(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 075 408 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
01.07.2009 Bulletin 2009/27

(51) Int Cl.:
F01D 5/14 *(2006.01)*

(21) Application number: **08173020.2**

(22) Date of filing: **29.12.2008**

(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: **28.12.2007 IT MI20072441**

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(54) **Last stage stator blade of a steam turbine low-pressure section**

(57) A last stage stator blade of a steam turbine low-pressure section has blade sections (S_1, S_2, ..., S_K) at respective section radii (R_{S1}, R_{S2}, ..., R_{SK}), joined according to a tangential stacking line (LEAN). The tangential stacking line (LEAN) is a fourth-order Bezier curve.

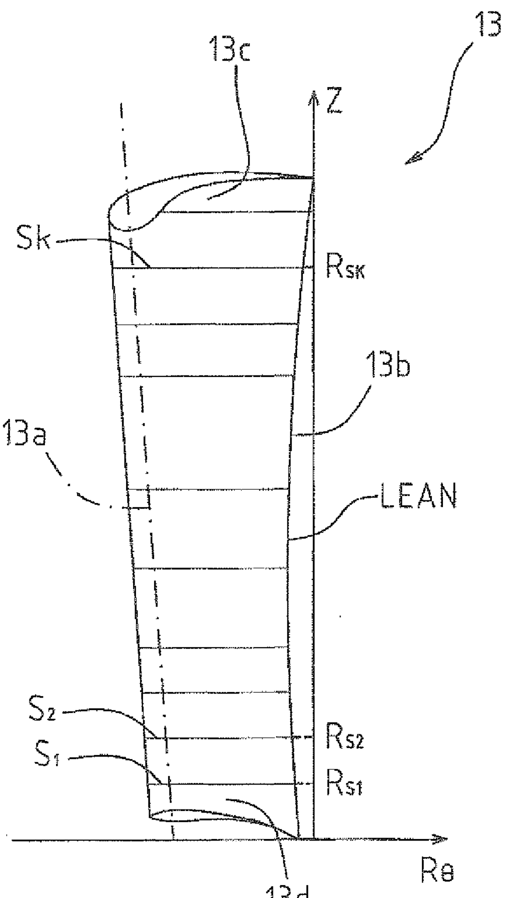

Fig.4

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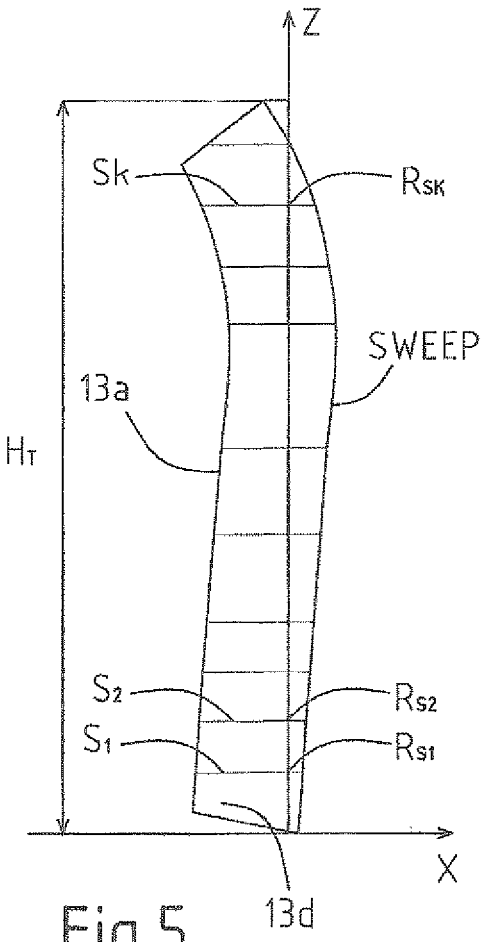

Fig.5

Description

[0001] The present invention relates to a last stage stator blade of a steam turbine low-pressure section.

[0002] As known, the design of the last stage of steam turbine low-pressure sections is particularly important. Indeed, given the large average radius of the blades and the consequent high speeds of the progressing flow, the power produced in the last stage of the low-pressure section is much higher than in the previous stages of the same section. Since the low-pressure section produces a considerable fraction of the overall power delivered by the turbine and, furthermore, in this section a lower number of stages than in the high and medium pressure sections exist, the efficiency of the last stage of the low-pressure section affects the overall efficiency of the whole turbine in a non-negligible manner.

[0003] On the other hand, the efficiency of the existing last stage stator blades is not adequate for processing the supersonic flow normally present between the blade base and the three-quarters of the blade height. Specifically, the blade height portions having the highest efficiency (i.e. the most remote stator blade portion from the turbine axis and the closest rotor blade portion) are not properly exploited because the flow is not adequately moved between the stator portion and the rotor portion of the last stage.

[0004] The overall efficiency of the turbines is thus strongly limited by the low efficiency of the last stage of the low-pressure section.

[0005] It is an object of the present invention to provide a last stage stator blade of a steam turbine low-pressure section which allows to overcome the described restrictions.

[0006] According to the present invention, a last stage stator blade of a steam turbine low-pressure section is provided as claimed in claim 1.

[0007] For a better understanding of the invention, an embodiment thereof will be described hereafter only by way of non-limitative example, and with reference to the accompanying drawings, in which:

- figure 1 is an axial longitudinal section of a low-pressure section of a steam turbine, incorporating stator blades according to an embodiment of the present invention;
- figure 2 is an enlarged detail of figure 1;
- figure 3 is an axonometric view of a stator blade according to an embodiment of the present invention;
- figure 4 is a side view of the stator blade in figure 3;
- figure 5 is a meridian view of the stator blade in figure 3;
- figure 6 is a graph which shows a tangential staking line of the stator blade in figure 3;
- figure 7 is a graph which shows an axial staking line of the stator blade in figure 3; and
- figure 8 shows the development according to a blade-to-blade plane of a section of part of the turbine in figure 1.

[0008] In figure 1, reference numeral 1 indicates a low-pressure section of a steam turbine. The low-pressure section 1 comprises a shaft 2, extending along a machine axis A, and a plurality of intermediate stages 3 and an outlet stage or last stage 5, all accommodated inside a casing 4. The intermediate stages 3 and the last stage 5 are arranged in sequence along the machine axis A according to a flow direction D of the steam.

[0009] Each intermediate stage 3 comprises a respective array of rotor blades 6 and a respective array of stator blades 7, facing each other. The rotor blades 6 radially extend from the shaft 2, to which they are fixed. The stator blades 7 of each array, also radially oriented, are fixed to the casing 4 by respective anchoring devices 8. The radially internal ends of the stator blades 7 of each array are provided with a roof.

[0010] Likewise, the last stage 5 comprises an array of rotor blades 12, radially arranged and fixed to the shaft 2, and an array of stator blades 13, placed upstream of the rotor blades 12 according to the flow direction D of the steam (see enlargement in figure 2). The height of rotor blades 12 is in the range between 88.9 cm (35") and 101.6 cm (40"), e.g. 93.98 cm (37").

[0011] The stator blades 13 are fixed to the casing 4 by means of anchoring devices 14, extend in the radial direction and have internal ends provided with roofs 15.

[0012] One of the stator blades 13 of the last stage 5 is shown more in detail in figures 3-8.

[0013] The stator blade 13 has a curvilinear leading edge 13a and a curvilinear trailing edge 13b and has a blade height H_T, defined by the difference between a maximum radial coordinate, according to a radial reference axis Z, of a peripheral portion or "tip" 13c, and a minimum radial coordinate of a base or "hub" portion 13d. The blade height H_T is in the range between 71 cm and 75 cm.

[0014] Hereinafter, the term "blade sections" will refer to cylindrical sections obtained by the intersection of the stator blade 13 with cylindrical surfaces having the machine axis A as axis and a given radius. The term "section radius R_S" of a blade section S means the radius of the cylindrical surface which generates the blade section S, i.e. the distance of the blade section S from the machine axis A according to a direction defined by the radial reference axis Z.

[0015] The stator blade 13 has blade sections S with respective section radii R_S, radially stacked and joined according to stacking lines (specifically, in figures 4 and 5, the blade sections S_1, S_2, ..., S_K, are shown with the respective section radii R_{S1}, R_{S2}, ..., R_{SK}). More specifically, the blade sections S_1, S_2, ..., S_K are stacked according to a tangential stacking line LEAN and to an axial stacking line SWEEP (figures 4 and 5). In practice, the blade sections S_1, S_2, ..., S_K are axially (according to a direction defined by a central reference axis X coinciding with the machine axis A of the turbine) and tangentially (according to a direction defined by a tangential reference axis Rθ, perpendicular to axis X and axis Z) translated with respect to a peripheral vertex V_P of the trailing edge 13b of the stator blade 13. The translation in the tangential and axial direction of each blade section S_1, S_2, ..., S_K is determined by the interpolation of the tangential stacking line LEAN and the axial stacking line SWEEP (figures 4 and 5), respectively, at the respective section radius R_{S1}, R_{S2}, ..., R_{SK}.

[0016] The tangential stacking line LEAN defines an orthogonal projection of the trailing edge 13b of the stator blade 13 on a plane (R, Rθ) perpendicular to the machine axis A and identified by radial reference axis Z and tangential reference axis Rθ (figure 4).

[0017] More in detail, the tangential stacking line LEAN is a fourth-order Bezier curve having a concavity towards a pressure side or belly 13e of the stator blade 13. The tangential stacking line LEAN is defined by four check points, as shown in figure 6, where Z indicates the radial reference axis and Rθ the tangential reference axis, perpendicular to the radial reference axis Z. A first check point 17 and a second check point 18 define one end at the periphery (at the tip) and one end at the base (at the hub) of the tangential stacking line LEAN, respectively. A third check point 19 and a fourth check point 20 define the concavity of the tangential stacking line LEAN. Specifically, the tangential stacking line LEAN has a tangent angle φ_T at the periphery or tip, defined by a direction parallel to the radial reference axis Z in the first check point 17 and by the line joining the first and third check points 17, 19; and a tangent angle φ_H at the base or at the hub, defined by a direction parallel to the radial reference axis Z in the second check point 18 and by the line joining the second and the fourth check points 18, 20. The concavity of the tangential stacking line LEAN is further determined by an influence range at the base or at the hub A_H and by an influence range at the periphery or at the tip A_T, given by the distance between the first and the third check points 17, 19 and by the distance between the second and the fourth check points 18, 20, respectively, in the direction of the radial reference axis Z. The influence range at the hub A_H and the influence range at the tip A_T are normalized as compared to the blade height H_T, are non-dimensional and vary between 0 and 0.5.

[0018] According to the invention, the tangential stacking line LEAN is defined by values of the tangent angle at the base φ_H in the range between 0° and 20°; by values of the tangent angle at the periphery φ_T in the range between 10° and 20°; by values of the influence range at the axis A_H in the range between 0.05 and 0.15; and by values of the influence range at the periphery A_T in the range between 0.15 and 0.25.

[0019] For a blade height H_T of 73.73 cm, for example, the angle at the axis (φ_H) is 18°; the angle at the periphery (φ_T) is 15°; the influence range at the axis (H_H) is 0.1; and the influence range at the periphery (H_T) is 0.22938.

[0020] The axial stacking line SWEEP defines a projection of the trailing edge 13b of the stator blade 13 on a meridian plane P_M, targeted by central reference axis X and radial reference axis Z, and passing through the peripheral vertex V_P of the trailing edge 13b (figures 5 and 7). For a first length 21 towards the hub portion 13c of the stator blade 13, the axial stacking line SWEEP is defined by a rectilinear segment and, for a second length 22 towards the tip portion 13d, by a fourth-order Bezier curve, joined to the rectilinear segment and tangential to the rectilinear segment itself at the joining point J. The first length 21 and the second length 22 each preferably extend for approximately half of the blade height H_T.

[0021] The peripheral portion 13c of the stator blade 13 is inclined with respect to the machine axis A so as to comply with the profile of the median channel of the turbine, which preferably has a taper ratio lower than 47°.

[0022] In the embodiment of the invention herein described, the blade sections S_1, S_2, ..., S_K have profiles 24a-24d such as to define converging-diverging blade-to-blade channels 25 between pairs of adjacent stator blades 13, as shown in figure 8 which represents a development on a blade-to-blade plane (i.e. on a plane obtained by developing a cylindrical intersection surface centered about the machine axis A and intersecting the stator blades 13). More in detail, on the pressure side of the stator blade 13, the profiles of the blade sections S_1, S_2, ..., S_K are defined by a fourth-order Bezier curve for an inlet part 24a, and by a first rectilinear segment, for an outlet part 24b. On the vacuum side or back 13f of the stator blade 13, the profiles of the blade sections S_1, S_2, ..., S_K are defined by a fourth-order Bezier curve for an inlet part 24c, and by a second rectilinear segment for an outlet part 24d.

[0023] The use of stator blades 13 as those described allows to considerably improve the efficiency of the last stage 5.

[0024] As compared to the known stator blades, joining the blade sections as described allows to reduce the Mach number where it is higher and thus more critical for the efficiency, i.e. at the outlet from the stator array at the lower part (at the base) of the blade. The Mach number slightly increases at the periphery of the stator blade. But in this region, the Mach number value is however considerably lower than at the base and does not significantly affect the efficiency. In general, the effect of the Mach number reduction at the base of the stator blade 13 prevails and the efficiency of the last stage is higher.

[0025] By virtue of the described stacking, the steam flow is optimally distributed to the meridian channel. In practice, the specific flow rate is modified so as to greatly exploit the meridian channel part having the highest efficiency, both in the stator portion (i.e. towards the periphery) and the rotor portion (close to the shaft). The shape of the stator blade 13 thus produces beneficial effects even on the array of the rotor blades 12 of the last stage 5, although without interventions on the structure thereof. The efficiency of the last stage is thus further increased.

[0026] As a consequence, the degree of reaction of the last stage 5 is reduced over 70% of the blade height H_T, while it is higher in the remaining portion. This means that the enthalpy difference used by the array of stator blades 13 is higher at the periphery (where the Mach number is lower and thus the efficiency is higher) and lower at the base.

[0027] As mentioned, the stator blade 13 also has beneficial effects on the array of rotor blades 12 of the last stage 5. Specifically, the flow exiting from the array of stator blades 13 is such that the Mach number related to the inlet of the array of rotor blades 12 increases at the base (where it is lower) and decreases at the periphery (where it is very high). Again, the effect related to the Mach number reduction in the regions where it is higher considerably prevails and is translated into an increase of the efficiency of the last stage 5 (at the top of the rotor blades 12 of the last stage 5 the flow is strongly transonic).

[0028] Using converging-diverging blade-to-blade channels contributes to reduce Mach number peaks and therefore contain losses.

[0029] It is finally apparent that changes and variations may be made to the described and illustrated blade without departing from the scope of the present invention as defined in the appended claims.

Claims

1. A last stage stator blade of a steam turbine low-pressure section, having blade sections (S_1, S_2, ..., S_K) at respective section radii (R_{S1}, R_{S2}, ..., R_{SK}), joined according to a tangential stacking line (LEAN), **characterized in that** the tangential stacking line (LEAN) is a fourth-order Bezier curve.

2. A stator blade according to claim 2, wherein the tangential stacking line (LEAN) has a concavity towards a side under pressure (13e) of the stator blade and is defined by:

   an angle (φ_H) at the base in the range between 0° and 20°;
   an angle (φ_H) at the periphery in the range between 10° and 20°;
   an influence range at the base (H_H) in the range between 0.05 and 0.15; and
   an influence range at the periphery (H_T) in the range between 0.15 and 0.25.

3. A blade according to claim 2, wherein:

   a blade height (H_T) is 73.73 cm;
   the angle (φ_H) at the base is 18°;
   the angle (φ_T) at the periphery is 15°;
   the influence range at the base (H_H) is 0.1; and
   the influence range at the periphery (H_T) is 0.22938.

4. A stator blade according to any one of the preceding claims, wherein the blade sections (S_1, S_2, ..., S_K) are further joined according to an axial stacking line (SWEEP).

5. A stator blade according to claim 4, wherein the axial stacking line (SWEEP) is defined for a first length (21) by a rectilinear segment and for a second length (22) by a fourth-order Bezier curve, joined to the rectilinear segment and tangential to the rectilinear segment in a joining point (J).

6. A stator blade according to claim 5, wherein the first length (21) and the second length (22) each extend for approximately half the blade height (H_T).

7. A stator blade according to any one of the preceding claims, wherein the blade sections (S_1, S_2, ..., S_K) have profiles (24a-24d) such as to define converging-diverging blade-to-blade channels (25).

8. A stator blade according to claim 7, wherein the profiles of the sections are defined:

   on a pressure side (13e) of the blade, for an inlet part (24a) by a fourth-order Bezier curve and for an outlet part (24b) by a first rectilinear segment; and
   on a vacuum side (13f) of the blade, for an inlet part (24c) by a fourth-order Bezier curve and for an outlet part (24d) by a second rectilinear segment.

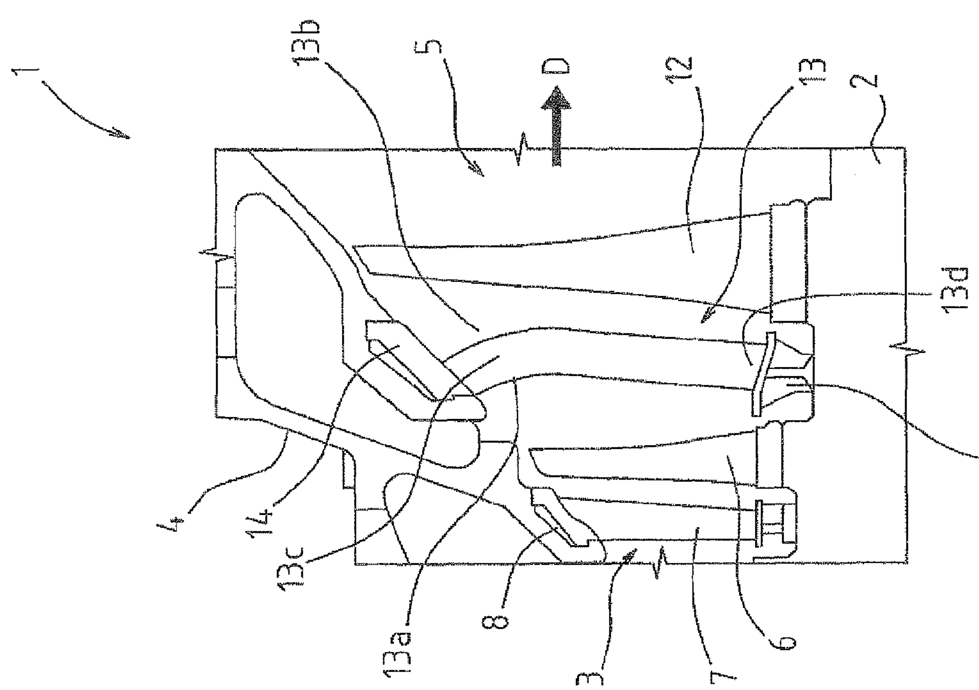

Fig.2

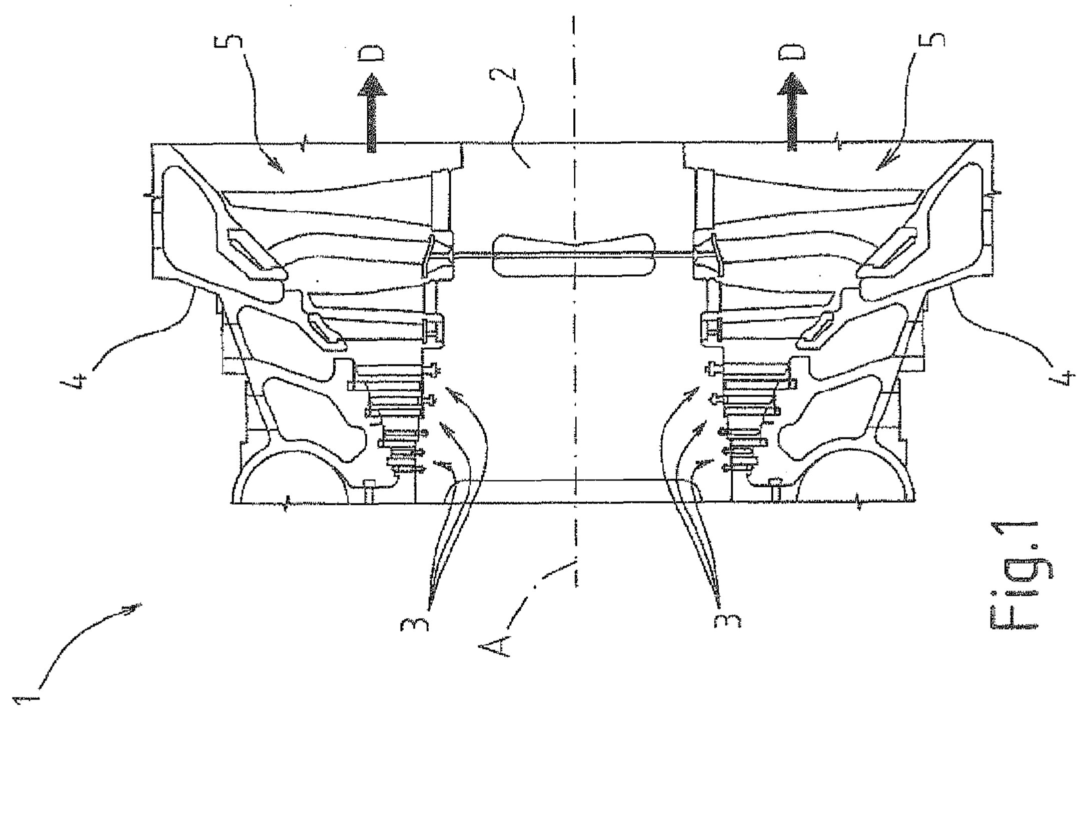

Fig.1

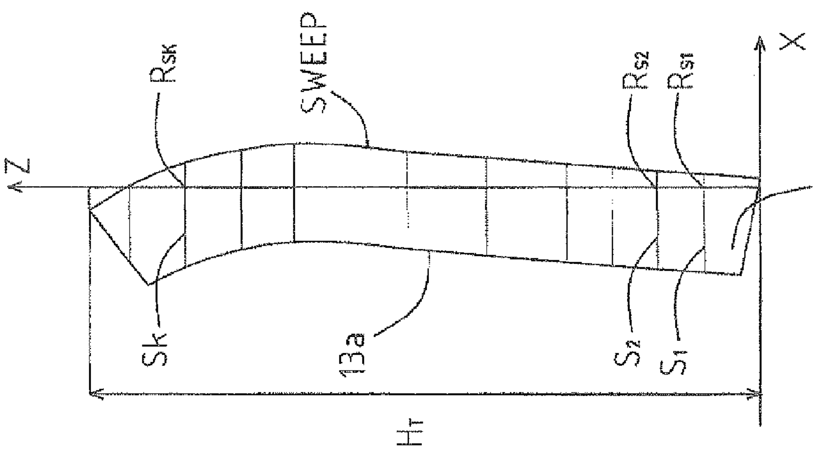

Fig.5

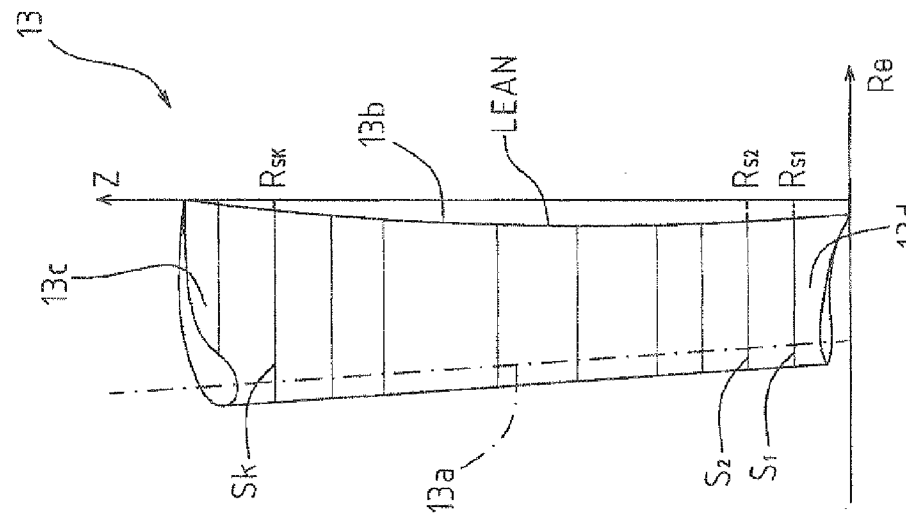

Fig.4

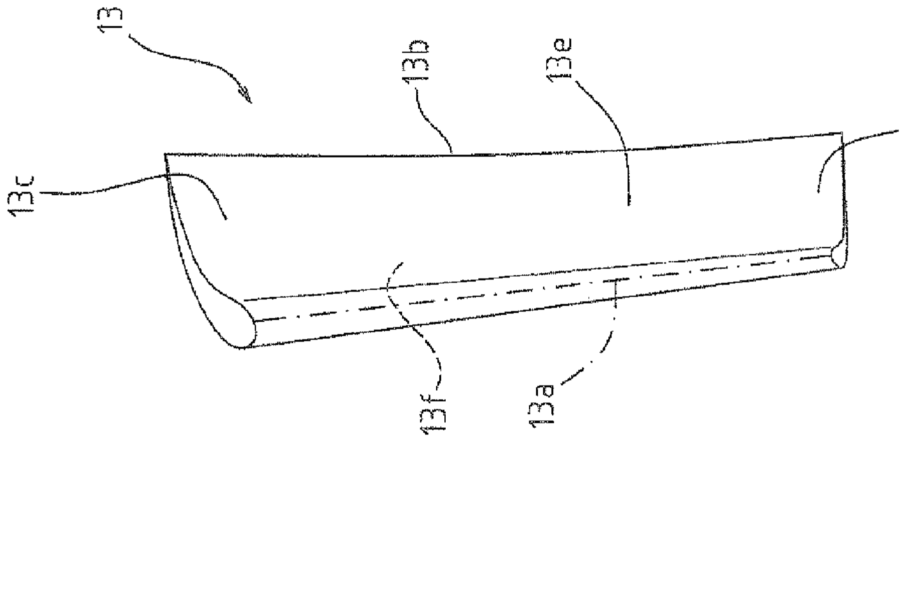

Fig.3

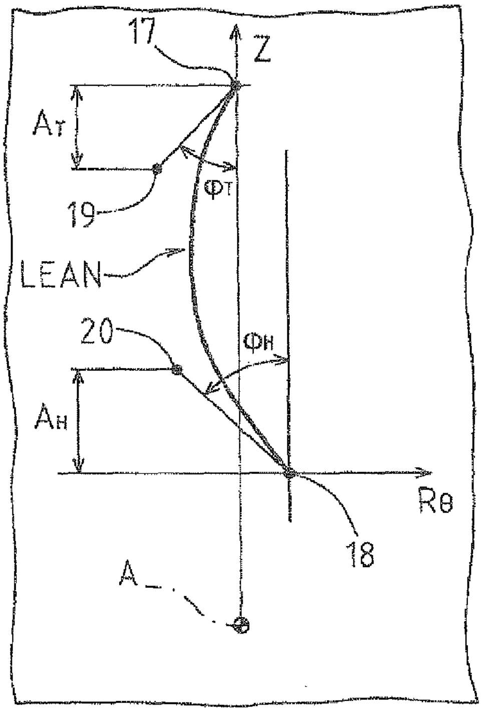

Fig.6

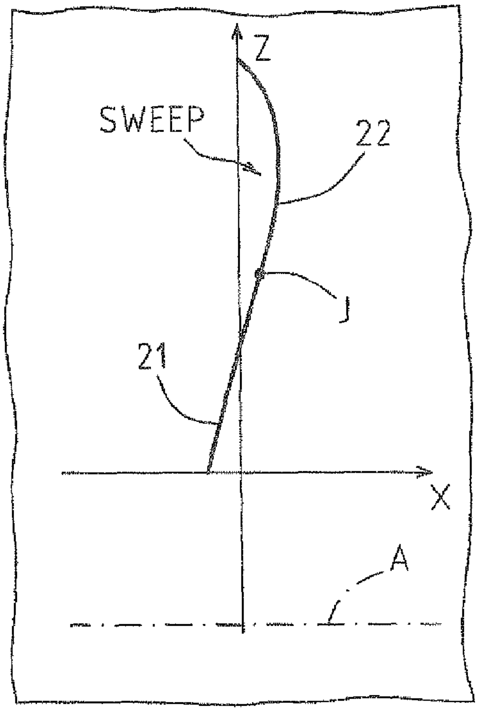

Fig.7

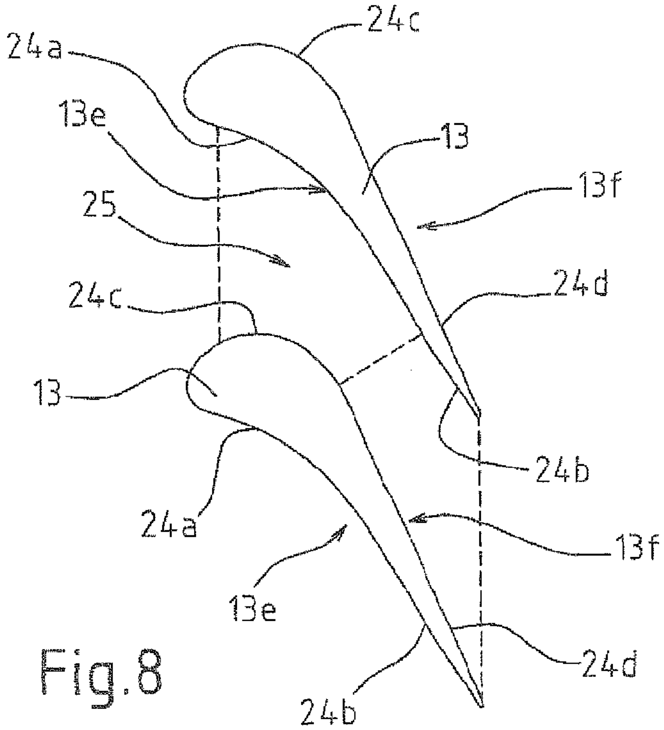

Fig.8