



(12)

EUROPEAN PATENT APPLICATION

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

(51) Int Cl.7: F01P 7/16

(21) Application number: 03022279.8

(22) Date of filing: 01.10.2003

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HU IE IT LI LU MC NL PT RO SE SI SK TR
Designated Extension States:
AL LT LV MK

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

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

(30) Priority: 02.10.2002 IT to20020852

(71) Applicant: Mark IV Systemes Moteurs (Société
Anonyme)
92400 Courbevoie (FR)

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

(57) 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 a radiator (4) via a control valve (5). The control system has a closed-

loop control system (14), which generates a first component P_{cl_loop} of the drive signal; and an open-loop control system (15), which generates a second component P_{op_loop} of the drive signal by means of an inverse model representing the engine-radiator thermal system.

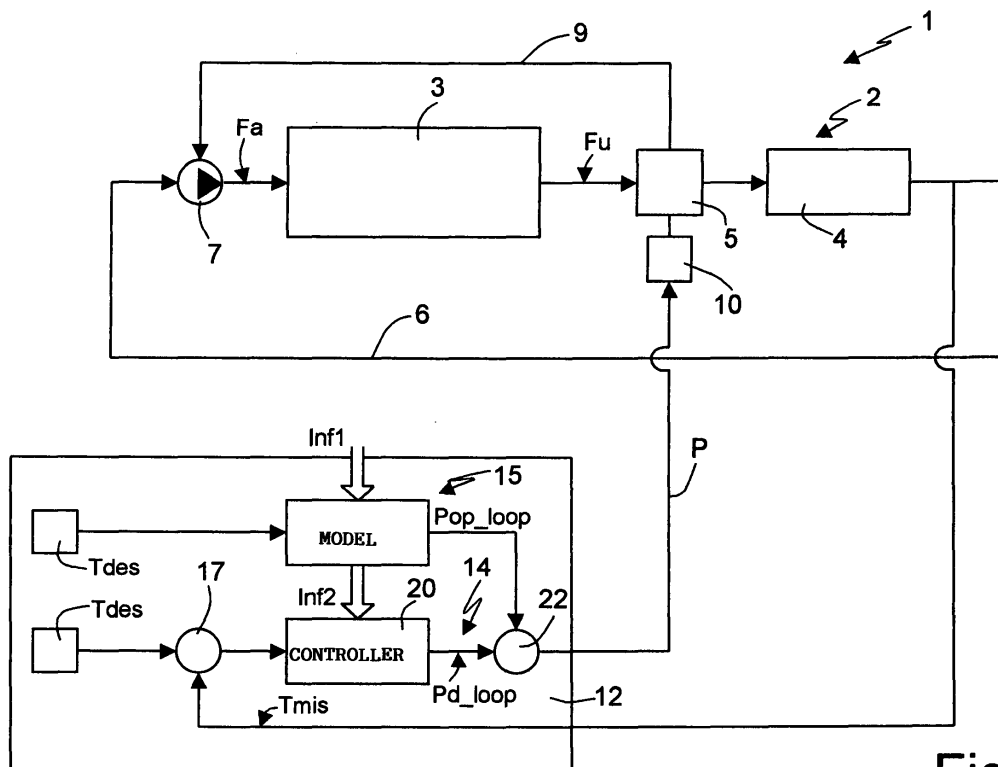


Fig.1

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..

[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 information 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 ϕ 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 ϕ 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 ω and the opening ϕ 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:

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

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_0 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_0 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:

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

[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:

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

where:

- M_m is the metal mass;
- C_m is the metal heat capacity;
- 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;
- 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.

[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.

[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:

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

[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.

[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.

[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 Inf1, 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 K_r 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 K_r , and generate the value Q_f 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 Q_f 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 Q_f , 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:

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

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_{oil} 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.

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:

- 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
- 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.

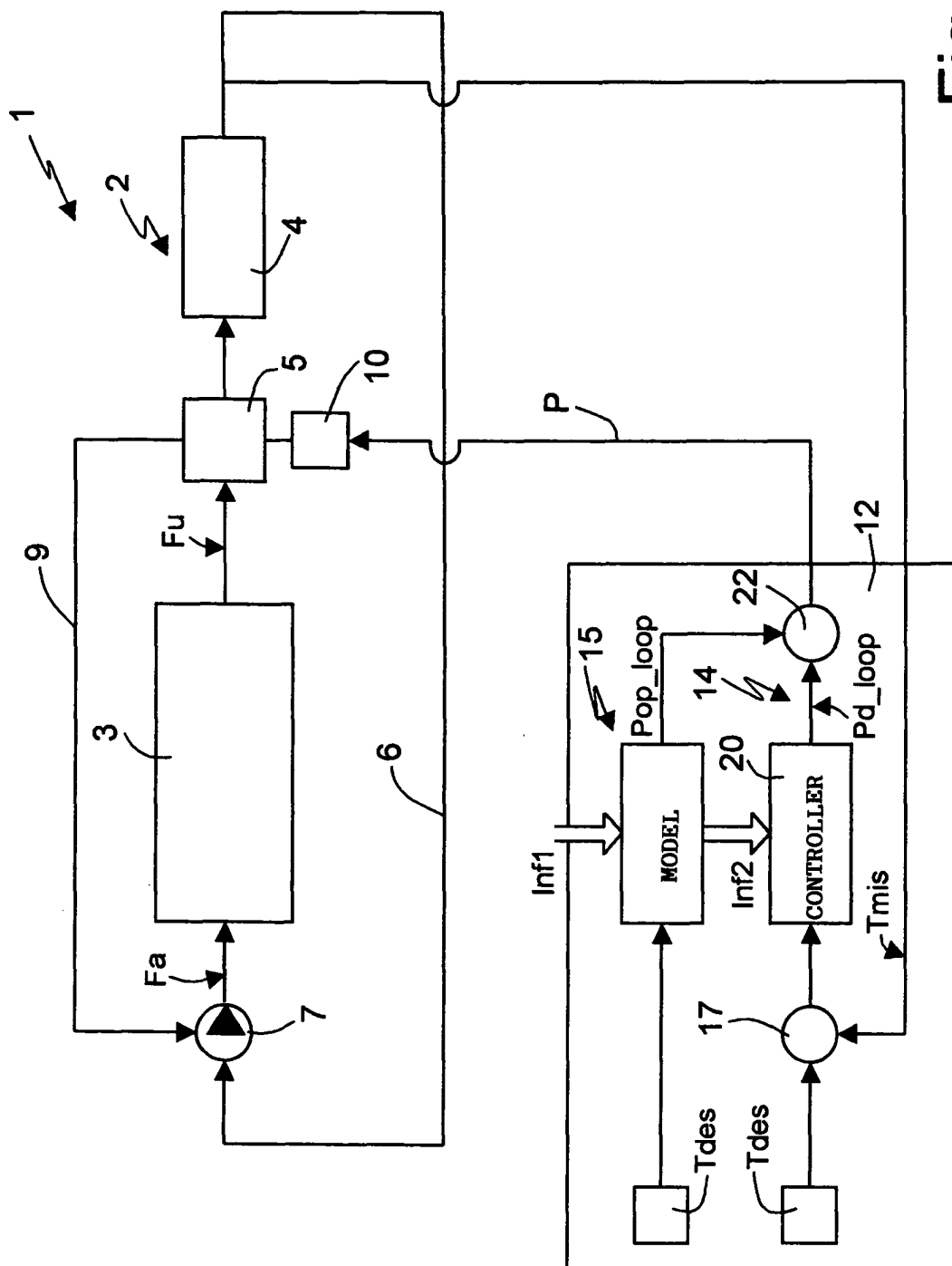


Fig. 1

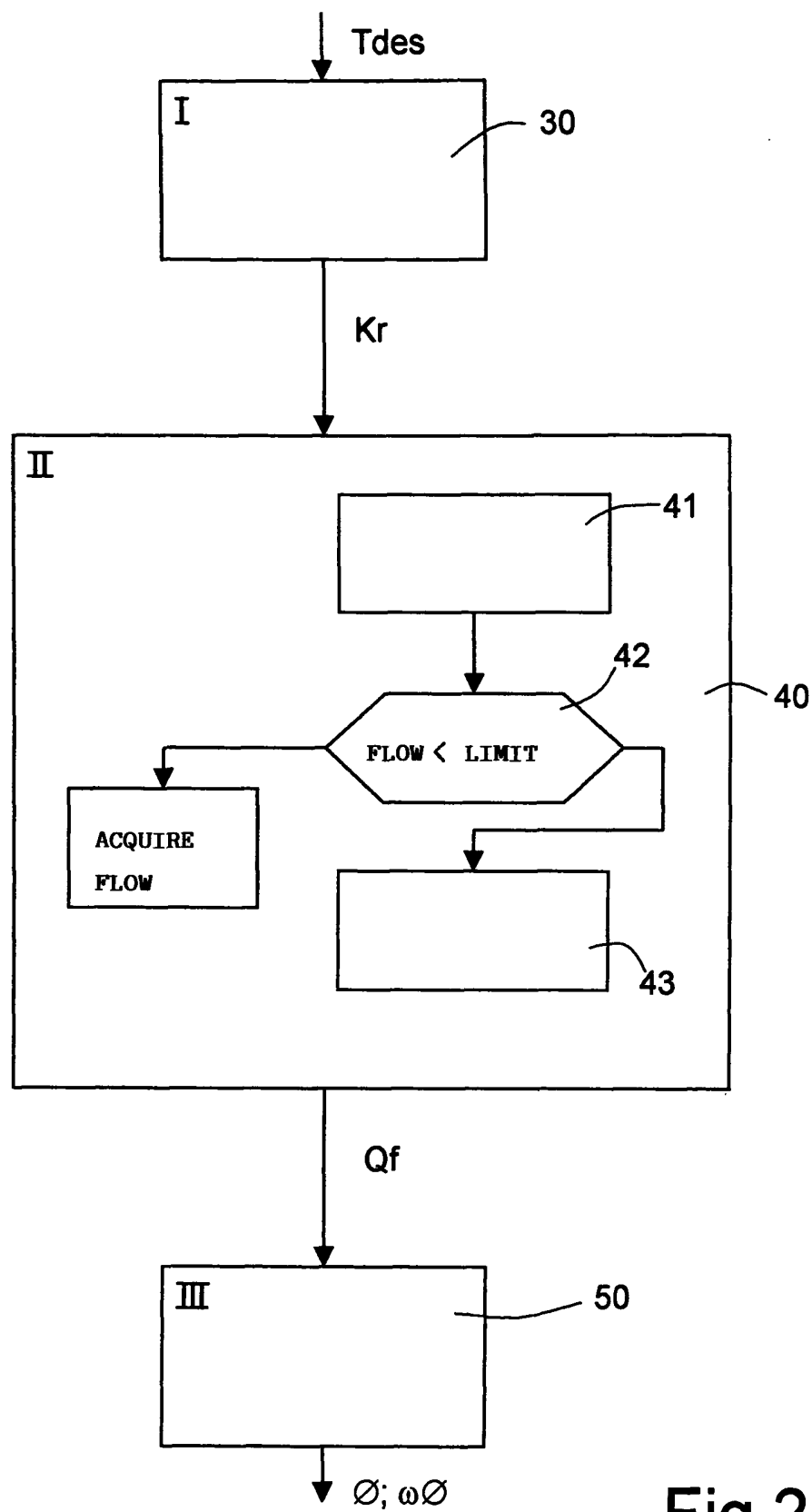


Fig.2



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 03 02 2279

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.CI.7)
A	PATENT ABSTRACTS OF JAPAN vol. 0176, no. 86 (M-1529), 15 December 1993 (1993-12-15) -& JP 05 231149 A (HONDA MOTOR CO LTD), 7 September 1993 (1993-09-07) * abstract *	1	F01P7/16
A	US 6 321 695 B1 (YOO ET AL.) 27 November 2001 (2001-11-27) * abstract; figures *	1	
A	US 5 758 607 A (BREDEL ET AL.) 2 June 1998 (1998-06-02) * column 4, line 1 - line 35; figure *	1	
P,A	DE 101 23 444 A (SIEMENS) 28 November 2002 (2002-11-28) * paragraph '0017! - paragraph '0027!; figures *	1,2,4,5	
P,A	DE 101 63 944 A (ROBERT BOSCH) 3 July 2003 (2003-07-03) * paragraph '0031! - paragraph '0038!; figures *	1-3	TECHNICAL FIELDS SEARCHED (Int.CI.7) F01P
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 6 January 2004	Examiner Kooijman, F
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03/02 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 03 02 2279

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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06-01-2004

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 05231149 A	07-09-1993	JP 3044503 B2	22-05-2000
		DE 69325044 D1	01-07-1999
		DE 69325044 T2	30-09-1999
		EP 0557113 A2	25-08-1993
		US 5390632 A	21-02-1995
US 6321695 B1	27-11-2001	NONE	
US 5758607 A	02-06-1998	DE 19519377 A1	28-11-1996
		DE 59610017 D1	06-02-2003
		EP 0744539 A2	27-11-1996
DE 10123444 A	28-11-2002	DE 10123444 A1	28-11-2002
		WO 02092975 A1	21-11-2002
DE 10163944 A	03-07-2003	DE 10163944 A1	03-07-2003
		WO 03056152 A1	10-07-2003