

(19)



(11)

EP 2 025 870 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

18.02.2009 Bulletin 2009/08

(51) Int Cl.:

F01D 5/18 (2006.01)

(21) Application number: **08161606.2**

(22) Date of filing: **31.07.2008**

(84) Designated Contracting States:

**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HR HU IE IS IT LI LT LU LV MC MT NL NO PL PT
RO SE SI SK TR**

Designated Extension States:

AL BA MK RS

(30) Priority: **31.07.2007 IT MI20071564**

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(54) Method for modifying a gas turbine blade

(57) A method for modifying a gas turbine blade (1) provided with an internal cooling circuit (3) in which a cooling fluid flows provides for calculating a distribution of the external temperature (T_E) of the blade (1); identifying critical zones of the blade (1) in which the external temperature (T_E) of the blade (1) exceeds a predetermined limit (T_L); and calculating a configuration of a plurality of through holes (16) to be made in the blade (1) and connected to the cooling circuit (3) of the blade (1) for lowering the external temperature (T_E) of said critical zones below the predetermined limit (T_L).

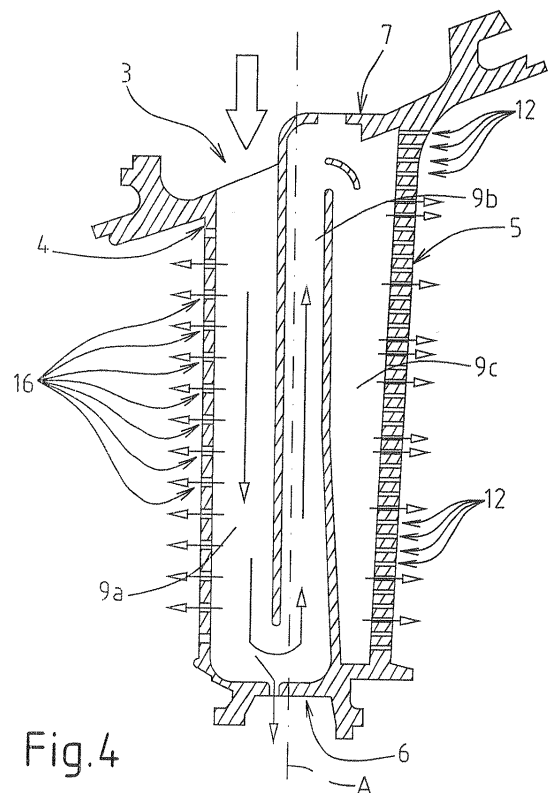


Fig.4

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Description

[0001] The present invention relates to a method for modifying a gas turbine blade. Specifically, the present invention relates to a method for modifying a gas turbine blade which, during system operation, highlighted damages caused by overheating.

[0002] A known type of gas turbine blade extends along a longitudinal axis and is provided with a cooling circuit in which a cooling fluid, generally air, flows. The cooling circuit includes a pipe coil-arranged inside the blade, which communicates with the outside of the blade by means of channels, essentially orthogonal to the blade axis and leading at the trailing edge of the blade. The air flow which flows in the cooling circuit removes heat by convection and lowers the temperature of the blade.

[0003] However a cooling circuit of this type is not always sufficient to ensure an adequate level of cooling, above all when the external wall of the blade is subjected to high temperature gas flows. Therefore, the material of the blade overheats and undergoes thermo-mechanical fatigue damages (cracks).

[0004] The leading edge of the blade is the zone which is the most subjected to this type of damage because its geometric conformation makes the internal convection cooling thereof extremely difficult.

[0005] Conventionally, the blades which show thermo-mechanical fatigue damages are repaired and reinstalled on the turbine because replacing the damaged blade with a new blade is too expensive. Repairing the damage, however, does not eliminate the problem of thermo-mechanical fatigue damages, which reoccur after a short time and essentially in the same points.

[0006] It is an object of the present invention to provide a method for modifying a gas turbine blade which is free from the drawbacks of the prior art noted herein; specifically, it is an object of the present invention to provide a method for modifying a gas turbine blade which results in a blade able to bear the thermal stresses to which the operating blade is subjected and which, at the same time, is simple and quick to be applied.

[0007] In accordance with these objects, the present invention relates to a method for modifying a gas turbine blade provided with an internal cooling circuit in which a cooling fluid flows; the method being characterized in that it includes the steps of:

- calculating a distribution of the external temperature of the blade;
- identifying critical zones of the blade in which the external temperature of the blade exceeds a predetermined limit;
- calculating a configuration of a plurality of through holes to be made in the blade and connected to the cooling circuit of the blade to cool said critical zones.

[0008] Further features and advantages of the present invention will be apparent from the following description

of a non-limitative embodiment thereof, with reference to the figures in the accompanying drawings, in which:

- figure 1 is a perspective view, with parts in section and parts removed for clarity, of a first detail of a gas turbine blade;
- figure 2 is a section view, with parts removed for clarity, of the blade in figure 1;
- figure 3 is a perspective view, with parts in section and parts removed for clarity, of a detail of a gas turbine blade modified in accordance with the method according to the present invention;
- figure 4 is a section view, with parts removed for clarity, of the blade in figure 3;
- figure 5 is a flow chart of the method for modifying a blade according to the present invention;
- figure 6 is a flow chart of a detail of the method for modifying a blade in figure 5;
- figure 7 is a flow chart of a detail of the method for modifying a blade in figure 5;
- figure 8 is a flow chart of a detail of the method for modifying a blade in figure 5; and
- figure 9 is a flow chart of a detail of the method for modifying a blade in figure 5.

[0009] In figure 1, reference number 1 indicates a blade of a gas turbine (not shown in the accompanying figures for simplicity), which extends along an axis A and is provided with a cooling circuit 3 in which a cooling fluid flows.

[0010] With reference to figure 2, the blade 1 comprises a leading edge 4, a trailing edge 5, a lower base 6, and an upper base 7, opposite to the lower base 6.

[0011] The cooling circuit 3 includes a pipe 9, coil-arranged and essentially defined by three segments 9a, 9b, 9c parallel to the axis A, an exhaust channel 10 arranged on the lower base 6 of the blade 1, and a plurality of channels 12, essentially arranged orthogonally to axis A of the blade along the trailing edge 5 of the blade 1.

[0012] The cooling fluid, generally air, enters the pipe 9 at the upper base 7 of the blade 1, flows in the pipe 9 and exits from the blade 1 through the exhaust channel 10 and the channels 12 (as shown by the arrows in figure). The cooling fluid flow inside the cooling circuit 3 allows to remove heat by convection and thus to lower the external temperature T_E of the blade 1.

[0013] Figure 3 shows the blade 1 modified in accordance with the method for modifying a gas turbine blade according to the present invention. Specifically, the modified blade 1 includes a plurality of film cooling holes 16 arranged along the leading edge 4. In the accompanying figures and in the examples described, the film cooling holes 16 are made along the leading edge 4, which is the most stressed zone from a thermal point of view during the operation of the blade 1 and thus requires a more incisive cooling action. It is understood that the method for modifying a blade, which will be described hereinafter, provides for calculating the optimal configuration, design-

ing and making the film cooling holes 16 in each zone of the blade 1 which has shown thermal strength problems.

[0014] Figure 4 shows the cooling circuit 3 of the blade 1 modified in accordance with the method for modifying a blade according to the present invention. The segment 9a of the modified cooling circuit 3 is directly connected to the through holes 16. Through the holes 16 the cooling fluid flows, which laps on the external surface of the modified blade 1, thus promoting the lowering of the external temperature T_E in the zone located about the holes 16. In the case of the example shown in the accompanying figures, the zone of the blade 1 which is externally lapped by the cooling fluid is the leading edge 4.

[0015] With reference to figure 5, the method for modifying a gas turbine blade according to the present invention essentially includes the steps of:

- calculating a distribution of the external temperature T_E of the blade 1 (block 20);
- identifying critical zones of the blade 1 in which the external temperature T_E of the blade exceeds a predetermined limit T_L (block 21);
- calculating a configuration of a plurality of through holes 16 to be made in the blade 1 for lowering the external temperature T_E in said critical zones below the predetermined limit T_L (block 22); and
- selectively calculating a new configuration of the cooling circuit 3 of the blade 1 (block 23).

[0016] Preferably, such a method applies to blades which have shown the presence of cracks during the laboratory tests which are normally carried out after approximately 25000 working hours. These tests usually include the use of fluorescent fluids which penetrate into the cracks, thus highlighting them.

[0017] With reference to figure 6, for calculating the distribution of the external temperature T_E of the blade 1 (block 20), the method firstly includes supplying a numeric model of the cooling circuit 3 of the blade 1 (block 26). Specifically, the numeric model of the cooling circuit 3 is essentially a combination of models (curve, pipe, bottleneck), the fluid-dynamic variable simulation of which is known.

[0018] The method then includes measuring a flow rate Q_M of the cooling fluid flowing in the cooling circuit 3 of the blade 1 (block 27); preferably, such a measurement is experimentally carried out by connecting the blade 1 to a pressurized circuit (not shown in the accompanying figures) provided with flow rate meters.

[0019] Subsequently, the numeric model of the cooling circuit 3 is calibrated according to the flow rate value Q_M of the cooling fluid (block 29) and tentative values T_{ET} of the external temperature of the blade 1 along a plurality of sections of the blade are determined (block 30).

[0020] At this point, the method includes calculating the values of the internal heat exchange coefficient C_I and the values of the external heat exchange coefficient C_E along the plurality of sections of the blade (block 31).

Specifically, the external heat exchange coefficient C_E is preferably calculated by means of the fluid-dynamic analysis of the thermal flow between gas and blade 1, while the internal heat exchange coefficient C_I is preferably calculated by means of a one-dimensional thermal analysis to evaluate the thermal flow between cooling fluid and blade 1.

[0021] Finally, if the internal heat exchange coefficient C_I and the external heat exchange coefficient C_E are not the same, the method includes updating the value or the values of the tentative external temperature T_{ET} , otherwise the tentative values T_{ET} are considered as external temperature T_E of the blade 1 (block 33).

[0022] With reference to figure 7, the step of calculating the configuration of the plurality of holes 16 (block 22) includes calculating the number N of through holes 16 and the diameter D of the holes 16 to be made in the blade 1. Specifically, the method provides for determining a tentative diameter value D_T of the holes 16 (block 35); determining a tentative number of holes N_T (block 36); calculating external temperature values T_E of the blade 1 according to the tentative number of holes N_T and to the tentative diameter value D_T (block 37); updating the tentative number of holes N_T if at least one external temperature value T_E is higher than the predetermined limit T_L and updating the tentative diameter value D_T of the holes 16 if at least one external temperature value T_E is higher than the predetermined limit T_L (critical condition) and if the tentative number of holes N_T is higher than a maximum number of holes N_L , defined beforehand on the basis of structural considerations.

[0023] With reference to figure 8, the step of calculating the configuration of the plurality of holes 16 (block 22) may be similarly carried out by firstly determining a tentative number of holes N_T (block 50); determining a tentative diameter D_T (block 51); calculating the external temperature T_E of the blade 1 according to the tentative diameter value D_T of the holes 16 and the tentative number of holes N_T (block 52); updating the tentative diameter D_T if at least one external temperature value T_E is higher than the predetermined limit T_L and finally updating the tentative number of holes N_T if at least one external temperature value T_E is higher than the predetermined limit T_L and if the tentative diameter value D_T is higher than a maximum diameter value D_L .

[0024] With reference to figure 9, once the configuration of a plurality of holes 16 (block 22) has been calculated, the method provides for selectively calculating a new configuration of the cooling circuit 3 of the blade 1 (block 23). Specifically, the calculation of the new configuration of the cooling circuit 3 is carried out if the available flow rate Q_M of the cooling fluid which is measured on the blade 1 before making the holes 16 is not sufficient for the new cooling system 3 provided with film cooling holes 16. Therefore, the method firstly provides for measuring the available flow rate Q_M of cooling fluid (block 60); such a measurement is carried out experimentally on the blade 1 which needs to be modified.

[0025] Subsequently, the method provides for calculating the requested flow rate Q_C of the cooling fluid flowing in the cooling circuit 3 connected to the holes 16 (block 61); such a flow rate Q_C is calculated considering the previously described numeric model. At this point, if the requested flow rate Q_C is higher than the available flow rate Q_M , the method provides for modifying the cooling circuit 3 so that the requested flow rate Q_C is either lower than or equal to the available flow rate Q_M .

[0026] Specifically, modifying the cooling circuit 3 includes calculating new tentative passage sections S_T of the cooling circuit 3 (block 62) and recalculating the requested flow rate Q_C (block 61) assuming that the cooling circuit is provided with the new tentative passage sections S_T . If the requested, newly calculated flow rate Q_C is still higher than the available flow rate Q_M , the tentative passage sections S_T are updated (block 62) and the requested flow rate Q_C is recalculated (block 61).

[0027] Once the optimal configuration of the cooling holes 16 and of the cooling circuit 3 has been obtained, the method provides for making holes 16 in the blade 1 according to the calculated configuration of the holes 16, and for possibly modifying the sections of the cooling circuit 3 of the blade 1 according to the calculated new configuration of the cooling circuit 3.

[0028] The present invention has the following advantages.

[0029] Firstly, in virtue of the method according to the present invention, it is possible to reuse a blade damaged by thermal stresses ensuring its correct cooling in operating conditions. This implies a considerable economic saving because the replace of the damaged blade with a new blade or the frequent repair of the damaged blade is avoided.

[0030] Furthermore, the method according to the present invention is particularly fast and effective for designing the configuration of film cooling holes and of the cooling circuit. Indeed, the method may essentially be fully automated and uses practical and fast calculation tools.

[0031] It is finally apparent that changes and variations may be made to the method described herein without departing from the scope of the appended claims.

Claims

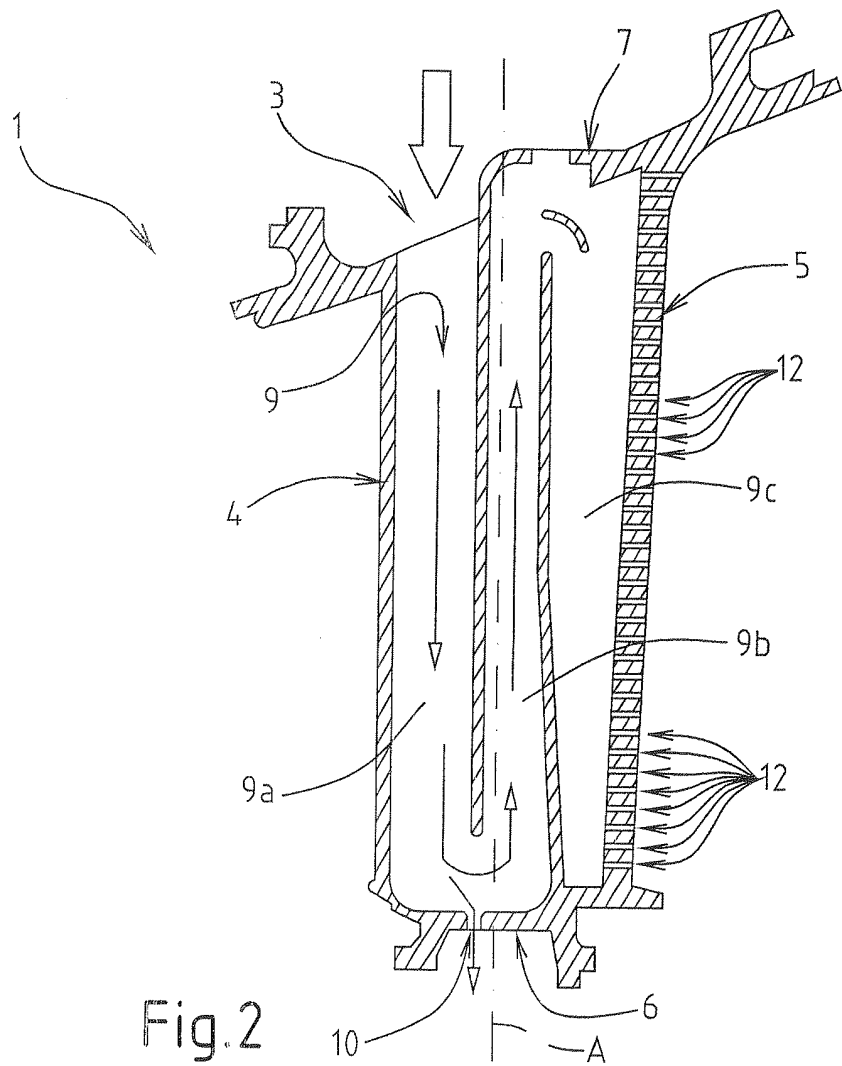
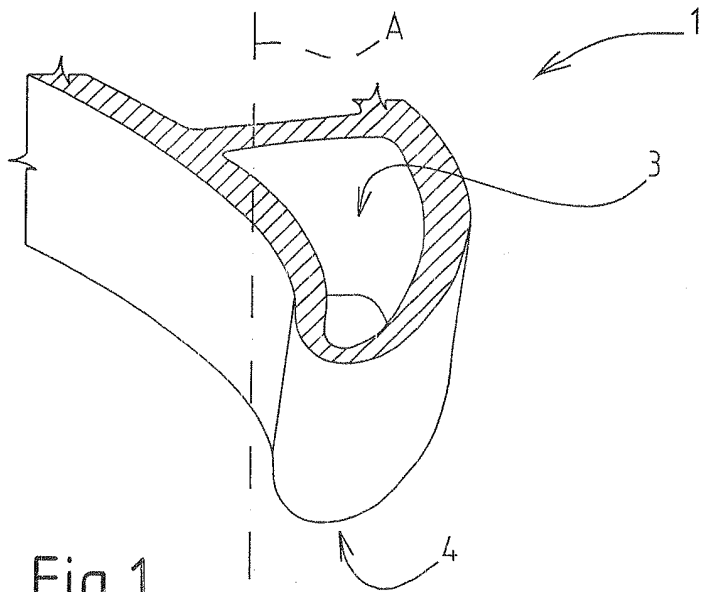
1. A method for modifying a gas turbine blade (1) provided with an internal cooling circuit (3) in which a cooling fluid flows; the method being **characterized in that** it includes the steps of:

calculating a distribution of the external temperature (T_E) of the blade (1);
 identifying critical zones of the blade (1) in which the external temperature (T_E) of the blade (1) exceeds a predetermined limit (T_L);
 calculating a configuration of a plurality of

through holes (16) to be made in the blade (1) and connected to the cooling circuit (3) of the blade (1) for lowering the external temperature (T_E) of said critical zones below the predetermined limit (T_L).

2. A method according to claim 1, **characterized in that** the step of calculating the configuration of a plurality of holes (16) includes the step of calculating the number (N) of holes (16) and the diameter (D) of the holes (16) to be made in the blade (1).
3. A method according to claim 2, **characterized in that** the step of calculating the number (N) of holes (16) and the diameter (D) of the holes (16) includes the step of determining a tentative diameter value (D_T) of the holes (16); determining a tentative number of holes (N_T); calculating the external temperature (T_E) values of the blade (1) according to the tentative number of holes (N_T) and to the tentative diameter value (D_T); updating the tentative number of holes (N_T) if at least one external temperature value (T_E) is higher than the predetermined limit (T_L).
4. A method according to claim 3, **characterized in that** the step of calculating the number (N) of holes (16) and the diameter (D) of the holes (16) includes the step of updating the tentative diameter value (D_T) if the tentative number of holes (N_T) is equal to a maximum number of holes (N_L) and if at least one external temperature value (T_E) is higher than the predetermined limit (T_L).
5. A method according to claim 2, **characterized in that** the step of calculating the number (N) of holes (16) and the diameter (D) of the holes (16) includes the step of determining a tentative number of holes (N_T); determining a tentative diameter value (D_T); calculating the external temperature values (T_E) of the blade (1) according to the tentative diameter value (D_T) and to the tentative number of holes (N_T); updating the tentative diameter value (D_T) if at least one external temperature value (T_E) is higher than the predetermined limit (T_L).
6. A method according to claim 5, **characterized in that** the step of calculating the number (N) of holes (16) and the diameter (D) of the holes (16) includes the step of updating the tentative number of holes (N_T) if the tentative diameter value (D_T) is equal to a maximum diameter value (D_L) and if at least one external temperature value (T_E) is higher than the predetermined limit (T_L).
7. A method according to anyone of the preceding claims, **characterized in that** the step of calculating the distribution of the external temperature (T_E) of the blade (1) includes the steps of:

- providing a numeric model for the cooling circuit (3) of the blade (1);
 measuring a flow rate (Q_M) of cooling fluid flowing in the cooling circuit (3) of the blade (1);
 determining a distribution of tentative external temperature values (T_{ET}) of the blade (1) along a plurality of sections of the blade (1);
 calculating the values of the internal heat exchange coefficient (C_I) between the blade (1) and the cooling fluid and the values of the external heat exchange coefficient (C_E) between the blade (1) and a working fluid in the turbine along the plurality of sections of the blade (1);
 updating the distribution of the tentative external temperature values (T_{ET}) of the blade (1) if the external heat exchange coefficient (C_E) is different from the internal heat exchange coefficient (C_I).
8. A method according to anyone of the preceding claims, **characterized in that** it includes the step of selectively calculating a new configuration of the cooling circuit (3) of the blade (1).
9. A method according to claim 8, **characterized in that** the step of selectively calculating a new configuration of the cooling circuit (3) of the blade (1) includes:
- measuring an available flow rate (Q_M) of cooling fluid flowing in the cooling circuit (3) of the blade (1);
 measuring a requested flow rate (Q_C) of cooling fluid flowing in the cooling circuit (3) connected to the holes (16);
 if the requested flow rate (Q_C) is higher than the available flow rate (Q_M), modifying the cooling circuit (3) so that the requested flow rate (Q_C) is lower than or equal to the available flow rate (Q_M).
10. A method according to claim 9, **characterized in that** the step of modifying the cooling circuit (3) includes the steps of calculating new tentative passage sections (S_T) of the cooling circuit (3); calculating the requested flow rate (Q_C) in the modified cooling circuit (3) with the new tentative passage sections (S_T); updating the new tentative passage sections (S_T) of the cooling circuit (3) if the requested flow rate (Q_C) is higher than the available flow rate (Q_M).
11. A method according to anyone of the preceding claims, **characterized in that** it includes the step of making the holes (16) according to the calculated configuration.



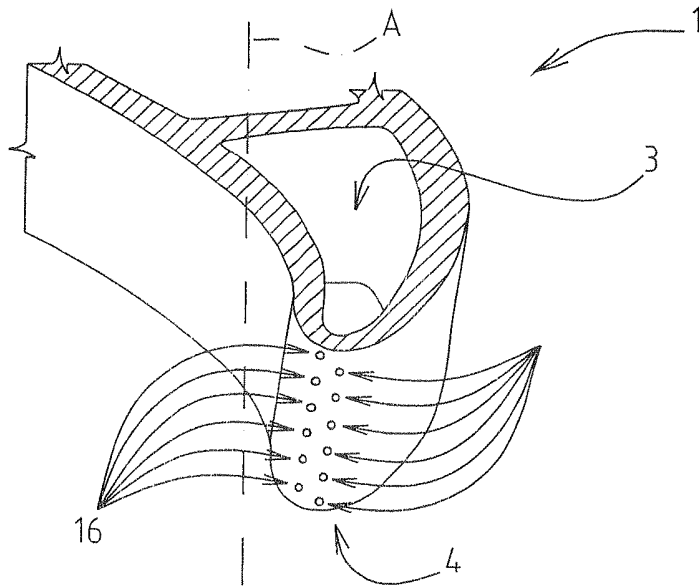


Fig.3

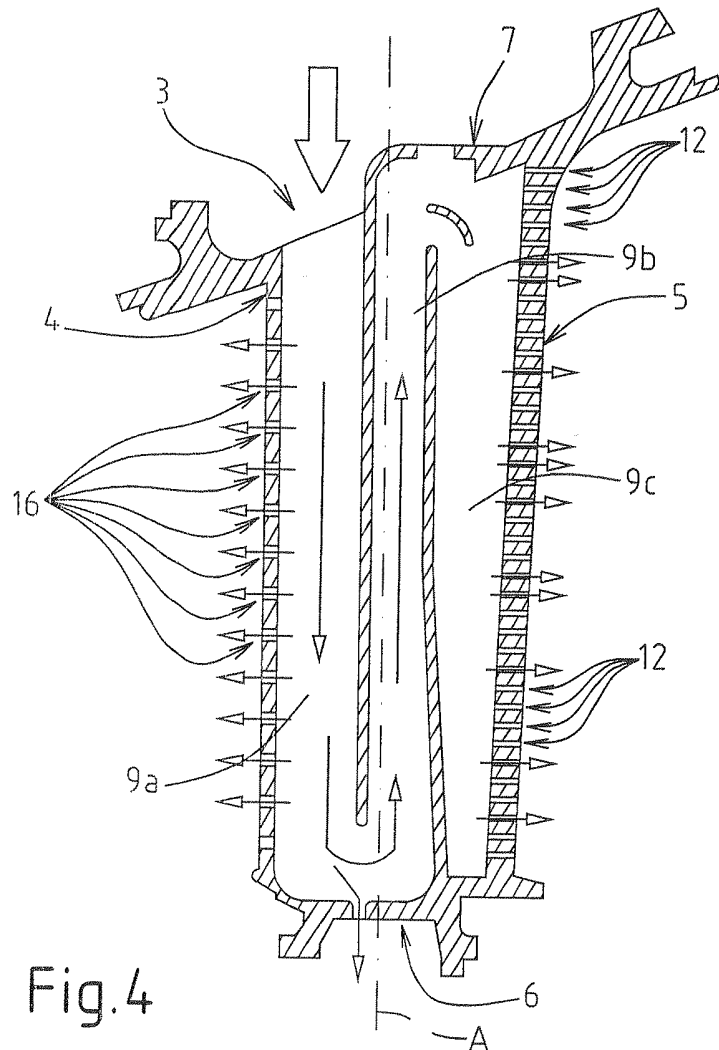


Fig.4

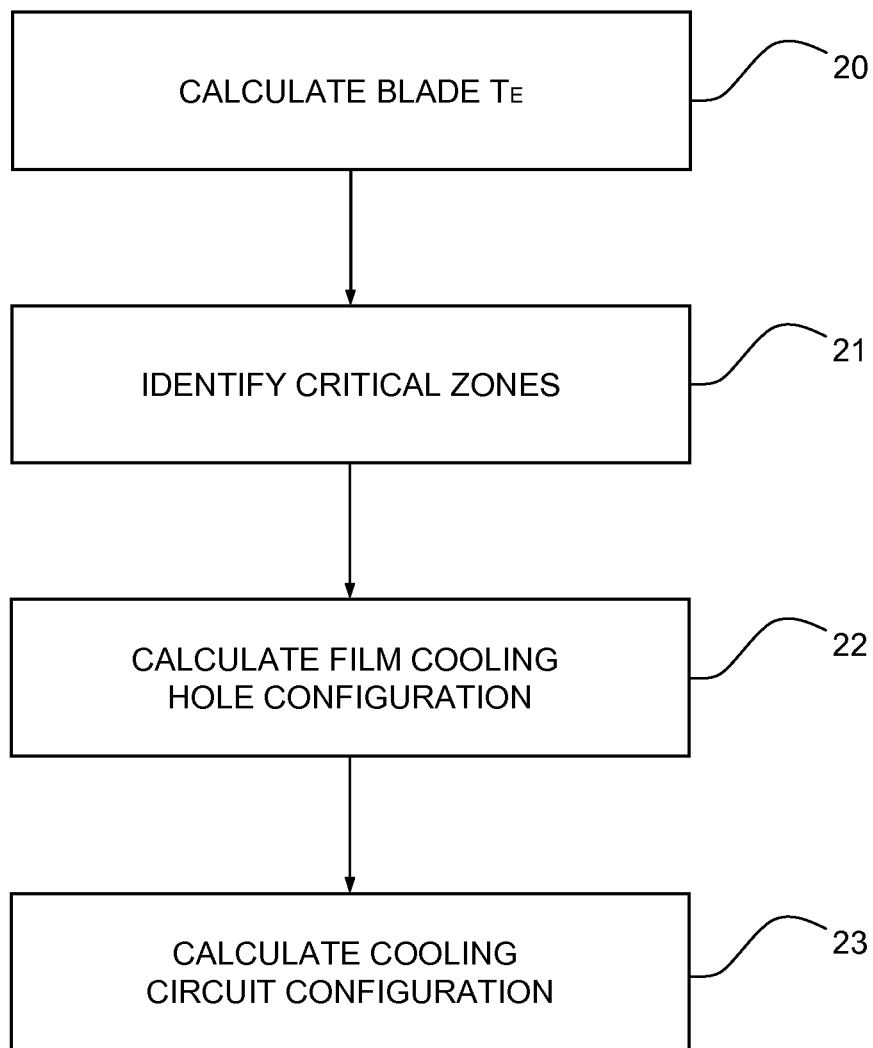


Fig. 5

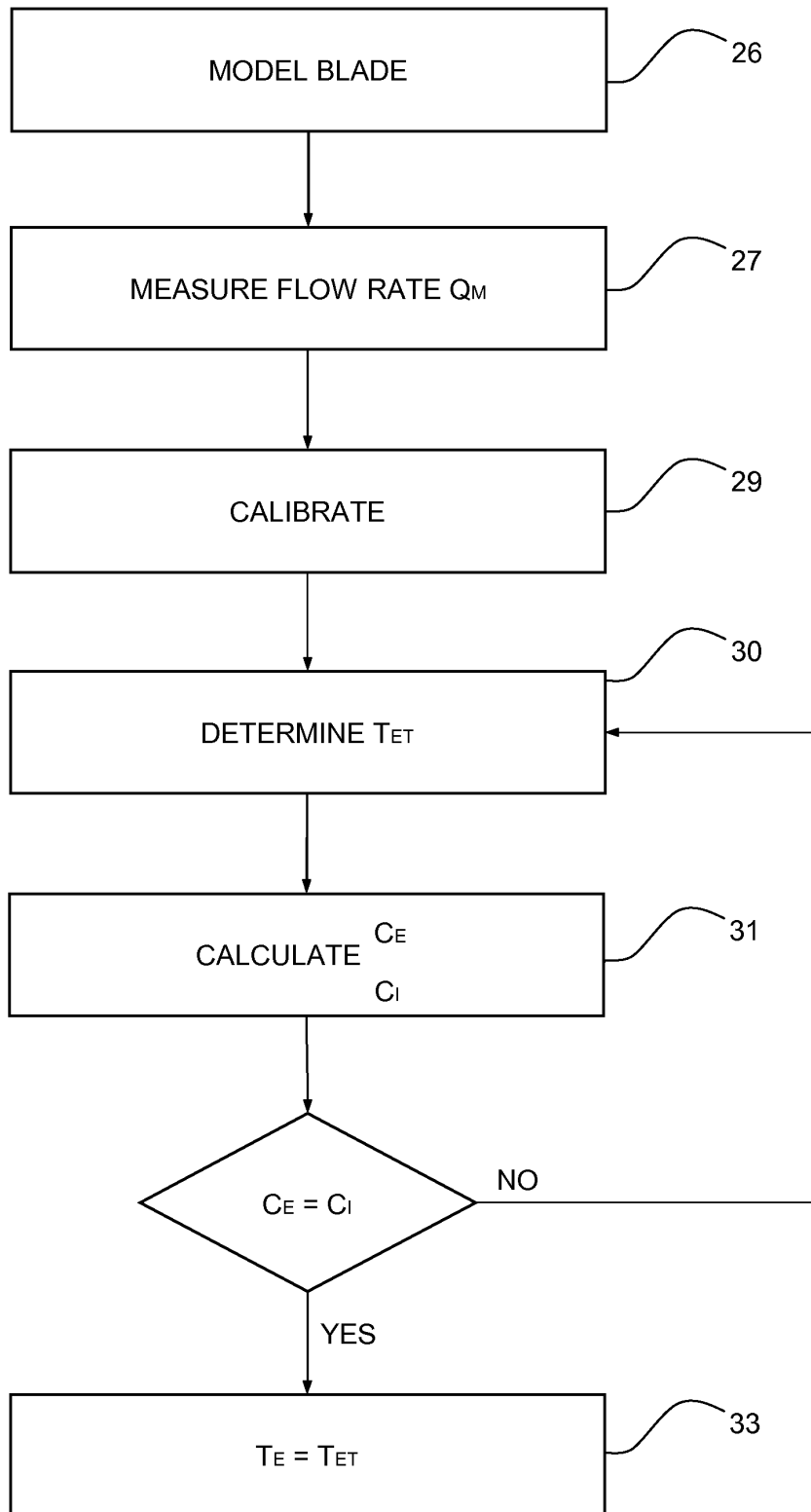


Fig. 6

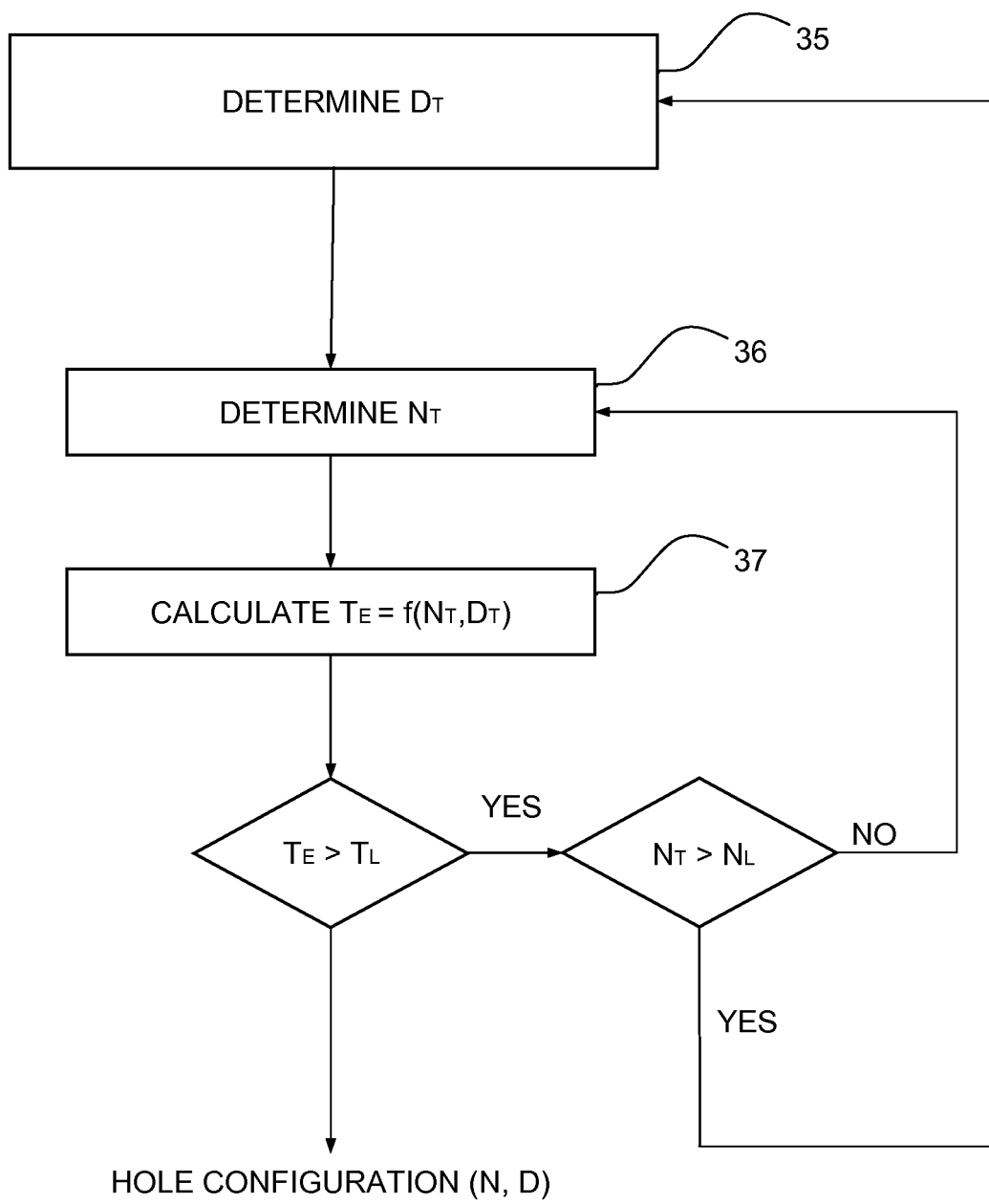


Fig. 7

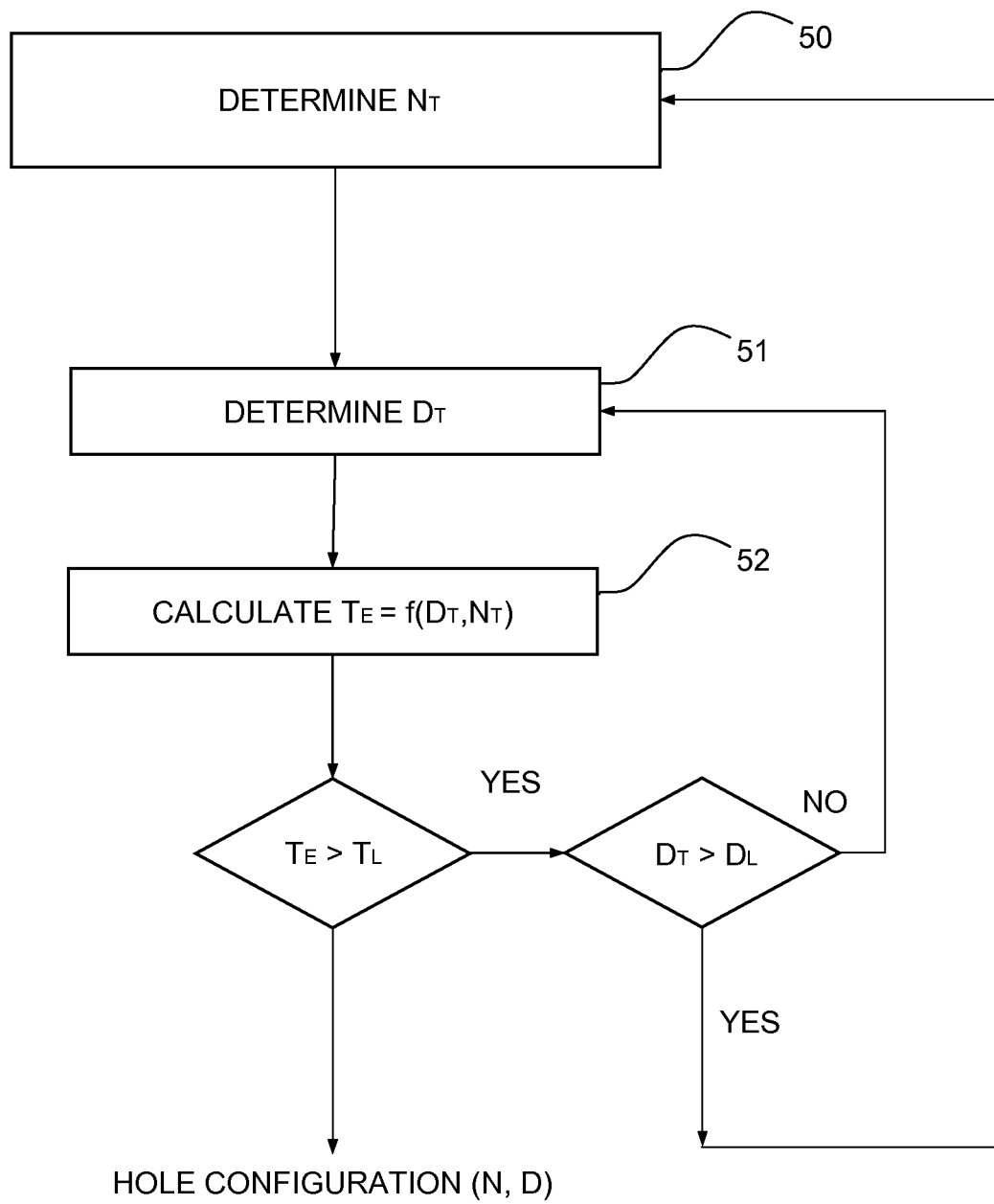


Fig. 8

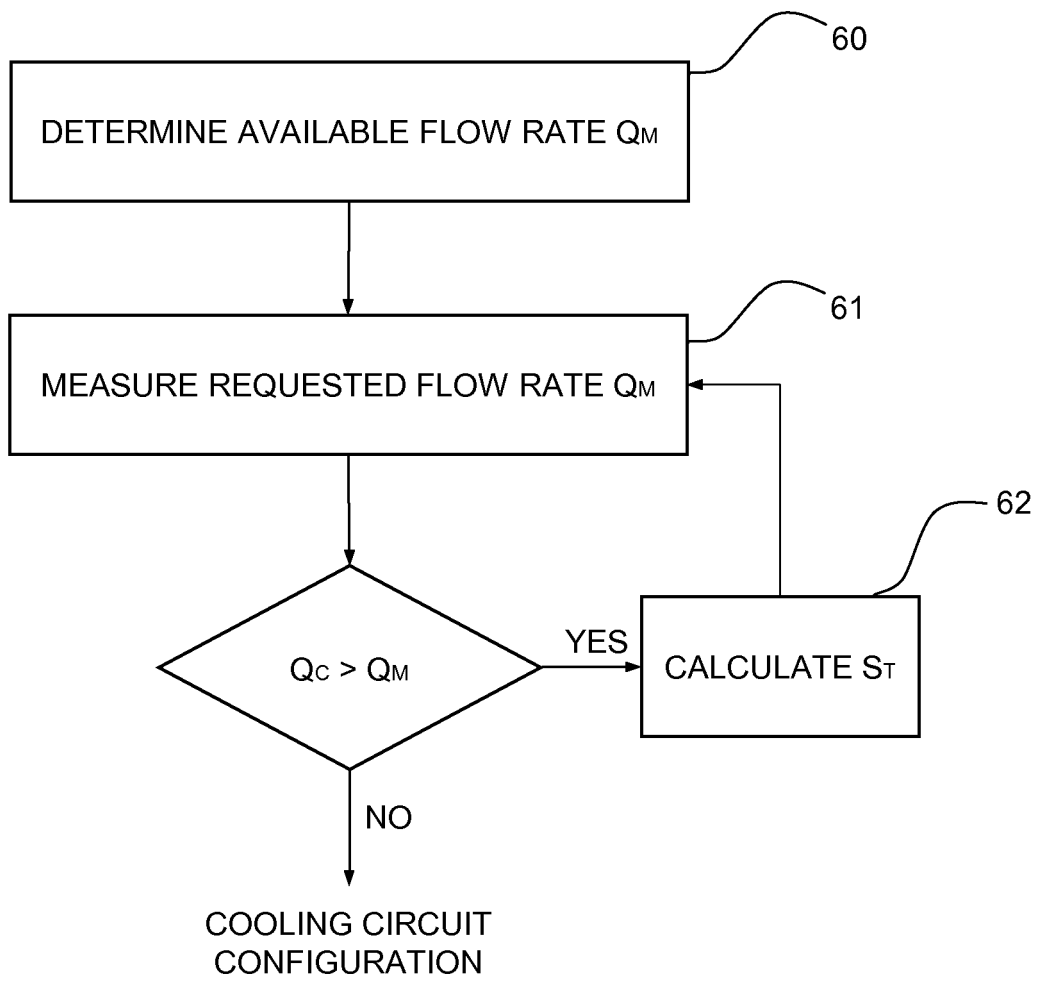


Fig. 9