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(54) **A method for thermally managing an internal combustion engine**

(57) Methods for thermally managing an internal combustion engine (101, 401) during engine warm-up or during warmed-up conditions of the engine, which internal combustion engine (101, 401) comprises an engine block (101, 402) with a fluid coolant flow passage (104, 404) therein, a cylinder head (106, 406) secured to the engine block 102, 402) and provided with a fluid coolant flow passage (108, 408) therein, and a first fluid coolant circuit (109, 409) comprising the fluid coolant flow passages (104, 108, 404, 408), the internal combustion engine (101, 401) being provided with a second fluid coolant circuit (111) connected to the first fluid coolant circuit (109, 409) and comprising a coolant pump (112) for producing coolant flow in the first fluid coolant circuit, temperature sensing means (115) and valve means (117), which methods comprise the step of preventing (202) the coolant pump (112) from pumping the fluid coolant and thus providing a stagnation of the fluid coolant in the first fluid coolant circuit (109, 409), and/or the step of controlling (205, 209) the coolant pump (112) to produce such a coolant flow so that the temperature *(T_{in})* of the fluid coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant (111) circuit is at least 10°C lower than the temperature *(T_{out})* of the fluid coolant discharged from the first fluid coolant circuit (109, 409) to the second fluid coolant circuit (111).

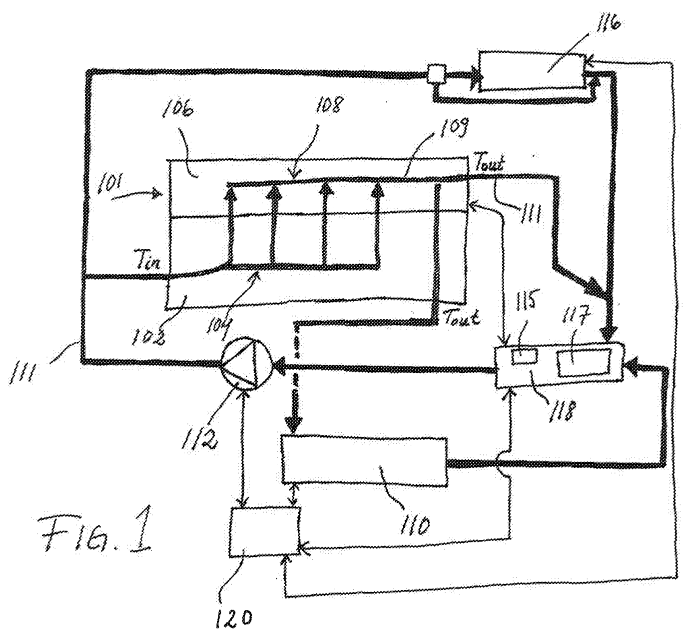

FIG. 1

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Description

Technical Field

[0001] The present invention relates to a method for thermally managing an internal combustion engine which comprises an engine block with a fluid coolant flow passage therein, a cylinder head secured to the engine block and provided with a fluid coolant flow passage therein, and a first fluid coolant circuit comprising the fluid coolant flow passages, the internal combustion engine being provided with a second fluid coolant circuit connected to the first fluid coolant circuit and comprising a heat exchanger for transferring heat from the fluid coolant, a coolant pump for producing coolant flow in the first fluid coolant circuit, temperature sensing means and valve means. Further, the present invention relates to an engine system comprising the above-mentioned internal combustion engine and at least one engine control unit adapted to performing the steps of such methods.

Background of the Invention

[0002] Prior to the present invention, several engine cooling systems or thermal management systems have been devised with various coolant circuits arrangements to improve operation of the internal combustion engine as well as operation of associated units, such as the passenger compartment heater and associated windowshield defroster. Especially, when starting a cold engine in cold weather the fuel consumption, and consequently the exhaust emissions, is increased because of increased friction in the engine. The temperature is an important factor to reduce the friction, and therefore it is desirable to use the heat from the engine in the most effective way. During the warm-up phase, the main heat sink is in the engine block. Obtaining a fast passenger compartment warm-up in cold weather has always been a challenge for the automobile manufacturers. However, many of the solutions today require additional, costly equipment.

[0003] US-A-5,735,238 discloses a heat management system for an internal combustion engine which provides a heat intensifying circuit to hasten engine warm-up. During the warm-up period, the coolant flow circuit includes only a coolant pump, cooling passages on the exhaust side of the cylinder head and the heat exchanger for the passenger compartment.

[0004] US-A-5,337,704 describes a cooling system for an internal combustion engine, which provides an initial engine warm-up flow circuit extending from a coolant pump, through cooling passages in the cylinder head, through a heat exchanger used to warm up the passenger compartment and back to the pump, whereby a temperature responsive flow control valve or thermostat prohibits a flow of a coolant from the cylinder head to cooling passages in the engine block.

[0005] DE-A1-41 05 199 discloses an internal combustion engine having a heat distribution circuit with a radiator, a latent heat store, a pump and a balancing container. Upon a cold-start, a valve is arranged to stop the flow of coolant to the crankcase, and the balancing container and the latent heat store are connected in series between the cylinder head and the pump. The aim is to ensure the speediest possible heating-up of the cylinder head from a cold start.

[0006] DE-A1-40 32 701 describes a combustion engine, where the main coolant circuit has a main pump which takes coolant from the heat exchanger and pumps it first through the engine block and then through the cylinder head and back to the heat exchanger. For a rapid warm-up, the main coolant circuit is shut off and coolant is pumped via a secondary circuit by an electrically driven pump through the cylinder head only. The secondary circuit contains a heat accumulator. The secondary circuit also has a heat exchanger and an interior heater.

[0007] US 4,319,547 discloses a liquid cooled internal combustion engine having coolant cavities in the cylinder block and cylinder head, connected to a coolant circulating pump through a temperature controlled regulating device. The arrangement is such that below a selected temperature coolant circulates through the cylinder head only while above this temperature the coolant circulates through both the cylinder head and the cylinder block.

[0008] JP 57193712 describes a method for shortening the time warm-up of an internal combustion engine in cold weather and sufficiently cool its cylinder, by using cooling water to cool the cylinder head and by using lubricating oil to cool the cylinder block. A cooling water passage extends between a cylinder head and a radiator so that cooling water is circulated by a pump.

[0009] The article "Das Wärmemanagement des neuen BMW-Reihen sechs zylindermotors" by Ulrich Hess et. al., MTZ 11/2005 Jahrgang 66, pages 872-877, discloses the use of an electric water pump system, where a very short stand still of the electric water pump is used to enhance the coolant and oil warm-up.

[0010] However, many of the above-mentioned solutions require the provision of additional equipment, such as an additional pump or an additional fluid coolant circuit, which affects the engine assembly and generates costs.

The Object of the Invention

[0011] The object of the present invention is thus to improve the thermal management of an internal combustion engine, and overcome the above-mentioned drawbacks.

Summary of *the Invention*

[0012] The above mentioned objects are attained by providing a method for thermally managing an internal combustion engine during warmed-up conditions of the engine as defined in the enclosed claim 1.

[0013] In prior art internal combustion engines, the difference, ΔT, between the temperature of the fluid coolant supplied to the first fluid coolant circuit from the second fluid coolant circuit and the temperature of the fluid coolant discharged from the first fluid coolant circuit to the second fluid coolant circuit is about 5°C, as the temperature of the coolant discharged from the first fluid coolant circuit is about 90°C and the temperature of the coolant supplied to the first fluid coolant circuit is about 85°C. According to the present invention, ΔT is at least 10°C, which represents such a low flow rate of the coolant so that the temperature of the coolant in the cylinder head is kept above 90°C, which higher than in prior art engines.

[0014] By keeping the coolant temperature of the cylinder head above 90°C, the inventor has found that the friction in the engine, inter alia between pistons and cylinder walls, is further decreased, resulting in a decrease in fuel consumption.

[0015] Further, heat enhances the wear on engine oil, as the degradation of the oil is enhanced by heat. Because of the low flow rate of the coolant, defined by ΔT ≥10°C, a coolant with a lower temperature, in relation to prior art, enters the engine. The inventor has found, because of the cooler coolant entering the engine, that the engine oil in the oil sump is kept at a lower temperature in relation to prior art, which results in a lower temperature of the engine oil, whereby the durability of the engine oil is enhanced and the oil consumption is thus decreased. Advantageously, the entry of the coolant from the second fluid coolant circuit to the first fluid coolant circuit is positioned in the engine block, i.e. when entering the engine, the coolant is first guided to the engine block and subsequently to the cylinder head.

[0016] According to an advantageous embodiment of the method according to the present invention, the coolant pump is controlled to produce such a coolant flow so that the coolant temperature of the cylinder head is above 100°C. Tests performed by the inventor have shown that the friction in the engine is still further decreased above this temperature level, resulting in a decrease in fuel consumption.

[0017] According to another advantageous embodiment of the method according to the present invention, the coolant pump is controlled to produce such a coolant flow so that the coolant temperature of the cylinder head is above 105°C. Tests performed by the inventor have shown that the friction in the engine is yet further decreased above this temperature level, resulting in a further decrease in fuel consumption.

[0018] According to a further advantageous embodiment of the method according to the present invention, the coolant pump is controlled to produce such a coolant flow so that the coolant temperature of the cylinder head is between 110-120°C. Tests performed by the inventor have shown that the friction in the engine is yet further decreased within this temperature range, resulting in a further decrease in fuel consumption.

[0019] According to another advantageous embodiment of the method according to the present invention, the coolant pump is controlled to produce such a coolant flow so that the temperature of the coolant supplied to the first fluid coolant circuit from the second fluid coolant circuit is below 85°C. The inventor has found that the entry of coolant, having a temperature below this temperature level, into the engine, further enhances the durability of the engine oil and the oil consumption is further decreased.

[0020] According to still another advantageous embodiment of the method according to the present invention, the coolant pump is controlled to produce such a coolant flow so that the temperature of the coolant supplied to the first fluid coolant circuit from the second fluid coolant circuit is below 75°C, advantageously below 70°C, or even below 65°C. The inventor has found that the entry of coolant, having a temperature below these temperature levels, into the engine, is especially advantageous as a further increase of the durability of the engine oil is attained, and the oil consumption is further decreased.

[0021] According to an advantageous embodiment of the method according to the present invention, the coolant pump is controlled to rapidly increase the flow rate of the coolant upon risk of knock, whereby the cylinder head is rapidly cooled off by the cold coolant provided by the present invention, and a fast knock control is provided and knock is prevented. As a result of this efficient knock control, the temperature of the cylinder head can be kept above said high temperature levels without any knock problems. The risk of knock is detected in a known manner.

[0022] Further, the above mentioned objects are attained by providing a method for thermally managing an internal combustion engine during engine warm-up as defined in the enclosed claim 10.

[0023] The major part of the heat from the combustion in the engine goes into the cylinder head, and the main part of the heat transmitted from the cylinder head to the engine block is transmitted via the coolant. By the control of the coolant flow according to this method, the heat is kept in the cylinder head and the heat transfer from the cylinder head, via the coolant, to the engine block is radically reduced.

[0024] Because of the low flow rate of the coolant, defined by ΔT ≥10°C, a coolant with a lower temperature enters the engine and the first fluid coolant circuit, in relation to cases with higher flow rates defined by a smaller ΔT, whereby less heat per coolant mass flow unit is transferred to the engine block. If the engine is provided with a first fluid coolant circuit allowing an internal flow from the cylinder head to the engine block, the heat transfer via the coolant within in the engine is also radically reduced because of said low coolant flow. If the second fluid coolant circuit only includes the coolant pump, and no heat exchangers, it is in principal the pipes or tubes of the second fluid coolant circuit which transfer heat from the coolant flowing in the second fluid coolant circuit. A lower flow rate of the coolant in the second fluid coolant circuit results in a larger heat transfer per coolant mass flow unit from the coolant via said pipes or tubes, since the coolant spends more time in said pipes or tubes, and thus provides a larger decrease in the temperature of the coolant, i.e. a larger ΔT. A higher flow rate of the coolant in the second fluid coolant circuit results in a lower heat transfer per coolant mass flow unit from the coolant present in said pipes of tubes, since the coolant spends less time in said pipes or tubes, and thus provides a smaller decrease in the temperature of the coolant, i.e. a smaller ΔT. This is still the case when the second fluid coolant circuit includes one or more heat exchangers, but then also these transfer heat from the fluid coolant. However, since the total amount of coolant passing through the second fluid coolant circuit per time unit is larger when the flow rate of the coolant is higher, the total heat transfer from the second fluid coolant circuit is larger.

[0025] Instead, a fast warm-up of the cylinder head is attained resulting in a fast warm-up of the coolant, the cylinder head, the pistons and the cylinders, whereby the friction and the fuel consumption is decreased, especially upon a cold start in cold climates, without any provision of additional equipment, such as an additional pump or a secondary fluid coolant circuit. Thus, this method can be applied to existing internal combustion engines without any substantial hardware alterations or additions. Tests and simulations performed by the inventor has shown that this method reduces the friction in the valve train and piston rings, as well as it heats the fresh charge which reduces throttle losses, that the a fuel efficiency was improved by 4%, and that it is possible to speed up the coolant warm-up phase by more than a factor of two. The tests showed a big increase in coolant temperature but only a small decrease in engine oil temperature. This is because the engine oil is heated in a much hotter cylinder head during warm-up. Advantageously, the heating of the transfer oil can be included in the warm-up process for active heating.

[0026] According to an advantageous embodiment of this method according to the present invention, the coolant pump is prevented from pumping the coolant, or by controlling the coolant pump to produce said coolant flow at least until the coolant temperature of the cylinder head has reached 100°C. Tests performed by the inventor have shown that the friction in the engine is still further decreased above this temperature level, resulting in a decrease in fuel consumption.

[0027] According to a further advantageous embodiment of this method according to the present invention, the coolant pump is prevented from pumping the coolant, or the coolant pump is controlled to produce said coolant flow at least until the coolant temperature of the cylinder head has reached 105°C. Tests performed by the inventor have shown that the friction in the engine is yet further decreased above this temperature level, resulting in a further decrease in fuel consumption.

[0028] According to another advantageous embodiment of this method according to the present invention, the coolant pump is prevented from pumping the coolant, or the coolant pump to produce said coolant flow at least until the coolant temperature of the cylinder head has reached 110°C. Tests performed by the inventor have shown that the friction in the engine is still further decreased above this temperature level, resulting in a further decrease in fuel consumption.

[0029] According to a further advantageous embodiment of this method according to the present invention, the coolant is pumped by means of a pump drivable decoupled from the engine. This can be an electric coolant pump, or a mechanically driven coolant pump which is drivable decoupled from the engine, e.g. a displacement pump. However, also other coolant pumps which can work decoupled from the engine are possible. For example, a mechanically driven coolant pump which is adapted to be "short-circuited", i.e. being provided with an additional circuit which can connect the outlet of the pump to the inlet of the pump.

[0030] The above mentioned objects are also attained by providing a method for thermally managing an internal combustion engine during engine warm-up as defined in the enclosed claim 16.

[0031] In cold climates and upon cold starts, instead of speeding up the warm-up of the engine, the focus may be to rapidly warm-up the passenger compartment. When the second fluid coolant circuit comprises a heat exchanger for transferring heat from the fluid coolant and for warming a passenger compartment, the heat originating from the cylinder head is transferred from the coolant in the heat exchanger for warming the passenger compartment, instead of aiming to retain as much heat as possible in the cylinder head. However, since the flow rate of the coolant, defined by ΔT≥10°C, also here is lower than in prior art, less energy or heat is transferred to the engine block and is in stead transferred to the passenger compartment, because of the above-mentioned facts. Hereby, the external heater on diesel engines can be replaced, because all heat which would be transferred from the engine block to the ambient instead is available for the passenger compartment warm-up

[0032] According to a further advantageous embodiment of this method according to the present invention, the coolant discharged from the fluid coolant flow passage of the cylinder head is guided to the heat exchanger for warming the passenger compartment. Hereby, a heat transfer from the coolant to the engine block at the outlet of the first fluid coolant circuit is prevented, allowing more heat to be transferred from the coolant in passenger compartment heat exchanger.

[0033] Further advantageous embodiments and aspects of the methods according to the present invention emerge from the detailed description of preferred embodiments.

[0034] The general inventive concept of the methods of the present invention is to provide a considerably low flow rate of the coolant during the engine warm-up phase or during steady state as presented above, a flow rate which is considerably lower in relation to prior art, or even provide a substantially stagnant coolant in the engine during a considerable part of the engine warm-up phase or during the whole warm-up phase.

[0035] According to advantageous embodiments of the above-mentioned methods according to the present invention, the coolant pump is controlled to produce such a coolant flow so that the temperature of the coolant supplied to the first fluid coolant circuit from the second fluid coolant circuit is at least 20°C lower than the temperature of the coolant discharged from the first fluid coolant circuit to the second fluid coolant circuit. Tests preformed by the inventor have shown that the flow rate of the coolant at this level results in that the heat transfer to the engine block is further reduced, and more heat is contained in the cylinder head or transferred to the passenger compartment.

[0036] According to further advantageous embodiments of the above-mentioned methods according to the present invention, the coolant pump is controlled to produce such a coolant flow so that the temperature of the coolant supplied to the first fluid coolant circuit from the second fluid coolant circuit is at least 30°C lower than the temperature of the coolant discharged from the first fluid coolant circuit to the second fluid coolant circuit. Tests preformed by the inventor have shown that the flow rate of the coolant at this level results in that the heat transfer to the engine block is still further reduced, and even more heat is contained in the cylinder head or transferred to the passenger compartment.

[0037] The methods of the present invention can be applied to different kinds of fluid coolant circuit designs, e.g. applied to a secondary fluid coolant circuit which only circulates coolant in the cylinder head during the warm-up phase not entering the engine block, applied to fluid coolant circuits with first fluid coolant circuits having an inlet for coolant provided in the cylinder head and/or the engine block, and an outlet for coolant provided in the cylinder head and/or the engine block, where the coolant is pumped from the engine block to the cylinder head, or vice versa, and applied to fluid coolant circuits with additional equipment included in the second fluid coolant circuit or the first fluid coolant circuit.

[0038] The methods of the present invention are advantageous for both petrol engines and diesel engines, especially during the warm-up phase of diesel engines, as the emissions of CO and HC are reduced because of the hotter combustion chamber and that the catalytic converter is subjected to a faster warm-up.

[0039] The present invention also provides an engine system as defined in claim 21.

Brief Description of *the Drawings*

[0040] The present invention will now be described, for exemplary purposes, in more detail by way of embodiments and with reference to the enclosed drawings, in which:

Fig. 1 is a schematic block diagram illustrating an engine system comprising an internal combustion engine, to which the methods of the present invention can be applied, and

Fig. 2 is a schematic flow diagram illustrating aspects of the methods according to the present invention,

Fig. 3 is a schematic flow diagram illustrating further aspects of the methods according to the present invention, and

Fig. 4 is a schematic block diagram illustrating a second engine system comprising an internal combustion engine, to which aspects of the methods of the present invention can be applied

Detailed Description of *Preferred Embodiments*

[0041] Fig. 1 schematically illustrates an engine system comprising an internal combustion engine 101 to which the methods of the present invention can be applied. The engine 101 comprises an engine block 102 with a fluid coolant flow passage 104 therein, a cylinder head 106 secured to the engine block 102 and provided with a fluid coolant flow passage 108 therein, and a first fluid coolant circuit 109 comprising the fluid coolant flow passages 104, 108. The internal combustion engine 101 is provided with a second fluid coolant circuit 111 connected to the first fluid coolant circuit 109 and comprising a heat exchanger 110, in the form of a radiator 110, with an inlet and an outlet for transferring heat from the coolant, an electric coolant pump 112 with an inlet and an outlet for producing coolant flow in the fluid coolant circuits, an oil cooler 116 for transferring heat from the motor oil, and temperature sensing means 115 and valve means 117 included in a thermostat 118. The temperature sensing means 115 is, inter alia, adapted to measure the coolant temperature of the cylinder head 106. The coolant temperature of the cylinder head 106 can for instance be measured by providing a leak flow of coolant from the cylinder head, the temperature of which leak flow is measured. The thermostat 118 receives, via its two inlets, coolant from the radiator 110, the internal combustion engine 101 and the oil cooler 116, and is arranged to control the coolant flow therefrom by means of its valve means 117.

[0042] Further, the engine system also comprises an engine control unit (ECU) 120, which can be provided as one unit, or as more than one logically interconnected physical units. The engine control unit 120 is adapted to receive data and control the electric coolant pump 112, the radiator 110, the oil cooler 116, and the thermostat 118.

[0043] Fig. 2 schematically illustrates a first and a second aspect of the method according to the present invention for thermally managing an internal combustion engine 101 during engine warm-up upon cold start. During the warm-up phase the coolant flow through the radiator 110 is stopped by the valve means of the thermostat 118 in a conventional way, at step 201. At step 202, the ECU 120 controls the electric coolant pump 112 to stand still, and prevents it from pumping the coolant, and thus provides a substantially stagnant fluid coolant in the first fluid coolant circuit 109. At step 203, the coolant temperature of the cylinder head 106 is sensed by the temperature sensing means 115 of the thermostat 118, and the ECU 120 receives this temperature data. If the coolant temperature of the cylinder head is below 110°C, the ECU 120 still controls the electric coolant pump 112 to stand still and thus prevented from pumping the coolant. If the coolant temperature of the cylinder head is above or equal to 110°C, the ECU 120 controls the electric coolant pump 112 to produce such a coolant flow in the fluid coolant circuits, at step 204, to keep a coolant temperature of 110°C in the cylinder head 106.

[0044] According to a second aspect of the method for engine warm-up, at step 205, ECU 120 controls the electric coolant pump 112 to pump the coolant at such a flow rate so that the temperature T_{in} of the coolant supplied to the first fluid coolant circuit 109 from the second fluid coolant circuit 111 is about 30°C lower, than the temperature T_{out} of the coolant discharged from the first fluid coolant circuit 109 to the second fluid coolant circuit 111, i.e. $\Delta T = T_{out} - T_{in} \approx 30°C$. At step 206, the coolant temperature of the cylinder head 106 is sensed by the temperature sensing means 115 of the thermostat 118, and the ECU 120 receives this temperature data. If the coolant temperature of the cylinder head is below 110°C, the ECU 120 controls the electric coolant pump 112 to keep pumping the coolant at above-mentioned low flow rate. If the coolant temperature of the cylinder head is above or equal 110°C, the ECU 120 controls the electric coolant pump 112 to pump the coolant at such a flow rate to keep a coolant temperature of about 110°C in the cylinder head 106, at step 207, which at least initially results in a flow rate increase.

[0045] In prior art internal combustion engines, T_{out} is conventionally 90°C and T_{in} is conventionally 85°C, which gives a 5 degrees difference between *Tout* and T_{in}. According to the aspects of the present invention, when the outlet of the first fluid coolant circuit 109 is provided in the cylinder head 106, T_{out} corresponds to the coolant temperature of the cylinder head 106, and when the coolant temperature of the cylinder head 106 reaches 110°C, T_{out} is about 110°C.

[0046] In Fig. 2, steps 204 and 207 of the first and second aspects of the method for thermally managing an internal combustion engine 101 during engine warm-up proceed to the first step, 208, of a third aspect of the method according to the present invention, for thermally managing an internal combustion engine 101 during warmed-up conditions of the engine, i.e. steady state. At step 208, during warmed-up conditions, the coolant flow through the radiator 110 is allowed by the valve means of the thermostat 118 in a conventional way, when necessary. At step 209, the ECU 120 controls the electric coolant pump 112 to pump the coolant at such a flow rate so that $\Delta T = T_{out} - T_{in} \approx 30°C$, to keep a coolant temperature of about 110°C in the cylinder head 106, and to produce such a coolant flow so that the temperature T_{in} of the coolant supplied to the first fluid coolant circuit 109 from the second fluid coolant circuit 111 is about 80°C. At step 210, the coolant temperature of the cylinder head 106 is sensed by the temperature sensing means 115 of the thermostat 118, and the ECU 120 receives this temperature data. If the coolant temperature of the cylinder head is within the range 110°C to 120 °C, the ECU 120 controls the electric coolant pump 112 to keep pumping the coolant at the same flow rate, at step 211. If the coolant temperature of the cylinder head is outside said range, the ECU 120 controls the electric coolant pump 112 to adjust the flow rate of the coolant, at step 212. If knock occurs, the ECU 120 controls the electric coolant pump 112 to rapidly increase the flow rate of the coolant, at step 213, whereby the cylinder head 106 is rapidly cooled off by the cold coolant, and a fast knock control is provided.

[0047] Fig. 3 illustrates further aspects of the methods according to the present invention. Instead of performing steps 202-204 or steps 205-207, during the engine warm-up as disclosed in Fig. 2, first, steps 201-203 are performed, and subsequently, steps 205-207 are performed, whereupon the steps of the third aspect of the method as disclosed in connection with Fig. 2 are performed.

[0048] In other aspects of the invention, steps 201-204 and/or steps 201 & 205-207 can be performed without proceeding to steps 208-213, and steps 208-213 can be performed without first performing steps 201-204 and/or steps 201 & 205-207.

[0049] Further, the first and second aspects of the method according to the present invention can be applied to the same engine system, alternating, or subsequently as disclosed in Fig. 3, or one can choose to apply only one of the first and second aspects of the method according to the present invention.

[0050] Advantageously, the coolant temperature in the cylinder head 106 is between 110°C and 120°C during steady state.

[0051] Fig. 4 schematically illustrates a second engine system comprising an internal combustion engine 401 to which the methods of the present invention can be applied. The engine 401 comprises an engine block 402 with a fluid coolant flow passage 404 therein, a cylinder head 406 secured to the engine block 402 and provided with a fluid coolant flow passage 408 therein, and a first fluid coolant circuit 409 comprising the fluid coolant flow passages 404, 408. In this engine system, the first fluid coolant circuit 409 has more passages adapted to guide coolant from the cylinder head to the engine block internally within the engine. Further, the engine system comprises a second heat exchanger 412 for transferring heat from the fluid coolant and for warming a passenger compartment. The second heat exchanger 412 receives coolant discharged from the fluid coolant flow passage of the cylinder head 406. The other elements of this engine system correspond the elements of the engine system of Fig. 1 and are provided with the same reference signs.

[0052] Naturally, the second heat exchanger 412 can also be present when applying the aspects discloses in connection with Figures 2 and 3, connected or disconnected.

[0053] According to a further aspect of the present invention, when the present focus is to rapidly warm-up the passenger compartment, which is an important issue especially in cold climates and upon cold starts, instead of speed up the warm-up of the engine, the coolant pump 112 is controlled to produce such a coolant flow so that the temperature T_{in} of the fluid coolant supplied to the first fluid coolant circuit 409 from the second fluid coolant circuit 111 is about 25°C lower than the temperature T_{out} of the fluid coolant discharged from the first fluid coolant circuit 409 to the second fluid coolant circuit 111. Because of the low flow rate of the coolant in the second heat exchanger 412, the coolant is subjected to a large temperature decrease in the second heat exchanger 412. According to this aspect, the flow rate of the coolant is higher in relation to the aspects of Figs. 2 and 3, but the flow rate of the coolant is still considerably lower in relation to prior art engine systems including a heat exchanger for warming a passenger compartment.

[0054] According to advantageous aspects of the present invention, ΔT is at least 20°C, advantageously at least 25°C, or even at least 30°C, for all methods of the present invention.

[0055] The invention is not limited to the embodiments described in the foregoing. It will be obvious that many different modifications are possible within the scope of the following claims.

Claims

1. A method for thermally managing an internal combustion engine (101, 401) during warmed-up conditions of the engine (101, 401), which internal combustion engine (101, 401) comprises an engine block (101, 402) with a fluid coolant flow passage (104, 404) therein, a cylinder head (106, 406) secured to the engine block (104, 402) and provided with a fluid coolant flow passage (108, 408) therein, and a first fluid coolant circuit (109, 409) comprising the fluid coolant flow passages (104, 108, 404, 408), the internal combustion engine (101, 401) being provided with a second fluid coolant circuit (111) connected to the first fluid coolant circuit (109, 409) and comprising at least one heat exchanger (110, 116, 412) for transferring heat from the fluid coolant, a coolant pump (112) for producing coolant flow in the first fluid coolant circuit (109, 409), temperature sensing means (115) and valve means (117), **characterized by** controlling (209) the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the fluid coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is at least 10°C lower than the temperature (T_{out}) of fluid coolant discharged from the first fluid coolant circuit (109, 409) to the second fluid coolant circuit (111), so that the temperature of the coolant in the cylinder head (106, 406) is above 90°C.

2. A method according to claim 1, **characterized by** controlling the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is at least 20°C lower than the temperature (T_{out}) of the coolant discharged from the first fluid coolant circuit (109, 409) to the second fluid coolant circuit (111).

3. A method according to claim 2, **characterized by** controlling the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is at least 30°C lower than the temperature (T_{out}) of the coolant discharged from the first fluid coolant circuit (109, 409) to the second fluid coolant circuit (111).

4. A method according to any of the claims 1 to 3, **characterized by** controlling (209) the coolant pump (112) to produce such a coolant flow so that the coolant temperature of the cylinder head (106, 406) is above 100°C.

5. A method according to claim 4, **characterized by** controlling (209) the coolant pump (112) to produce such a coolant flow so that the coolant temperature of the cylinder head (106, 406) is above 105°C.

6. A method according to claim 5, **characterized by** controlling (209) the coolant pump (112) to produce such a coolant flow so that the coolant temperature of the cylinder head (106, 406) is between 110-120°C.

7. A method according to any of the claims 1 to 6, **characterized by** controlling (209) the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is below 85°C.

8. A method according to claim 7, **characterized by** controlling (209) the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is below 75°C.

9. A method according to claim 7 or 8, **characterized by** controlling (213) the coolant pump (112) to rapidly

increase the flow rate of the coolant upon risk of knock, whereby a fast knock control is provided.

10. A method for thermally managing an internal combustion engine (101, 401) during engine warm-up, which internal combustion engine (101, 401) comprises an engine block (102, 402) with a fluid coolant flow passage (104, 404) therein, a cylinder head (106, 406) secured to the engine block (102, 402) and provided with a fluid coolant flow passage (108, 408) therein, and a first fluid coolant circuit (109, 409) comprising the fluid coolant flow passages (104, 108, 404, 408), the internal combustion engine (101, 401) being provided with a second fluid coolant circuit (111) connected to the first fluid coolant circuit (109, 409) and comprising a coolant pump (112) for producing coolant flow in the first fluid coolant circuit (109, 409), temperature sensing means (115) and valve means (117), **characterized by** preventing (202) the coolant pump (112) from pumping the fluid coolant and thus providing a substantially stagnant fluid coolant in the first fluid coolant circuit (109, 409), or by controlling (205) the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is at least 10°C lower than the temperature (T_{out}) of the fluid coolant discharged from the first fluid coolant circuit (109, 409) to the second fluid coolant circuit (111), at least until the temperature of the coolant in the cylinder head (106, 406) has reached 90°C.

11. A method according to claim 10, **characterized by** controlling the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is at least 20°C lower than the temperature (T_{out}) of the coolant discharged from the first fluid coolant circuit (109, 409) to the second fluid coolant circuit (111).

12. A method according to claim 11, **characterized by** controlling the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is at least 30°C lower than the temperature (T_{out}) of the coolant discharged from the first fluid coolant circuit (109, 409) to the second fluid coolant circuit (111).

13. A method according to any of the claims 10 to 12, **characterized by** preventing (202) the coolant pump (112) from pumping the coolant, or by controlling (205) the coolant pump (112) to produce said coolant flow at least until the coolant temperature of the cylinder head (106, 406) has reached 100°C.

14. A method according to claim 13, **characterized by** preventing (202) the coolant pump (112) from pumping the coolant, or by controlling (205) the coolant pump (112) to produce said coolant flow at least until the coolant temperature of the cylinder head (106, 406) has reached 105°C.

15. A method according to claim 14, **characterized by** preventing (202) the coolant pump (112) from pumping the coolant, or by controlling (205) the coolant pump (112) to produce said coolant flow at least until the coolant temperature of the cylinder head (106, 406) has reached 110°C.

16. A method for thermally managing an internal combustion engine (101, 401) during engine warm-up, which internal combustion engine (101, 401) comprises an engine block (102, 402) with a fluid coolant flow passage (104, 404) therein, a cylinder head (106, 406) secured to the engine block (102, 402) and provided with a fluid coolant flow passage (108, 408) therein, and a first fluid coolant circuit (109, 409) comprising the fluid coolant flow passages (104, 108, 404, 408), the internal combustion engine (101, 401) being provided with a second fluid coolant circuit (111) connected to the first fluid coolant circuit (109, 409) and comprising a coolant pump (112) for producing coolant flow in the first fluid coolant circuit (109, 409), a heat exchanger (412) for transferring heat from the fluid coolant and for warming a passenger compartment and temperature sensing means (115) and valve means (117), **characterized by** controlling the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the fluid coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is at least 10°C lower than the temperature (T_{out}) of the fluid coolant discharged from the first fluid coolant circuit (109, 409) to the second fluid coolant circuit (111).

17. A method according to claim 16, **characterized by** controlling the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is at least 20°C lower than the temperature (T_{out}) of the coolant discharged from the first fluid coolant circuit (109, 409) to the second fluid coolant circuit (111).

18. A method according to claim 17, **characterized by** controlling the coolant pump (112) to produce such a coolant flow so that the temperature (T_{in}) of the coolant supplied to the first fluid coolant circuit (109, 409) from the second fluid coolant circuit (111) is at least 30°C lower than the temperature (T_{out}) of the coolant discharged from the first fluid coolant circuit (109, 409) to the second fluid coolant circuit (111).

19. A method according to any of the claims 16 to 18, **characterized by** guiding coolant discharged from the fluid coolant flow passage (108, 408) of the cylinder head (106, 406) to the heat exchanger (412) for warming the passenger compartment.

20. A method according to any of the previous claims 1 to 19, **characterized by** pumping the coolant by means of a pump (112) drivable decoupled from the engine.

21. An engine system comprising an internal combustion engine (101, 401) which comprises an engine block (102, 402) with a fluid coolant flow passage therein (104, 404), a cylinder head (106, 406) secured to the engine block (102, 402) and provided with a fluid coolant flow passage (108, 408) therein, and a first fluid coolant circuit (109, 409) comprising the fluid coolant flow passages (104, 108, 404, 408), the internal combustion engine (101, 401) being provided with a second fluid coolant circuit (111) connected to the first fluid coolant circuit (109, 409) and comprising at least one heat exchanger (110, 118, 412) for transferring heat from the fluid coolant, a coolant pump (112) for producing coolant flow in the first fluid coolant circuit (109, 409), temperature sensing means (115) and valve means (117), which engine system comprises at least one engine control unit (120), **characterized in that** the engine control unit (120) is adapted to perform the steps of any of the claims 1 to 20.

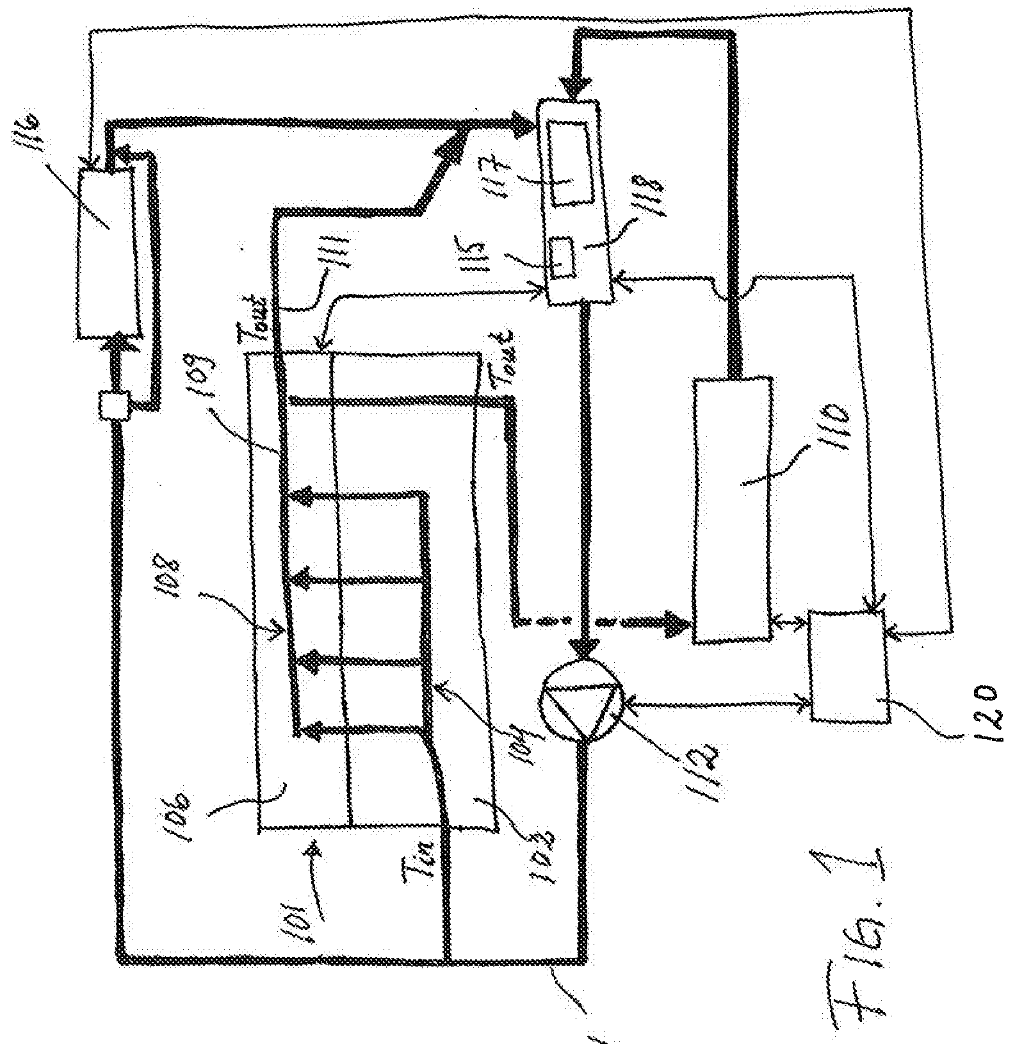
116
117
118
115
111
Tout
Tout
109
108
110
106
101
Tin
103
104
112
120
111

FIG. 1

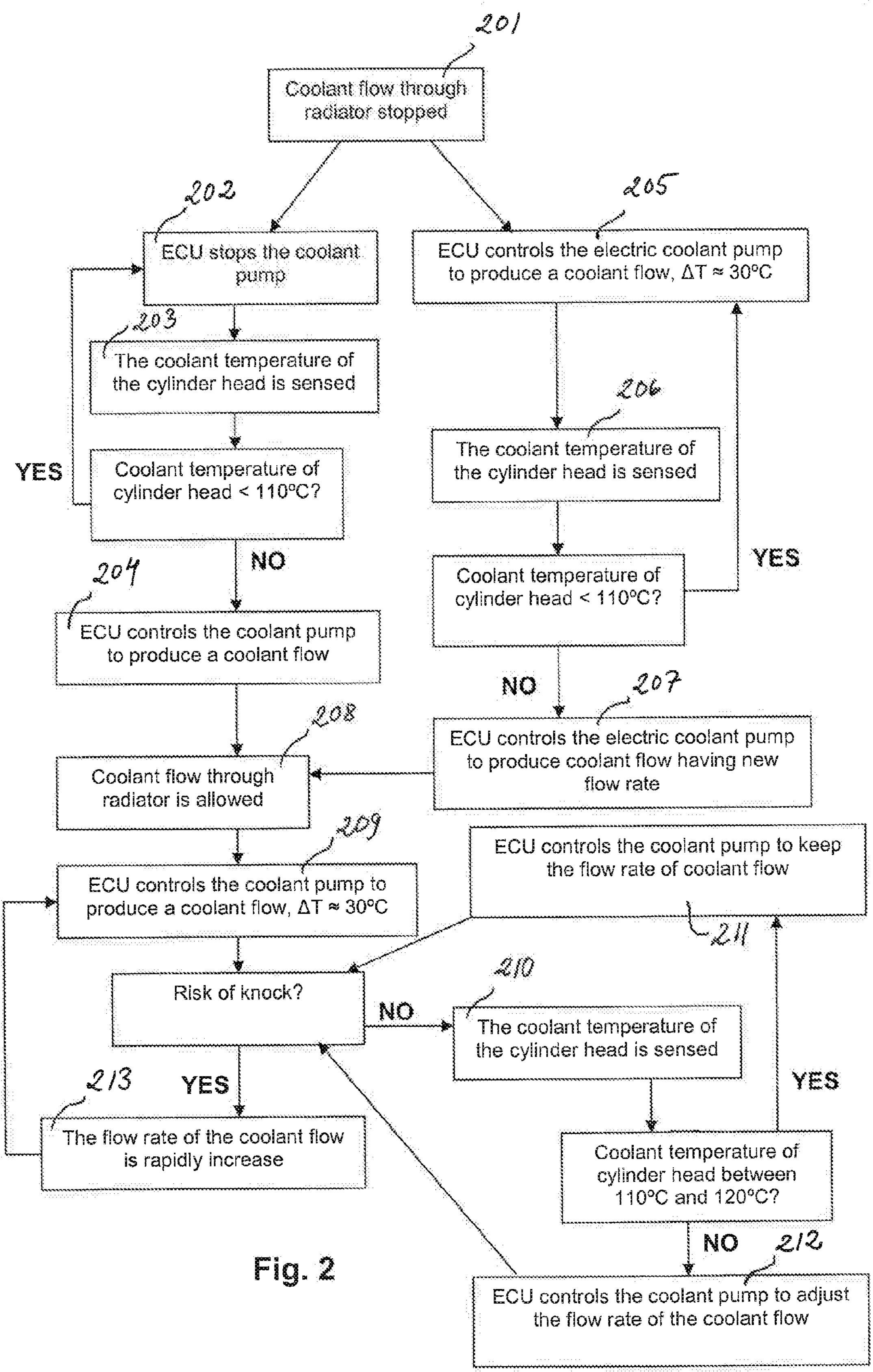
201
Coolant flow through radiator stopped
202
ECU stops the coolant pump
203
The coolant temperature of the cylinder head is sensed
Coolant temperature of cylinder head < 110°C?
YES
NO
204
ECU controls the coolant pump to produce a coolant flow
205
ECU controls the electric coolant pump to produce a coolant flow, ΔT ≈ 30°C
206
The coolant temperature of the cylinder head is sensed
Coolant temperature of cylinder head < 110°C?
YES
NO
207
ECU controls the electric coolant pump to produce coolant flow having new flow rate
208
Coolant flow through radiator is allowed
209
ECU controls the coolant pump to produce a coolant flow, ΔT ≈ 30°C
ECU controls the coolant pump to keep the flow rate of coolant flow
211
Risk of knock?
NO
210
The coolant temperature of the cylinder head is sensed
YES
213
YES
The flow rate of the coolant flow is rapidly increase
Coolant temperature of cylinder head between 110°C and 120°C?
NO
212
ECU controls the coolant pump to adjust the flow rate of the coolant flow

Fig. 2

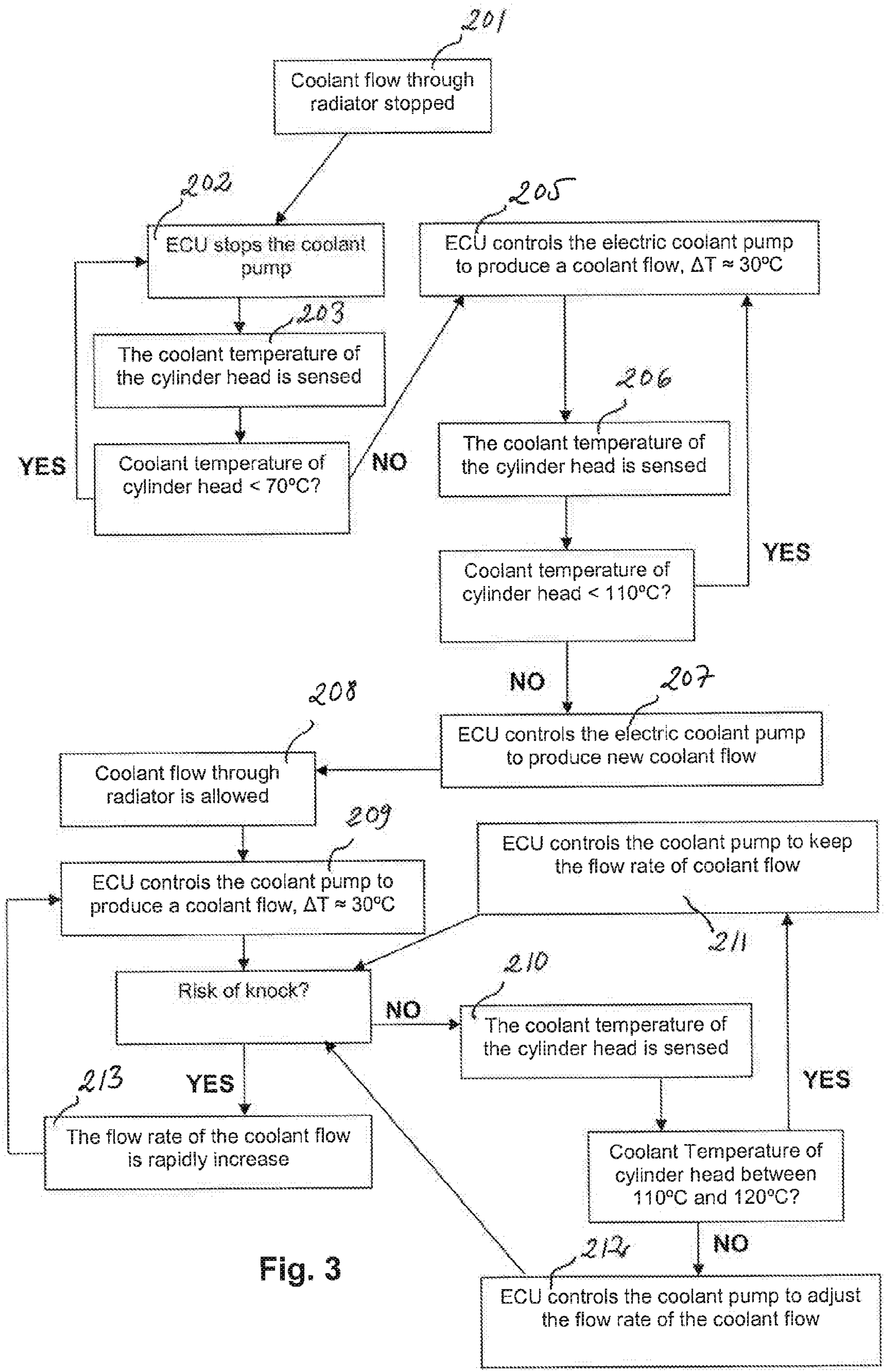
201
Coolant flow through radiator stopped
202
ECU stops the coolant pump
203
The coolant temperature of the cylinder head is sensed
Coolant temperature of cylinder head < 70°C?
YES
NO
205
ECU controls the electric coolant pump to produce a coolant flow, ΔT ≈ 30°C
206
The coolant temperature of the cylinder head is sensed
Coolant temperature of cylinder head < 110°C?
YES
NO
207
ECU controls the electric coolant pump to produce new coolant flow
208
Coolant flow through radiator is allowed
209
ECU controls the coolant pump to produce a coolant flow, ΔT ≈ 30°C
ECU controls the coolant pump to keep the flow rate of coolant flow
211
Risk of knock?
NO
210
The coolant temperature of the cylinder head is sensed
213
YES
The flow rate of the coolant flow is rapidly increase
YES
Coolant Temperature of cylinder head between 110°C and 120°C?
NO
212
ECU controls the coolant pump to adjust the flow rate of the coolant flow

Fig. 3

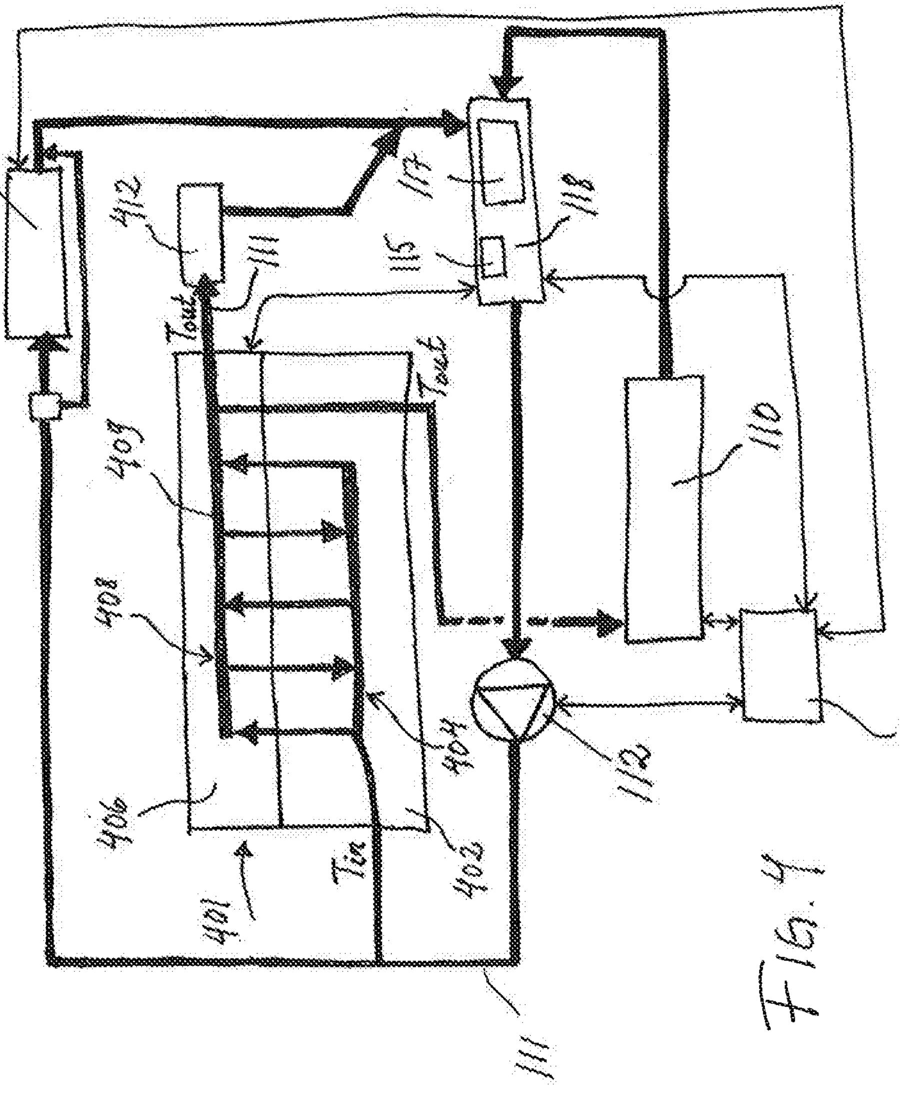
116
412
111
117
115
118
Tout
Tout
409
408
406
401
Tin
402
404
112
110
120
111

FIG. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 07 11 0663

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	20 November 2007	MATRAY, J

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EUROPEAN SEARCH REPORT

Application Number
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	20 November 2007	MATRAY, J

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