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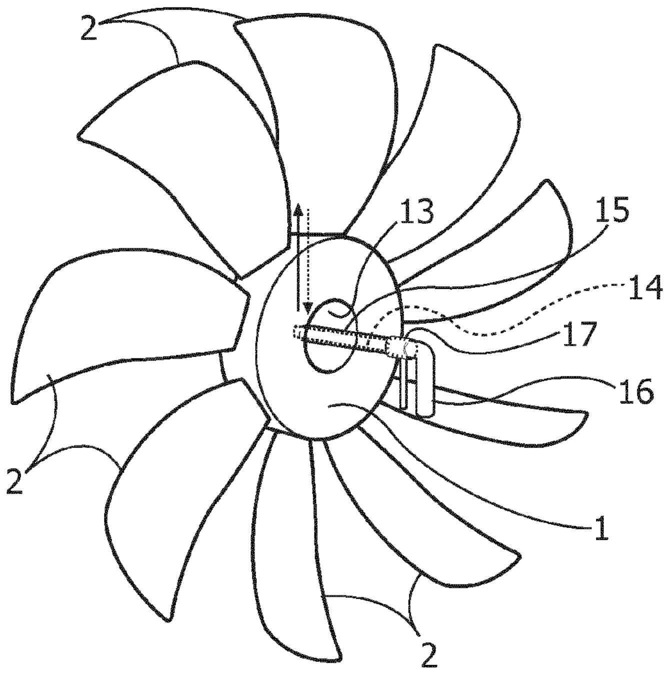
(54) **Variable-geometry fan and method for control thereof**

(57) A variable-geometry fan, in particular for cooling the lubricant of an internal-combustion engine, comprising a hub (1) bearing a ring of blades (2) having an elastically deformable structure and incorporating laminas (11) made of a shape-memory alloy. The application of thermal energy to the laminas (11), so as to vary the geometry of the blades (2), envisages circulation of a hot fluid and of a cold fluid through internal ducts (9) of the blades (2).

FIG. 1



EP 2 587 070 A2

Description

Field of the invention

[0001] The present invention relates to cooling fans, in particular, albeit not exclusively, for cooling the lubricant of internal-combustion engines of industrial vehicles and the like.

[0002] Fans of this sort traditionally comprise a rotating hub bearing a ring of blades: in order to regulate the flow of air generated in use by the fan, so as to guarantee optimal cooling conditions, it is known to modify the geometrical configuration of the blades.

Prior art

[0003] The European patent application No. EP-2078865A2 filed in the name of the present applicant describes a variable-geometry fan in which the configuration of the blades is varied with the use of a shape-memory material. More in particular, each blade of the fan has an elastically deformable structure incorporating at least one lamina made of a shape-memory metal alloy designed to be heated to modify the profile of the blade and thus regulate the flow of air produced by the fan, even keeping the speed of rotation thereof unaltered. Heating of the laminas made of shape-memory alloy is obtained by the Joule effect, i.e., via the supply of appropriately controlled electric current through the laminas themselves.

[0004] This solution, albeit altogether satisfactory and effective, in certain applications could be improved further in terms of rapidity and promptness of variation of the geometry, in particular as regards restoration of the original configuration of the blades, i.e., the configuration prior to heating of the shape-memory laminas.

Summary of the invention

[0005] According to the invention, the above object is achieved via a variable-geometry fan of the type defined in the pre-characterizing part of Claim 1, the peculiar characteristic of which lies in the fact that the control means for applying thermal energy to the laminas made of shape-memory alloy of the blades so as to vary the geometry thereof include a circuit for circulation of a thermal fluid through internal channels of each blade.

[0006] According to the invention, the circulation circuit includes a first delivery and return line for a hot liquid, a second delivery and return line for a cold liquid, and respective solenoid valves driven by an electronic control unit as a function of the temperature of the engine lubricant to which the fan is to be operatively associated.

[0007] The electronic control unit can be programmed so as to drive the two solenoid valves according to different logics as a function of the need of use of the fan.

[0008] Yet a further object of the invention is a method for controlling the geometry of the blades of the variable-geometry fan.

Brief description of the drawings

[0009] The invention will now be described in detail with reference to the annexed drawings, which are provided purely by way of non-limiting example and in which:

- Figure 1 is a schematic perspective view of a variable-geometry fan according to the invention;
- Figure 2 shows the electro-hydraulic scheme of the control system of the fan;
- Figure 3 shows a detail of Figure 1 at a larger scale;
- Figures 4 and 5 are two perspective views that show respective components of Figure 3;
- Figure 6 is a schematic front perspective view of one of the blades of the fan;
- Figure 7 is a cross-sectional view at a larger scale according to the line VII-VII of Figure 6;
- Figure 8 is a perspective view at a larger scale sectioned according to line VIII-VIII of Figure 3;
- Figure 9 shows a variant of Figure 8; and
- Figures 10, 11 and 12 are three flowcharts that exemplify respective different operating logics of the control system of the fan according to the invention.

Detailed description of the invention

[0010] With initial reference to Figure 1, the variable-geometry fan according to the invention, which can be used, for example, for cooling the lubricant of the internal-combustion engine of an industrial vehicle, comprises, in a way generally in itself known, a hub 1 provided for being governed in rotation with usual modalities and fitted on the periphery of which is a ring of blades 2.

[0011] Each blade 2 is constituted by an elastically deformable body incorporating one or more laminas of a shape-memory alloy, generally according to what is described and illustrated in the aforesaid European patent application No. EP-2078865A2.

[0012] In detail, each blade 2 is shaped with specific profiles appropriately studied with a view to maximizing the fluid-dynamic efficiency, and consists in a matrix made of a thermosetting or thermoplastic polymeric plate, possibly fibre-reinforced. The solution that appears currently most promising from the industrial standpoint envisages the use of a thermoplastic material, for example, nylon, and injection-moulding manufacturing techniques. More in particular, each blade 2 can be made in the way represented schematically in Figure 7, with two distinct half-shells 3, 4 formed with respective channels 5, 6. The two half-shells 3, 4 are then fitted together permanently via fixed joints 7, 8 (and/or gluing or else other equivalent systems) in such a way that the two channels 5, 6 are set facing one another so as to define an internal duct 9. Said duct 9, the path of which can, for example, be the one represented schematically with a dashed line in Figure 6, defines a circuit for circulation of a thermal fluid, which will be described in what follows.

[0013] With reference once again to Figure 7, the hermetic seal of the duct 9 is guaranteed by gaskets 10, for example, made of silicone material, inserted in corresponding facing recesses of the two half-shells 3, 4.

[0014] Set within the duct 9, along its entire path or more conveniently only in some stretches (for example, three in number as represented in Figure 6) are laminas 11 made of a shape-memory metal alloy. Typically, the laminas 11 are made of an NiTi-based alloy, and are gripped between the half-shells 3, 4 along the middle of the channel 11. In this way, the opposite faces of each lamina 11 facing the channel 5 and the channel 6, respectively, in the way represented in Figure 7, can be both lapped by the thermal fluid circulating along the duct 9.

[0015] The duct 9 of each blade 2 is connected to a tubular connector 12, for example, screwed on the periphery of the hub 1 and in communication with a radial manifold or distributor, designated as a whole by 13 in Figure 2, set within the hub 1 itself.

[0016] The radial distributor 13 communicates with an inlet duct 14 and with an outlet duct 15 set one inside another coaxially with respect to the hub 1 and rotating together with it. As is illustrated in detail in Figures 4, 5 and 8, the inlet duct 14 and the outlet duct 15 are rotatably fitted to respective stationary tubular connectors 16, 17 set radially with respect to the hub and in turn communicating with a double hydraulic circuit, represented schematically in Figure 2 and designated as a whole by 18.

[0017] The hermetic seal between each rotatable duct 14, 15 and the corresponding stationary connector 16, 17 is obtained by means of respective annular flanges 19, 20 and 21, 22 in mutual sliding contact, it being possible for said contact to be direct (in the way represented in Figure 8) or else envisage the use of annular sliding bearings 23, 24 set between the flanges 19, 20 and 21, 22 (in the way represented in Figure 9).

[0018] With reference now to Figure 2, the double hydraulic circuit 18 includes a first delivery line 25 and a first return line 26 for circulation, via a pump 27, of a hot liquid coming from a reservoir 28, and a second delivery line 29 and a second return line 30 for circulation, via a pump 31, of a cold liquid coming from a reservoir 35.

[0019] The hot liquid and the cold liquid can be advantageously constituted by the cooling liquid or glycol itself of the internal-combustion engine to which the fan according to the invention is to be operatively associated. In particular, the hot liquid of the reservoir 28 may consist of a certain amount of cooling glycol drawn off prior to its entry into the corresponding cooling radiator, whilst the cold liquid of the reservoir 35 may be the coolant itself leaving the radiator. Alternatively, the cold liquid may come from an autonomous circuit distinct from that of the glycol for cooling the engine, as also the hot liquid may be supplied by an autonomous circuit.

[0020] Designated by 32 and 33 are two three-way solenoid valves that control the communication between the first delivery line 25 and the first return line 26 on one side, and between the second delivery line 29 and the second return line 30 on the other, with the stationary inlet duct 16 and rotating inlet duct 14 and with the stationary outlet duct 17 and rotating outlet duct 15 which are in turn connected, in the way clarified previously, with the ducts 9 of the blades 2 incorporating the shape-memory laminas 11.

[0021] The solenoid valves 32, 33 are operatively connected to an electronic control unit 34 that governs driving thereof, as a function of the temperature of the engine lubricant exposed to the flow generated by the fan, according to different logics that can be selectively modified through programming thereof. For detecting the temperature of the engine lubricant a transducer of a conventional type is provided, not illustrated in the drawings, connected to the control unit 34.

[0022] Three examples of possible control logics will now be described with reference to the flowcharts of Figures 10, 11 and 12.

[0023] The control logic exemplified in Figure 10 is of the on/off type: the activation of the shape-memory laminas 11 is connected to the maximum deformation attainable for a given arrangement of the laminas themselves. The parameter that determines circulation of the hot/cold glycol is obviously the temperature of the lubricating oil detected inside the engine. If the temperature detected exceeds an upper threshold value (for example, 80°C), set in the testing stage, the electronic control unit 34 actuates the solenoid valves 32 and 33 so as to open the communication between the hot circuit (first delivery line 25, first return line 26) and the ducts 9 of the blades 2, through the inlet ducts 16, 14 and the outlet ducts 15, 17. The glycol, which is already at the temperature necessary to guarantee maximum deformation of the blade profile, thus circulates in the ducts 9. Once the temperature of the lubricant has dropped to a lower threshold value, which also has been set in the testing stage (for example, 75°C), the control unit 34 interrupts delivery of the hot liquid and opens the communication between the circuit of the cold liquid (second delivery line 29, second return line 30) and the ducts 9, until the blade geometry is brought back into the initial configuration as a result of return of the shape-memory laminas 11 into the starting position. This is obtained in a faster and more efficient way than in the case of a natural, i.e., non-forced, cooling of the laminas 11.

[0024] The deformation set will be equal to the maximum deformation attainable, in relation to the dimensions of the fan and for a given distribution of the shape-memory laminas 11 within each blade 2. Once these operating parameters are fixed it is possible to define the temperature of the hot glycol capable of ensuring the maximum expected deformation.

[0025] The second control logic, implemented according to the flowchart of Figure 11, is instead of a modular type: in the testing stage, all the variables that enable deformation of the blade profile to be brought about up to the required degree of deformation are determined. For a given geometrical arrangement of the shape-memory laminas 11 the first decision regards the expected degree of deformation: this choice is strictly linked to the performance curve of the fan and to the type of the engine to which it is associated. Once these three parameters have been set, it is possible to derive the point of operation of the system and hence the temperature of the glycol that must be reached to guarantee the expected deformation. It follows, for example, that in the presence of fans of modest dimensions the temperature of the glycol capable of activating the shape-memory laminas 11 will be more contained than in the case of fans of larger dimensions.

[0026] Also in this case, activation of the shape-memory laminas 11 is governed as a function of the detected temperature of the engine lubricant. However, unlike the previous logic, it is possible to decide in the testing stage the degree of deformation with which to operate. The choice of not exploiting the maximum deformation of the shape-memory laminas 11, and hence of the blades 2, results in an energy saving deriving from a lower temperature of the incoming glycol, and in a longer fatigue life of the fan that is not used to the maximum of its potential.

[0027] Also with the control logic defined by the flowchart of Figure 11, the upper threshold temperature of the lubricant beyond which activation of the shape-memory laminas 11 occurs is assumed as being 80°C, and the lower threshold temperature 75°C.

[0028] The third control logic exemplified by the flowchart of Figure 12 is also of a modular type, like the previous one, but the decisions during testing regard, in addition to the expected degree of deformation, also the time t_1 necessary for completing the deformation, and hence the reduction of the temperature of the oil. The cooling times are then evaluated in relation to a safety parameter Δt, which is also set in the testing stage. Once the performance curve of the fan and the type of the engine to which it is associated have been identified, as described previously, it is possible to define the point of operation of the system and hence the temperature T_G of the glycol to be reached to guarantee the expected deformation.

[0029] Activation is always determined by measuring the temperature of the engine lubricating oil, but the times fixed in the testing stage enter into play. Consider, for reasons of simplicity, a numerical example: t_1 is assumed as being 120 s, and Δt 50 s. When the temperature of the oil detected is higher than 80°C assumed as upper limit value, circulation of the hot glycol is activated.

[0030] Once a time shorter than $t_1 - \Delta t$ has elapsed, two conditions may present:

- if the temperature of the oil has dropped below the maximum value, it means that the deformation reached has already had the effect of reducing the temperature, and it is thus possible to activate the circuit of the cold glycol and thus complete the cycle of activation;
- if the temperature of the oil is still higher than the threshold value, given that there are once again 70 s available for reducing the temperature, it is sufficient to prolong circulation of the glycol at T_G.

[0031] If, instead, a time equal to or longer than $t_1 - \Delta t$ has elapsed and the temperature of the glycol is still above the threshold of 75°C, a heater further heats the glycol above T_G in such a way as to increase the level of deformation of the blade profile and enable return within the threshold value in the pre-set time.

[0032] In this way, it is possible to guarantee a modular deformation of the blade profile respecting the times set in the testing stage. It is important in this case to emphasize the advantages in terms of energy saving, thanks to the fact that the temperature of the glycol is brought above T_G only when necessary. Moreover, a longer working life of the fan is achieved since it is not used to the maximum of its potential.

[0033] Finally, this third control logic can be viewed in relation to the different environmental conditions in which the fan will operate in use. For example, in the case of operation at low winter temperatures, the conditions could be such as not to require heating of the glycol to a temperature $T > T_G$, thus limiting the power absorbed.

[0034] Of course, without prejudice to the principle of the invention, the details of construction and the embodiments may vary widely with respect to what is described and illustrated herein, without thereby departing from the scope of the invention as defined in the ensuing claims.

[0035] Thus, optimization of the temperatures of transformation of the NiTi shape-memory laminas inserted within the blades can enable use of the hot fluid already present within the vehicle (glycol of the engine cooling system) for activation of the laminas themselves and consequent modification of the blade profile. The hot glycol could be drawn off prior to its entry into the engine radiator and conveyed within the blades of the fan according to the modalities already indicated. At the end of the activation envisaged, cooler fluid will be conveyed into the blades to favour subsequent cooling of the laminas and thus accelerate and favour return of the blades into their initial configuration. In relation to the thermal sizing for the engine of the vehicle, for the cooling step colder glycol could be used by drawing it off at the outlet from the radiator (if ΔT is sufficient) or by providing a dedicated circuit of cooler fluid. In this way, stagnation of hot fluid within the blades is avoided, and return to the initial configuration, which will be facilitated by the convection effect of the flow of air that traverses the fan, is favoured.

[0036] Moreover it may be contemplated, according to a different operating logic, that it is the temperature of the engine compartment, and hence of the air that traverses the fan, that determines optimal configuration of the geometry of the blades that is designed to enable the due flowrate of cooling air. In this case, possibly envisaging that the laminas are partially exposed and consequently lapped by, and in direct contact with, the air to improve heat exchange, it is possible to enable a progressive regulation of the geometry of the blades. The fluid-heating and cooling circuits would no longer be necessary, but the convection effect and the transition of crystalline phases that occur in the laminas in relation to the temperature of the air would bring about continuous adaptation of the geometry of the blades to the required operating conditions.

Claims

1. A variable-geometry fan, in particular for cooling the lubricant of an internal-combustion engine, comprising a rotating hub (1) bearing a ring of blades (2) each having an elastically deformable structure incorporating at least one lamina made of a shape-memory alloy (11), and control means (9, 18, 34) for applying thermal energy to said at least one lamina (11) so as to vary the geometry of the blade (2), said fan being **characterized in that** said control means include a circuit (18) for circulation of a thermal fluid through internal ducts (9) of each blade (2).

2. The fan according to Claim 1, **characterized in that** said circuit (18) for circulation of a thermal fluid includes a first delivery line (25) and a first return line (26) for a hot liquid, a second delivery line (29) and a second return line (30) for a cold liquid, solenoid-valve means (32, 33) for opening and respectively closing the communication between said ducts (9) and said first lines (25, 26) or said second lines (29, 30), and an electronic control unit (34) operatively connected to said solenoid valves (32, 33).

3. The fan according to Claim 2, **characterized in that** said electronic control unit (34) is configured for driving opening and closing of said solenoid-valve means (32, 33) as a function of the temperature of the engine lubricant.

4. The fan according to Claim 3, **characterized in that** said electronic control unit (34) is configured for operating according to selectively modifiable logics.

5. The fan according to one or more of the preceding claims, **characterized in that** said at least one shape-memory lamina (11) is set along said internal ducts (9) of the blade (2).

6. The fan according to Claim 5, **characterized in that** said at least one shape-memory lamina (11) is exposed in said internal duct (9) on both of its faces.

7. The fan according to one or more of the preceding claims, **characterized in that** the hub (1) has a radial distributor (13) communicating with the internal ducts (9) of the blades (2) and connected to an inlet duct (14) and to an outlet duct (15) of said thermal fluid set coaxially with respect to the hub (1).

8. The fan according to Claim 7, **characterized in that** said inlet and outlet ducts include respective rotatable sections (14, 15) turning with said hub (1) and connected to respective stationary sections (16, 17) via sliding-seal connectors (19, 20; 21, 22).

9. The fan according to Claim 8, **characterized in that** said sliding-seal connectors (19, 20; 21, 22) include annular sliding bearings (23; 24).

10. The fan according to one or more of the preceding claims, **characterized in that** each blade (2) is formed by a pair of half-shells (3, 4) seal-fitted together and having respective channels (5, 6) facing one another to form said ducts (9).

11. The fan according to one or more of the preceding claims, **characterized in that** said thermal fluid is constituted by the coolant of the internal-combustion engine.

12. A method for controlling the geometry of the blades of a variable-geometry fan, in particular for cooling the lubricant of an internal-combustion engine, in which said blades (2) have an elastically deformable structure incorporating laminas made of a shape-memory alloy (11) to which thermal energy is applied, said method being **characterized in that** application of the thermal energy envisages circulation of a thermal fluid through internal ducts (9) of each blade (2), to which ducts (9)said laminas (11) are exposed.

13. The method according to Claim 12, **characterized in that** the thermal fluid includes a hot liquid and a cold liquid, circulation of which through said internal ducts (9) is controlled as a function of the temperature of the lubricant of the engine to which the fan is applied.

14. The method according to Claim 12, **characterized in that** said thermal fluid is the coolant of the internal-combustion engine to which the fan is applied.

FIG. 1

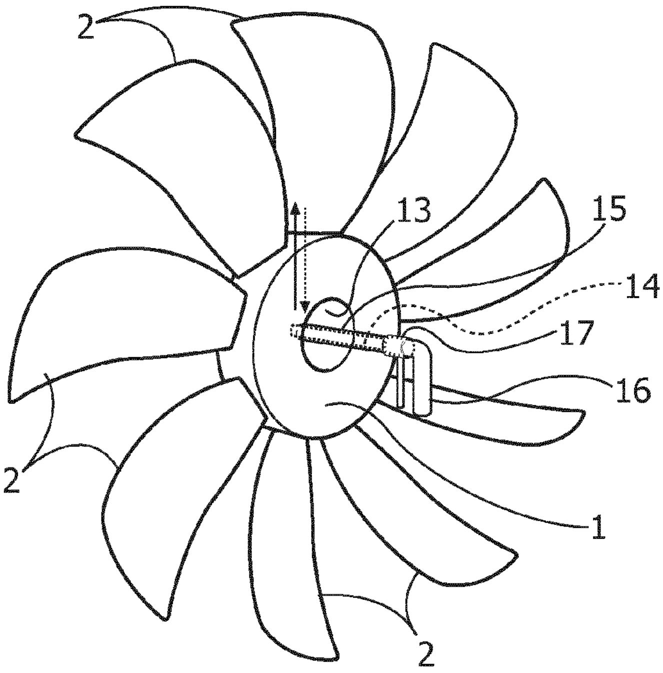
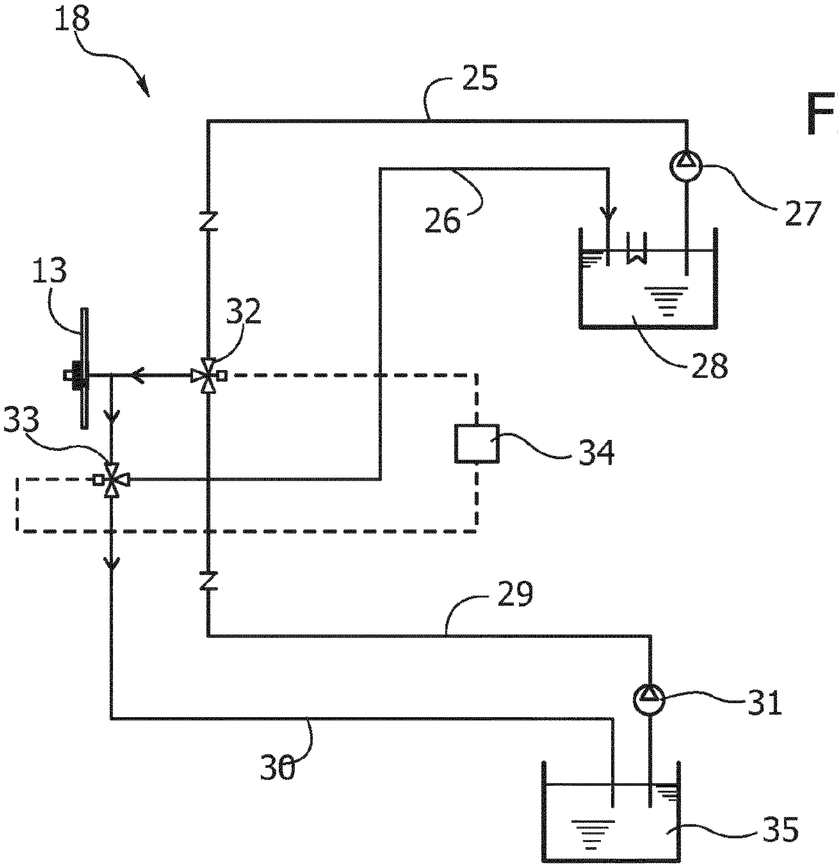


FIG. 2



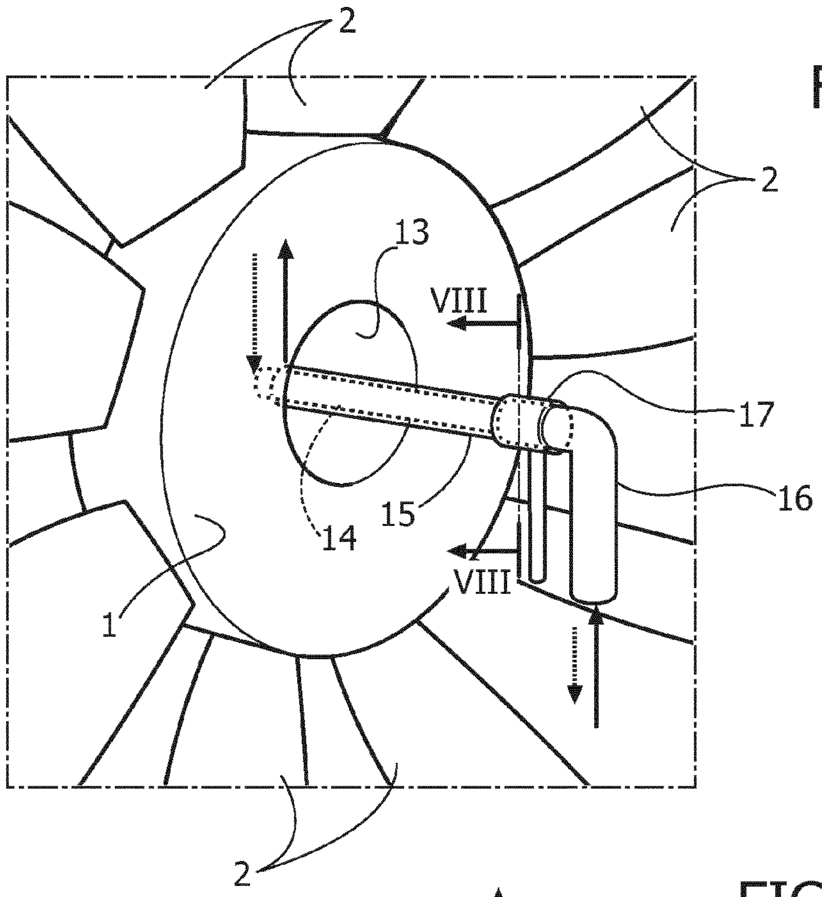


FIG. 3

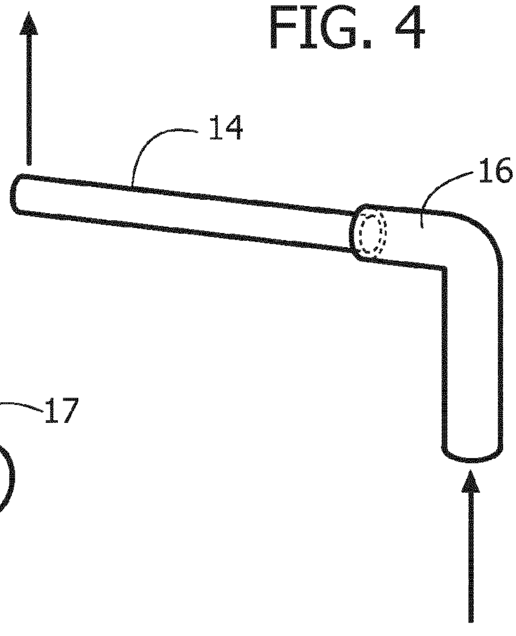


FIG. 4

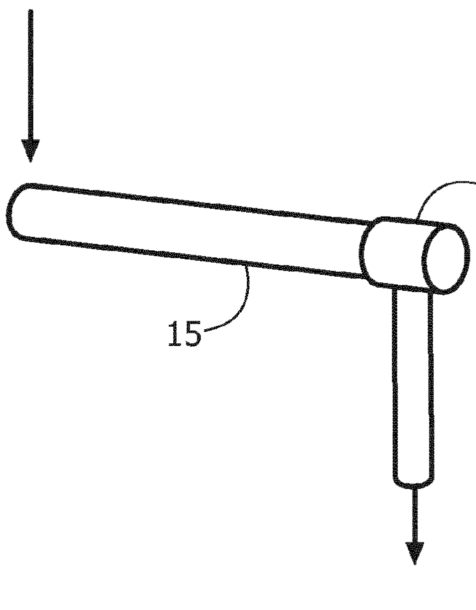


FIG. 5

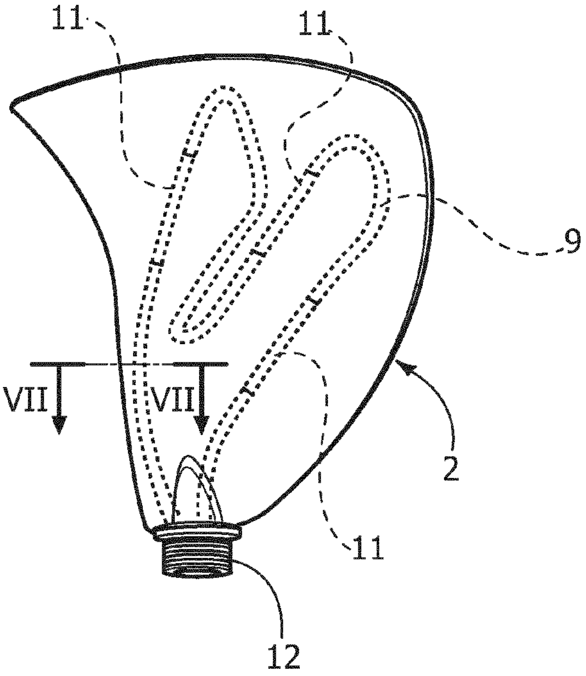


FIG. 6

FIG. 7

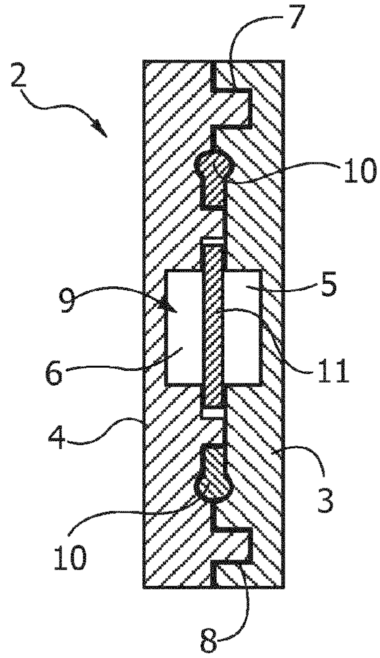


FIG. 8

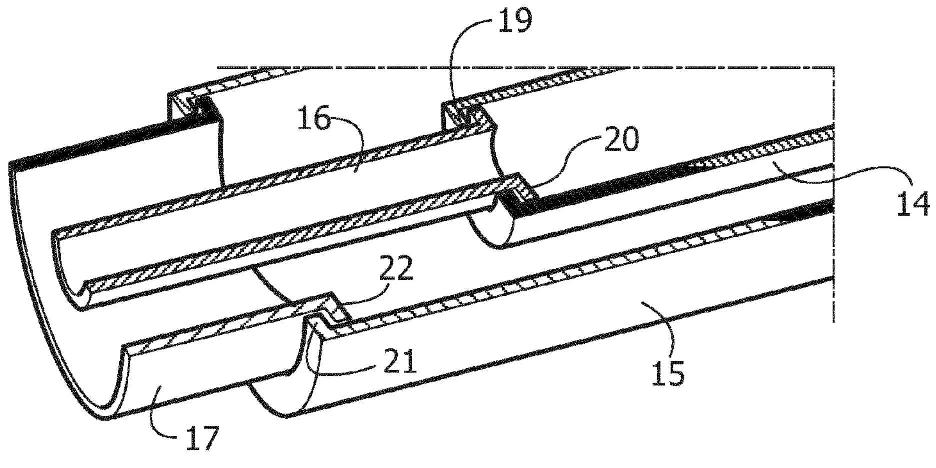


FIG. 9

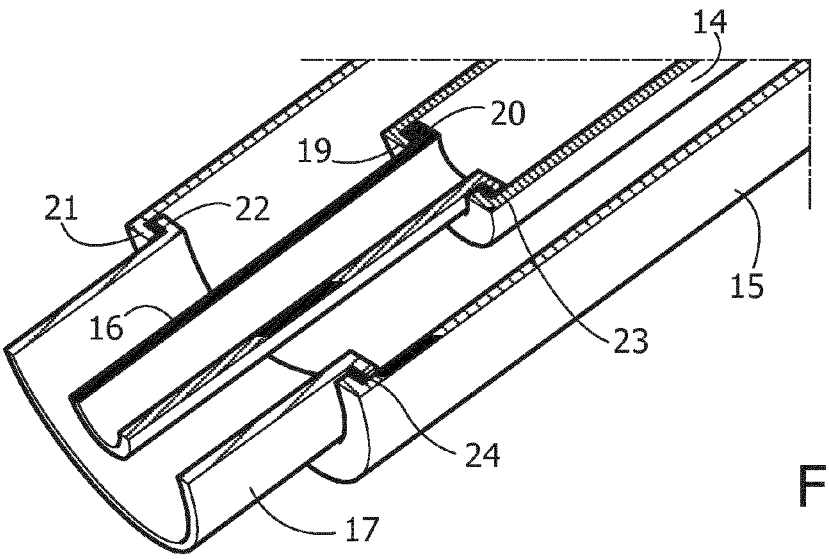

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FIG. 10

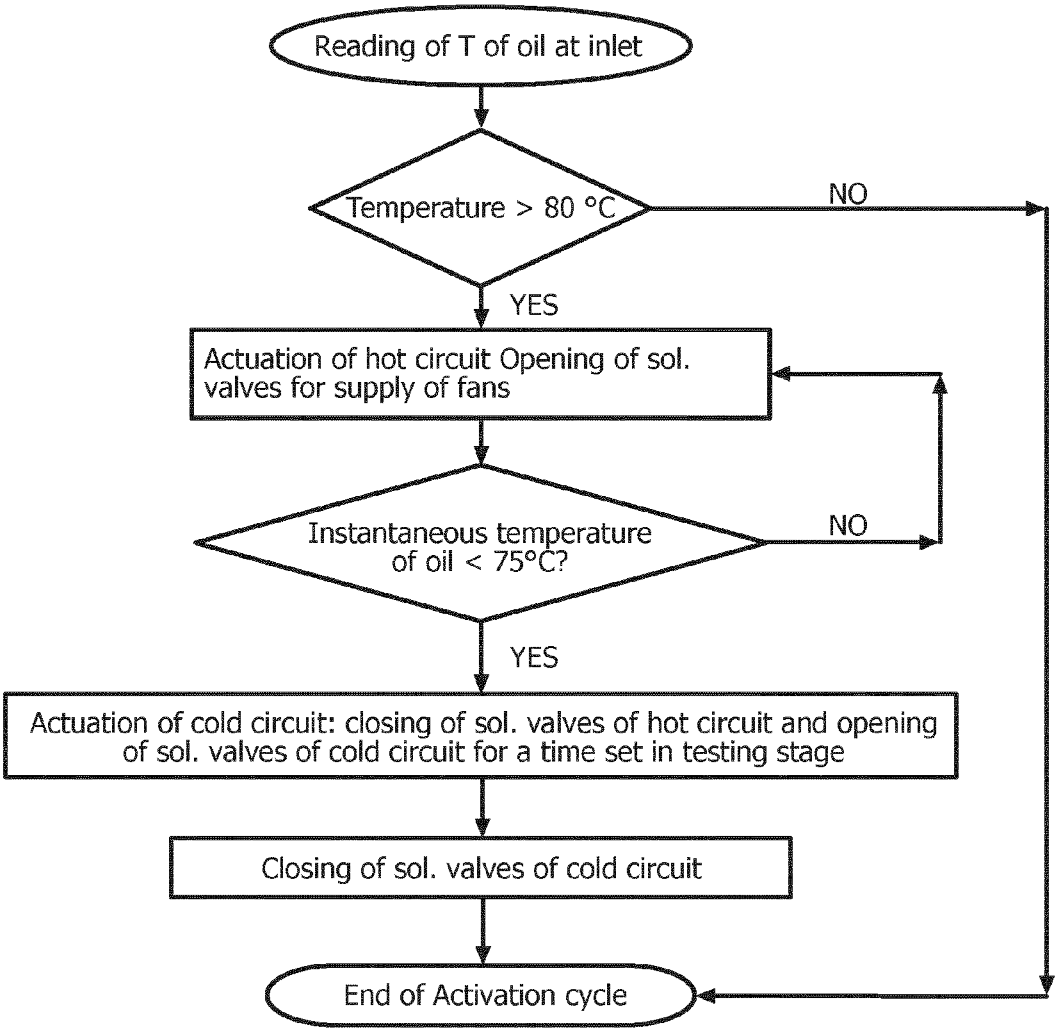

Reading of T of oil at inlet
Temperature > 80 °C
NO
YES
Actuation of hot circuit Opening of sol. valves for supply of fans
Instantaneous temperature of oil < 75°C?
NO
YES
Actuation of cold circuit: closing of sol. valves of hot circuit and opening of sol. valves of cold circuit for a time set in testing stage
Closing of sol. valves of cold circuit
End of Activation cycle

FIG. 11

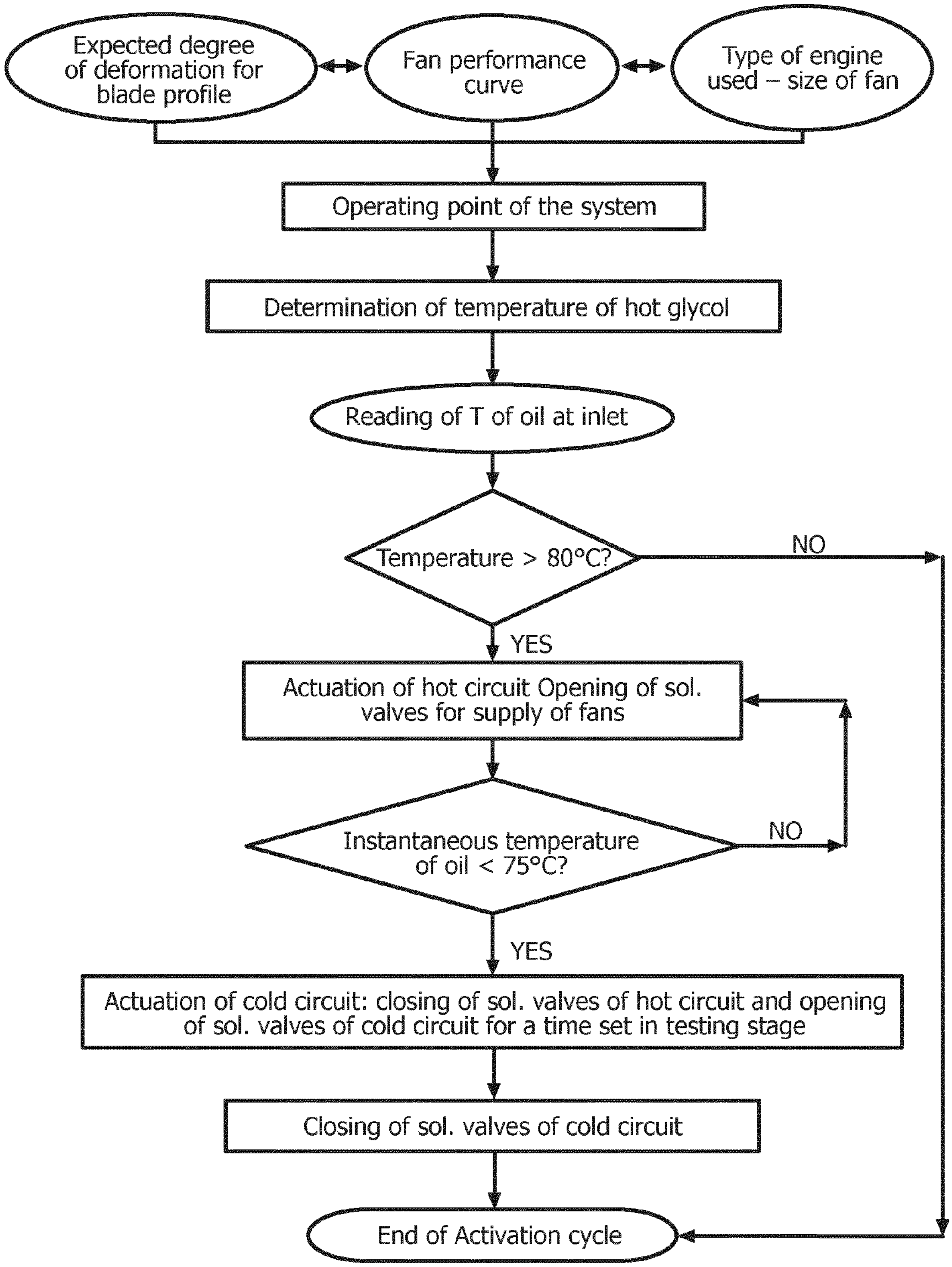
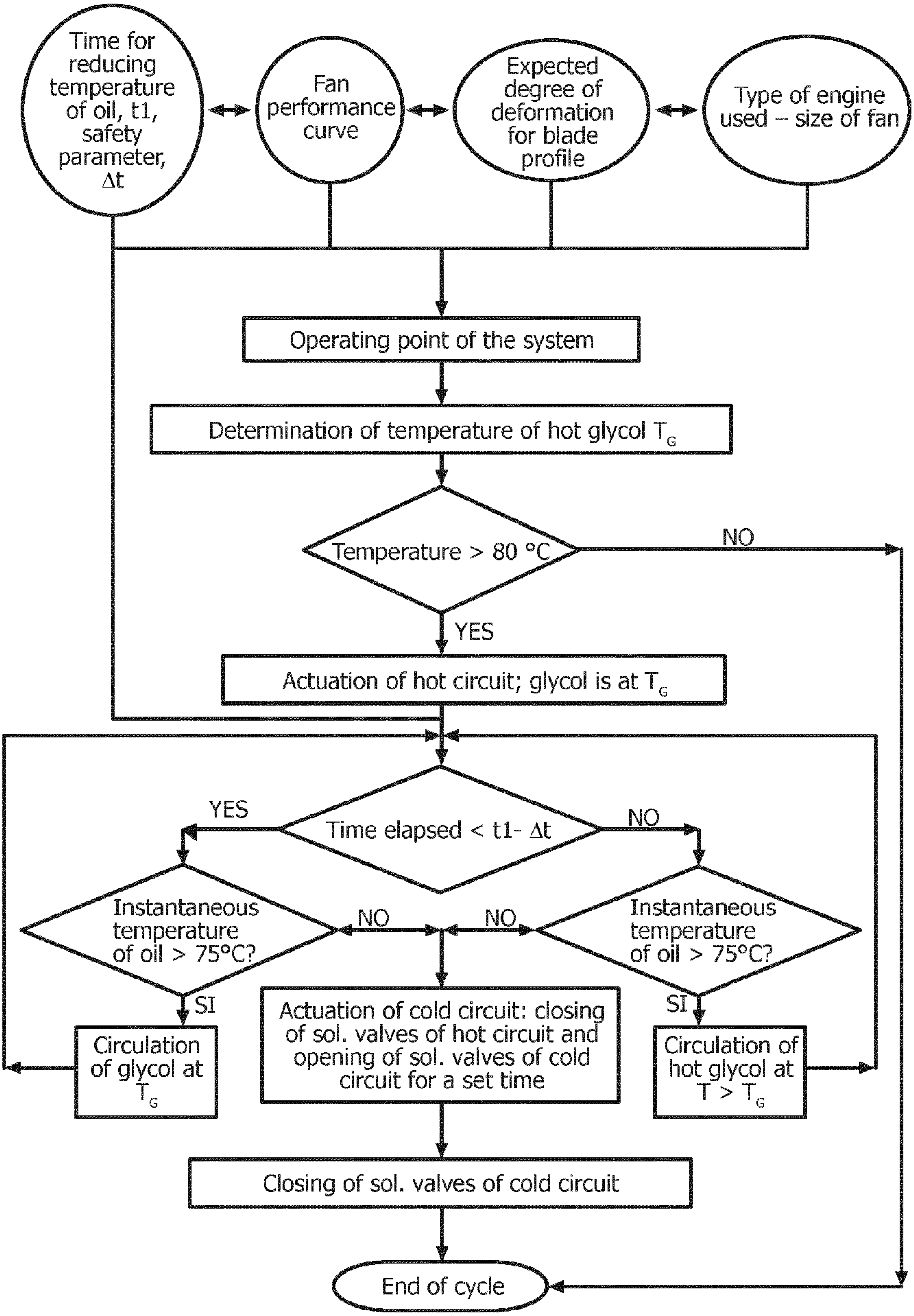

Expected degree of deformation for blade profile
Fan performance curve
Type of engine used – size of fan
Operating point of the system
Determination of temperature of hot glycol
Reading of T of oil at inlet
Temperature > 80°C?
NO
YES
Actuation of hot circuit Opening of sol. valves for supply of fans
Instantaneous temperature of oil < 75°C?
NO
YES
Actuation of cold circuit: closing of sol. valves of hot circuit and opening of sol. valves of cold circuit for a time set in testing stage
Closing of sol. valves of cold circuit
End of Activation cycle

FIG. 12


Time for reducing temperature of oil, t1, safety parameter, Δt
Fan performance curve
Expected degree of deformation for blade profile
Type of engine used – size of fan
Operating point of the system
Determination of temperature of hot glycol T_G
Temperature > 80 °C
NO
YES
Actuation of hot circuit; glycol is at T_G
Time elapsed < t1- Δt
YES
NO
Instantaneous temperature of oil > 75°C?
NO
NO
Instantaneous temperature of oil > 75°C?
SI
SI
Circulation of glycol at T_G
Actuation of cold circuit: closing of sol. valves of hot circuit and opening of sol. valves of cold circuit for a set time
Circulation of hot glycol at T > T_G
Closing of sol. valves of cold circuit
End of cycle

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 2078865 A2 **[0003] [0011]**