust flow into an engine intake stream, determining characteristics of the working fluid, and in response to a determination of an unfavorable characteristic, closing the first EGR valve and opening a second EGR valve to divert the exhaust flow through a cooler and into the engine intake system.

[0009] In a further embodiment of the methods, the working fluid may be diverted to bypass an engine turbine when the working fluid is in a state unsuitable for introduction to the turbine. The working fluid is instead routed through an expansion valve before continuing through the WHR loop.

[0010] These and other embodiments of the system may be more readily understood with reference to the following description and the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIGURE 1 is a schematic of a engine system having an EGR system and a WHR system; and

[0012] FIGURE 2 is a schematic of an embodiment of the protection system for a WHR system and an Engine in accordance with the present disclosure.

DETAILED DESCRIPTION

[0013] Generally speaking, and with reference to the schematic of Fig. 1, an engine 120 operates to drive a transmission 122 which turns a drive shaft coupled to wheels and ultimately propels a vehicle. The engine 120 is kept within a desired temperature operating range by a cooling system 124. However, engine combustion may cause engine chambers to exceed a 2500 °F threshold temperature at which point the production of nitrogen oxides (NOx) reaches an unsatisfactory level.

[0014] As a means for preventing the production of NOx, an EGR system 130 is employed. As a means for utilizing some of the energy from the heat expelled by the EGR system 130, a WHR system 150 recovers heat from the exhaust flow through the boiler 132 and the super heater 134 and then uses the energy to drive a turbine 152. However, as the engine exhaust gets hotter, the working fluid of the WHR begins to breakdown. The engine controller has the ability to shut down the EGR to let the working fluid cool, but such a situation is potentially damaging to engine components.

[0015] Accordingly, the present system 10 operates to provide a second EGR system 330 which can take over for the first EGR system 230 to allow the working fluid to cool without creating damaging conditions for other engine components, and to thereby protect the engine and an intake system from such damaging conditions.

[0016] With reference to FIG. 2, an embodiment of the system 10 can be seen to comprise an engine 220 coupled to a transmission 222 and having a cooling system 224 comprised of a fan 225, radiator 227 and coolant loop 229 for maintaining a desired operating temperature range in the engine 220. The engine 220 also includes an intake system 226 and an exhaust system 228, as well as a first exhaust gas recirculation (EGR) system 230, a waste heat recovery (WHR) system 250, and a second exhaust gas recirculation (EGR) system 330.

The first EGR system 230 creates an exhaust flow by diverting a portion of the engine exhaust stream 240 into a first passage 236 with the opening of a first EGR valve 238. The first passage 236 connects at a discharge end to the engine intake system 226. Within the first EGR passage 236, a super heater 234 and a boiler 232 are used to cool the exhaust flow through the passage 236 before introducing the flow into the intake system 226.

[0017] As for the WHR system 250, the following components are fluidly connected by a loop 251 of working fluid, preferably refrigerant: pump 253, filter 254, check valve 255, recuperator 256, turbine 252 connected by a drive shaft 257 to a torque converter 258, condenser 259, and sight glass 260. For certain operations, a bypass valve 262 is added before the loop 251 enters the turbine 252, to divert working fluid directly from the super heater 234 into a variable expansion valve 265 and then into the super recuperator 256 of the WHR system 250. Additionally, the recuperator 256 includes its own bypass valve 263.

[0018] A second EGR system 330 is connected to bridge the engine intake system 226 and the engine exhaust system 228, arranged serially to the first EGR system 230. A second passage 336 connects the EGR system 330 to the exhaust system 228 and, when opened, a second EGR valve 338 allows the vacuum pressure of the intake system 226 to draw a portion of the exhaust stream 240 into the passage 336. The exhaust flow in the second EGR system 330 passes through a high-temperature cooler 334 and then into a low-temperature cooler 332. Exiting the low-temperature cooler 332, the exhaust flow enters the engine intake system 226. In order to cool the exhaust flow, the engine cooling loop 229 connects to the low-temperature cooler 332 and high-temperature cooler 334 passing in a heat-exchange relationship with the exhaust flow before returning to the engine 220.

[0019] Finally, an engine control unit (ECU) 270 is electronically coupled to and controls operation of the first EGR valve 238, second EGR valve 338, the bypass valve 262 and the recuperator bypass valve 263. Other components of the exhaust system 228 and intake system 226 include intake throttle 280, HP-CAC 281, HP-compressor 282, LP-CAC 283, LP-compressor 284, HP-turbine 285 with a bypass valve 286, and LP-turbine 287.

[0020] In the present system 10, a portion of the engine exhaust gas stream 240 is routed into the first EGR passage 236, through the super heater 234 and the boiler 232, then into the intake system 226 of the engine 220, by opening the first EGR valve 238. Heat from the exhaust flow transfers into the working fluid (refrigerant) in the WHR system 250 through the super heater 234 and the boiler 232. The pressure of vaporization of the hot working fluid is dramatically decreased through the turbine 252 while still in the vapor phase.

[0021] Unlike prior systems, however, if the temperature of the hot exhaust flow is too high, as determined by a first sensor 290 feeding information to the ECU 270, or if the working fluid is reaching a breakdown temperature as determined by a second sensor 292 also feeding information to the ECU 270, then the ECU will signal the first EGR valve 238 to close and signal the second EGR valve 338 to open, thereby diverting the exhaust flow into the second EGR system 330.

[0022] The disruption of flow through the first EGR system 230 allows the working fluid of the WHR system 250 to cool before reaching a temperature where it may begin to break down. Further, by opening the second EGR valve 338 of the second EGR system 330, a portion of the extremely hot exhaust flow is diverted from the turbo charger 285 where it may cause damage. The diverted flow enters the second EGR system 330 at passage 336. The flow encounters a high-temperature cooler 334 where the temperature of the exhaust flow is reduced through heat exchange with the radiator fluid loop 229. The exhaust flow continues entering low-temperature cooler 332 where it is cooled further before being routed to enter the engine intake system 226.

[0023] When the first EGR system 230 is bypassed, the working fluid cools and falls out of a vapor phase. When the working fluid is not in the vapor phase as it reaches the inlet of turbine 252, as determined by second sensor 292 feeding information to the ECU 270, then the working fluid is diverted to pass through the variable expansion valve 265 to protect the turbine 252. The noted sensors 290, 292 feed information to the ECU 270 related to characteristics (e.g., temperature, pressure) of the exhaust flow and the working fluid.

[0024] Whether the low-pressure, hot gas passes through the turbine 252 or is diverted through the variable expansion valve 265, it then passes through the recuperator 256 to reduce the working fluid temperature on the condenser 259. After the working fluid is cooled by the recuperator 256, it enters into the condenser 259 to return fully to liquid phase. In the liquid phase, the working fluid can be more readily handled without damaging other system components. The fully sub-cooled fluid passes through the sight glass 260 and into the pump 253. The pump 253 is used to control the amount of working fluid in the WHR system 250. From the pump 253, the fluid passes through a filter 254, a check valve 255, the recuperator 256 again—the high-side fluid picks up heat from the low-side fluid returning to the condenser 259—the boiler 232, and then the super heater 234. In passing through the latter two components, as described above, the working fluid picks up waste heat and is changed to vapor form.

[0025] The bypass valve 262 is controlled by real-time signals from the ECU 270. Preferably, the signals for the bypass valve 262 are based on either the state of the working fluid or the status of the first EGR system 230. Sensors 290, 292, either temperature or pressure, are used to feed information to the ECU 270 about the characteristics of the exhaust stream entering the first EGR system 230 and/or the working fluid. The bypass valve 262 controls working fluid amounts through the turbine 252 by bypassing working fluid directly to the variable expansion valve 265 when necessary, as illustrated in FIG. 2.

CLAIMS

What is claimed is:

1. A protection system for a waste heat recovery system, the protection system comprising:

a first exhaust gas recirculation (EGR) valve positioned within a first EGR passage which fluidly connects an engine exhaust stream and an engine intake stream;

a second exhaust gas recirculation (EGR) valve positioned within a second EGR passage which fluidly connects the engine exhaust stream and the engine intake stream;

a waste heat recovery (WHR) system for recovering heat from a first EGR stream passing through the first EGR passage, the WHR system comprising:

a fluid loop including a fluid pump continuously circulating a working fluid from an outlet end of the pump to an inlet end of the pump, wherein the fluid loop passes into and out of a thermal exchange with the first EGR stream as it passes through the first EGR passage; and

a sensor for determining a characteristic of the working fluid passing out of thermal exchange with the first EGR stream; and

a controller electronically coupled to the sensor, the first EGR valve and the second EGR valve, wherein the controller closes the first EGR valve and opens the second EGR valve in response to a signal from the sensor.

2. The protection system of Claim 1, wherein the second EGR passage is downstream of the first EGR passage.

3. The protection system of Claim 1, wherein the sensor is a temperature sensor and the signal is a temperature of the working fluid.

4. The protection system of Claim 1, wherein the sensor is a pressure sensor and the signal is a pressure of the working fluid.

5. The protection system of Claim 1, further comprising an EGR cooler fluidly coupled to the second EGR passage.

6. The protection system of Claim 5, further comprising an engine cooling loop, wherein the engine cooling loop flows from an engine radiator into the EGR cooler.

7. The protection system of Claim 6, wherein the EGR cooler comprises a low-temperature cooler fluidly coupled to a high-temperature cooler.

8. The protection system of Claim 1, wherein the first EGR valve and the second EGR valve are comprised of a single three-way valve.

9. The protection system of Claim 1, further comprising a bypass valve coupled to the WHR fluid loop to bypass a turbine.

10. The protection system of Claim 9, wherein the bypass valve is opened when the first EGR valve is closed.

11. The protection system of Claim 9, further comprising an expansion valve fluidly coupled to the bypass valve wherein working fluid bypassing the turbine is directed into the expansion valve.

12. The protection system of Claim 9, wherein the bypass valve is electronically coupled to the controller.

13. A protection system for preventing breakdown of working fluid in a waste heat recovery (WHR) system, the protection system comprising:

a first exhaust gas recirculation (EGR) valve positioned within a first EGR passage fluidly connecting an engine exhaust stream and an engine intake stream;

a super heater fluidly coupled by an inlet and an outlet to the first EGR passage after the first EGR valve;

a boiler fluidly coupled by an inlet to the super heater and by an outlet to the first EGR passage;

a first sensor for determining a characteristic of the engine intake stream;

a waste heat recovery (WHR) system for recovering heat from an EGR stream passing through the first EGR passage, the WHR system comprising:

a fluid loop including a fluid pump continuously circulating a working fluid from an outlet end of the pump to an inlet end of the pump, wherein the loop passes into and out of the boiler and then into and out of the super heater;

a condenser coupled to the fluid loop;

a turbine coupled to the fluid loop;

a recuperator coupled to the fluid loop;

a second sensor for determining a state of the working fluid before it enters the turbine; and

a bypass valve coupled to the fluid loop for diverting the working fluid away from the turbine;

a second exhaust gas recirculation (EGR) valve positioned within a second EGR passage fluidly connecting the engine exhaust stream and the engine intake stream;

a controller electronically coupled to the first EGR valve, the second EGR valve, the first sensor, the second sensor and the bypass valve, wherein the controller opens the second EGR valve and closes the first EGR valve in response to a signal from the first sensor, and wherein the controller opens the bypass valve in response to a signal from the second sensor.

14. A method for protecting components of an engine system and a waste heat recovery system comprising the steps of:

opening a first EGR valve to divert an exhaust flow from a portion of an engine exhaust stream through an EGR passage;

directing the exhaust flow through a super heater and a boiler coupled to the EGR passage;

pumping a working fluid through a waste heat recovery (WHR) system fluid loop thermally coupled to the EGR passage;

exchanging heat between the exhaust flow and the working fluid as the two pass through the boiler and the super heater to cool the exhaust flow;

introducing the cooled exhaust flow into an engine intake stream;

determining characteristics of the heated working fluid;

closing the first EGR valve to discontinue exhaust flow from a portion of the engine exhaust stream;

opening a second EGR valve to divert an alternate exhaust flow from a portion of an engine exhaust stream through a second EGR passage;

exchanging heat between the alternate exhaust flow and a cooling loop to cool the alternate exhaust flow;

introducing the cooled alternate exhaust flow into an engine intake stream.

15. The method of Claim 14, wherein the step of determining characteristics of the heated working fluid comprises the step of sensing the working fluid temperature.

16. The method of Claim 14, wherein the step of closing the first EGR valve is done in response to determining characteristics of the working fluid.

17. The method of Claim 16, wherein the characteristics of the working fluid comprise a temperature close to a threshold temperature.

18. The method of Claim 14, further comprising the step of bypassing a turbine in the waste heat recovery loop when the first EGR valve is closed.

19. The method of Claim 18, further comprising the step of expanding the working fluid in a variable expansion valve.

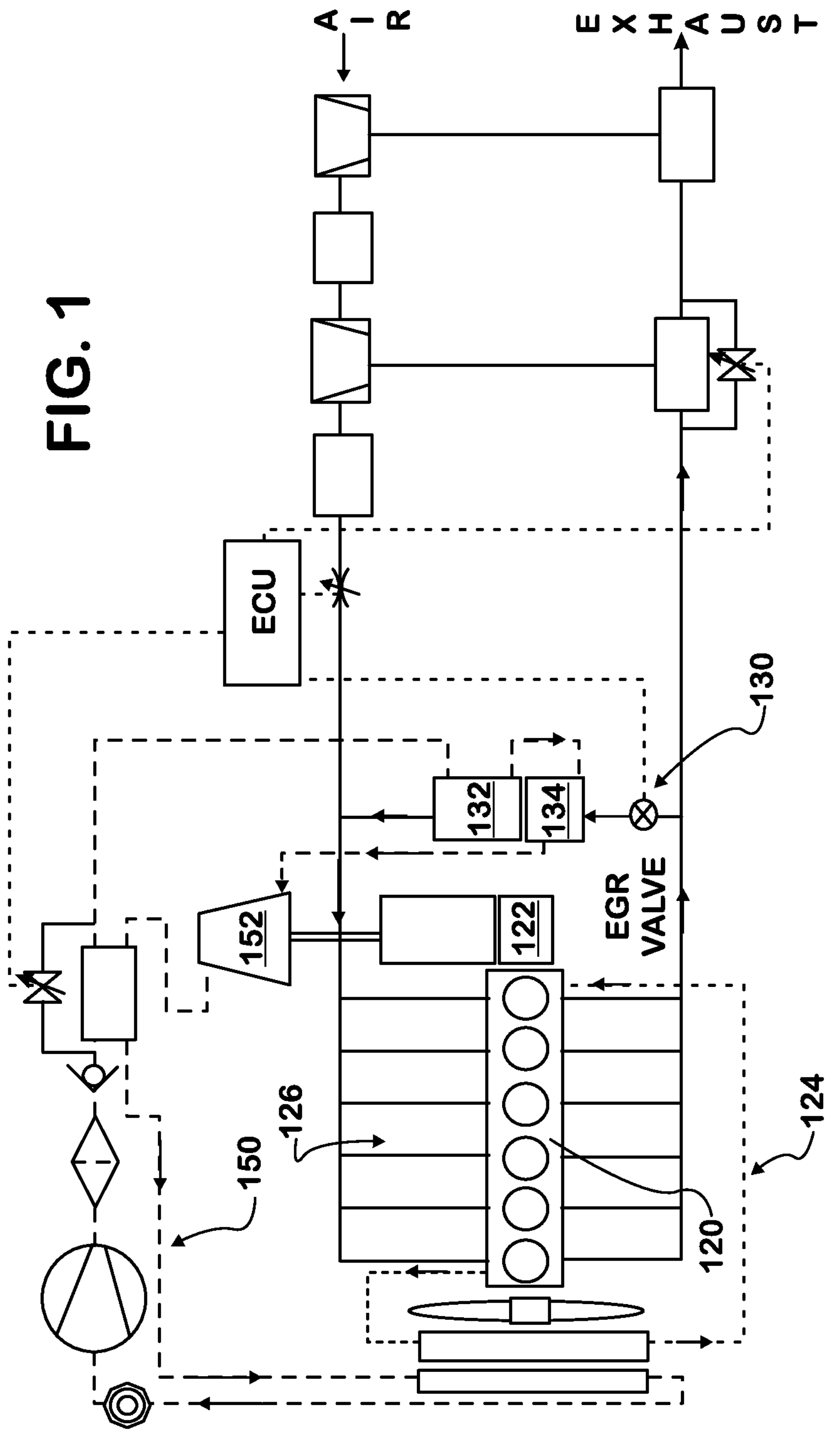

FIG. 1

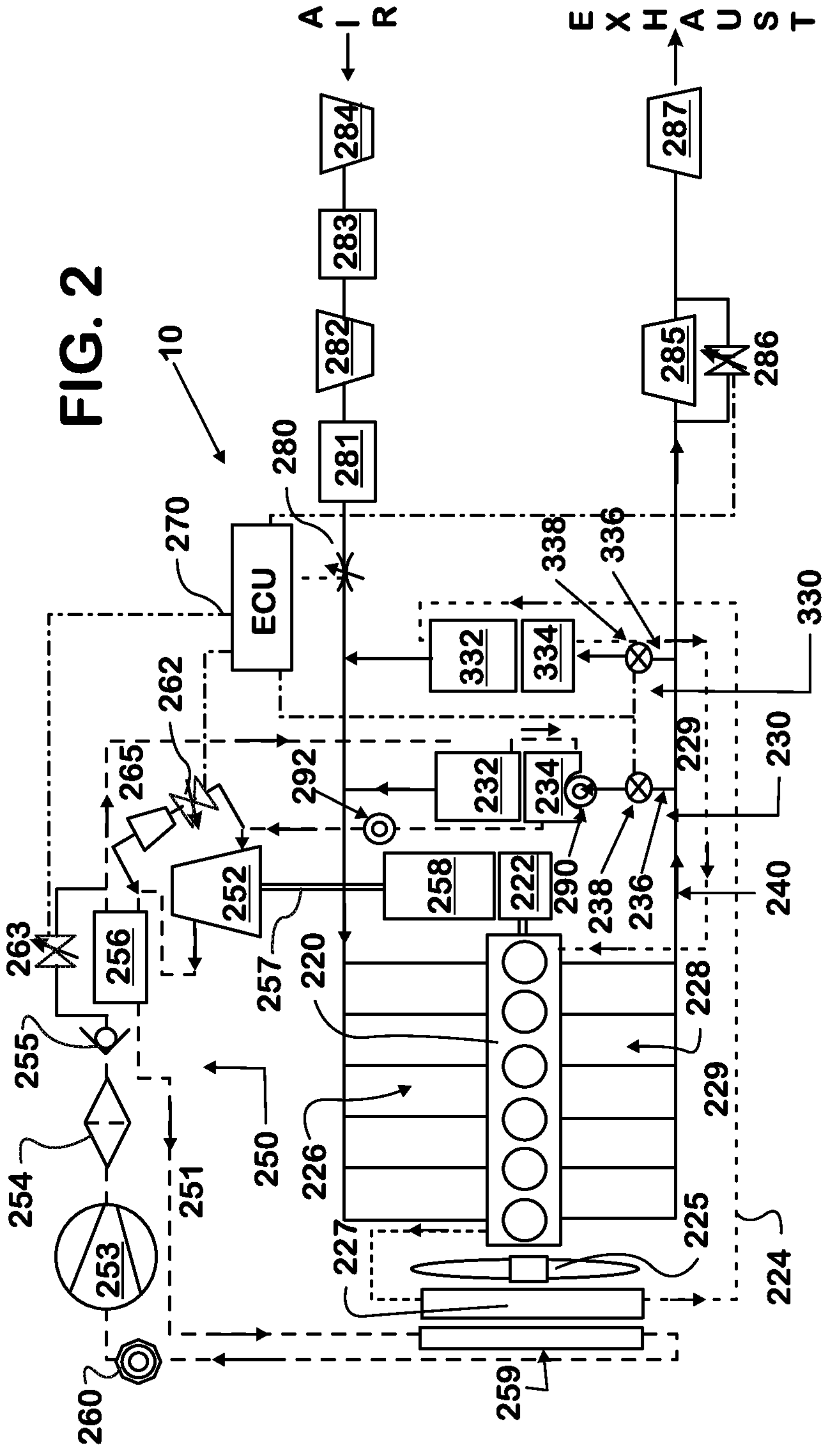
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FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 11/50306

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F02B 33/44 (2012.01)
USPC - 60/605.2
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)
USPC: 60/605.2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 60/595, 598, 605.1, 605.2, 661, 670 (keyword limited; terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Thomson Innovation [USGrant, GB App, USApp, FR App, WO App, DE Util, EP Grant, DE Grant, EP App, DE App, JP Util, JP Grant, JP App, CN Util, CN App, KR Util, KR Grant, KR App]; Google Scholar; EGR, WHR, waste heat, exhaust, sensor, pump, cooler, valve, radiator, boiler, superheater, bypass, condenser, recuperator

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 20040093866 A1 (Ishikawa) 20 May 2004 (20.05.2004) para [0032]-[0033]	1-19
Y	US 7,997,076 B2 (Ernst) 16 August 2011 (16.08.2011) col 2, ln 21-62	1-19
Y	US 7,461,641 B1 (Styles et al.) 09 December 2008 (09.12.2008) col 2, ln 28-45	6
Y	US 20100293943A1 (Teng et al.) 25 November 2010 (25.11.2010) para [0018]-[0020]	7
Y	US 7,971,578 B2 (Lim et al.) 05 July 2011 (05.07.2011) col 1, ln 37-40	8
Y	JP11223301 A (Sawa) 17 August 1999 (17.08.1999) abstract	9, 10, 12-13, 18-19
Y	US 7,305,976 B1 (Clarke) 11 December 2007 (11.12.2007) col 2, ln 56-67	10
Y	US 20110036113 A1 (Kopko et al.) 17 February 2011 (17.02.2011) para [0033]	11, 19
Y	JP 10281408 A (Yano) 23 October 1998 (23.10.1998) abstract	13, 18
A	US 2011/0072818 A1 (COOK) 31 March 2011 (31.03.2011), entire document especially paras [0041], [0061], [0067]-[0073], [0143], [0219]	1-19
A	US 2009/0013977 A1 (BRECHEISEN) 15 January 2009 (15.01.2009), entire document especially the Abstract; Fig 1; para [0016], [0019]-[0020]	1-19
A	US 2007/0144501 A1 (JOERGL et al.) 28 June 2007 (28.06.2007), entire document especially Fig 1; para [0006]	1-19

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"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
"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
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 January 2012 (28.01.2012)	10 FEB 2012

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774