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(71) Applicant: **JAGUAR LAND ROVER LIMITED** [GB/GB]; Abbey Road, Whitley, Coventry Warwickshire CV3 4LF (GB).

(72) Inventors: **BRISCOE, Stuart**; c/o Jaguar Land Rover, Patents Department W/1/073, Abbey Road, Whitley, Coventry Warwickshire CV3 4LF (GB). **HUTCHINS, William**; c/o Jaguar Land Rover, Patents Department W/1/073, Abbey Road, Whitley, Coventry Warwickshire CV3 4LF (GB).

(74) Agent: **HOLMES, Matthew**; c/o Jaguar Land Rover, Patents Department W/1/073, Abbey Road, Whitley, Coventry Warwickshire CV3 4LF (GB).

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(54) **Title**: METHOD OF CONTROLLING A THERMAL MANAGEMENT SYSTEM

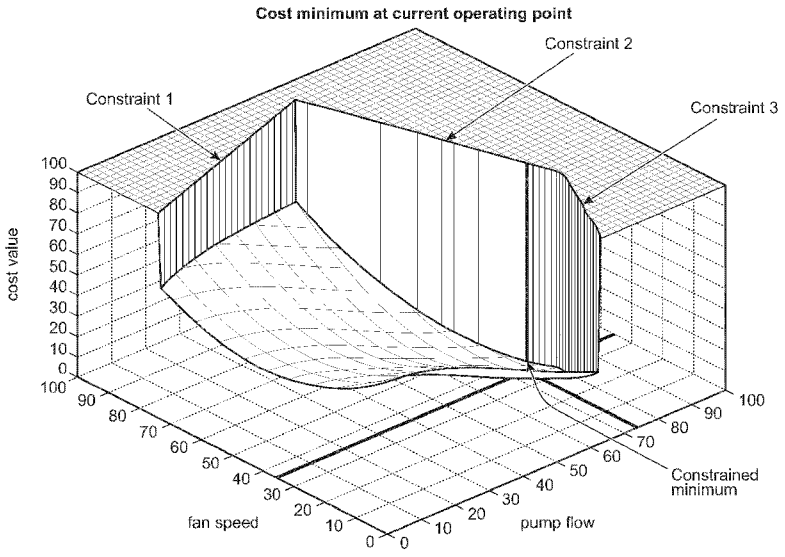


FIGURE 7

(57) **Abstract**: A method of controlling a thermal management system, the method comprising: • (i) monitoring one or more variables of the thermal management system; • (ii) determining, in dependence upon said monitoring, a current cooling requirement of the system; • (iii) determining a plurality of viable operating points suitable for providing the current cooling requirement; • (iv) estimating a cost associated with each of said viable operating points; • (v) selecting a viable operating point in dependence upon the estimated costs; and • (vi) adjusting one or more controllable components of the thermal management system in dependence upon a selected viable operating point.

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METHOD OF CONTROLLING A THERMAL MANAGEMENT SYSTEM

TECHNICAL FIELD

The present invention relates to a method of controlling a system for providing thermal management and more particularly, but not exclusively, to a method of controlling a system for providing thermal management in a vehicle. Such a system is used to control the temperature of the powertrain of the vehicle and other components and features, such as the cabin of the vehicle.

Aspects of the invention relate to a method, to a vehicle to a program, to a thermal management system and to a control unit.

BACKGROUND

Powertrains of vehicles generate heat and typically, a cooling system is provided to cool the powertrain. The temperatures of other components and features of the vehicle also need to be managed to ensure the components operate within a safe temperature range and/or to provide comfort to the passengers of the vehicle. Typically, known cooling systems for internal combustion engines comprise a pump driven directly by the engine itself. The pump provides a supply of coolant to the engine and to other components of the vehicle. A radiator is typically used to cool the coolant. In this way, as coolant is recirculated by the pump, the coolant continuously cools the engine. The pump and cooling system need to be of a sufficient capacity such that when the engine is operating at a high temperature, the cooling system can nevertheless cool the engine to prevent damage, fatigue or failure of the engine or its components that can be caused if the engine is operated at too high a temperature. A vehicle engine may operate at a high temperature, for example due to the vehicle working hard by travelling uphill, towing a heavy load and/or travelling in a hot climate. Vehicles are typically provided with a cooling system wherein the pump is constantly operated at its maximum output, irrespective of the actual temperature of the engine, the climate the vehicle is in, or the current and changing workload placed on the engine of the vehicle. Typically, vehicles are driven, for a significant proportion of their working life, in scenarios where they do not require the cooling pump to operate at its maximum output, and savings in fuel and therefore cost could be made by having a more efficient thermal management system.

In recent developments in the field of cooling systems for vehicles, variably operable pumps have been utilised which are controllable by a control unit coupled thereto. In dependence upon data gathered by the control unit relating to the temperature of the engine, the control

unit determines an appropriate rate for the variable pump to supply coolant such that a more energy efficient system is formed.

Additionally, in other recent developments in the field of cooling systems for vehicles, radiators with active cooling vanes have been developed which can be controlled to allow specific sections of the radiator grille to be blanked off (closed) when air flow through the radiator is not required.

The present invention seeks to present a further improvement in the field of controlling a system for providing thermal management in a vehicle, by providing an improved control strategy.

Whereas the invention has beneficial application for vehicles such as cars, trucks, trains and the like, the control strategy disclosed herein may have beneficial application in other fields, for example in buildings, other machinery and the like.

SUMMARY OF THE INVENTION

Aspects of the invention provide a method, a vehicle, a control unit, a thermal management system and a program as claimed in the appended claims.

According to an aspect of the invention for which protection is sought, there is provided a method of controlling a thermal management system, the method comprising:

(i) monitoring one or more variables of the thermal management system;

(ii) determining, in dependence upon said monitoring, a current cooling requirement of the system;

(iii) determining a plurality of viable operating points suitable for providing the current cooling requirement;

(iv) determining an estimated cost associated with more than one of said plurality of viable operating points;

(v) determining a selected viable operating point in dependence upon the estimated costs; and

(vi) adjusting one or more controllable components of the thermal management system in dependence upon the selected viable operating point.

Optionally, the method additionally comprises repeating steps (i) to (vi) periodically in order to periodically adjust the operation of the thermal management system. In this way, the

thermal management system is regularly and frequently monitored and the controllable components of the thermal management system adjusted to ensure that the cooling and heating requirements of for example, a vehicle engine, a vehicle cabin and/or other components of a vehicle are continually met and are met in a fuel efficient and/or cost efficient way.

When the thermal management system is a cooling system of a vehicle, the method enables careful control and refinement of the way the cooling system operates in response to the vehicle's current cooling requirements. This is in order to constantly provide only the cooling that is necessary and to use the most cost effective (i.e., lowest fuel consuming) method to achieve that. This is also subject to ensuring that the vehicle is cooled to ensure optimum working conditions for components and further subject to ensuring that operation of components of the system are not adjusted too significantly in order to avoid, for example, thermal shocks and thermal jitter.

Optionally, the method additionally comprises:

(i) determining one or more constraints on the thermal management system; applying the constraints to said plurality of viable operating points; and thereby

(ii) generating a reduced number of viable operating points and determining the selected viable operating point therefrom.

Optionally, said determining an estimated cost associated with more than one of said plurality of viable operating points comprises, determining an estimated cost associated only with each viable operating point of the reduced number of viable operating points.

Optionally, the step of determining a selected viable operating point in dependence upon estimated costs further comprises:

(i) limiting the extent to which said one or more controllable components of the thermal management system can be adjusted and thereby reducing the number of viable operating points for selection.

The thermal management system may be disposed within a vehicle having a power source comprising one or both of: an internal combustion engine; a rechargeable battery pack.

The one or more controllable components of the thermal management system of the vehicle may comprise one or more of:

(i) a variable pump for pumping coolant about the thermal management system;

(ii) a fan associated with a radiator of the vehicle; and

(iii) one or more active vanes associated with a radiator grille of the vehicle.

Optionally, the one or more variables of the thermal management system of the vehicle comprise one or more of:

(i) a temperature of coolant exiting said power source of the vehicle;

(ii) a temperature under the bonnet of the vehicle;

(iii) a current coolant flow rate;

(iv) a speed of the vehicle;

(v) the power source of the vehicle;

(vi) a temperature of coolant exiting the radiator;

(vii) a rate at which air is flowing into the radiator;

(viii) one or more positions of the one or more active vanes;

(ix) the rate at which the radiator cooling fan is operating;

(x) a maximum under bonnet temperature;

(xi) the amount or rate of heat rejection to an Exhaust Gas Regeneration system;

(xii) a position of one or more valves within the system;

(xiii) an operational requirement of a cabin heater; and

(xiv) an operational requirement of a cabin cooler.

Optionally, determining a plurality of viable operating points comprises determining a plurality of combinations of:

(i) a rate of operation of the variable pump; and

(ii) a rate of operation of a fan associated with a radiator of the vehicle; and

(iii) a position for the one or more active vanes;

suitable for achieving the current cooling requirement of the system.

According to another aspect of the disclosure for which protection is sought, there is provided a vehicle comprising a power source and a thermal management system comprising a control unit, the control unit configured to carry out the method of any of the preceding paragraphs.

1. According to another aspect of the invention for which protection is sought there is provided a thermal management system comprising:

a network of pathways configured to convey coolant liquid;

a variably controllable pump configured to pump coolant liquid about the network of pathways;

a radiator disposed in said network of pathways;

a variably controllable cooling fan and/or a plurality of active vanes associated with said radiator;

monitoring means configured to monitor one or more variables of the thermal management system; and

a control unit in communication with said pump, said cooling fan and/or vanes, and said monitoring means,

wherein the control unit is configured to: determine a current cooling requirement of the system in dependence on a signal received from said monitoring means; determine a plurality of viable operating points suitable for providing the current cooling requirement; determine an estimated cost associated with more than one of said plurality of viable operating points; determine a selected viable operating point in dependence on the estimated costs; and adjust one or more the pump, the cooling fan and the vanes in dependence on the selected operating point.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives, and in particular the individual features thereof, set out in the preceding paragraphs, in the claims and/or in the following description and drawings, may be taken independently or in any combination thereof. For example, features described in connection with one embodiment are applicable to all embodiments, unless such features are incompatible.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIGURE 1 is an illustration of a vehicle comprising a system for thermal management having a control unit (not shown) configured to carry out a method of thermal management optimisation according to an embodiment of the disclosure;

FIGURE 2 is a schematic illustration of the system of Figure 1 showing the control unit;

FIGURE 2B is a schematic illustration of heating nodes within the thermal management system and showing heat transfer into and out of each heating node;

FIGURE 3 is a schematic illustration of the steps of the method of thermal management optimisation carried out by the control unit of the system comprised in the vehicle of Figures 1 and 2 according to an embodiment of the invention;

FIGURE 4 is a graphical representation of the amount of heat energy (in kW) that can be rejected by the radiator in dependence on the combination of air flow (in kgh^{-1}) and coolant flow (in $kgmin^{-1}$);

FIGURE 5 is the graphical representation of Figure 4, wherein constraints, based upon vehicle conditions at a first time, on the air flow and coolant flow respectively are shown;

FIGURE 6 is the graphical representation of Figure 4, wherein constraints, based upon vehicle conditions at a second time, on the air flow and coolant flow respectively are shown;

FIGURE 7 is a graphical representation of a first cost analysis conducted by the control unit in performing the method of thermal management optimisation according to an aspect of the disclosure, wherein for illustrative purposes, cost has been plotted against combinations of radiator cooling fan speed and coolant pump flow that may meet the currently determined requirements of the thermal management system;

FIGURE 8 is a graphical representation of a second cost analysis conducted by the control unit in performing the method of thermal management optimisation according to an aspect of the disclosure, wherein for illustrative purposes, cost has been plotted against combinations of radiator cooling fan speed and coolant pump flow that may meet the currently determined requirements of the thermal management system; and

FIGURE 9 is a graphical representation of a third cost analysis conducted by the control unit in performing the method of thermal management optimisation according to an aspect of the disclosure, wherein for illustrative purposes, cost has been plotted against combinations of radiator cooling fan speed and coolant pump flow that may meet the currently determined requirements of the thermal management system.

DETAILED DESCRIPTION OF EMBODIMENTS

Detailed descriptions of specific embodiments of the methods, systems, vehicles and programs of the present invention are disclosed herein. It will be understood that the disclosed embodiments are merely examples of the way in which certain aspects of the invention can be implemented and do not represent an exhaustive list of all of the ways the

invention may be embodied. Indeed, it will be understood that the methods, systems, vehicles and programs described herein may be embodied in various and alternative forms. The Figures are not necessarily to scale and some features may be exaggerated or minimised to show details of particular components. Well-known components, materials or methods are not necessarily described in great detail in order to avoid obscuring the present disclosure. Any specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the invention.

The present invention relates to a strategy or method of thermal management for a cooling system, optionally for a vehicle. Where the system may be in a vehicle, a powertrain and one or more auxiliary components, that act as heat sources or heat sinks, are provided within the vehicle. The heat generated by the powertrain varies depending upon factors such as driving conditions, ambient temperature, vehicle speed and vehicle load. Additionally, one or more cooling sources are provided which are to some extent at least, controllable or variable. For example, a radiator grille and cooling fan; and a variable pump for pumping coolant (heat transfer fluid) through the system.

In dependence upon a variety of factors, as will be described below, a control unit of the cooling system is configured to monitor vehicle data received from one or more sensors and control modules of the vehicle that are coupled to the system. In this way, a current cooling requirement of the system can be determined.

In the method of the present disclosure, a range of viable operating conditions (also referred to as points) that would meet the current cooling requirement is determined. The control unit then analyses or estimates a cost associated with each viable operating condition. In the present method a most cost-efficient operating condition (also referred to as an “operating point”) for the system is selected in order to meet the current cooling requirement and components of the system are operated or controlled in accordance with the selected viable operating point. Optionally, prior to determining a selected, most cost-efficient, operating condition, the present method further comprises applying certain limits or constraints which may reduce the number of viable operating conditions for selection. The step of applying additional constraints is beneficially carried out in order to avoid for example, thermal jitter, thermal shocks and the occurrence of significant steps in operating condition of particular components. A cost estimation may then only be performed on the reduced number of viable operating conditions (in order to reduce the number of required computations) and the

selected viable operating point is selected from the reduced number of viable operating conditions based upon a lowest cost estimation.

It will be apparent that the cooling system 90 in relation to which the thermal management method of the disclosure is described is actually a temperature management system 90 that enables the transfer of heat energy. At times, the temperature management system 90 causes or allows an increase in temperature of one or more components, a decrease in temperature or one or more other components and/or maintenance of temperature of one or more other components. As such, the term “cooling system” should be interpreted to mean a system that effects temperature management, including cooling, heating and/or temperature maintenance. Additionally it will be realised, upon reading the following, that the temperature management system 90 is configured and arranged to concurrently effect heating of one component and cooling of another component in certain operating conditions.

Referring now to Figure 1, there is shown a vehicle 10 comprising a power source 80 which forms part of a powertrain of the vehicle 10. In the presently illustrated embodiment the power source 80 is an internal combustion engine 80. The internal combustion engine 80 is disposed in an engine bay behind a radiator grille of a radiator 22. In other embodiments, it is envisaged that the vehicle 10 is an all-electric vehicle and that the power source is a rechargeable battery pack. In yet further envisaged embodiments, it is envisaged that the vehicle is a hybrid vehicle comprising two power sources: an internal combustion engine and a rechargeable electric battery pack. In dependence upon the power output required by the power source, the time the power source has been in use, the ambient temperature and other factors, the power source 80 generates heat energy.

A temperature management system 90 shown schematically in Figure 2 is provided to pump coolant about parts of the power source 80 and optionally about other parts of the vehicle 10. The temperature management system 90 optionally comprises an adjustable or variably controllable pump 40 that is remotely controllable by a pump control module (not shown). The flow-rate at which coolant is pumped about the cooling system 90 is therefore controllable or at least adjustable and can be monitored by a control unit 500 configured to carry out the method of the present disclosure. The control unit 500 is coupled by direct or indirect connection to the pump 40. The pump 40 provides a first controllable cooling source. In other envisaged embodiments more than one control unit having a processor is utilised in the performance of the method of the present disclosure.

A network of pathways (see solid arrows in Figures 2 and 2B) is disposed within and around the engine 80 and other components of the vehicle 10. The network of pathways provides pumped coolant liquid. One or more valves (V), openable and closable in response to temperature, pressure and/or electronic command signals are positioned within the network of pathways to control the flow routes available for the pumped coolant liquid. Optionally at least one valve is provided to selectively control the flow of coolant through a cylinder head ('CH') and cylinder or engine block ('CB') of the engine 80. However, in other envisaged embodiments where the powertrain of the vehicle 10 comprises an alternative power supply 80, such as a rechargeable battery pack, the network of pathways for the flow of coolant is alternatively configured and such a valve ('V') is not necessarily provided.

The network of pathways preferably includes pathways for conveying coolant to, and from: the cylinder head 'CH' of the engine 80; the cylinder block 'CB' of the engine 80; a radiator 22 having an associated controllable cooling fan 30; at least one heat exchanger for the HVAC system 50 providing temperature control to the cabin 14; a transmission oil cooler 15 (not shown in Figure 2, but see Figure 2B); and one or more exhaust gas regeneration system 60a, 60b, 60c heat exchangers and valves. In other embodiments, the network of pathways may include additional, fewer or alternative components, for example a cooler for a turbocharger and/or an air conditioning system.

The radiator 22 sits behind a grille provided at the front of the vehicle 10. A radiator cooling fan 30 (not shown in Figure 1) is disposed on the internal side of the radiator grille to provide air flow to reduce the temperature of coolant flowing through the radiator 22. The radiator 22 cooling fan 30 is operable at different speeds and is controllable by a fan control module (not shown) and can be monitored and/or controlled by the control unit 500 (which may comprise a fan control module) configured to carry out the method of the present disclosure. The control unit 500 is coupled by direct or indirect connection to the cooling fan 30. The radiator 22 provides a second controllable cooling source.

The radiator grille comprises a plurality of controllable and as such "active", cooling vanes 12a, 12b, 12c, 12d, 12e, which are each movable from a closed position wherein an aperture 13d, 13e of the radiator grille 22 is blanked off (in other words, does not permit any air flow therethrough) to an open position in which maximum air-flow therethrough is permitted. Two vanes 12d, 12e are illustrated in their open position, wherein an aperture 13d, 13e associated with each vane 12d, 12e respectively is open and permits full air flow therethrough. The maximum air flow permitted through the radiator grille is dependent upon

the speed and direction of the vehicle 10 and is affected by the environment and climate in which the vehicle 10 is being driven.

The position of each cooling vane 12a, 12b, 12c, 12d, 12e is individually and independently controlled between the closed position; one or more intermediate positions; and the open position. In other embodiments the vanes 12a, 12b, 12c, 12d, 12e are all simultaneously operable such that they are all either open, closed or all at an intermediate position therebetween. In yet further envisaged embodiments, the vanes 12a, 12b, 12c, 12d, 12e are operable in groups such that a first group of vanes is opened whilst a second group of vanes is, for example, closed. The position of the active vanes 12 -12e can be monitored by a control unit 500 configured to carry out the method of the present disclosure. The control unit 500 is coupled by direct or indirect connection to the active vanes 12 -12e.

The vehicle 10 additionally comprises a Heating Ventilation and Air Conditioning (HVAC) system 50 for controlling the temperature within a cabin 14 of the vehicle. The control unit 500 is coupled directly or indirectly to the HVAC system 50 or via a control module for the HVAC system 50 in order that the control unit 500 can gather status information about the HVAC system 50. Such status information optionally includes, for example, a cabin temperature requirement set by a passenger; and an actual temperature of the cabin 14. Preferably, but nevertheless optionally, the control unit 500 of the thermal management system 90 is coupled to a control module for the HVAC system 50 such that the control unit 500 of the thermal management system 90 can issue command signals to the control module for the HVAC system 50.

The exhaust gas regeneration (EGR) components 60a, 60b, 60c facilitate the utilisation of heat energy that is normally wasted by being expelled from a vehicle with exhaust gases. One or more heat exchangers enable the transfer and as such capture of heat energy from the exhaust gas to coolant being pumped about the cooling system. Whether coolant flows through the one or more heat exchangers for the EGR system is controllable using one or more valves (V) and by virtue of the variably controllable pump 40; the rate at which coolant flows through the EGR system 60a, 60b, 60c is also controllable. Optionally, in the present embodiment the EGR system 60a, 60b, 60c comprises a Low Pressure Exhaust Gas Regeneration (LP EGR) system 60c and a High Pressure Exhaust Gas Regeneration (HP EGR) system 60a, 60b and coolant can be routed through one or both of the LP EGR and HP EGR (not shown individually in Figure 2, see Figure 2B).

Turning to Figure 3, a schematic illustration is provided of the method performed by the present embodiment of the disclosure. The illustrated steps are described as:

A1. monitoring one or more variables (including temperature) of the thermal management system 90;

A2. determining, in dependence upon said monitoring, a current cooling requirement of the system 'CR';

A3. determining a plurality of viable operating points 'VOP' suitable for achieving the current cooling requirement 'CR' (or a level of cooling within a calibrateable tolerance of the current cooling requirement 'CR');

A4. estimating a cost associated with more than one of said plurality of viable operating points 'VOP';

A5. determining a selected viable operating point 'SVOP' in dependence upon the estimated costs; and

A6. adjusting one or more controllable components of the thermal management system 90 in dependence upon the selected viable operating point 'SVOP'.

The current cooling requirement 'CR', is determined in dependence upon: the current temperature of the heat sources within the system 90, a maximum temperature of the heat sources and/or a preferred temperature range of the heat sources to achieve optimum performance; and in dependence upon the heat sinks within the system 90, specifically, their current temperature.

Optionally, a factor to allow for a degree of headroom within the system 90 is incorporated into the determination of current cooling requirement 'CR' in order to ensure that a sufficient tolerance and a sufficient safety margin is included. The selected viable operating point 'SVOP' is one which will at least substantially achieve the current cooling requirement 'CR'. Preferably, but nevertheless optionally, the selected viable operating point 'SVOP' is one which is estimated to achieve the current cooling requirement 'CR' or slightly greater than the current cooling requirement 'CR', but not less than the current cooling requirement 'CR'.

In the method of the presently described embodiment, certain components of the vehicle 10 are classified or treated as heat sources (i.e., generators of heat). These include, without limitation:

the fuel injected into the engine 80;

lubricating oil in the engine 80;

transmission oil in the transmission system; and

exhaust gas and exhaust components.

Additionally, other components of the system 90 can be classified or treated as heat sinks (i.e., removers of heat). These include:

the heat exchanger for the cabin heater of the HVAC system 50; and

the EGR system (an LP EGR cooler 60c and an HP EGR cooler 60a each comprise heat exchangers for extracting heat energy from the exhaust components).

In order to determine a current cooling requirement 'CR', the method of the present embodiment monitors and considers a variety of factors (A1) that affect the overall requirement for cooling. More specifically, the method considers:

factors or variables effecting the degree to which the radiator 22 is required to extract heat from the coolant flowing within the system; and

factors or variables effecting the degree to which the radiator 22 is able to reject heat to air.

In embodiments of the present method, the factors or variables (A1) affecting the degree to which the radiator 22 is required to extract heat from the coolant flowing within the system 90 optionally include:

the coolant flow rate ('CF');

the temperature of coolant leaving the engine 80; and

the temperature of coolant leaving the radiator 22.

Factors or variables A1 affecting the degree to which the radiator 22 is able to reject heat optionally include:

the rate at which air is flowing ('AF') into the radiator 22;

the rate at which the radiator 22 cooling fan 30 is operating;

the speed of the vehicle 10;

the position of the controllable active vanes 12a, 12b, 12c, 12d, 12e etc;

the under bonnet temperature; and

the amount or rate of heat rejection to the EGR system 60a, 60b, 60c.

The present method optionally comprises monitoring all of the above listed variables, optionally using a control module 500, a vehicle communications network and control signals and/or sensor signals respectively from:

(i) a control signal associated with the variably controllable coolant pump 40:

(ii) one or more temperature sensors within the system 90 including a temperature sensor disposed proximate the exit point for coolant leaving the engine 80;

(iii) a control signal from the cooling fan 30;
(iv) a vehicle speed signal optionally from an ECU of the vehicle 10;
(v) one or more control signals associated with the active vanes 12a, 12b, 12c, 12d, 12e etc;
(vi) a temperature sensor associated with the underside of the bonnet;
(vii) one or more control signals associated with the HVAC system 50; and
(viii) one or more control signals associated with the EGR system 60a, 60b, 60c.

The above data signals may be transmitted to the control unit via a Controller Area Network (CAN) of the vehicle 10, and/or wirelessly and/or directly from a control module for another vehicle system (for example, the ECU) or any suitable combination thereof, such that the control unit 500 of the present thermal management system 90 has the above listed data and can monitor and interpret the same.

Determining a current cooling requirement (CR) may be done by using a heat balance equation, such as:

$$Q_{\text{current cooling requirement}} = Q_{\text{fuel}} - Q_{\text{cabin heater}} + Q_{\text{EGR cooler}} + Q_{\text{engine oil}} + \dots$$

Wherein $Q_{\text{current cooling requirement}}$ is the current cooling requirement ('CR'), which may also be referred to as the heat rejection required by the radiator 22. In other words, it is the total heat energy that the thermal management system needs to expel. The total heat energy that the system needs to expel (the cooling requirement 'CR') may be estimated or derived by summing the heat energy at one or more of a number of heat transfer nodes of the vehicle 10.

In Figure 2B, there is shown schematically a model of the heat transfer nodes of the thermal management system 90 of the vehicle 10. The solid black lines indicate interconnecting pipes in relation to which there is an associated mass flow rate and temperature of the coolant passing therethrough. As such, for each transfer node (indicated by a solid oval and a dashed arrow into and/or out of the node) there is an amount of heat (Q_{fuel}, $Q_{\text{cabinheater}}$, $Q_{\text{EGRcooler}}$, $Q_{\text{engine oil}}$) into or out of the node that can be quantified by the associated mass flow rate and associated temperature.

For a given current cooling requirement 'CR' there may exist a range of combinations of operating conditions (viable operating points 'VOP'). Because for a given current cooling requirement 'CR', more than one, indeed a plurality of viable operating conditions 'VOPs' may be available, each of which could provide a currently required radiator cooling 'CR' (or

thereabouts), the present method optionally determines an estimate of the cost associated with more than one of the plurality of viable operating conditions 'VOP's and in some embodiments determines an estimate of the cost associated with each of the plurality of viable operating conditions 'VOP's. On the basis of those associated cost estimates, a selected viable operating condition (SVOP) is determined for the system 90 to adopt. Repeatedly this is carried out so that the system 90 is operated in a cost efficient manner whilst providing sufficient cooling to the heat generators, sufficient heat to the heat sinks and maintaining a safe level of performance of all components. The rate of repetition is preferably selected such that the system is operated more efficiently but is not subjected to extreme or too rapid switching of operating conditions. The rate of repetition may be based upon time (i.e, periodically) or in other embodiments, the method is repeated in dependence upon a change in a monitored variable.

In the present method, a viable operating condition 'VOP' to achieve a current required radiator cooling 'CR' can be achieved by changing one or a combination of both of: the air flow 'AF' through the radiator 22; and the rate of coolant flow 'CF'. As such a wide range of viable operating conditions 'VOP's may be available at any given time for the required radiator cooling 'CR' and in the present method, the costs associated with each of them (subject to applied constraints) are estimated and compared in order to identify a 'VOP' that should be selected.

In Figure 4, a graphical representation of the amount of heat energy (in kW) that can be rejected by the radiator 22 in dependence upon the combination of air flow (in $kg.h^{-1}$) and coolant flow (in $kg.\ min^{-1}$) is shown. Coolant flow 'CF' is provided along the x-axis; and air flow 'AF' is provided along the y-axis. A series of curves are plotted on the graph, each one relating to a different specific radiator heat rejection (in kW). The radiator heat rejection (in kW) is constant along each curve. A diagonal arrow on the graph of Figure 4 indicates increasing radiator heat rejection (in kW). It can be seen therefore that for a current radiator cooling requirement 'CR' computed at a particular time, for example a cooling requirement 'CR' of 100kW, a range of combined values of air flow 'AF' and coolant flow 'CF' are available for selection. For example, a coolant flow rate of $120kgmin^{-1}$ and an air flow of $1kgh^{-1}$ will achieve the radiator cooling requirement of 100kW; alternatively, a coolant flow rate of $200kgmin^{-1}$ and an air flow of $0.85kgh^{-1}$ will also achieve the radiator cooling requirement of 100kW.

At a first time (t_1), the vehicle 10 travelling at a speed $\upsilon(t_1)$, has a maximum coolant flow rate $CF_{max}(t_1)$ that may be governed by the temperature of the engine 80 (during a warm-up phase it is desirable not to cool the engine 80 too much to enable the engine 80 to reach an optimum operating temperature as quickly as possible). This represents a first constraint at the first time (t_1) since the cooling fan 30 cannot or should not be operated above this maximum coolant flow rate $CF_{max}(t_1)$. Similarly, at first time (t_1) there is a minimum coolant flow rate $CF_{min}(t_1)$, which for example may be dictated by a requirement on the system 90, such as but not limited to an air conditioning unit being operational. This represents a second constraint at the first time (t_1) since the cooling fan 30 cannot or should not be operated below this minimum coolant flow rate $CF_{min}(t_1)$. In Figure 5, the dashed straight lines at $CF_{min}(t_1)$ and $CF_{max}(t_1)$ illustrate these constraints or boundaries.

Similarly, at first time (t_1), the vehicle 10 travelling at a speed $\upsilon(t_1)$, has a maximum air flow rate $AF_{max}(t_1)$ that may be governed by the vehicle speed $\upsilon(t_1)$. This represents a third constraint at the first time (t_1) since air flow above this maximum air flow rate $AF_{max}(t_1)$ cannot or should not be achieved. Similarly, at first time (t_1) there is a minimum air flow rate $AF_{min}(t_1)$, which for example may be dictated by a requirement on the system 90 and/or the speed of the vehicle. This represents a fourth constraint at the first time (t_1) since air flow below this minimum air flow rate $AF_{min}(t_1)$ cannot or should not be achieved. In Figure 5, the dashed straight lines at $AF_{min}(t_1)$ and $AF_{max}(t_1)$ illustrate these third and fourth constraints or boundaries.

As can be seen in Figure 5 a reduced number of viable operating points 'VOP' are indicated by the section of the curve (and just above) corresponding to a radiator heat rejection of 100kW (and just above) that is within the rectangle bounded by the first, second, third and fourth constraints.

In the method of the present embodiment, the number of viable operating points is reduced by the application of the first to fourth constraints. One of the viable operating points 'VOP' from the reduced number of viable operating points 'VOP' is selected based upon a cost estimate associated with each of the viable operating points 'VOP' in the reduced number or limited selection.

Optionally in an algorithm of an arrangement of the system 90, the rectangle defined by the first to fourth constraints may be effectively sub-divided by a grid, for example a 5 x 5 grid.

For each grid location having an average radiator heat rejection below the required radiator heat rejection 'CR' of 100kW a "maximum cost" is associated with it. Then, for all other grid locations having an average radiator heat rejection at or above the required radiator heat rejection 'CR' of 100kW, a cost estimate is made. This provides one of a variety of ways, of analysing the selection of operating points within the rectangle defined by the first to fourth constraints in order to find the selected viable operating point i.e., the VOP in the rectangle having the lowest cost.

It will be appreciated that other computer implemented methods may be used and may be suitable for identifying viable operating points, applying constraints to restrict the number of viable operating points, for that restricted number of viable operating points associating a cost with each one and then selecting a 'SVOP' based upon the viable operating point with the lowest associated cost. As such, the specific order in which the method of the present disclosure is described, illustrated and claimed should not necessarily be taken to be limiting.

Once a selected viable operating point has been determined components of the vehicle 10 will be controlled in order to achieve the selected air flow and coolant flow. For example, the cooling fan 30 and/or active vanes 12a, 12b, 12c, 12d, 12e may be adjusted in order to achieve the desired air flow and the pump flow may be adjusted in order to achieve the desired coolant flow.

Subsequently, at a second, later time t_2, the process is repeated. The required radiator cooling 'CR' is estimated, and is optionally estimated to be about 125kW. In the graph of Figure 6 this is shown by arrow 'VOP'. At time t_2 the vehicle 10 has a greater vehicle speed (t_2) and as such, the maximum air flow $AF_{max}(t_2)$ is greater than before. Similarly, the coolant flow rate has a higher maximum $CF_{max}(t_2)$, for example, because the engine 80 has warmed-up and has reached a minimum preferred temperature and greater coolant flow is considered to be acceptable. The rectangle defined by the first to fourth constraints at time t_2 shown on Figure 6 illustrates again how the number of viable operating points may be reduced. Then a cost associated with each of the reduced number of viable operating points lying within the constraints may be estimated, and based upon the estimated cost associated with each viable operating point of the reduced number, a selected viable operating point ('SVOP') is determined.

In the present embodiment, the following factors for controlling the air flow through the radiator are optionally considered in how to achieve the desired cooling, along with the cost of using them:

- the rate at which the cooling fan 30 associated with the radiator 22 is operating is controllable up to a maximum limit defined, inter alia, by the electrical load of the cooling fan 30 on an electrical power supply (battery) within the vehicle 10;

- the cost of operating the cooling fan 30 may be directly proportional to the electrical load required by the cooling fan 30. Fuel energy is converted to electrical energy to operate the fan 30 and this is estimated or calculated to quantify the cost of using the fan;

- the positions of the active vanes 12 a- 12f associated with the radiator 22 are controllable up to a limit determined by the amount of vehicle drag;

- increasing vehicle drag increases the amount of fuel energy required to power the vehicle 10. As such, there is a cost associated with opening the active vanes 12a-12d to increase air flow through the radiator 22; and

- vehicle speed affects the air flow through the radiator and as mentioned above there is a cost associated with the fuel energy required to power the vehicle 10. Vehicle speed is a variable that directly and indirectly affects the amount of cooling required and obtainable via air flow through the radiator 22. It is not controllable by the system 90, but it is nevertheless monitored by the system and the cost of it may be incorporated into the method of controlling the system.

In the present embodiment, the following factors for controlling the rate of coolant flow are considered in how to achieve the desired cooling, along with the cost of using them:

- changing the flow rate of the variably controllable pump 40. Energy is required to operate the pump 40, which may be a combination of both of the fuel driving the engine 80 when the pump 40 is directly driven by the engine 80; and an additional energy cost associated with an electrically powered restrictor for selectively reducing the pump 40 output (optionally by the

positioning of a restricting shroud over the pump 40. Additionally, losses from the pump limit the extent to which pump control can manipulate coolant flow;

and

- one or more valves of the system are openable by use of an electrically heated thermostat. As such if the actual engine out temperature is insufficient to open the valve, electrical energy can be used to artificially force the valve to open, thus opening or changing the routes available for coolant flow and as such manipulating the flow of coolant. There is a cost associated with the electrical energy used to manipulate the valve in this way and additionally there is a limited range in which this manipulating manner is available for use.

In estimating a cost associated with a set of operating conditions of a viable operating point, the method optionally involves estimating a relative cost rather than an absolute cost. The absolute or relative cost may be calculated in terms of an energy cost (kW), in terms of fuel consumption, in terms of CO_2 emission, in financial terms and optionally in terms of any other suitable quantifier. Optionally the cost may be calculated in terms of a component use time or component use rate or component wear – for example, a higher pump or fan speed for a given effect may be considered more costly in terms of the percentage use of the life span of that component or the resultant wear to that component, whereas if the same effect may be achieved by opening a vane, that single vane actuation (as opposed to the increased continual fan/pump rotation or rotation speed) may be considered less costly.

For illustrative purposes in Figure 7, there is shown a three-dimensional graphical representation of the estimated cost that is associated with a plurality of viable operating points 'VOP's. In this illustration, each 'VOP' is defined by a value of cooling fan 30 speed and a value of pump 40 flow rate. As such, the radiator cooling effect of air flow is being considered as achieved or influenced solely by cooling fan speed and not in dependence upon active vane position. It is preferred however, that in embodiments of the invention consideration is given to the most cost effective way to achieve a desired air flow through the radiator dependent upon controlling more than only the cooling fan. Nevertheless, for the purpose of describing the invention, it is sufficient to show in Figure 7 how cost can be mapped for combinations of cooling fan speed and pump flow rate and how the viable combinations of these variables can be reduced by applied constraints and then a selection of how to operate various components of the system 90 made based upon the cost of the remaining options of 'VOP'.

As described an aspect of the method involves applying constraints or restrictions to the primary list of viable operating conditions. Optionally, this is done by stipulating for example a maximum operating value for one or more or a combination of the variables forming each viable operating point 'VOC'. For example, to manage electrical load on the vehicle's electrical system by the cooling fan 30 and pump 40 which may both be electrically operated and are operating simultaneously, there may be combinations of values of the two that cannot be permitted. Furthermore, the following may be considered:

- Minimum / maximum flows for component protection
- Transient limits to avoid thermal shock etc.
- Component constraints (minimum / maximum fan flow, pump flow, thermostat heating)
- Vehicle speed "free" airflow available
- Engine out coolant temperature
- Ambient temperature

As such, further constraints are applied, to avoid thermal shocks, avoid system jitter and/or to remove temporary transient effects and the like.

It can be seen in each of Figures 7, 8 and 9 that applying constraints reduces the number of viable operating points (VOC) and can affect the cost analysis.

After such constraints have been applied, the method involves determining a selected viable operating condition based upon cost, such that the system 90 is operated within an acceptable temperature range for the workload that the vehicle 10 is currently outputting, which temperature is controlled and achieved at the lowest possible energy cost subject to safe working performance of the individual components within the system 90. The method is repeated and analysis and adjustment repeatedly conducted in order to ensure that as the performance of the vehicle, environmental factors and operational requirements change that the thermal management system 90 performs sufficient cooling and in an efficient manner.

It will be appreciated that in other embodiments of the invention, the number, type and range of components and variables monitored may differ from that shown in dependence upon the vehicle type, size and design and/or in dependence upon how refined the implemented method needs to be. For example, the greater the number of factors and variables that are considered in computing a required cooling requirement 'CR', the more accurate that

required cooling requirement 'CR' may be. The greater the number of components that are controllable and the greater the accuracy with which they can be controlled, the more accurate the system will be in achieving the required cooling requirement 'CR'. However, this may need to be balanced against the processing resource devoted to continually monitoring and adjusting the components. In a system with less regular monitoring or monitoring fewer factors and variables, the less accurate the computed required cooling requirement 'CR' may be and indeed the less accurate the system may be at achieving it. Nevertheless, the system may still be very beneficial because the system may still reduce the amount of cooling being conducted so that overcooling and unnecessary fuel consumption is avoided and/or may achieve the requisite cooling in a more efficient manner.

To what extent unnecessary fuel consumption is avoided may depend upon the comprehensiveness of the monitoring, analysis and adjustment that is performed by the system. As such, the methods and systems presented herein can be embodied in various forms, with various degrees of complexity and with different amounts of cost saving benefit. It will be appreciated however that a cost saving benefit may be achieved by any of them. In view of the varying degrees of complexity that a system according to the invention may take, it will be appreciated that algorithms prepared for operating such systems may take many and various forms.

The following numbered paragraphs contain statements of invention:

1. A method of controlling a thermal management system, the method comprising:
   (i) monitoring one or more variables of the thermal management system;
   (ii) determining, in dependence upon said monitoring, a current cooling requirement of the system;
   (iii) determining a plurality of viable operating points suitable for providing the current cooling requirement;
   (iv) determining an estimated cost associated with more than one of said plurality of viable operating points;
   (v) determining a selected viable operating point in dependence upon the estimated costs; and
   (vi) adjusting one or more controllable components of the thermal management system in dependence upon the selected viable operating point.

2. A method according to paragraph 1 comprising repeating steps (i) to (vi) periodically, or in response to a change in the one or more variables, in order to repeatedly adjust the operation of the thermal management system.

3. A method according to paragraph 1 or 2 comprising the steps of:
   (i) determining one or more constraints on the thermal management system; applying the constraints to said plurality of viable operating points; and thereby
   (ii) generating a reduced number of viable operating points and determining the selected viable operating point therefrom.

4. A method according to paragraph 3 wherein said determining an estimated cost associated with more than one of said plurality of viable operating points comprises, determining an estimated cost associated only with each viable operating point of the reduced number of viable operating points.

5. A method according to paragraph 3 wherein the step of selecting a viable operating point in dependence upon estimated costs further comprises:
   (i) limiting the extent to which said one or more controllable components of the thermal management system can be adjusted and thereby reducing the number of viable operating points for selection.

6. A method according to any paragraph 5 wherein the thermal management system is disposed within a vehicle having a power source comprising one or both of: an internal combustion engine; a rechargeable battery pack.

7. A method according to paragraph 6 wherein the one or more controllable components of the thermal management system of the vehicle comprise one or more of:
   (i) a variable pump for pumping coolant about the thermal management system;
   (ii) a fan associated with a radiator of the vehicle; and
   (iii) one or more active vanes associated with a radiator grille of the vehicle.

8. A method according to paragraph 7 wherein the one or more variables of the thermal management system of the vehicle comprise one or more of:
   (i) a temperature of coolant exiting said power source of the vehicle;
   (ii) a temperature under the bonnet of the vehicle;

(iii) a current coolant flow rate;
(iv) the speed of the vehicle;
(v) a temperature of coolant exiting the radiator;
(vi) a rate at which air is flowing into the radiator;
(vii) one or more positions of the one or more active vanes;
(viii) the rate at which the radiator cooling fan is operating;
(ix) the maximum under bonnet temperature;
(x) the amount or rate of heat rejection to an Exhaust Gas Regeneration system;
(xi) a position of one or more valves within the system;
(xii) an operational requirement of a cabin heater; and
(xiii) an operational requirement of a cabin cooler.

9. A method according to paragraph 8 wherein determining a plurality of viable operating points comprises determining a plurality of combinations of:
(i) a rate of operation of the variable pump; and
(ii) a rate of operation of a fan associated with a radiator of the vehicle; and
(iii) a position for the one or more active vanes;

suitable for achieving the current cooling requirement of the system.

10. A control unit for a thermal management system configured to carry out the method paragraph 1.

11. A thermal management system comprising a control unit as set out in paragraph 10.

12. A thermal management system comprising:
a network of pathways configured to convey coolant liquid;
a variably controllable pump configured to pump coolant liquid about the network of pathways;
a radiator disposed in said network of pathways;
a variably controllable cooling fan and/or a plurality of active vanes associated with said radiator;
monitoring means configured to monitor one or more variables of the thermal management system; and
a control unit in communication with said pump, said cooling fan and/or vanes, and said monitoring means,

wherein the control unit is configured to: determine a current cooling requirement of the system in dependence on a signal received from said monitoring means; determine a plurality of viable operating points suitable for providing the current cooling requirement; determine an estimated cost associated with more than one of said plurality of viable operating points; determine a selected viable operating point in dependence on the estimated costs; and adjust one or more the pump, the cooling fan and the vanes in dependence on the selected operating point.

13. A vehicle comprising a power source, and a thermal management system comprising a control unit, the control unit configured to carry out the method of any of paragraph 1.

14. A program for a control unit of a thermal management system, the program configured and arranged such that when running on the control unit, the control unit is configured to carry out the method of any of paragraph 1.

CLAIMS

1. A method of controlling a thermal management system, the method comprising:
   a. monitoring one or more variables of the thermal management system;
   b. determining, in dependence upon said monitoring, a current cooling requirement of the system;
   c. determining a plurality of viable operating points suitable for providing the current cooling requirement;
   d. determining an estimated cost associated with more than one of said plurality of viable operating points;
   e. determining a selected viable operating point in dependence upon the estimated costs; and
   f. adjusting one or more controllable components of the thermal management system in dependence upon the selected viable operating point.

2. A method according to claim 1 comprising repeating steps (i) to (vi) periodically, or in response to a change in the one or more variables, in order to repeatedly adjust the operation of the thermal management system.

3. A method according to claim 1 or 2 comprising the steps of:
   a. determining one or more constraints on the thermal management system; applying the constraints to said plurality of viable operating points; and thereby
   b. generating a reduced number of viable operating points and determining the selected viable operating point therefrom.

4. A method according to claim 3 wherein said determining an estimated cost associated with more than one of said plurality of viable operating points comprises determining an estimated cost associated only with each viable operating point of the reduced number of viable operating points.

5. A method according to any one of claims 1 to 4 wherein the step of determining a selected viable operating point in dependence upon estimated costs further comprises:
   a. limiting the extent to which said one or more controllable components of the thermal management system can be adjusted and thereby reducing the number of viable operating points for selection.

6. A method according to any claim 1 to 5 wherein the thermal management system is disposed within a vehicle having a power source comprising one or both of: an internal combustion engine; a rechargeable battery pack.

7. A method according to claim 6 wherein the one or more controllable components of the thermal management system of the vehicle comprise one or more of:
   a. a variable pump for pumping coolant about the thermal management system;
   b. a fan associated with a radiator of the vehicle; and
   c. one or more active vanes associated with a radiator grille of the vehicle.

8. A method according to claim 7 wherein the one or more variables of the thermal management system of the vehicle comprise one or more of:
   a. a temperature of coolant exiting said power source of the vehicle;
   b. a temperature under the bonnet of the vehicle;
   c. a current coolant flow rate;
   d. the speed of the vehicle;
   e. a temperature of coolant exiting the radiator;
   f. a rate at which air is flowing into the radiator;
   g. one or more positions of the one or more active vanes;
   h. the rate at which the radiator cooling fan is operating;
   i. the maximum under bonnet temperature;
   j. the amount or rate of heat rejection to an Exhaust Gas Regeneration system;
   k. a position of one or more valves within the system;
   l. an operational requirement of a cabin heater; and
   m. an operational requirement of a cabin cooler.

9. A method according to claim 7 or 8 wherein determining a plurality of viable operating points comprises determining a plurality of combinations of:
   a. a rate of operation of the variable pump;
   b. a rate of operation of a fan associated with a radiator of the vehicle;
   c. a position for the one or more active vanes;

   suitable for achieving the current cooling requirement of the system.

10. A vehicle comprising a power source and a thermal management system comprising a control unit, the control unit configured to carry out the method of any of claims 1 to 9.

11. A control unit for a thermal management system configured to carry out the method of any of claims 1-9.

12. A thermal management system comprising a control unit as claimed in claim 11.

13. A thermal management system comprising:

a network of pathways configured to convey coolant liquid;

a variably controllable pump configured to pump coolant liquid about the network of pathways;

a radiator disposed in said network of pathways;

a variably controllable cooling fan and/or a plurality of active vanes associated with said radiator;

monitoring means configured to monitor one or more variables of the thermal management system; and

a control unit in communication with said pump, said cooling fan and/or vanes, and said monitoring means,

wherein the control unit is configured to: determine a current cooling requirement of the system in dependence on a signal received from said monitoring means; determine a plurality of viable operating points suitable for providing the current cooling requirement; determine an estimated cost associated with more than one of said plurality of viable operating points; determine a selected viable operating point in dependence on the estimated costs; and adjust one or more the pump, the cooling fan and the vanes in dependence on the selected operating point.

14. A program for a control unit of a thermal management system, the program configured and arranged such that when running on the control unit, the control unit is configured to carry out the method of any of claims 1 to 9.

15. A method, system, vehicle or program, substantially as disclosed herein with reference to and/or as illustrated by the accompanying Figures.

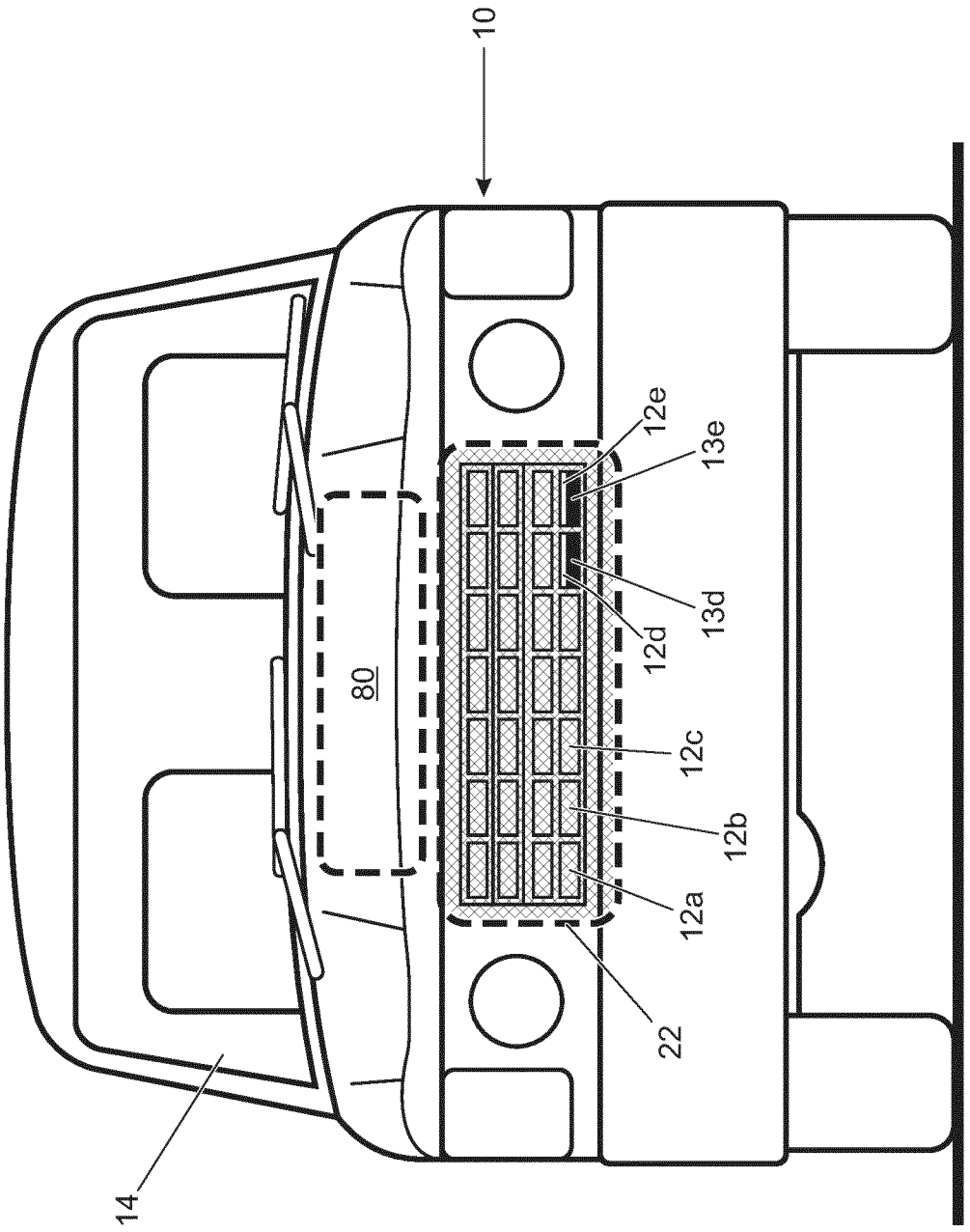


FIGURE 1

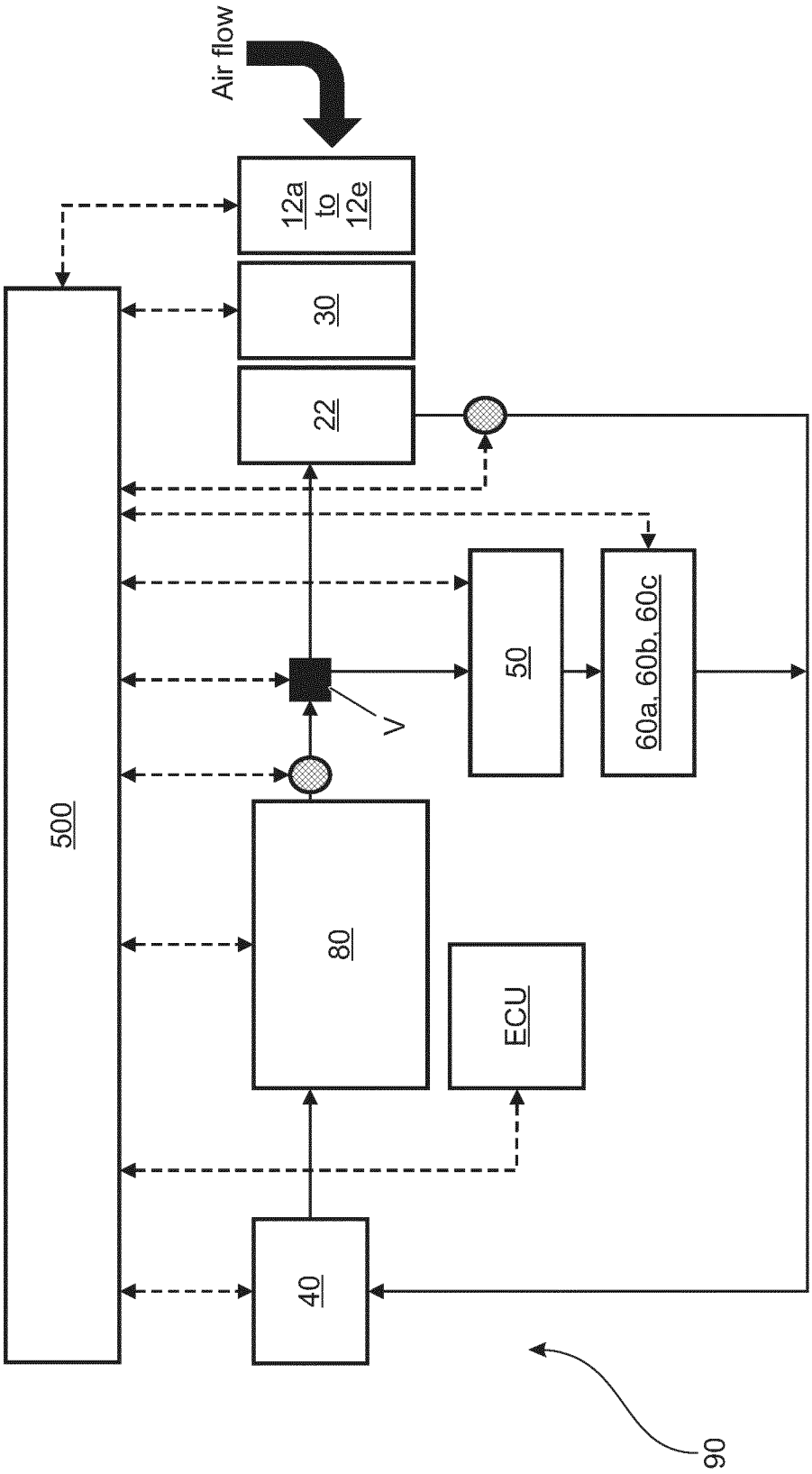


FIGURE 2

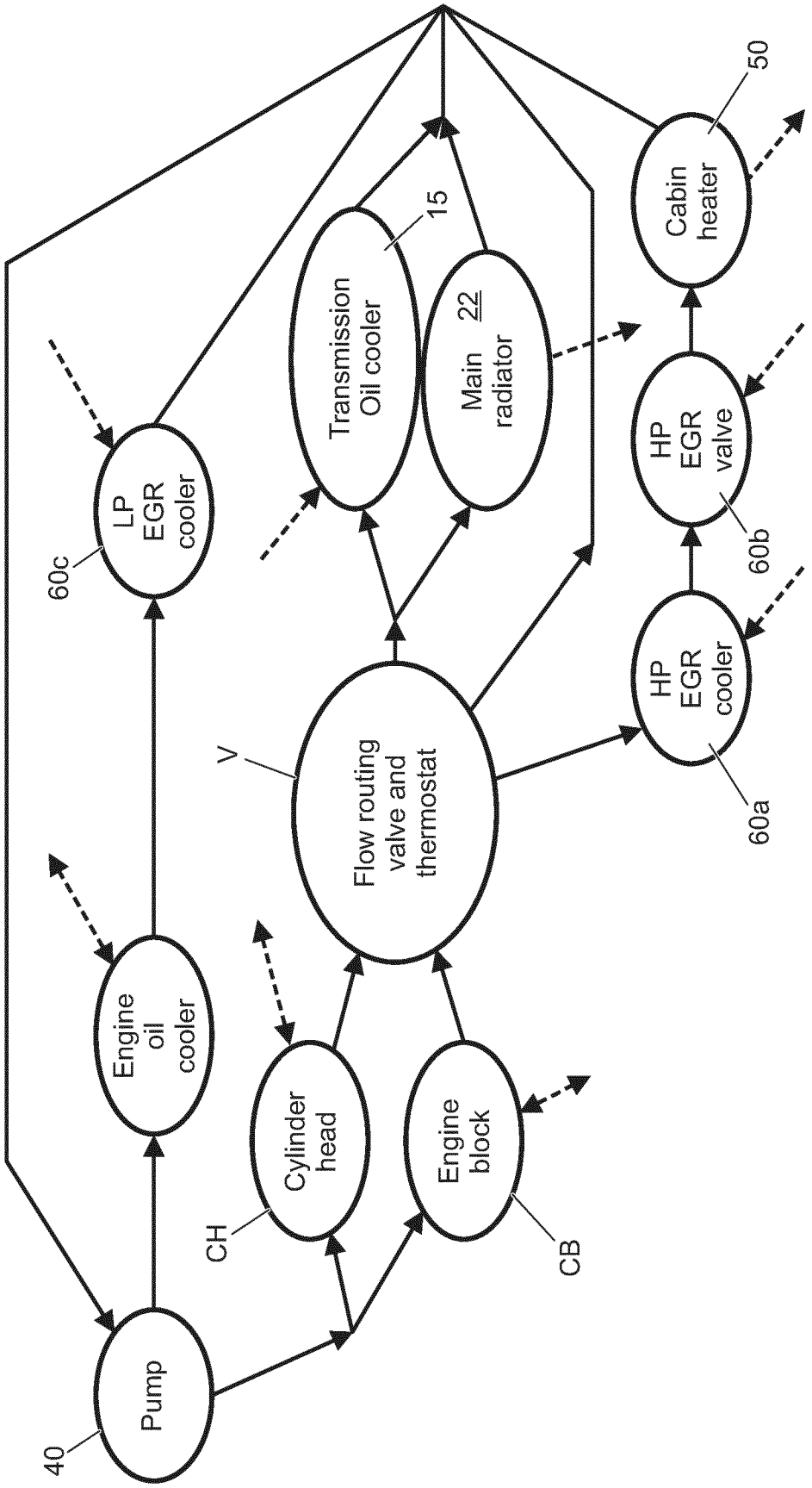

Pump
40
Engine oil cooler
LP EGR cooler
60c
Cylinder head
CH
Engine block
CB
Flow routing valve and thermostat
V
Transmission Oil cooler
15
Main 22 radiator
HP EGR cooler
60a
HP EGR valve
60b
Cabin heater
50

FIGURE 2B

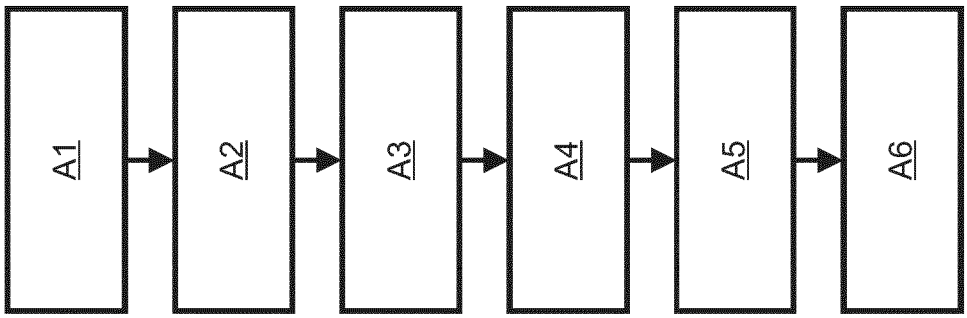


FIGURE 3

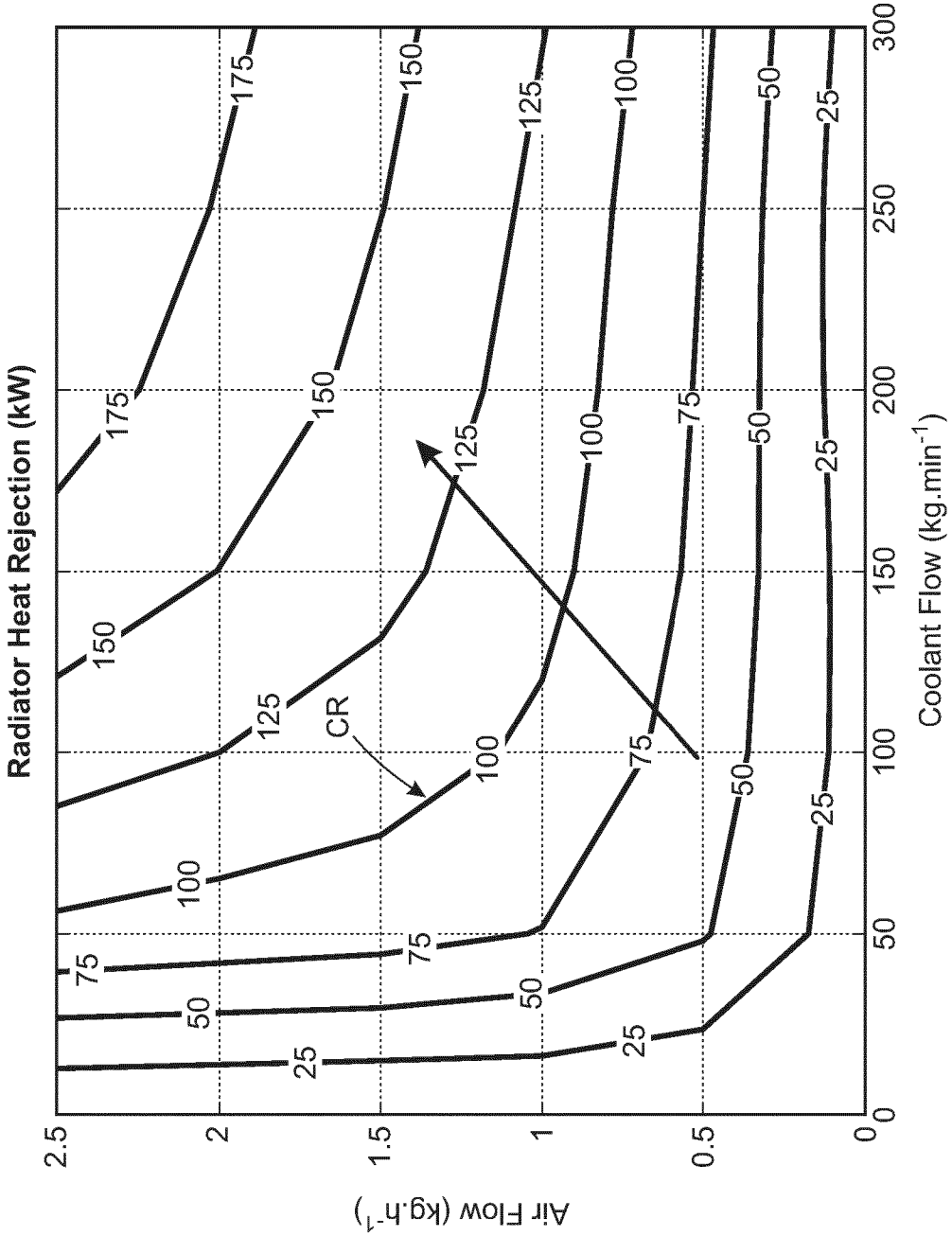

Radiator Heat Rejection (kW)
Coolant Flow (kg.min-1)
Air Flow (kg.h-1)
CR
175
150
125
100
75
50
25
0
50
100
150
200
250
300
0.5
1
1.5
2
2.5

FIGURE 4

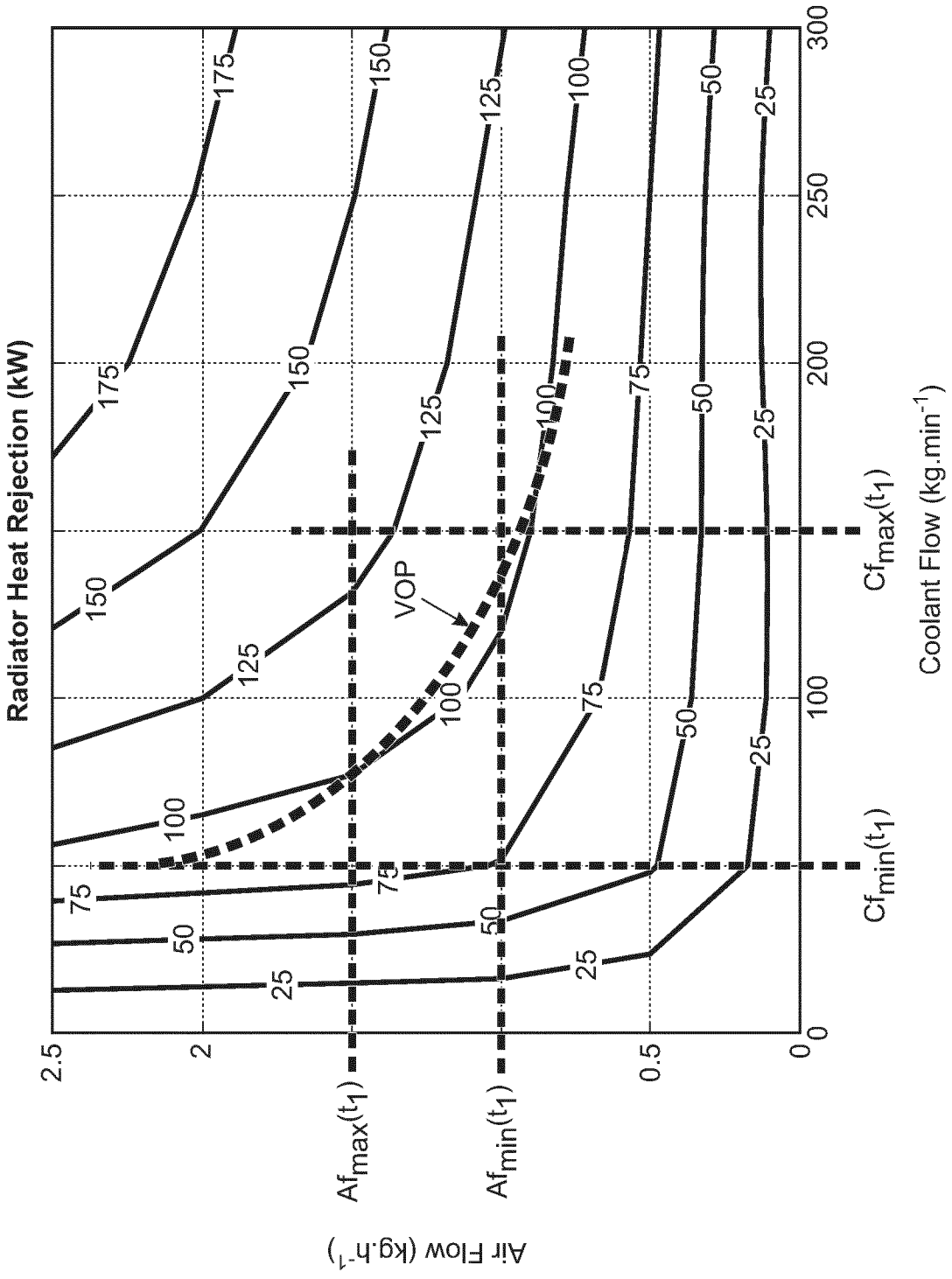

Radiator Heat Rejection (kW)
Air Flow (kg.h-1)
Coolant Flow (kg.min-1)
Afmax(t1)
Afmin(t1)
Cfmax(t1)
Cfmin(t1)
VOP
2.5
2
0.5
0
300
250
200
100
0
175
150
125
100
75
50
25

FIGURE 5

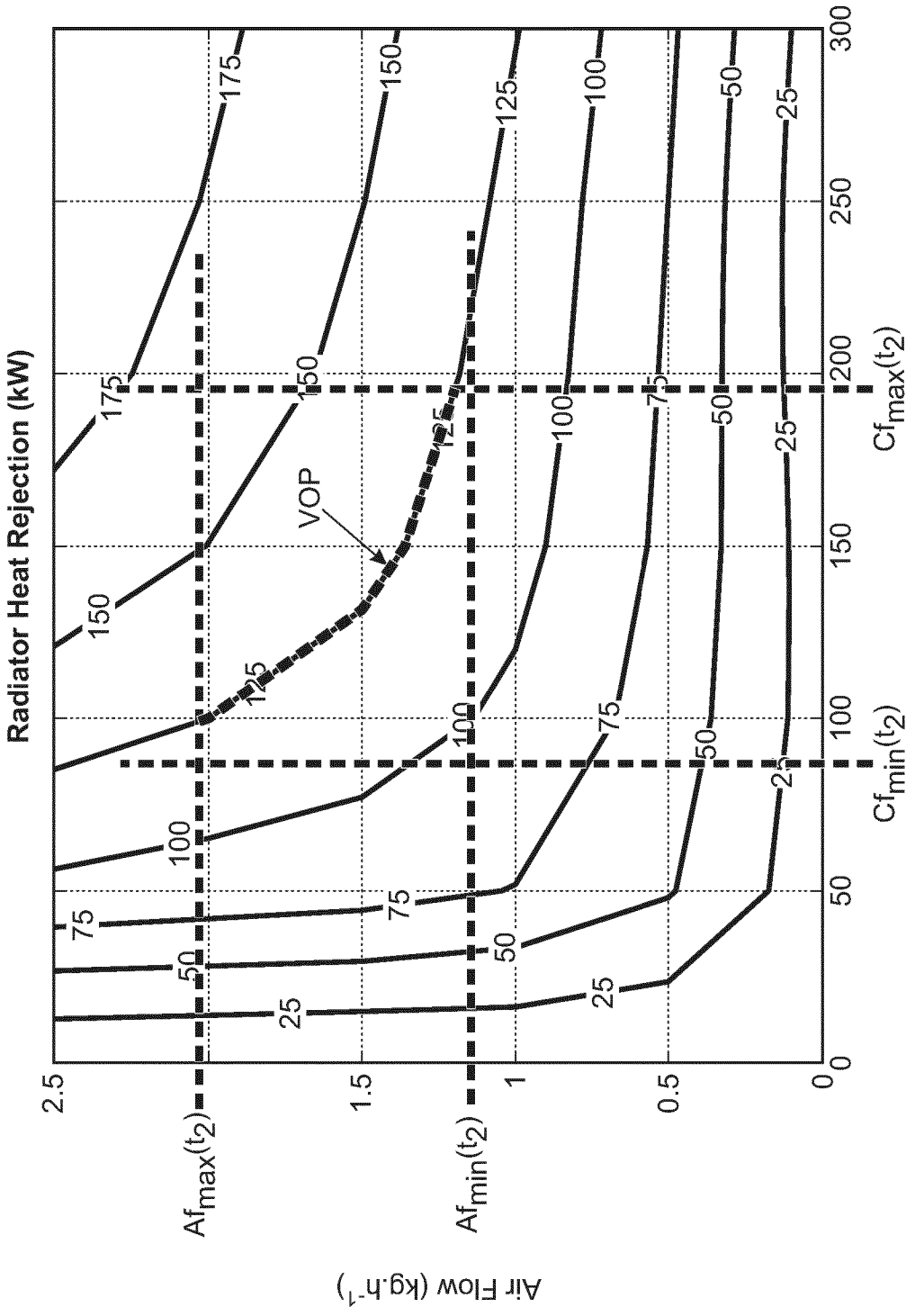

Radiator Heat Rejection (kW)
Air Flow (kg.h-1)
Coolant Flow (kg.min-1)
VOP
Afmax(t2)
Afmin(t2)
Cfmax(t2)
Cfmin(t2)
2.5
1.5
1
0.5
0
300
250
200
150
100
50
0
175
150
125
100
75
50
25

FIGURE 6

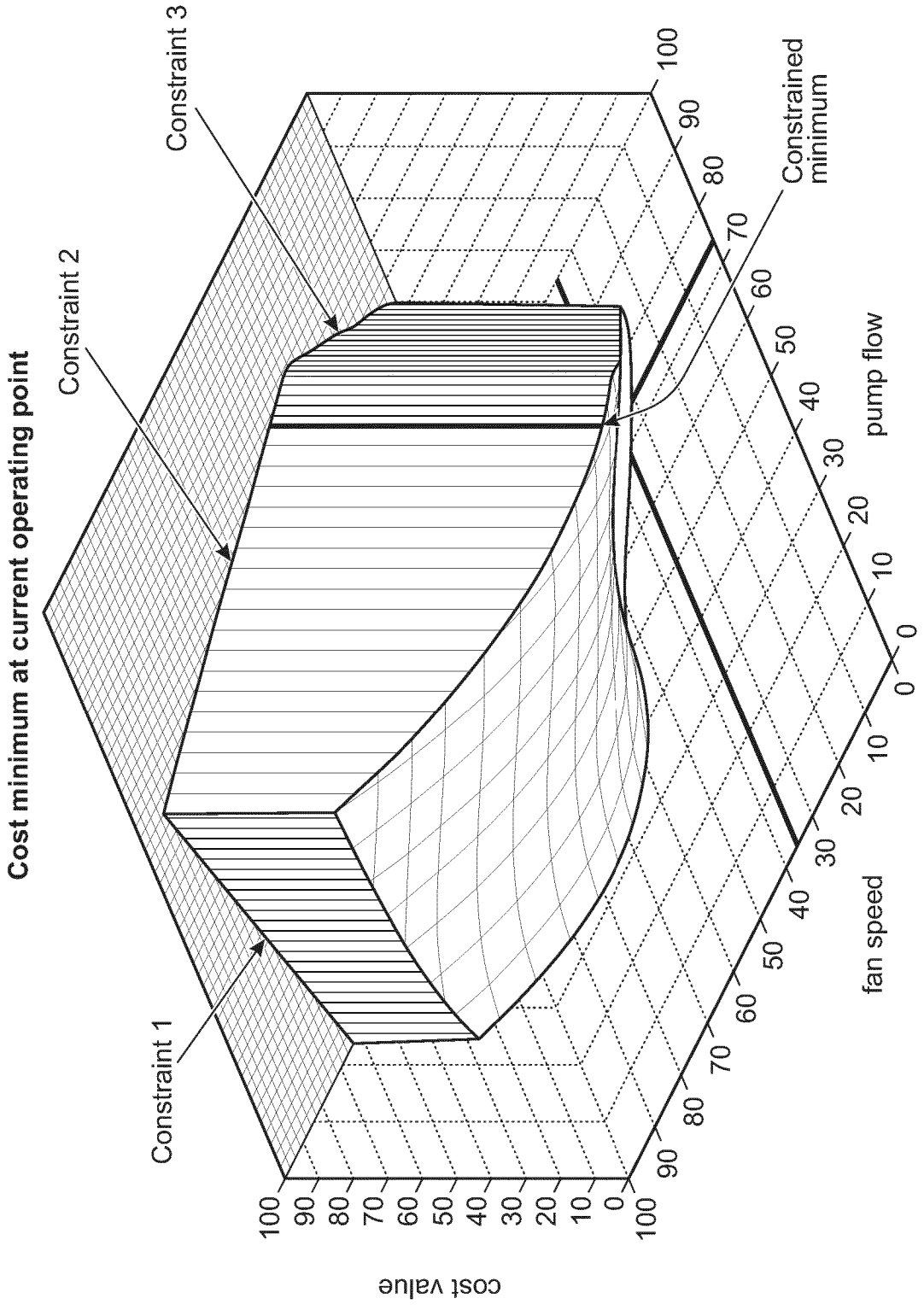

Cost minimum at current operating point
Constraint 1
Constraint 2
Constraint 3
Constrained minimum
cost value
fan speed
pump flow
0
10
20
30
40
50
60
70
80
90
100

FIGURE 7

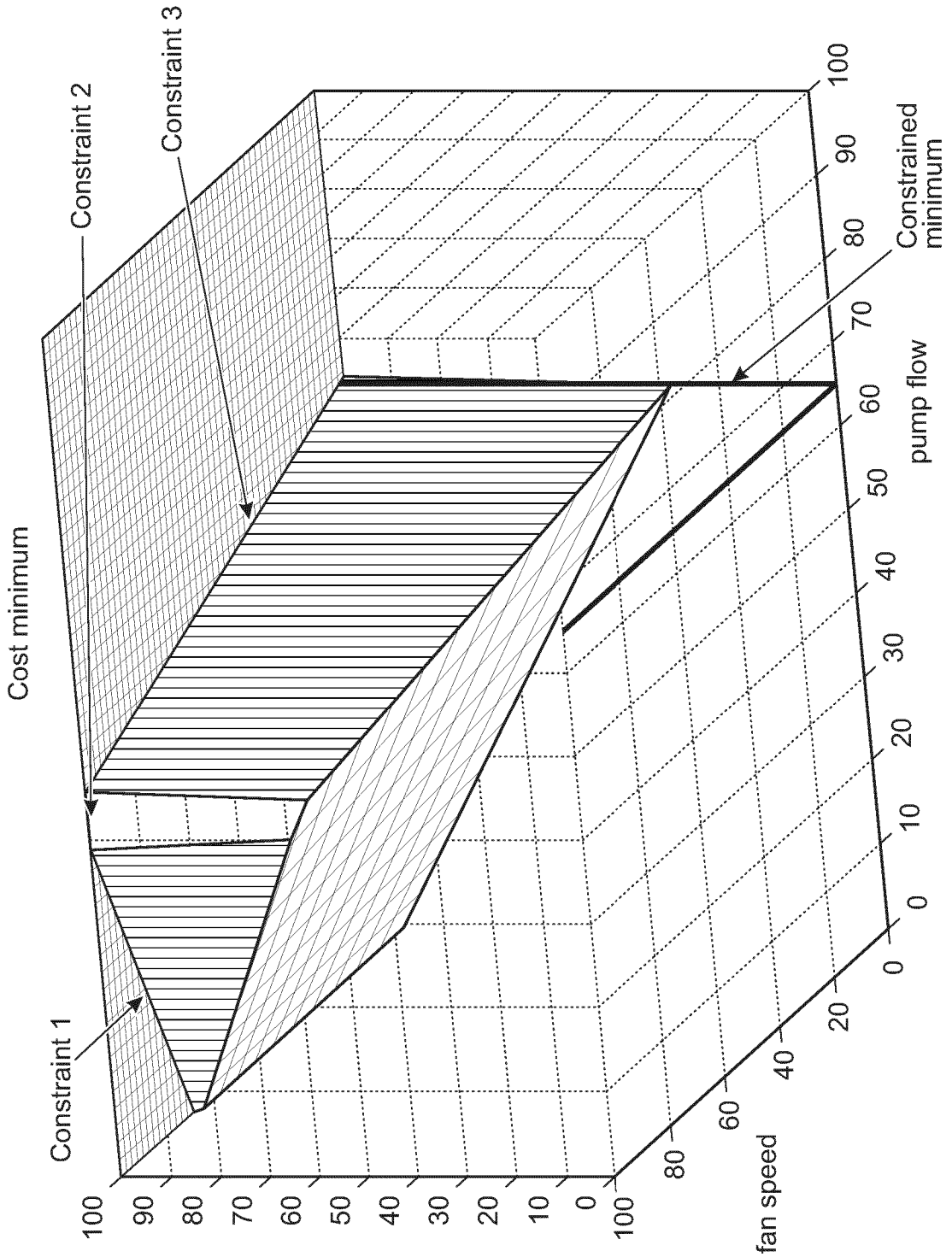

Cost minimum
Constraint 1
Constraint 2
Constraint 3
Constrained minimum
fan speed
pump flow
0
10
20
30
40
50
60
70
80
90
100

FIGURE 8

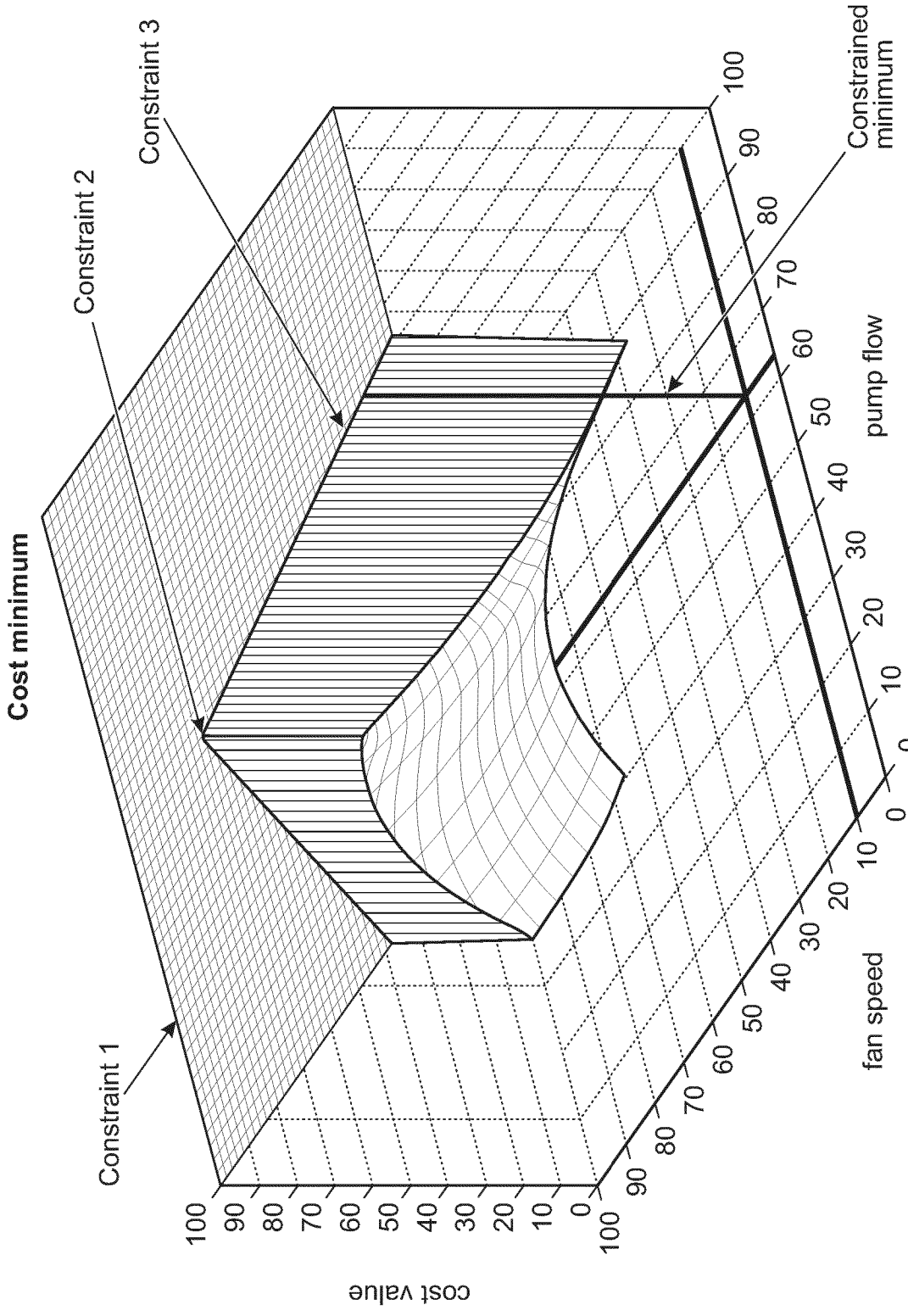

Cost minimum
Constraint 1
Constraint 2
Constraint 3
Constrained minimum
cost value
fan speed
pump flow
0
10
20
30
40
50
60
70
80
90
100

FIGURE 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/075695

A. CLASSIFICATION OF SUBJECT MATTER
INV. G05D23/19
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G05D F01P B60L H05K G05B B60H F24F

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/272173 A1 (RECKELS DIETER [US] ET AL) 29 November 2007 (2007-11-29)	1,6-14
A	paragraphs [0002], [0008], [0011], [0014] - [0015], [0023], [0025], [0073] - [0076], [0113] - [0116]; claims 1-2,5-6; figures 2-5, 5b paragraphs [0120], [0122] - [0124], [0127] - [0128]	2-5,15

X	WO 2006/034718 A1 (DANFOSS AS [DK]; LARSEN LARS FINN SLOTH [DK]; THYBO CLAUS [DK]) 6 April 2006 (2006-04-06)	1,11
A	page 22 - page 23; claims 1-2,5-7,9-10,12; figure 2	2-10, 12-15

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

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
17 March 2015	24/03/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Mallet, Philippe

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2014/075695

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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