



(11) **EP 1 405 992 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:  
**30.01.2008 Bulletin 2008/05**

(51) Int Cl.:  
**F01P 7/16<sup>(2006.01)</sup>**

(21) Application number: **03022279.8**

(22) Date of filing: **01.10.2003**

(54) **Control system for controlling a vehicle engine cooling system**

Regelsystem zur Regelung eines Kühlungssystems einer Brennkraftmaschine eines Kraftfahrzeugs

Système de commande pour commander un système de refroidissement d'un moteur à combustion interne de véhicule

(84) Designated Contracting States:  
**AT DE ES FR GB**

(30) Priority: **02.10.2002 IT to20020852**

(43) Date of publication of application:  
**07.04.2004 Bulletin 2004/15**

(73) Proprietor: **Mark IV Systemes Moteurs (Société Anonyme)**  
**92400 Courbevoie (FR)**

(72) Inventor: **Cipollone, Roberto**  
**67100 l'Aquila (IT)**

(74) Representative: **Bongiovanni, Simone et al**  
**Studio Torta S.r.l**  
**Via Viotti 9**  
**10121 Torino (IT)**

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## Description

**[0001]** The present invention relates to a control system for controlling a vehicle engine cooling system.

**[0002]** Known cooling systems supply cooling water to an internal combustion engine, which in turn supplies water to the inlet of a radiator via a thermostatic control valve, and the water from the radiator is pumped back into the engine. The control valve also recirculates part of the water from the engine along a bypass conduit extending from the control valve to the engine cooling water inlet; and, before the water is recirculated, parallel branches may supply other user devices, such as the exhaust gas cooler before recirculation, passenger compartment heater, engine oil cooler, etc., see for example JP 05 231 149 A.

**[0003]** In such control systems, the cooling water temperature is regulated solely by the thermostatic valve, which is by nature extremely inaccurate (some known thermostatic valves, for example, operate on the basis of wax expansion, a poorly repeatable phenomenon which is difficult to control.

**[0004]** Failure of the valve to provide for accurate cooling water temperature control results in temperature oscillations, so that the cooling system must frequently be oversized to achieve acceptable cooling of the engine in all operating conditions.

**[0005]** It is an object of the present invention to provide a control system for controlling a vehicle engine cooling system, designed to eliminate the drawbacks of known control systems by permitting "smart" temperature control.

**[0006]** According to the present invention, there is provided a control system for controlling a cooling system of a vehicle engine, wherein an internal combustion engine receives a stream  $F_a$  of cooling fluid, and supplies a stream of fluid  $F_u$  to the inlet of at least a radiator via regulating means controllable by a drive signal; said control system being characterized by comprising: a closed-loop control system, which receives a reference signal  $T_{des}$  related to a desired operating temperature of the engine, and a signal  $T_{mis}$  representing a measured operating temperature of the engine, said closed-loop control system generating a first component  $P_{cl\_loop}$  of said drive signal; and an open-loop control system, which receives at least said reference signal  $T_{des}$ , and generates a second component  $P_{op\_loop}$  of said drive signal by means of a model representing the inverse engine-radiator thermal system.

**[0007]** By virtue of the feedback control introduced by the open-loop control system, the temperature of the cooling fluid thus converges to the reference temperature.

**[0008]** In the event of sluggish feedback control response, due to the physical inertia of the engine-radiator system, so that the value of the closed-loop generated drive signal is inadequate to deal with changing conditions, the open-loop control system (based on a mathematical model and therefore not subject to any delay) reacts immediately to generate an overall drive signal of adequate value.

**[0009]** A preferred, non-limiting embodiment of the invention will be described by way of example with reference to the accompanying drawings, in which:

Figure 1 shows, schematically, a control system for controlling a vehicle engine cooling system in accordance with the teachings of the present invention;

Figure 2 shows modelling operations performed by the control system according to the present invention.

**[0010]** Number 1 in Figure 1 indicates as a whole a control system for controlling a cooling system 2 connected to an internal combustion engine 3 of a vehicle (not shown). Internal combustion engine 3 receives a stream  $F_a$  of cooling fluid (water for instance in the described example), and supplies a stream of water  $F_u$  to the inlet of a radiator 4 via a control valve 5. Radiator 4 in turn supplies a stream of water which is pumped back along a conduit 6 to engine 3 by a pump 7. Control valve 5 (known type) also recirculates part of stream  $F_u$  along a recirculating conduit 9 extending from control valve 5 to the engine cooling water inlet.

**[0011]** Control valve 5 operates under control of an actuator 10, which receives a drive signal P from an electronic central control unit 12.

**[0012]** Electronic central control unit 12 generates the drive signal by means of a closed-loop control system 14 and an open-loop control system 15.

**[0013]** More specifically, closed-loop control system 14 comprises an adding node 17, to which are supplied, with opposite signs, a signal related to the measured operating temperature of the engine, in particular a signal representing the measured temperature  $T_{mis}$  of cooling water stream  $F_u$  at the outlet of engine 3, and a reference signal  $T_{des}$  representing a desired target operating temperature of the engine, in particular a target temperature of the stream of cooling water. Adding node 17 generates an error signal  $T_{des} - T_{mis}$ , which is supplied to a controller block 20 (e.g. a PID block) to generate a first drive signal component  $P_{cl\_loop}$  which in turn is supplied to an adding node 22.

**[0014]** Alternatively, the measured operating temperature of the engine may be defined by the temperature, measured at characteristic points on the engine, of the metal from which the engine is made; in which case, the reference temperature represents a target temperature of characteristic points of the engine.

**[0015]** A second drive signal component  $P_{op\_loop}$  is supplied by open-loop control system 15, which receives infor-

mation relating to reference signal  $T_{des}$ , and generates the second component  $P_{op\_loop}$  by means of a mathematical model representing the inverse engine-radiator thermal system.

[0016] The second component  $P_{op\_loop}$  is also supplied to adding node 22, which generates drive signal  $P = P_{op\_loop} + P_{cl\_loop}$ .

[0017] The way in which the two signals are added in Figure 1 is shown purely by way of reference, and in actual fact is to be understood as any function which, given the two contributions, produces a combined action designed to activate control valve 5.

[0018] Open-loop control system 15 comprises a number of blocks which together define a model of the engine-radiator thermal system.

[0019] More specifically, open-loop control system 15 (Figure 2) comprises a first block 30 (detailed below), which receives the desired engine operating temperature value  $T_{des}$  (i.e. the desired cooling water temperature or the desired metal temperature at given points on the engine), and generates the estimated value of a coefficient  $K_r$  representing, in an appropriate model, the heat exchange performance of the radiator required to maintain the desired temperature value  $T_{des}$ .

[0020] Open-loop control system 15 comprises a second block 40, which receives the estimated value of coefficient  $K_r$ , and generates the value of the cooling water flow  $Q_f$  which must be physically circulated in radiator 4 to maintain the desired temperature value  $T_{des}$ . The cooling water flow value is expressed as a function of the radiator fan operating state (on/off), and possibly fan speed in the case of electric fans with continuous or step speed adjustment.

[0021] Open-loop control system 15 comprises a third block 50, which receives the calculated cooling water flow value  $Q_f$  and information relating to the fan on/off state or fan speed in the case of continuous or step speed adjustment.

[0022] In a first variation, block 50 calculates, on the basis of the information received, the opening value  $\phi$  of control valve 5 required to maintain the desired temperature value  $T_{des}$ .

[0023] The valve opening value refers not only to valve 5 in the Figure 1 embodiment, but also to the auxiliary valves (not shown in Figure 1 for the sake of simplicity) controlling cooling water flow in the various branches of the cooling circuit. Variations in the opening or closure of the auxiliary valves, in fact, affects cooling water flow to radiator 4.

[0024] The above calculation is performed using an appropriate table, which supplies an opening value  $\phi$  of valve 5 (and any auxiliary valves) for each input value  $Q_f$ . The first variation is advantageously used when the speed of pump 7 cannot be adjusted independently, in which case, flow can only be regulated by working on the opening of control valve 5 (and any auxiliary valves).

[0025] In a second variation, block 50 calculates, on the basis of the information received, the pump speed  $\omega$  and the opening  $\phi$  of valve 5 (and any auxiliary valves) which together provide for maintaining the desired temperature value  $T_{des}$ . The pump speed and opening of valve 5 are selected to maximize a given requirement, such as minimizing consumption or reducing noise. The second variation is advantageously used when pump 7 allows of independent speed adjustment, in which case, flow can be regulated by working both on the opening of control valve 5 (and any auxiliary valves) and on the speed of the pump (electrically powered, program-powered by the drive shaft via friction wheels, electromagnetic clutches, etc..).

[0026] More specifically, first block 30 calculates the estimated value of coefficient  $K_r$  using the equation:

$$K_r = f(S_h, H_h, T_m, T_{des}, T_o, k_{cc}, L_o, k_{egr}, k_{oil}) \quad (1)$$

where:

- $S_h$  is the engine-cooling water heat exchange surface;
- $H_h$  is the engine-cooling water heat exchange coefficient;
- $T_m$  is the engine metal temperature;
- $T_o$  is the ambient temperature;
- $K_{cc}$  is a parameter by which to determine the thermal power required by the passenger compartment conditioner;
- $K_{egr}$  is a parameter by which to determine the thermal power exchanged by the EGR exchanger;
- $K_{oil}$  is a parameter by which to determine the thermal power exchanged by the oil exchanger;
- $T_{des}$  is the target temperature;
- $L_o$  is the thermal inertia of the cooling water.

[0027] Equation (1) as shown above may obviously be based on a subset of the above nine input variables.

[0028] Equation (1) may be derived from analytical formulation, or from a test-based data table, or from a combination of the two. By means of engine sensor readings (or information derived from processing them), the data of which constitutes an information flow "inf1" supplied to the model (Figure 1), the parameters of equation (1) can be updated

continuously, or in predetermined time steps, or with reference to mileage, or on command.

[0029] One example of analytical formulation of equation (1) is shown below:

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$$K_r = K_{cc} + \frac{S_h H_h (\hat{T}_m - T_{des})}{T_{des} - T_0} - \frac{1}{L_0} \frac{dT_{des}}{dt}$$

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[0030] The engine metal temperature  $T_m$  may be measured using an appropriate sensor (not shown) on the engine, or may be estimated, in which case, an equation of the following type may advantageously be used:

$$\hat{T}_m = f(M_m, C_m, Q_{load}, S_m, H_m, T_0, S_h, H_h, T_{fc}, K_r, K_{cc}, K_{olio}, K_{egr}) \text{ _____ (2)}$$

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where:

- $M_m$  is the metal mass;
- $C_m$  is the metal heat capacity;
- 20 -  $Q_{load}$  is the thermal load exchanged by the engine;
- $S_m$  is the engine-air heat exchange surface;
- $H_m$  is the engine-air heat exchange coefficient;
- $S_h$  is the engine-cooling water heat exchange surface;
- $H_h$  is the engine-cooling water heat exchange coefficient;
- 25 -  $T_0$  is the ambient temperature;
- $T_{fc}$  is the engine outlet cooling water temperature;
- $K_{cc}$  is a parameter by which to determine the thermal power required by the passenger compartment conditioner;
- $K_{egr}$  is a parameter by which to determine the thermal power exchanged by the EGR exchanger;
- $K_{oil}$  is a parameter by which to determine the thermal power exchanged by the oil exchanger.

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[0031] Equation (2) as shown above may obviously be based on a subset of the above twelve input variables.

[0032] Equation (2) may be derived from a mathematical model, which determines the metal temperature at various characteristic points of the engine, or from a table of values memorized beforehand on the basis of test results, or from a combination of the two.

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[0033] In a preferred example of a mathematical model, metal temperature  $T_m$  may be estimated advantageously using a non-linear observer of the type below:

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$$\frac{d\hat{T}_m}{dt} = \frac{1}{M_m C_m} \left\{ Q_{load} - S_m H_m (\hat{T}_m - T_0) - S_h H_h (\hat{T}_m - T_{mis.cf}) \right\}$$

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[0034] More specifically, second block 40 comprises a block 41, which applies the  $K_r$  value to a first table which in return supplies the value  $Q_f$  of the cooling water flow required by the radiator to maintain the desired temperature value  $T_{des}$ . The first table calculates flow in a condition in which the radiator fan is off.

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[0035] Block 41 is followed by a block 42, which determines whether the calculated flow value is below a given limit value. If it is, the flow measured using the first table is acquired and used for subsequent calculations. Conversely, block 42 is followed by a block 43, which applies the  $K_r$  value to a second table which in return supplies the value  $Q_f$  of the cooling water flow which must be physically implemented to maintain the desired temperature value  $T_{des}$ . The second table calculates flow in a condition in which the radiator fan is on, and likewise in the event the speed of the radiator fan is continuously or step adjustable.

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[0036] The advantages of the control system according to the present invention will be clear from the foregoing description. Being a smart system, the control system according to the invention provides for all-round cooling water temperature control, thus greatly improving performance of all the thermal functions dependent on the engine cooling system, e.g. the vehicle heating system, EGR exhaust gas cooling system, etc.

[0037] Clearly, changes may be made to the control system as described and illustrated herein without, however, departing from the scope of the present invention.

[0038] For example, in addition to receiving information flow  $Inf_1$ , the open-loop control system model (Figure 1) may

also supply an information flow Inf2 to controller 20 of closed-loop control system 14 to continuously update the control parameters of controller 20.

**[0039]** Information flow Inf2 thus provides for updating the parameters of the controller on the basis of information flow Inf1 from the engine.

**[0040]** Information flows Inf1, Inf2 may even be disabled or accentuated in relation to particular operating conditions of the engine.

## Claims

1. A control system for controlling a cooling system (2) of a vehicle engine, wherein an internal combustion engine (3) receives a stream  $F_a$  of cooling fluid, and supplies a stream of fluid  $F_u$  to the inlet of at least a radiator (4) via regulating means (5) controllable by a drive signal (P); said control system being **characterized by** comprising:

- a closed-loop control system (14), which receives a reference signal  $T_{des}$  related to a desired operating temperature of the engine, and a signal  $T_{mis}$  representing a measured operating temperature of the engine, said closed-loop control system generating a first component  $P_{cl\_loop}$  of said drive signal; and
- an open-loop control system (15), which receives at least said reference signal  $T_{des}$ , and generates a second component  $P_{op\_loop}$  of said drive signal by means of a model representing the inverse engine-radiator thermal system.

2. A control system as claimed in Claim 1, wherein said reference signal is defined by a target temperature of the cooling fluid; said signal  $T_{mis}$  representing a measured temperature of the engine cooling fluid.

3. A control system as claimed in Claim 1, wherein said reference signal is defined by a target temperature of characteristic points of said engine; said signal  $T_{mis}$  representing a measured temperature of the metal of said engine.

4. A control system as claimed in Claim 1, wherein said closed-loop control system (14) comprises a first adding node (17) to which are supplied, with opposite signs, said reference signal  $T_{des}$  and said signal  $T_{mis}$ ; said first adding node (17) generating an error signal which is supplied to controller means (20) generating said first component  $P_{cl\_loop}$  of said drive signal.

5. A control system as claimed in Claim 4, wherein a second adding node (22) is provided, which receives said first and said second component of said drive signal to generate said drive signal.

6. A control system as claimed in Claim 1, wherein said open-loop control system comprises first calculating means (30), which receive the desired temperature value  $T_{des}$ , and generate the estimated value of a coefficient  $Kr$  by which to determine performance of the radiator in terms of heat exchange with the outside, and which must be physically implemented to maintain the desired temperature value  $T_{des}$ .

7. A control system as claimed in Claim 6, wherein said open-loop control system (15) comprises second calculating means (40), which receive said value of the coefficient  $Kr$ , and generate the value  $Qf$  of the cooling fluid flow which must be physically circulated in the radiator to maintain said desired temperature value  $T_{des}$ .

8. A control system as claimed in Claim 7, wherein said cooling fluid flow value  $Qf$  is expressed as a function of the operating state (on/off) of the fan associated with the radiator, or of the continuously or step adjustable speed of the fan.

9. A control system as claimed in Claim 7 or 8, wherein said open-loop control system (15) comprises third calculating means (50), which receive said cooling fluid flow value, and generate, on the basis of information supplied to their input, the opening value of said regulating means (5) by which to main the desired temperature value  $T_{des}$ .

10. A control system as claimed in Claim 7 or 8, wherein said open-loop control system (15) comprises third calculating means (50), which receive the calculated said cooling fluid flow value  $Qf$ , and generate, on the basis of information supplied to their input, the speed of a pump of said cooling system and the opening of said regulating means (5) which together provide for maintaining the desired temperature value  $T_{des}$ .

11. A control system as claimed in Claim 6, wherein the first calculating means (30) calculate the estimated value of

the coefficient  $K_r$  by means of an equation:

$$K_r = f(S_h, H_h, T_{metallo}, T_{des}, T_0, k_{cc}, L_0, k_{egr}, k_{oil}) \quad (1)$$

based on at least two of the following variables:

- $S_h$  which represents the engine-cooling fluid heat exchange surface;
- $H_h$  which represents the engine-cooling fluid heat exchange coefficient;
- $T_m$  which represents the engine metal temperature;
- $T_0$  which represents the ambient temperature;
- $K_{cc}$  which is a parameter by which to determine the thermal power required by the passenger compartment conditioner;
- $K_{egr}$  which represents a parameter by which to determine the thermal power exchanged by the EGR exchanger;
- $K_{oil}$  which is a parameter by which to determine the thermal power exchanged by the oil exchanger;
- $T_{des}$  which represents the target temperature;
- $L_0$  which represents the thermal inertia of the cooling fluid.

12. A control system as claimed in Claim 11, wherein said equation is analytical.

13. A control system as claimed in Claim 11, wherein said equation comprises a database formed experimentally.

14. A control system as claimed in Claim 11, wherein said equation is of the type:

$$K_r = K_{cc} \frac{S_h H_h (\hat{T}_m - T_{des})}{T_{des} - T_0} - \frac{1}{L_0} \frac{dT_{des}}{dt}$$

15. A control system as claimed in Claim 11, wherein said metal temperature  $T_m$  is measured by means of a sensor on the engine.

16. A control system as claimed in Claim 11, wherein said metal temperature  $T_m$  is determined by means of an equation:

$$\hat{T}_m = f(M_m, C_m, Q_{load}, S_m, H_m, T_0, S_h, H_h, T_{mis}, K_r, K_{cc}, K_{olio}, K_{egr}) \quad (2)$$

based on at least two of the following variables:

- $M_m$  which represents the metal mass;
- $C_m$  which represents the metal heat capacity;
- $Q_{load}$  which represents the thermal load exchanged by the engine;
- $S_m$  which represents the engine-air heat exchange surface;
- $H_m$  which represents the engine-air heat exchange coefficient;
- $S_h$  which represents the engine-cooling fluid heat exchange surface;
- $H_h$  which represents the engine-cooling fluid heat exchange coefficient;
- $T_0$  which represents the ambient temperature;
- $T_{mis}$  which represents the engine outlet cooling fluid temperature;
- $K_{cc}$  which is a parameter by which to determine the thermal power required by the passenger compartment conditioner;
- $K_{egr}$  which is a parameter by which to determine the thermal power exchanged by the EGR exchanger;
- $K_{olio}$  which is a parameter by which to determine the thermal power exchanged by the oil exchanger.

17. A control system as claimed in Claim 16, wherein said equation (2) is based on a mathematical model which determines the metal temperature at various characteristic points of the engine.

5 18. A control system as claimed in Claim 16, wherein said equation (2) is based on a database memorized on the basis of test measurements.

19. A control system as claimed in Claim 7, wherein said second calculating means (40) comprise:

10 - a first table which, on the basis of a received value of the coefficient  $K_r$ , supplies the value  $Q_f$  of the cooling fluid flow necessary to maintain the desired temperature value  $T_{des}$ ; said first table calculating the cooling fluid flow in a condition in which the fan associated with the radiator is off; and

15 - comparing means (42) for determining whether the calculated cooling fluid flow value is below a given limit value; if it is, the cooling fluid flow obtained using the first table is acquired and used in the model; conversely, a second table is selected, which supplies the value  $Q_f$  of the cooling fluid flow to the radiator required to maintain the desired temperature value  $T_{des}$ ; said second table calculating the cooling fluid flow in a condition in which the fan associated with the radiator is on.

20. A control system as claimed in Claim 1, wherein said model of said open-loop control system (15) receives a number of information items (Inf1) detected on said engine, and updates the model on the basis of the information items.

21. A control system as claimed in Claim 20, wherein said model supplies an information flow (Inf2) to a controller (20) of said closed-loop control system (14) to continuously update the control parameters of the controller.

## 25 Patentansprüche

1. Steuersystem zum Steuern eines Kühlsystems (2) eines Fahrzeugmotors, wobei ein interner Verbrennungsmotor (3) einen Strom  $F_a$  aus Kühlfluid empfängt und einen Strom aus Fluid  $F_u$  über Regulierungseinrichtungen (5), die durch ein Ansteuersignal (P) gesteuert werden können, dem Einlass wenigstens eines Kühlers (4) zuführt, wobei das Steuersystem **dadurch gekennzeichnet ist, dass** es umfasst:

35 ein geschlossenes Regelsystem (14), das ein Referenzsignal  $T_{des}$ , das sich auf eine erwünschte Betriebstemperatur des Motors bezieht, und ein Signal  $T_{mis}$ , das eine gemessene Betriebstemperatur des Motors darstellt, empfängt, wobei das geschlossene Regelsystem eine erste Komponente  $P_{cl\_loop}$  des Ansteuersignals erzeugt und

ein offenes Regelsystem (15), das wenigstens das Referenzsignal  $T_{des}$  empfängt und eine zweite Komponente  $P_{op\_loop}$  des Ansteuersignals mit Hilfe eines Modells erzeugt, das das inverse Motor-Kühler-Wärmesystem darstellt.

40 2. Steuersystem nach Anspruch 1, wobei das Referenzsignal durch eine Solltemperatur des Kühlfluids definiert wird und das Signal  $T_{mis}$  eine gemessene Betriebstemperatur des Motorkühlfluids darstellt.

3. Steuersystem nach Anspruch 1, wobei das Referenzsignal durch eine Solltemperatur von charakteristischen Punkten des Motors definiert wird und das Signal  $T_{mis}$  eine gemessene Temperatur des Metalls des Motors darstellt.

45 4. Steuersystem nach Anspruch 1, wobei das geschlossene Regelsystem (14) einen ersten Addierknoten (17) umfasst, an den das Referenzsignal  $T_{des}$  und das Signal  $T_{mis}$  mit umgekehrten Vorzeichen bereitgestellt werden, wobei der erste Addierknoten (17) ein Fehlersignal erzeugt, das in die Steuereinrichtung (20) eingespeist wird, die die erste Komponente  $P_{cl\_loop}$  des Ansteuersignals erzeugt.

50 5. Steuersystem nach Anspruch 4, wobei ein zweiter Addierknoten (22) bereitgestellt ist, der die erste und die zweite Komponente des Ansteuersignals empfängt, um das Ansteuersignal zu erzeugen.

55 6. Steuersystem nach Anspruch 1, wobei das offene Regelsystem erste Berechnungseinrichtungen (30) umfasst, die den erwünschten Temperaturwert  $T_{des}$  empfangen und den geschätzten Wert eines Koeffizienten  $K_r$  erzeugen, mit dem die Leistung des Kühlers in Bezug auf einen Wärmeaustausch mit der Außenseite zu bestimmen ist und die physikalisch implementiert werden muss, um den erwünschten Temperaturwert  $T_{des}$  vorzuhalten.

7. Steuersystem nach Anspruch 6, wobei das offene Regelsystem (15) zweite Berechnungseinrichtungen (40) umfasst, die den Wert des Koeffizienten  $K_r$  empfangen und den Wert  $Q_f$  des Kühlfluid-Durchflusses erzeugen, der physikalisch in dem Kühler zirkuliert werden muss, um den erwünschten Temperaturwert  $T_{des}$  vorzuhalten.
- 5 8. Steuersystem nach Anspruch 7, wobei der Kühlfluid-Durchflusswert  $Q_f$  als eine Funktion des Betriebszustands (EIN/AUS) des dem Kühler zugehörigen Gebläses oder der kontinuierlichen oder stufenweise einstellbaren Drehzahl des Gebläses ausgedrückt wird.
- 10 9. Steuersystem nach Anspruch 7 oder 8, wobei das offene Regelsystem (15) dritte Berechnungseinrichtungen (50) umfasst, die den Kühlfluid-Durchflusswert empfangen und auf Basis von an ihren Eingängen bereitgestellten Informationen den Öffnungswert der Regulierungseinrichtungen (5) erzeugen, durch den der erwünschte Temperaturwert  $T_{des}$  vorgehalten wird.
- 15 10. Steuersystem nach Anspruch 7 oder 8, wobei das offene Regelsystem (15) dritte Berechnungseinrichtungen (50) umfasst, die den berechneten Kühlfluid-Durchflusswert  $Q_f$  empfangen und auf Basis von an ihren Eingängen bereitgestellten Informationen die Geschwindigkeit einer Pumpe des Kühlsystems und die Öffnung der Regulierungseinrichtungen (5) erzeugen, die zusammen das Vorhalten des erwünschten Temperaturwertes  $T_{des}$  sichern.
- 20 11. Steuersystem nach Anspruch 6, wobei die ersten Berechnungseinrichtungen (30) den geschätzten Wert des Koeffizienten  $K_r$  mit Hilfe einer Gleichung

$$K_r = f(S_h, H_h, T_m, T_{des}, T_0, k_{cc}, L_0, k_{egr}, k_{oil}) \quad (1)$$

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berechnen, die auf wenigstens zwei der folgenden Variablen basiert:

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- $S_h$ , welche die Motorkühlfluid-Wärmeaustauschfläche darstellt;
- $H_h$ , welche den Motorkühlfluid-Wärmeaustauschkoeffizienten darstellt;
- $T_m$ , welche die Motormetalltemperatur darstellt;
- $T_0$ , welche die Umgebungstemperatur darstellt;
- $K_{cc}$ , welche ein Parameter ist, durch den die Wärmeleistung zu bestimmen ist, die für die Fahrgastraumklimaanlage erforderlich ist;
- 35 -  $K_{egr}$ , welche einen Parameter darstellt, durch den die durch den AGR-Wärmeaustauscher ausgetauschte Wärmeleistung zu bestimmen ist;
- $K_{oil}$ , welche ein Parameter ist, durch den die durch den Ölaustauscher ausgetauschte Wärmeleistung zu bestimmen ist;
- $T_{des}$ , welche die Zieltemperatur darstellt;
- 40 -  $L_0$ , welche die thermische Trägheit des Kühlfluids darstellt.

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12. Steuersystem nach Anspruch 11, wobei die Gleichung analytisch ist.
13. Steuersystem nach Anspruch 11, wobei die Gleichung eine Datenbank umfasst, die auf Versuchen aufgebaut ist.
- 45 14. Steuersystem nach Anspruch 11, wobei die Gleichung folgenden Typs ist:

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$$K_r = K_{cc} \frac{S_h H_h (\dot{T}_m - T_{des})}{T_{des} - T_0} - \frac{1}{L_0} \frac{dT_{des}}{dt}$$

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15. Steuersystem nach Anspruch 11, wobei die Metalltemperatur  $T_m$  mit Hilfe eines Sensors auf dem Motor gemessen wird.
16. Steuersystem nach Anspruch 11, wobei die Metalltemperatur  $T_m$  mittels einer Gleichung

$$\hat{T}_m = f(M_m, C_m, Q_{load}, S_m, H_m, T_o, S_h, H_h, T_{mis}, K_r, K_{cc}, K_{olio}, K_{egr}) \quad (2)$$

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bestimmt wird, die auf wenigstens zwei der folgenden Variablen basiert:

- $M_m$ , welche die Metallmasse darstellt;
- $C_m$ , welche die Metall-Wärmekapazität darstellt;
- $Q_{load}$ , welche die durch den Motor ausgetauschte Wärmelast darstellt;
- $S_m$ , welche die Motorluft-Wärmeaustauschfläche darstellt;
- $H_m$ , welche den Motorluft-Wärmeaustauschkoeffizienten darstellt;
- $S_h$ , welche die Motorkühlfluid-Wärmeaustauschfläche darstellt;
- $H_h$ , welche den Motorkühlfluid-Wärmeaustauschkoeffizienten darstellt;
- $T_o$ , welche die Umgebungstemperatur darstellt;
- $T_{mis}$ , welche die Motorauslass-Kühlfluidtemperatur darstellt;
- $K_{cc}$ , welche ein Parameter ist, durch den die Wärmeleistung zu bestimmen ist, die für die Fahrgastraumklimaanlage erforderlich ist;
- $K_{egr}$ , welche einen Parameter darstellt, durch den die durch den AGR-Wärmeaustauscher ausgetauschte Wärmeleistung zu bestimmen ist;
- $K_{oil}$ , welche ein Parameter ist, durch den die durch den Ölaustauscher ausgetauschte Wärmeleistung zu bestimmen ist.

17. Steuersystem nach Anspruch 16, wobei die Gleichung (2) auf einem mathematischen Modell basiert, das die Metalltemperatur an verschiedenen charakteristischen Punkten des Motors bestimmt.

18. Steuersystem nach Anspruch 16, wobei die Gleichung (2) auf einer Datenbank basiert, die auf Basis von Prüfmessungen eingelesen wurde.

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19. Steuersystem nach Anspruch 7, wobei die zweiten Berechnungseinrichtungen (40) umfassen:

- eine erste Tabelle, die auf Basis eines empfangenen Wertes des Koeffizienten  $K_r$  den Wert  $Q_f$  des Kühlfluid-Durchflusses bereitstellt, der erforderlich ist, um den erwünschten Temperaturwert  $T_{des}$  vorzuhalten, wobei die erste Tabelle den Kühlfluid-Durchfluss in einem Zustand berechnet, in dem das dem Kühler zugehörige Gebläse abgeschaltet ist, und
- Vergleichseinrichtungen (42) zum Bestimmen, ob der berechnete Kühlfluid-Durchflusswert unter einem gegebenen Grenzwert ist, falls er es ist, wird der unter Verwendung der ersten Tabelle erhaltene Kühlfluid-Durchfluss bezogen und in dem Modell genutzt,
- umgekehrt wird eine zweite Tabelle gewählt, die den Wert  $Q_f$  des Kühlfluid-Durchflusses, der erforderlich ist, um den erwünschten Temperaturwert  $T_{des}$  vorzuhalten, für den Kühler bereitstellt, wobei die zweite Tabelle den Kühlfluid-Durchfluss in einem Zustand berechnet, in dem das dem Kühler zugehörige Gebläse eingeschaltet ist.

20. Steuersystem nach Anspruch 1, wobei das Modell des offenen Regelsystems (15) eine Anzahl von Informationselementen (Inf1), die an dem Motor detektiert werden, empfängt und das Modell auf Basis der Informationselemente aktualisiert.

21. Steuersystem nach Anspruch 20, wobei das Modell einen Informationsstrom (Inf2) für einen Controller (20) des geschlossenen Regelsystems (14) bereitstellt, um die Steuerparameter des Controllers kontinuierlich zu aktualisieren.

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## Revendications

1. Système de commande pour commander un système de refroidissement (2) d'un moteur de véhicule, dans lequel un moteur à combustion interne (3) reçoit un flux  $F_a$  de liquide de refroidissement et fournit un flux de fluide  $F_u$  à l'entrée d'au moins un radiateur (4) par le biais d'un moyen de régulation (5) pouvant être commandé par un signal

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d'entraînement ou de commande (P) ;

ledit système de commande étant **caractérisé en ce qu'il** comprend :

- 5           - un système de commande à boucle fermée (14) qui reçoit un signal de référence  $T_{des}$  lié à une température de fonctionnement souhaitée du moteur et un signal  $T_{mis}$  représentant une température de fonctionnement mesurée du moteur, ledit système de commande à boucle fermée générant une première composante  $P_{boucle\_f}$  dudit signal d'entraînement ou de commande ; et
- 10          - un système de commande à boucle ouverte (15) qui reçoit au moins ledit signal de référence  $T_{des}$  et génère une seconde composante  $P_{boucle\_o}$  dudit signal d'entraînement ou de commande au moyen d'un modèle représentant le système thermique radiateur/moteur inverse.
2. Système de commande selon la revendication 1, dans lequel ledit signal de référence est défini par une température cible du liquide de refroidissement ; ledit signal  $T_{mis}$  représentant une température mesurée du liquide de refroidissement de moteur.
- 15          3. Système de commande selon la revendication 1, dans lequel ledit signal de référence est défini par une température cible de points caractéristiques dudit moteur ; ledit signal  $T_{mis}$  représentant une température mesurée du métal dudit moteur.
- 20          4. Système de commande selon la revendication 1, dans lequel ledit système de commande à boucle fermée (14) comprend un premier noeud d'ajout (17) auquel sont fournis, avec des signes opposés, ledit signal de référence  $T_{des}$  et ledit signal  $T_{mis}$  ; ledit premier noeud d'ajout (17) générant un signal d'erreur qui est fourni au moyen d'unités de commande (20) générant ladite première composante  $P_{boucle\_f}$  dudit signal d'entraînement ou de commande.
- 25          5. Système de commande selon la revendication 4, dans lequel un second noeud d'ajout (22) est prévu, qui reçoit ladite première composante et ladite seconde composante dudit signal d'entraînement ou de commande pour générer ledit signal d'entraînement.
- 30          6. Système de commande selon la revendication 1, dans lequel ledit système de commande à boucle ouverte comprend des premiers moyens de calcul (30) qui reçoivent la valeur de température souhaitée  $T_{des}$  et génèrent la valeur estimée d'un coefficient  $K_r$  par lequel est déterminée la performance du radiateur en termes d'échange de chaleur avec l'extérieur et qui doit être physiquement mis en oeuvre pour maintenir la valeur de température souhaitée  $T_{des}$ .
- 35          7. Système de commande selon la revendication 6, dans lequel ledit système de commande à boucle ouverte (15) comprend des deuxièmes moyens de calcul (40) qui reçoivent ladite valeur du coefficient  $K_r$  et génèrent la valeur  $Q_f$  du flux de liquide de refroidissement qui doit être mis en circulation physiquement dans le radiateur afin de maintenir ladite valeur de température souhaitée  $T_{des}$ .
- 40          8. Système de commande selon la revendication 7, dans lequel ladite valeur de flux de liquide de refroidissement  $Q_f$  est exprimée en fonction de l'état de fonctionnement (marche/arrêt) du ventilateur associé au radiateur ou de la vitesse ajustable en continu ou par étape du ventilateur.
- 45          9. Système de commande selon la revendication 7 ou 8, dans lequel ledit système de commande à boucle ouverte (15) comprend des troisièmes moyens de calcul (50) qui reçoivent ladite valeur de flux de liquide de refroidissement et génèrent sur la base des informations fournies à leur entrée, la valeur d'ouverture dudit moyen de régulation (5) par laquelle on maintient la valeur de température souhaitée  $T_{des}$ .
- 50          10. Système de commande selon la revendication 7 ou 8, dans lequel ledit système de commande à boucle ouverte (15) comprend des troisièmes moyens de calcul (50) qui reçoivent la valeur de flux de fluide de refroidissement calculée  $Q_f$  et génèrent sur la base des informations fournies à leur entrée, la vitesse d'une pompe dudit système de refroidissement et l'ouverture dudit moyen de régulation (5) qui, ensemble, permettent de maintenir la valeur de température souhaitée  $T_{des}$ .
- 55          11. Système de commande selon la revendication 6, dans lequel les premiers moyens de calcul (30) calculent la valeur estimée du coefficient  $K_r$  au moyen d'une équation :

$$K_r = f(S_h, H_h, T_m, T_{des}, T_0, k_{cc}, L_0, k_{egr}, k_{huile}) \text{ _____ (1)}$$

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sur la base d'au moins deux des variables suivantes :

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- $S_h$  qui représente la surface d'échange de chaleur entre le moteur et le liquide de refroidissement ;
- $H_h$  qui représente le coefficient d'échange de chaleur entre le moteur et le liquide de refroidissement ;
- $T_m$  qui représente la température du métal du moteur ;
- $T_0$  qui représente la température ambiante ;
- $K_{cc}$  qui est un paramètre par lequel on détermine la puissance thermique requise par le climatiseur de l'habitacle ;
- $K_{egr}$  qui représente un paramètre par lequel on détermine la puissance thermique échangée par l'échangeur EGR (recirculation des gaz d'échappement) ;
- $K_{huile}$  qui est un paramètre par lequel on détermine la puissance thermique échangée par l'échangeur d'huile ;
- $T_{des}$  qui représente la température cible ;
- $L_0$  qui représente l'inertie thermique du liquide de refroidissement.

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20 12. Système de commande selon la revendication 11, dans lequel ladite équation est analytique.

13. Système de commande selon la revendication 11, dans lequel ladite équation comprend une base de données formée de manière expérimentale.

25 14. Système de commande selon la revendication 11, dans lequel ladite équation est du type :

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$$K_r = K_{cc} + \frac{S_h H_h (\hat{T}_m - T_{des})}{T_{des} - T_0} - \frac{1}{L_0} \frac{dT_{des}}{dt}$$

35

15. Système de commande selon la revendication 11, dans lequel ladite température de métal  $T_m$  est mesurée au moyen d'un capteur sur le moteur.

16. Système de commande selon la revendication 11, dans lequel ladite température de métal  $T_m$  est déterminée au moyen d'une équation :

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$$\hat{T}_m = f(M_m, C_m, Q_{charge}, S_m, H_m, T_0, S_h, H_h, T_{fc}, K_r, K_{cc}, K_{huile}, K_{egr}) \text{ _____ (2)}$$

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sur la base d'au moins deux des variables suivantes :

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- $M_m$  qui représente la masse du métal ;
- $C_m$  qui représente la capacité de chaleur du métal ;
- $Q_{charge}$  qui représente la charge thermique échangée par le moteur ;
- $S_m$  qui représente la surface d'échange de chaleur entre le moteur et l'air ;
- $H_m$  qui représente le coefficient d'échange de chaleur entre le moteur et l'air ;
- $S_h$  qui représente la surface d'échange de chaleur entre le moteur et le liquide de refroidissement ;
- $H_h$  qui représente le coefficient d'échange de chaleur entre le moteur et le liquide de refroidissement ;
- $T_0$  qui représente la température ambiante ;
- $T_{mis}$  qui représente la température du liquide de refroidissement à la sortie du moteur ;
- $K_{cc}$  qui est un paramètre par lequel on détermine la puissance thermique requise par le climatiseur de l'habitacle ;
- $K_{egr}$  qui représente un paramètre par lequel on détermine la puissance thermique échangée par l'échangeur

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EGR (recirculation des gaz d'échappement) ;

-  $K_{\text{huile}}$  qui est un paramètre par lequel on détermine la puissance thermique échangée par l'échangeur d'huile.

- 5
17. Système de commande selon la revendication 16, dans lequel ladite équation (2) est basée sur un modèle mathématique qui détermine la température du métal en divers points caractéristiques du moteur.
18. Système de commande selon la revendication 16, dans lequel ladite équation (2) est fondée sur une base de données mémorisée sur la base des mesures d'essai.
- 10
19. Système de commande selon la revendication 7, dans lequel lesdits deuxièmes moyens de calcul (40) comprennent :
- une première table qui, sur la base d'une valeur reçue du coefficient  $K_r$ , fournit la valeur  $Q_f$  du flux de liquide de refroidissement nécessaire pour maintenir la valeur de température souhaitée  $T_{\text{des}}$  ; ladite première table calculant le flux de liquide de refroidissement dans une condition dans laquelle le ventilateur associé au radiateur est à l'arrêt ; et
  - des moyens de comparaison (42) pour déterminer si la valeur de flux de liquide de refroidissement calculée est inférieure à une valeur limite ; si oui, le flux de liquide de refroidissement obtenu en utilisant la première table est acquis et utilisé dans le modèle ; dans le cas contraire, une seconde table est sélectionnée qui fournit la valeur  $Q_f$  du flux de liquide de refroidissement au radiateur requise pour maintenir la valeur de température souhaitée  $T_{\text{des}}$  ; ladite seconde table calculant le flux de liquide de refroidissement dans une condition dans laquelle le ventilateur associé au radiateur est en marche.
- 15
20. Système de commande selon la revendication 1, dans lequel ledit modèle dudit système de commande à boucle ouverte (15) reçoit un certain nombre d'éléments d'information (Inf1) détectés sur ledit moteur et met à jour le modèle sur la base des éléments d'information.
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21. Système de commande selon la revendication 20, dans lequel ledit modèle fournit un flux d'information (Inf2) à une unité de commande (20) dudit système de commande à boucle fermée (14) afin de mettre à jour en continu les paramètres de commande de l'unité de commande.
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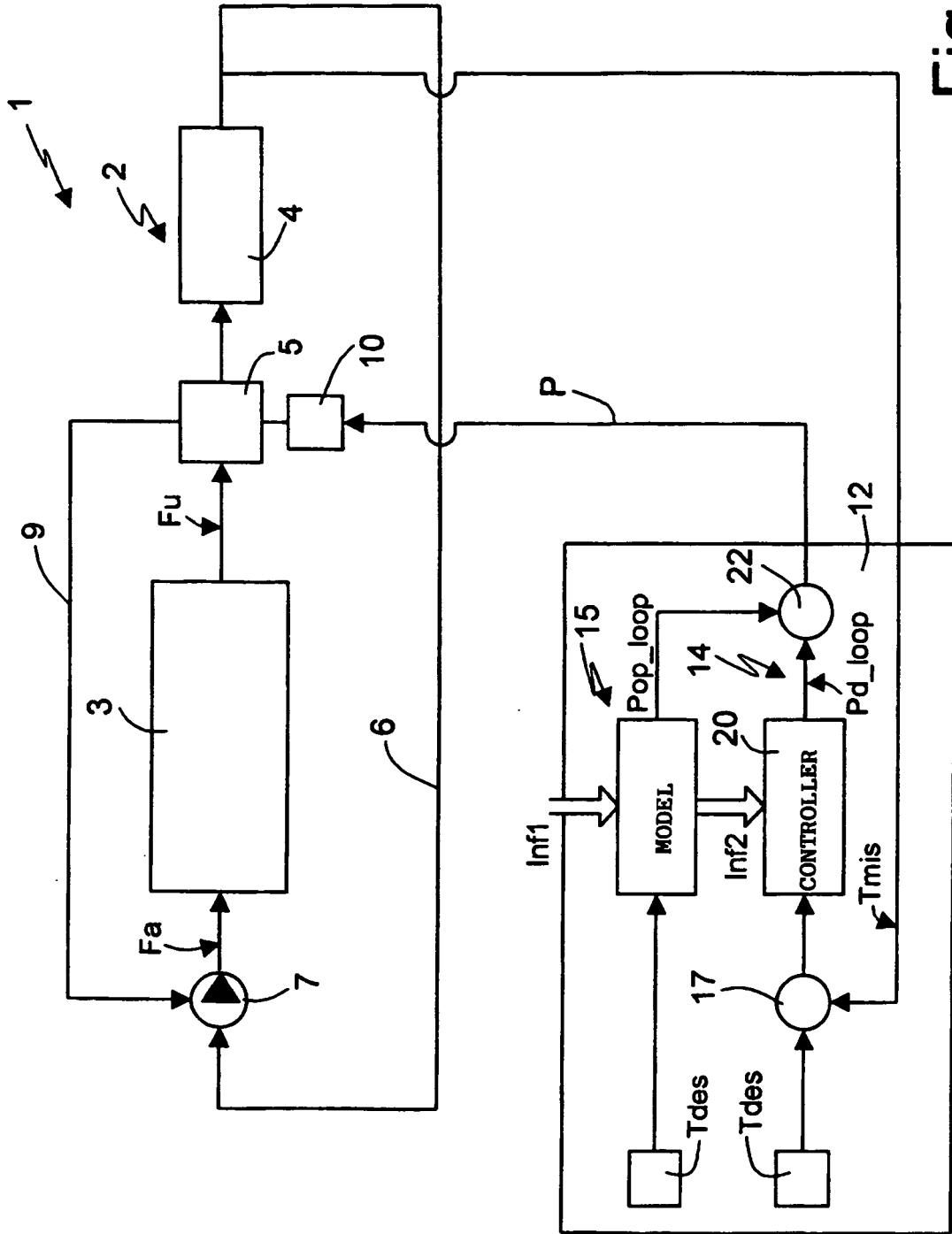


Fig.1

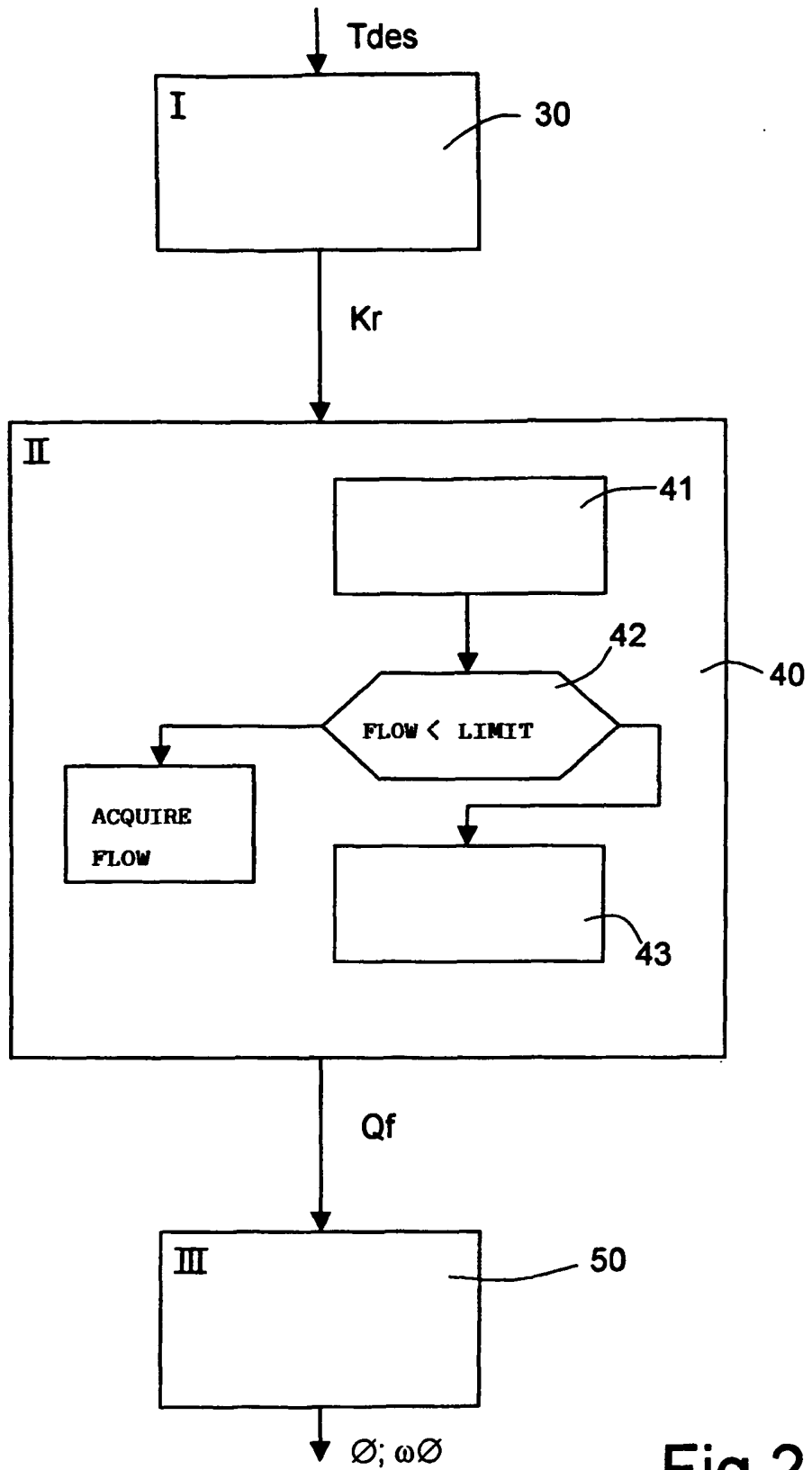


Fig.2

**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- JP 05231149 A [0002]