(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
9 June 2016 (09.06.2016)

(10) International Publication Number
WO 2016/089285 A1

(51) International Patent Classification:
F02G 5/02 (2006.01) *F01N 9/00* (2006.01)
F01N 5/02 (2006.01)

(21) International Application Number:
PCT/SE2015/051263

(22) International Filing Date:
25 November 2015 (25.11.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1451471-5 3 December 2014 (03.12.2014) SE

(71) Applicant: **SCANIA CV AB** [SE/SE]; 151 87 Södertälje (SE).

(72) Inventors: **DELLRUD, Jan**; Tomteborg Önnemo, 646 94 Björnlunda (SE). **CHABO, Alexander**; Hasselvägen 7, 147 33 Tumba (SE). **TYSK, Peter**; Bondegatan 8b, 722 11 Västerås (SE). **FLEMMER, Henrik**; Persmässgränd 12, 129 44 Hägersten (SE).

(74) Agent: **GARDEMARK, Niklas**; Scania CV AB, 151 87 Södertälje (SE).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: 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.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) **Title**: A METHOD FOR CONTROLLING A WASTE HEAT RECOVERY SYSTEM AND A WASTE HEAT RECOVERY SYSTEM

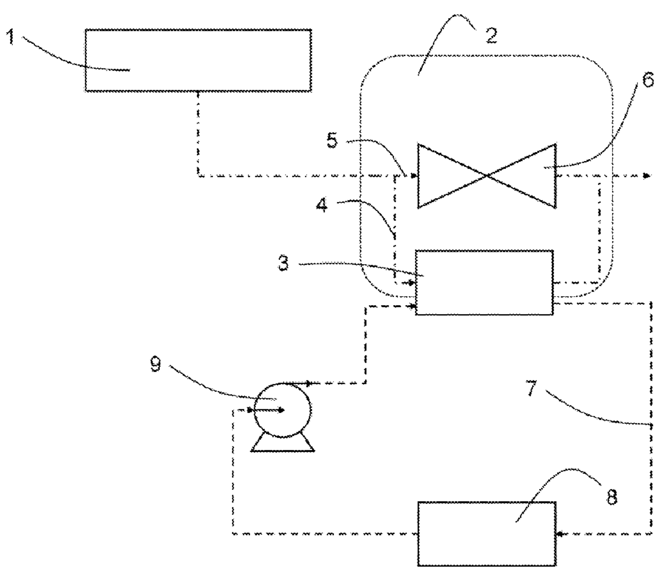

Fig. 1

(57) **Abstract**: A waste heat recovery (WHR) system for use in a drive system and a method for controlling such a system. The system includes a heat exchanger (3), an exhaust channel (4) for carrying exhaust gas from a combustion engine (1) through the heat exchanger, a bypass channel (5) connected to the exhaust channel and bypassing the heat exchanger, an adjustable valve (6) for adjusting the mass flow of exhaust gas through each of the exhaust channel and the bypass channel, and a coolant channel (7) for carrying a coolant fluid through the heat exchanger. The method comprises the steps of determining a current value of a mass flow MF_{CF1} of coolant flu id through the heat exchanger, an entrance temperature T_{EG1} of the exhaust gas before entry into the heat exchanger, and an entrance temperature T_{CF1} of the coolant fluid before entry into the heat exchanger. A setpoint S_1 for a mass flow MF_{EG1} of exhaust gas through the heat exchanger at which a net power gain P_{net} of the drive system is maximized is determined using said determined values. A current value of the mass flow MF_{EG1} of exhaust gas through the heat exchanger is determined and the adjustable valve is controlled so that the mass flow M F_{EG1} is adjusted toward the determined setpoint S_1.

WO 2016/089285 A1

A method for controlling a waste heat recovery system and a waste heat recovery system

FIELD OF THE INVENTION

The invention relates to a method for controlling a waste heat recovery system for recovering waste heat from a combustion engine in a drive system, in particular in a drive system of a motor vehicle. The invention also relates to a waste heat recovery system, a computer program, a computer program product, an electronic control unit and a motor vehicle.

Waste heat recovery systems may be used in vehicles in order to extract waste heat energy from the exhaust gases and thereby increase the fuel economy of the vehicle. Thermoelectric generators (TEGs) may be used in such systems in order to convert waste heat into electricity, but also other kinds of heat exchangers may be used.

PRIOR ART

WO2011/037526 discloses a waste heat recovery system including a thermoelectric generator (TEG) for extracting electricity from a waste heat medium in a vehicle powered by a combustion engine. The waste heat recovery system comprises a heat exchanger in the form of a TEG, an exhaust channel configured to carry an exhaust gas originating from the combustion engine through the TEG, a bypass channel connected to the exhaust channel upstream of the TEG and bypassing the TEG, an adjustable valve by means of which the mass flow of exhaust gas through each of the exhaust channel and the bypass channel can be adjusted, and a coolant channel configured to carry a coolant fluid through the TEG. The adjustable valve can be adjusted in response to the measured or estimated temperature of the exhaust gases. If the exhaust gases are too hot or too cold, a portion of the exhaust gases are led through the bypass channel in order to protect the TEG. Thus, the system is primarily configured to protect the TEG from overheating.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide on one hand a method for controlling a waste heat recovery system for recovering waste heat from a combustion engine in a drive system, and on the other hand a waste heat recovery system, which are in at least some aspect improved with respect to previously known methods and systems.

According to the invention, this object is with respect to the method achieved by means of a method according to the appended claim 1. With the inventive method, the waste heat recovery system can be controlled so that the net power gain P_{net} of the drive system is maximized, rather than the power gain of the at least one heat exchanger. The net power gain P_{net} is here defined as the sum of the total power gains obtainable from the waste heat recovery system and the total power losses arising in the drive system as a result of the waste heat recovery system. In consequence, in a vehicle with a drive system comprising said waste heat recovery system, the fuel economy may be improved by using the method according to the present invention. Preferably, but not necessarily, the heat exchanger is placed in an after treatment system of the drive system.

According to an embodiment of the invention, the step of determining the setpoint S_1 for the mass flow MF_{EG1} of exhaust gas through the first heat exchanger comprises the steps of:

- choosing a set of test values representing the mass flow MF_{EG1} of exhaust gas through the first heat exchanger,
- iteratively calculating the net power gain P_{net} using said test values until said net power gain P_{net} is at a maximum,
- outputting the test value at which the net power gain P_{net} is at a maximum as said setpoint S_1.

In this embodiment, the setpoint S_1 is determined using an iterative algorithm for calculating the net power gain P_{net}. The set of test values is preferably chosen such that the initial net power gain P_{net} is small. After each iteration, it is checked whether the net power gain P_{net} is larger than in the previous iteration, and if so, the algorithm continues to calculate the net power gain for the successive test value. If not, the preceding test value is output as the setpoint S_1. In this way, the setpoint S_1 can be found within a short running time.

According to another embodiment of the invention, wherein the system further comprises a cooler connected to the first coolant channel and a coolant fluid pump, the method further comprises the steps of:

- determining a setpoint S_2 for the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump at which the net power gain P_{net} of the drive system is at a maximum,
- controlling the coolant fluid pump so that the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump is adjusted toward the determined setpoint S_2.

In this embodiment, the method is implemented in a system comprising a cooling system with a coolant fluid pump. In addition to controlling the first adjustable valve controlling the amount of exhaust gas carried through the heat exchanger and the bypass channel respectively, the method according to this embodiment allows to control the coolant fluid pump such that the net power gain P_{net} is optimized. This allows for a more accurate control of the waste heat recovery system.

According to another embodiment of the invention, the step of determining a setpoint S_2 for the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump comprises determining a power consumption P_{pump} of the coolant fluid pump. In this way, also power losses occurring at the coolant fluid pump are taken into account in the optimization of the net power gain P_{net}.

According to another embodiment of the invention, wherein the cooler comprises at least one radiator for cooling the coolant fluid, and a charge air cooler for cooling an air flow coming from a turbo charger and flowing through the charge air cooler toward an air inlet of the combustion engine, the method further comprises the step of:

- determining a power loss P_{CAC} in the charge air cooler due to a temperature increase of the air flowing through the charge air cooler caused by the at least one radiator.

In this way, an even more accurate control of the heat recovery system can be achieved, since the method allows to control the waste heat recovery system such that the power losses P_{CAC} in the charge air cooler have a minimum impact on the net power gain P_{net}. The method according to this embodiment is suitable for use in a drive system in which a coolant fluid flowing through the charge air cooler is separate from the coolant fluid flowing through the at least one radiator, i.e. wherein separate closed cooling systems are used, which are arranged so that they interact with each other.

According to another embodiment of the invention, the power loss P_{CAC} in the charge air cooler is used in the step of determining a setpoint S_2 for the mass flow MF_{CF} of coolant fluid through the coolant fluid pump. According to another embodiment of the invention, the power loss P_{CAC} in the charge air cooler is used in the step of determining a setpoint S_1 for a mass flow MF_{EG1} of exhaust gas through the first heat exchanger. Of course, it is possible to simultaneously use the power loss P_{CAC} in the charge air cooler in the step of determining a setpoint S_1 and in the step of determining a setpoint S_2.

According to another embodiment of the invention, wherein the system further comprises

- a second heat exchanger,

- a second exhaust channel connected to the first exhaust channel and configured to carry an exhaust gas originating from the combustion engine through the second heat exchanger,
- a second bypass channel connected to the second exhaust channel upstream of the second heat exchanger and bypassing the second heat exchanger,
- a second adjustable valve by means of which the mass flow of exhaust gas through each of the second exhaust channel and the second bypass channel can be adjusted,
- a second coolant channel connected to the first coolant channel and configured to carry a coolant fluid through the second heat exchanger,

the method further comprises the steps of:

- determining an entrance temperature T_{EG2} of the exhaust gas before entry into the second heat exchanger,
- controlling the second adjustable valve in response to said determined entrance temperature T_{EG2} of the exhaust gas before entry into the second heat exchanger.

In this embodiment, the method is used in a system comprising at least two heat exchangers, of which the first one may for example be placed in an after treatment system and the second one may for example be placed in an exhaust gas recirculation system. The method allows the exhaust gas flow through the second heat exchanger to be controlled such that damages due to high temperatures of the exhaust gases are avoided. A heat exchanger placed in the exhaust gas recirculation system may otherwise reach relatively high temperatures at which e.g. a thermoelectric generator may be damaged.

According to another embodiment of the invention, wherein the system further comprises a third adjustable valve connecting the first coolant channel and the second coolant channel, the method further comprises the step of:

- determining a current value of the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump,
- determining a setpoint S_3 for a ratio $R=MF_{CF1}/MF_{CF2}$ of the mass flow MF_{CF1} of coolant fluid through the first heat exchanger to the mass flow MF_{CF2} of coolant fluid through the second heat exchanger at which a net power gain P_{net} of the waste heat recovery system is maximized using the determined current value of the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump as an input value for calculating the net power gain P_{net},
- controlling the third adjustable valve so that said ratio R of the mass flows of coolant fluid is adjusted toward the determined setpoint S_3.

In this embodiment, the waste heat recovery system can be controlled such that the mass flow of coolant fluid through the first and the second heat exchanger respectively is adjusted such that the net power gain P_{net} is optimized. This has proved to be efficient for increasing the net power gain P_{net} of the drive system, since it enables reduction of the total mass flow MF_{CF} of coolant fluid, thereby reducing energy consumption of the coolant fluid pump.

According to another embodiment of the invention, the power loss P_{CAC} in the charge air cooler is used in the step of determining a setpoint S_3 for the ratio MF_{CF1}/MF_{CF2} of the mass flow MF_{CF1} of coolant fluid through the first heat exchanger to the mass flow MF_{CF2} of coolant fluid through the second heat exchanger. This allows for increased accuracy in the determination of the setpoint S_3.

According to another embodiment of the invention, the method further comprises the step of determining a torque of the combustion engine. According to another embodiment of the invention, the method further comprises the step of determining a rotational speed of the combustion engine. These embodiments enable theoretical modeling of the temperature of the exhaust gases and reduce the need for temperature sensors mounted in the waste heat recovery system, thus decreasing the complexity of the system. Preferably, both the torque and the rotational speed are determined and used for temperature modeling.

The object of the present invention is, with respect to the system, achieved by means of a waste heat recovery system for recovering waste heat from a combustion engine in a drive system according to the independent appended system claim. Advantages and embodiments of such a system appear from the method described above and also from the following detailed description.

In other aspects, the invention also relates to a computer program having the features of claim 14, a computer program product having the features of claim 15, an electronic control unit having the features of claim 16 and a motor vehicle according to claims 17 and 18.

Other advantageous features as well as advantages of the present invention will appear from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will in the following be further described by means of example with reference to the appended drawings, wherein

Fig. 1	shows a schematic overview of a drive system including a waste heat recovery system according to a first embodiment of the invention,
Fig. 2	shows a schematic overview of a drive system including a waste heat recovery system according to a second embodiment of the invention,
Fig. 3	shows a flow chart of a method according to a first embodiment of the invention, and
Fig. 4	shows a schematic drawing of a control unit for implementing a method according to the invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

A drive system including a combustion engine 1, an after treatment system 2, and a waste heat recovery (WHR) system according to an embodiment of the invention is schematically shown in fig. 1. The WHR system includes a heat exchanger in the form of a thermoelectric generator (TEG) 3 placed in connection with the after treatment system 2, an exhaust channel 4 configured to carry an exhaust gas originating from the combustion engine through the TEG 3, and a bypass channel 5 which is connected to the exhaust channel 4 upstream of the TEG 3 and which bypasses the TEG 3. The WHR system further includes an adjustable valve 6 by means of which the mass flow of exhaust gas through each of the exhaust channel 4 and the bypass channel 5 can be adjusted. The WHR system also comprises a coolant channel 7 connected to a cooler 8, which coolant channel 7 is configured to carry a coolant fluid through the TEG 3. A pump 9 is arranged to pump the coolant fluid through the TEG 3 and the cooler 8.

In a method for controlling the WHR system according to a first embodiment of the invention, a current value of a mass flow MF_{CF1} of coolant fluid through the TEG 3, equal to the mass flow MF_{CF} of coolant fluid through the coolant fluid pump 9, is determined in a step A1, see fig. 3. This can be performed e.g. by determining the temperature increase and the pressure drop across the TEG 3 or across the pump 9, but also by sensing the mass flow MF_{CF1} directly or by theoretical modeling. In a step A2, an entrance temperature T_{EG1} of the exhaust gas before entry into the TEG 3 is determined. This can be performed either by measuring the temperature using a sensor, or by modeling using e.g. the torque and the rotational speed of the combustion engine 1 as input parameters. In a step A3, an entrance temperature T_{CF1} of the coolant fluid before entry into the TEG 3 is determined. In a step A4, a setpoint S_1 for a mass flow MF_{EG1} of exhaust gas through the TEG 3 is determined, at which a net power gain P_{net} of the drive system is maximized. The setpoint S_1 is determined using said determined entrance temperature T_{EG1} of the exhaust gas, said determined entrance temperature T_{CF1} of the coolant fluid, and said determined current value of the mass flow MF_{CF1} of coolant fluid through the first heat exchanger as input values for calculating the net power gain P_{net}. This is preferably done iteratively by first calculating the net power gain P_{net} for a first test value $MF_{EG1;min}$ representing the mass flow MF_{EG1} of exhaust gas through the TEG 3, thereafter iterating for a second test value $MF_{EG1;min} + \Delta MF_{EG1}$, wherein ΔMF_{EG1} represents a small change in mass flow MF_{EG1}, and checking whether the net power gain P_{net} is larger or smaller for this second test value. As soon as a test value $MF_{EG1;x}$ has been found at which the net power gain P_{net} is at a maximum, this test value $MF_{EG1;x}$ is output as the setpoint S_1. In a step A5, a current value of the mass flow MF_{EG1} of exhaust gas through the TEG 3 is determined, e.g. by a mass flow sensor (not shown) or by measuring temperature and pressure differences across the TEG 3. In a step A6, the adjustable valve 6 is controlled so that the current value of the mass flow MF_{EG1} of exhaust gas through the TEG 3 is adjusted toward the determined setpoint S_1 and so that the remaining exhaust gas is led through the bypass channel 5. In this way, the WHR system can be controlled to maximize the net power gain P_{net} of the drive system. The calculation of the setpoint S_1 can e.g. be carried out by a control unit (not shown) which is also used for controlling the adjustable valve 6. Before outputting the setpoint S_1, it is preferably checked that the setpoint S_1 represents a mass flow MF_{EG1} within an allowed span, so that overheating of the TEG 3 is avoided.

To further increase the net power gain P_{net} of the drive system, also a setpoint S_2 for the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump 9, which here equals the mass flow MF_{CF1} of coolant fluid pumped through the TEG 3, can be determined. Preferably, the power consumption P_{pump} of the coolant fluid pump is determined for this purpose, and the setpoint S_2 is calculated as the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump 9 that gives rise to the largest net power gain P_{net} of the drive system. The coolant fluid pump 9 is controlled so that the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump 9 is adjusted toward the determined setpoint S_2.

Another drive system including a WHR system according to the invention is shown in fig. 2. The drive system includes a combustion engine 1, an after treatment system 2 and further an exhaust recirculation system 10. The WHR system includes a first heat exchanger in the form of a first TEG 3 placed in connection with the after treatment system 2, a first exhaust channel 4 configured to carry an exhaust gas originating from the combustion engine 1 through the first TEG 3, and a first bypass channel 5 which is connected to the first exhaust channel 4 upstream of the first TEG 3 and which bypasses the TEG 3. The WHR system further includes a first adjustable valve 6 by means of which the mass flow of exhaust gas through each of the first exhaust channel 4 and the first bypass channel 5 can be adjusted. The WHR system also comprises a first coolant channel 7 configured to carry a coolant fluid through the TEG 3. A coolant fluid pump 9 is arranged to pump the coolant fluid through the TEG 3 and a cooler including a first radiator 11 and a second radiator 12. The cooler further includes a charge air cooler 13. The WHR system also includes a second heat exchanger in the form of a second TEG 14 placed in connection with the exhaust recirculation system 10, a second exhaust channel 15 connected to the first exhaust channel 4 and configured to carry an exhaust gas originating from the combustion engine 1 through the second TEG 14, and a second bypass channel 16 which is connected to the second exhaust channel 15 upstream of the second TEG 14 and which bypasses the second TEG 14. The WHR system further includes a second adjustable valve 17 by means of which the mass flow of exhaust gas through each of the second exhaust channel 15 and the second bypass channel 16 can be adjusted. The WHR system also includes a second coolant channel 18 for carrying coolant fluid through the second TEG 14, and a three-way adjustable valve 19 placed between the first coolant channel 7 and the second coolant channel 18, by means of which the ratio $R=MF_{CF1}/MF_{CF2}$ of mass flow of coolant fluid through the first TEG 3 and the second TEG 14 respectively can be varied.

In a method according to an embodiment of the invention, the method is implemented for the drive system shown in fig. 2. In this embodiment, a setpoint S_1 for the mass flow MF_{EG1} of exhaust gas through the TEG 3, a setpoint S_2 for the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump 9 and a setpoint S_3 for the ratio $R=MF_{CF1}/MF_{CF2}$ of mass flow of coolant fluid through the first TEG 3 and the second TEG 14 respectively are set. As described above, a current value of a mass flow MF_{CF} of coolant fluid through the coolant fluid pump 9 is determined, as well as an entrance temperature T_{EG1} of the exhaust gas before entry into the first TEG 3, and an entrance temperature T_{CF1} of the coolant fluid before entry into the first TEG 3. The power consumption P_{pump} of the coolant fluid pump is also determined and used in the step of determining the setpoint S_2.

Also, a power loss P_{CAC} in the charge air cooler is determined. This power loss P_{CAC} is mainly due to a temperature increase of the air flowing through the charge air cooler 13 caused by the radiators 11, 12. With the air flow shown in fig. 2, the second radiator 12, placed before the charge air cooler 13, is the main source for the temperature increase in the charge air cooler 13. The power loss P_{CAC} is used both in the step of determining the setpoint S_1 and in the step of determining the setpoint S_2.

The setpoint S_3 for a ratio $R=MF_{CF1}/MF_{CF2}$ of the mass flow MF_{CF1} of coolant fluid through the first TEG 3 to the mass flow MF_{CF2} of coolant fluid through the second TEG 14 is determined as the ratio R at which the net power gain P_{net} of the waste heat recovery system is maximized. The setpoint S_3 is determined using the determined current value of the mass flow MF_{CF} of coolant fluid through the coolant fluid pump 9 and the power loss P_{CAC} in the charge air cooler 13 as input values for calculating the net power gain P_{net}. The three-way adjustable valve 19 is controlled so that said ratio $R=MF_{CF1}/MF_{CF2}$ of the mass flows of coolant fluid is adjusted toward the determined setpoint S_3.

In this embodiment, it is also possible to determine an entrance temperature T_{EG2} of the exhaust gas before entry into the second TEG 14, either by means of sensing or by modeling. The second adjustable valve 17 can then be controlled in response to the determined entrance temperature T_{EG2}. If the temperature T_{EG2} is too high, the second adjustable valve 17 is controlled so that all or part of the exhaust gases are led through the second bypass channel 16. If the temperature T_{EG2} is within a predetermined acceptable span, all or part of the exhaust gases are led through the second TEG 14.

In a preferred embodiment of the inventive method, it is checked before outputting each of the setpoints S_1, S_2, S_3 that the setpoint S_1 represents a mass flow MF_{EG1} within an allowed span, that the setpoint S_2 represents a mass flow MF_{CF} within an allowed span and that the setpoint S_3 represents a mass flow ratio within an allowed span, so that overheating of each of the TEGs 3, 14 is avoided.

In a preferred embodiment of the inventive method, the setpoints S_1, S_2, S_3 are calculated using the algorithm Alg1 presented at the end of the detailed description. In this algorithm, the net power gain P_{NET} is calculated for a system such as the one shown in fig. 2.

In the first for loop, a value of the mass flow MF_{CF} of coolant fluid pumped through the pump 9 is set, and the power loss P_{CAC} occurring at the charge air cooler 13 due to a temperature increase herein is determined. This loop also calculates the power loss P_{pump} at the pump 9, which is related to the total mass flow MF_{CF} of coolant fluid pumped through the pump 9.

Inside the first for loop, the second for loop has the purpose of determining how to divide the mass flow MF_{CF} of coolant fluid through the pump 9 between the first TEG 3 and the second TEG 14. The loop sets a value of the ratio $R=MF_{CF1}/MF_{CF2}$ and calculates the power gain P_2 obtainable at the second TEG 14 for said ratio R.

Inside the second for loop, the third for loop steps through different mass flows MF_{EG1} of exhaust gas through the first TEG 3 placed in the after treatment system 2. It calculates the power gain P_1 and the power loss P_{1loss} in the first TEG 3, occurring due to back pressure in the after treatment system 2, and it also calculates the total net power gain P_{net} by summing up all power gains and power losses.

When the third for loop is finished, a new value representing the mass flow MF_{CF} of coolant fluid through the pump 9 is set and the calculations are repeated. In this way, the net power gain P_{net} will start out as a small value and will successively increase. When the net power gain P_{net} starts to decrease, the iteration is aborted. The setpoints S_1, S_2, S_3 that are output by the algorithm are the values set by the previous iteration for the mass flow MF_{EG1} of exhaust gas through the first TEG 3, for the mass flow MF_{CF} of coolant fluid through the pump 9, and for the ratio $R=MF_{CF1}/MF_{CF2}$, respectively. Before sending the setpoints S_1, S_2, S_3 to a respective control unit, it is checked that the setpoints S_1, S_2, S_3 are within an allowed span. If not, the setpoints are set to predefined values so that overheating of any of the TEGs 3, 14 is prevented.

The intervals of the for loops are thereafter modified by the ranges r_{EG1}, r_{CF} and r_{Div} respectively, and moved in the direction of where the optimum is most likely to be found the next time the algorithm is run. The algorithm is preferably run with a predetermined frequency, for example such that the setpoints S_1, S_2, S_3 are updated at a frequency of 1 Hz.

In other embodiments, the method may be implemented in a WHR system in which it is only necessary to determine a setpoint S_1 for the mass flow MF_{EG1} of exhaust gas through a first or a single heat exchanger. In this case, the algorithm may be simplified by reducing the amount of for loops.

In a simple WHR system used in a method according to the invention, the coolant fluid may also be carried through the first and the second heat exchanger through one single coolant channel, without a three-way valve for dividing the mass flow MF_{CF} of coolant fluid between the first and the second heat exchanger. In this case, the mass flow MF_{CF1} through the first heat exchanger equals the mass flow MF_{CF} through the pump located in the coolant channel.

Computer program code for implementing a method according to the invention is suitably included in a computer program which is readable into an internal memory of a computer, such as the internal memory of an electronic control unit of a motor vehicle. Such a computer program is suitably provided through a computer program product comprising a data storing medium readable by an electronic control unit, which data storing medium has the computer program stored thereon. Said data storing medium is for example an optical data storing medium in the form of a CD-ROM-disc, a DVD-disc, etc., a magnetic data storing medium in the form of a hard disc, a diskette, a tape etc., or a Flash memory or a memory of the type ROM, PROM, EPROM or EEPROM.

Fig. 4 illustrates very schematically an electronic control unit 40 comprising an execution means 41, such as a central processor unit (CPU), for executing a computer program. The execution means 41 communicates with a memory 42, for example of the type RAM, through a data bus 43. The control unit 40 comprises also a non-transitory data storing medium 44, for example in the form of a Flash memory or a memory of the type ROM, PROM, EPROM or EEPROM. The execution means 41 communicates with the data storing medium 44 through the data bus 43. A computer program comprising computer program code for implementing a method according to the invention is stored on the data storing medium 44.

The invention is of course not in any way restricted to the embodiments described above, but many possibilities to modifications thereof would be apparent to a person with skill in the art without departing from the scope of the invention as defined in the appended claims.

Algorithm Alg1: Optimization pseudo code

```
Data: Input values from sensor signals or modeled input values
Result: Outputs setpoints S_1, S_2, S_3
for    MF_CF = MF_CF;min : MF_CF;max do
       Remember_MF_CF
       P_CAC = f (...)
       P_pump = f (...)
       for    R = Div_min : Div_max do
              Remember_R
              P_2 = f (...)
              for    MF_EG1 = MF_EG1;min: MF_EG1;max do
                     Remember_MF_EG1;min
                     P_1 = f (...)
                     P_1loss= f (...)
                     P_net = P_2 + P_1 - P_CAC – P_1loss - P_pump
              end
       end
       if P_net < P_net;old then
              Break
       end
end
if     Remember_/MF_CF/R/MF_EG1 in allowed span then
       S_1 = Remember_MF_EG1 ← previous
       S_2 = Remember_MF_CF ← previous
       S_3 = Remember_R ← previous
else
       S_1 = PreDefined
       S_2 = PreDefined
       S_3 = PreDefined
end
MF_EG1;min = S_1 - r_EG1
MF_EG1;max = S_1 + r_EG1
MF_CF;min = S_2 - r_CF
MF_CF;max = S_2 + r_CF
Div_min = S_3 - r_Div
Div_max = S_3 + r_Div
```

CLAIMS

1. A method for controlling a waste heat recovery system for recovering waste heat from a combustion engine (1) in a drive system, the waste heat recovery system including:

- a first heat exchanger (3),
- a first exhaust channel (4) configured to carry an exhaust gas originating from the combustion engine (1) through the first heat exchanger (3),
- a first bypass channel (5) connected to the first exhaust channel (4) upstream of the first heat exchanger (3) and bypassing the first heat exchanger (3),
- a first adjustable valve (6) by means of which the mass flow of exhaust gas through each of the first exhaust channel (4) and the first bypass channel (5) can be adjusted,
- a first coolant channel (7) configured to carry a coolant fluid through the first heat exchanger (3),

characterized in

that the method comprises the steps of:

- determining a current value of a mass flow MF_{CF1} of coolant fluid through the first heat exchanger (3),
- determining an entrance temperature T_{EG1} of the exhaust gas before entry into the first heat exchanger (3),
- determining an entrance temperature T_{CF1} of the coolant fluid before entry into the first heat exchanger (3),
- determining a setpoint S_1 for a mass flow MF_{EG1} of exhaust gas through the first heat exchanger (3) at which a net power gain P_{net} of the drive system is maximized using said determined entrance temperature T_{EG1} of the exhaust gas, said determined entrance temperature T_{CF1} of the coolant fluid, and said

determined current value of the mass flow MF_{CF1} of coolant fluid through the first heat exchanger (3) as input values for calculating the net power gain P_{net},

- determining a current value of the mass flow MF_{EG1} of exhaust gas through the first heat exchanger (3),
- controlling the first adjustable valve (6) so that the mass flow MF_{EG1} of exhaust gas through the first heat exchanger (3) is adjusted toward the determined setpoint S_1.

2. The method according to claim 1, wherein the step of determining the setpoint S_1 for the mass flow MF_{EG1} of exhaust gas through the first heat exchanger (3) comprises the steps of:

- choosing a set of test values representing the mass flow MF_{EG1} of exhaust gas through the first heat exchanger (3),
- iteratively calculating the net power gain P_{net} using said test values until said net power gain P_{net} is at a maximum,
- outputting the test value at which the net power gain P_{net} is at a maximum as said setpoint S_1.

3. The method according to claim 1 or 2, wherein the system further comprises a cooler (8) connected to the first coolant channel (7) and a coolant fluid pump (9), the method further comprising the steps of:

- determining a setpoint S_2 for the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump (9) at which the net power gain P_{net} of the drive system is at a maximum,
- controlling the coolant fluid pump (9) so that the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump (9) is adjusted toward the determined setpoint S_2.

4. The method according to claim 3, wherein the step of determining a setpoint S_2 for the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump (9) comprises determining a power consumption P_{pump} of the coolant fluid pump (9).

5. The method according to claim 3 or 4, wherein the cooler comprises at least one radiator (11, 12) for cooling the coolant fluid, and a charge air cooler (13) for cooling an air flow coming from a turbo charger and flowing through the charge air cooler (13) toward an air inlet of the combustion engine (1), wherein the method further comprises the step of:

- determining a power loss P_{CAC} in the charge air cooler (13) due to a temperature increase of the air flowing through the charge air cooler caused by the at least one radiator (11, 12).

6. The method according to claim 5, wherein the power loss P_{CAC} in the charge air cooler (13) is used in the step of determining a setpoint S_2 for the mass flow MF_{CF} of coolant fluid through the coolant fluid pump (9).

7. The method according to claim 5 or 6, wherein the power loss P_{CAC} in the charge air cooler (13) is used in the step of determining a setpoint S_1 for a mass flow MF_{EG1} of exhaust gas through the first heat exchanger (3).

8. The method according to any one of the preceding claims, wherein the system further comprises:

- a second heat exchanger (14),

- a second exhaust channel (15) connected to the first exhaust channel (4) and configured to carry an exhaust gas originating from the combustion engine (1) through the second heat exchanger (14),
- a second bypass channel (16) connected to the second exhaust channel (15) upstream of the second heat exchanger (14) and bypassing the second heat exchanger (14),
- a second adjustable valve (17) by means of which the mass flow of exhaust gas through each of the second exhaust channel (15) and the second bypass channel (16) can be adjusted,
- a second coolant channel (18) connected to the first coolant channel (7) and configured to carry a coolant fluid through the second heat exchanger (14),

the method further comprising the steps of:

- determining an entrance temperature T_{EG2} of the exhaust gas before entry into the second heat exchanger (14),
- controlling the second adjustable valve (17) in response to said determined entrance temperature T_{EG2} of the exhaust gas before entry into the second heat exchanger (14).

9. The method according to claim 8 in combination with any of claims 3–7, wherein the system further comprises a third adjustable valve (19) connecting the first coolant channel (7) and the second coolant channel (18), the method further comprising the step of:

- determining a current value of the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump (9),
- determining a setpoint S_3 for a ratio $R=MF_{CF1}/MF_{CF2}$ of the mass flow MF_{CF1} of coolant fluid pumped through the first heat exchanger (3) to the mass flow MF_{CF2} of coolant fluid through the

second heat exchanger (14) at which a net power gain P_{net} of the waste heat recovery system is maximized using the determined current value of the mass flow MF_{CF} of coolant fluid pumped through the coolant fluid pump (9) as an input value for calculating the net power gain P_{net},

- controlling the third adjustable valve (19) so that said ratio R of the mass flows of coolant fluid is adjusted toward the determined setpoint S_3.

10. The method according to claim 9, wherein the power loss P_{CAC} in the charge air cooler (13) is used in the step of determining a setpoint S_3 for the ratio $R=MF_{CF1}/MF_{CF2}$ of the mass flow MF_{CF1} of coolant fluid through the first heat exchanger (3) to the mass flow MF_{CF2} of coolant fluid through the second heat exchanger (14).

11. The method according to any one of the preceding claims, further comprising the step of determining a torque of the combustion engine (1).

12. The method according to any one of the preceding claims, further comprising the step of determining a rotational speed of the combustion engine (1).

13. A waste heat recovery system for recovering waste heat from a combustion engine (1) in a drive system, the waste heat recovery system including:

- a first heat exchanger (3),

- a first exhaust channel (4) configured to carry an exhaust gas originating from the combustion engine (1) through the first heat exchanger (3),
- a first bypass channel (5) connected to the first exhaust channel (4) upstream of the first heat exchanger (3) and bypassing the first heat exchanger (3),
- a first adjustable valve (6) by means of which the mass flow of exhaust gas through each of the first exhaust channel (4) and the first bypass channel (5) can be adjusted,
- a first coolant channel (7) configured to carry a coolant fluid through the first heat exchanger (3),

characterized in that the system further comprises:

- means for determining a current value of a mass flow MF_{CF1} of coolant fluid through the first heat exchanger (3),
- means for determining an entrance temperature T_{EG1} of the exhaust gas before entry into the first heat exchanger (3),
- means for determining an entrance temperature T_{CF1} of the coolant fluid before entry into the first heat exchanger (3),
- means for determining a setpoint S_1 for a mass flow MF_{EG1} of exhaust gas through the first heat exchanger (3) at which a net power gain P_{net} of the drive system is maximized using said determined entrance temperature T_{EG1} of the exhaust gas, said determined entrance temperature T_{CF1} of the coolant fluid, and said determined current value of the mass flow MF_{CF1} of coolant fluid through the first heat exchanger (3) as input values for calculating the net power gain P_{net},
- means for determining a current value of the mass flow MF_{EG1} of exhaust gas through the first heat exchanger (3),

- means for controlling the first adjustable valve (6) so that the mass flow MF_{EG1} of exhaust gas through the first heat exchanger (3) is adjusted toward the determined setpoint S_1.

14. A computer program comprising computer program code for causing a computer to implement a method according to any one of the claims 1–12 when the computer program is executed in the computer.

15. A computer program product comprising a data storage medium (44) which can be read by a computer and on which the program code of a computer program according to claim 14 is stored.

16. An electronic control unit (40) of a motor vehicle comprising an execution means (41), a memory (42) connected to the execution means (41) and a data storage medium (44) which is connected to the execution means (41) and on which the computer program code of a computer program according to claim 14 is stored.

17. A motor vehicle comprising an electronic control unit (40) according to claim 16.

18. A motor vehicle according to claim 17, wherein the motor vehicle is a truck or a bus.

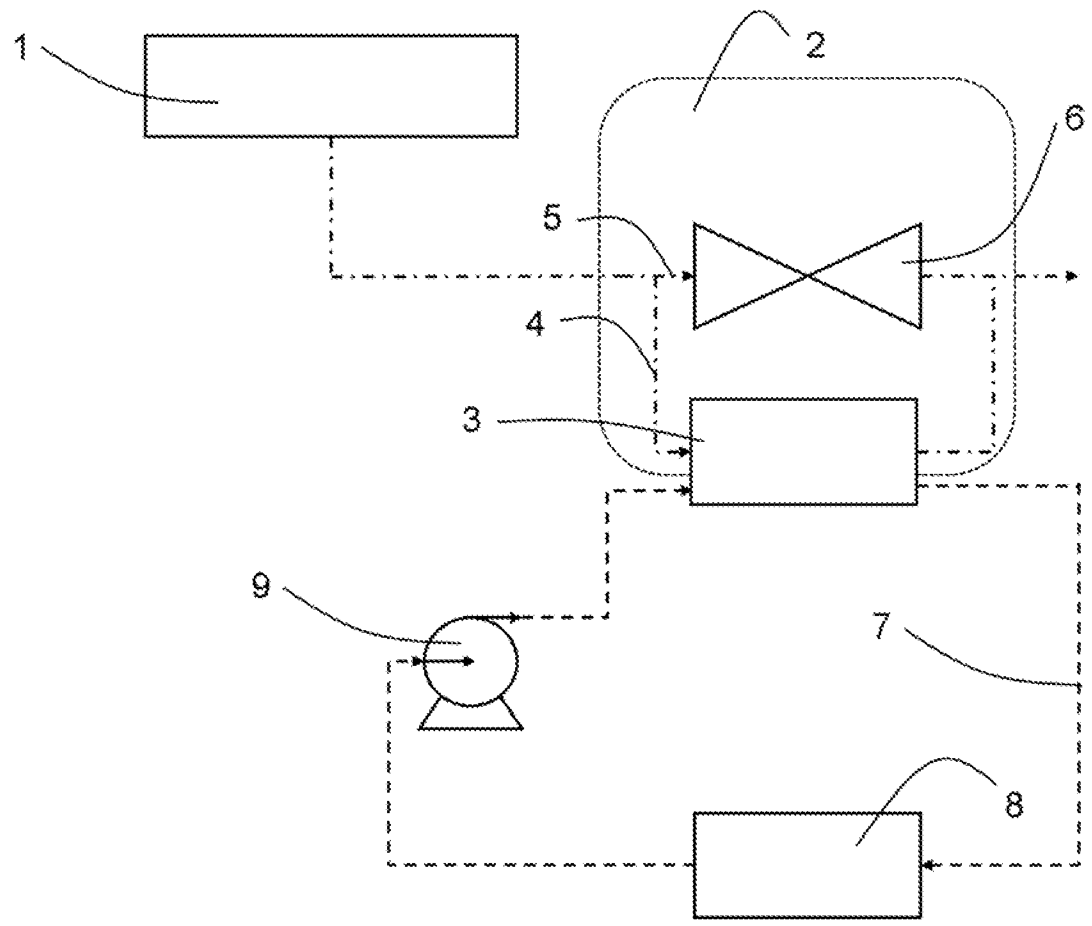

Fig. 1

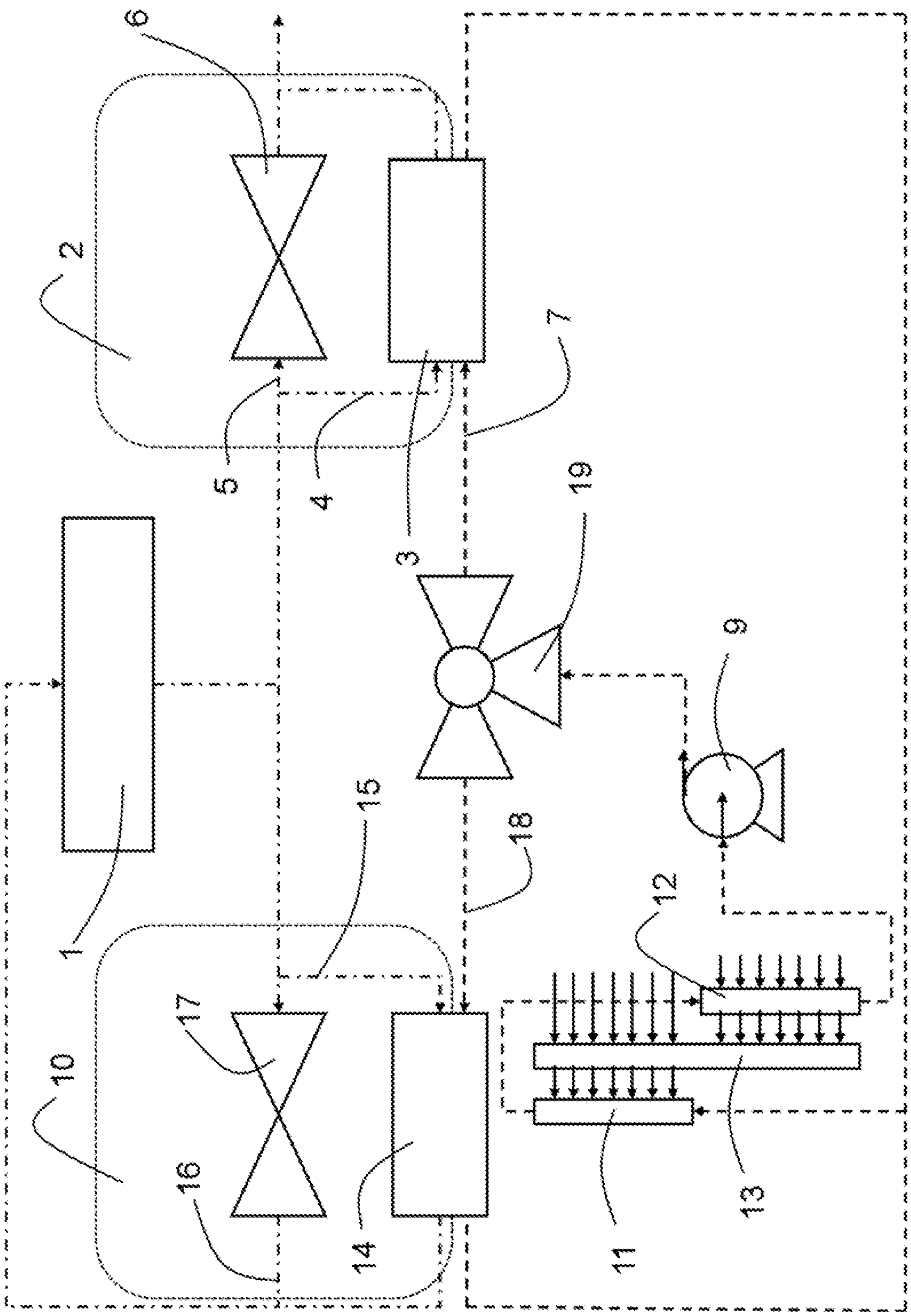

Fig. 2

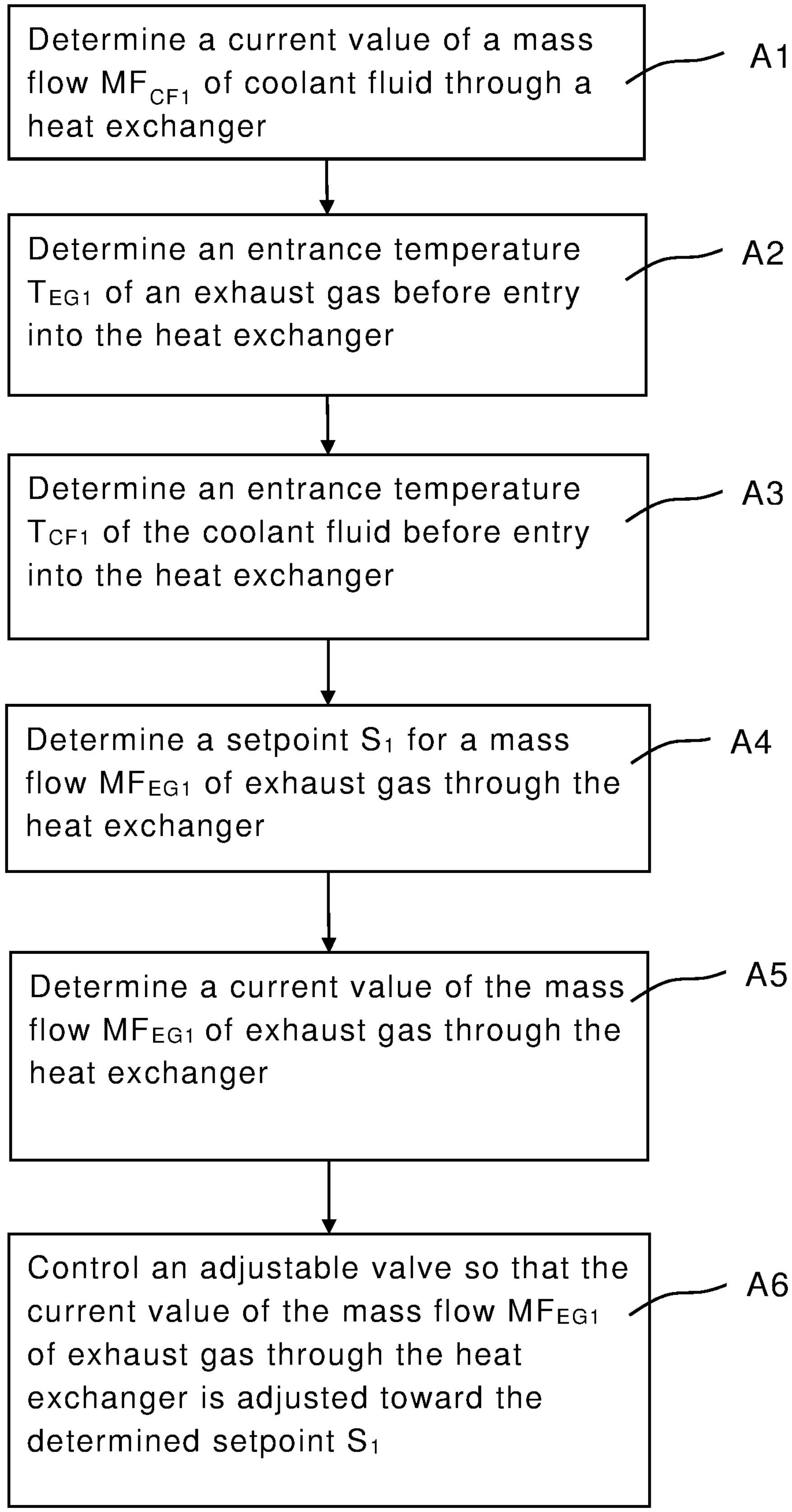
Determine a current value of a mass flow MF_{CF1} of coolant fluid through a heat exchanger
A1
Determine an entrance temperature T_{EG1} of an exhaust gas before entry into the heat exchanger
A2
Determine an entrance temperature T_{CF1} of the coolant fluid before entry into the heat exchanger
A3
Determine a setpoint S_1 for a mass flow MF_{EG1} of exhaust gas through the heat exchanger
A4
Determine a current value of the mass flow MF_{EG1} of exhaust gas through the heat exchanger
A5
Control an adjustable valve so that the current value of the mass flow MF_{EG1} of exhaust gas through the heat exchanger is adjusted toward the determined setpoint S_1
A6

Fig. 3

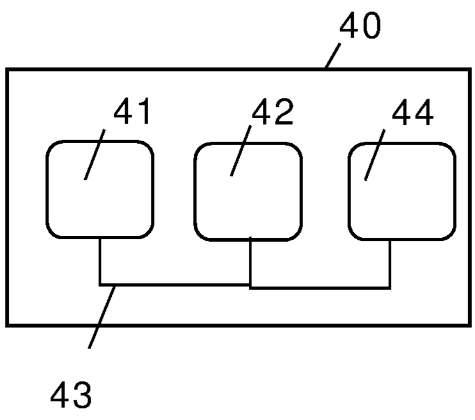

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2015/051263

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: F01K, F01N, F02G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, PAJ, WPI data, COMPENDEX, INSPEC, PUBSUBS, XPSPRNG

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 102012204262 A1 (BAYERISCHE MOTOREN WERKE AG), 19 September 2013 (2013-09-19); abstract; paragraphs [0006]-[0009], [0013]-[0025], [0027], [0032]; figures --	1-18
A	US 20130079981 A1 (MEISNER GREGORY P), 28 March 2013 (2013-03-28); abstract; paragraphs [0018]-[0030]; figures --	1-18
A	FR 2997446 A1 (RENAULT SAS), 2 May 2014 (2014-05-02); abstract; page 11, line 1 - page 13, line 5; figure 1; claim 1 --	1-18

☐ 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
- "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
22-03-2016	23-03-2016

Name and mailing address of the ISA/SE	Authorized officer
Patent- och registreringsverket Box 5055 S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Niels Rasmussen Telephone No. + 46 8 782 28 00

Continuation of: second sheet

International Patent Classification (IPC)

F02G 5/02 (2006.01)
F01N 5/02 (2006.01)
F01N 9/00 (2006.01)

DE	102012204262	A1	19/09/2013	NONE			
US	20130079981	A1	28/03/2013	US	8554407	B2	08/10/2013
FR	2997446	A1	02/05/2014	CN	104755718	A	01/07/2015
				EP	2914823	A1	09/09/2015
				WO	2014067835	A1	08/05/2014