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(54) TURBINE AND TURBINE BLADE

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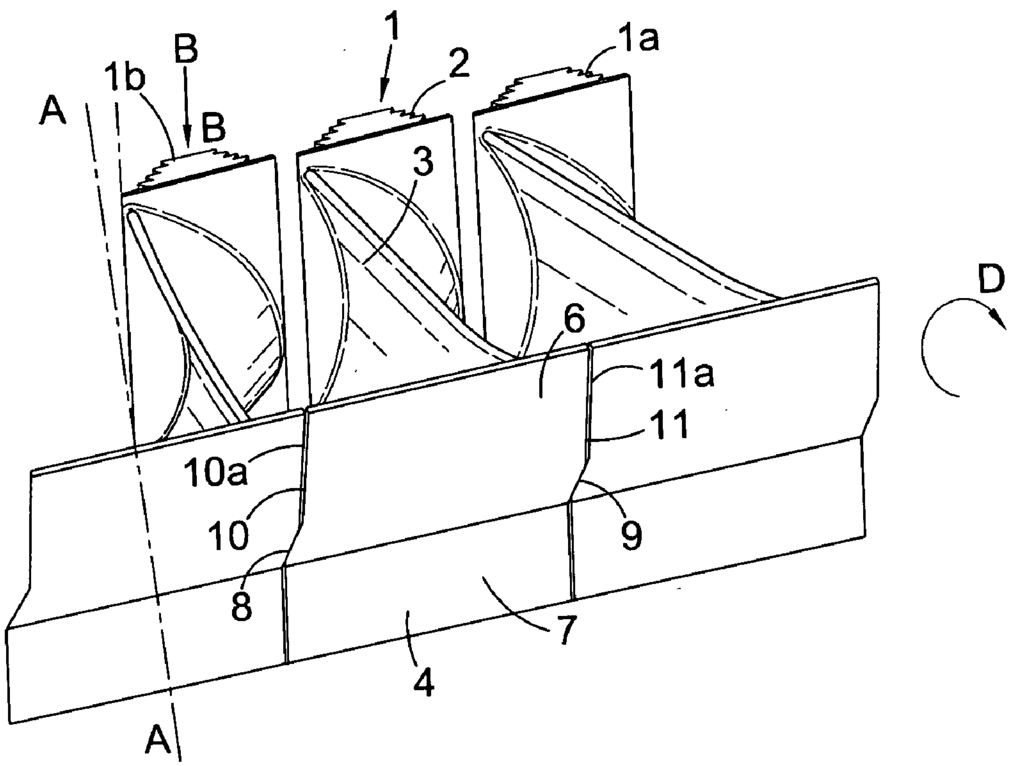
(57) **ABSTRACT**

In order to provide a turbine in which fir tree root or similar types of turbine blades can be inserted into the turbine shaft at an angle close to the axial direction without frictional blocking of shroud sections, each blade comprising a root for insertion into the shaft, along an insertion axis which is at an angle of not more than 30° the axial direction, an aerofoil section and a shroud section, each shroud having lateral surface sections comprising a contact surface section and a free surface section, the contact surface sections of adjacent shroud sections contacting one another, the free surface sections of adjacent shroud sections being spaced from one another. Each contact surface section lies at an angle of from 20° to 50° to the axial direction and each free surface section lies at an angle of not more than 30° to the axial direction, each contact surface section lies at a greater angle to the axial direction of the shaft than the corresponding free surface section. The contact surface sections suitably lie at an angle of about 30° to the axial direction of the shaft.



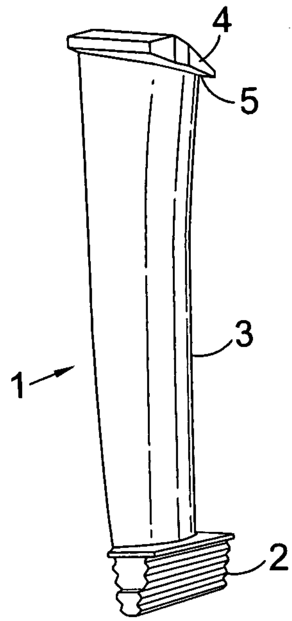


Fig. 1

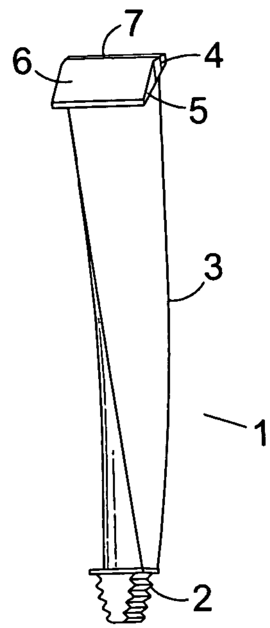


Fig. 2

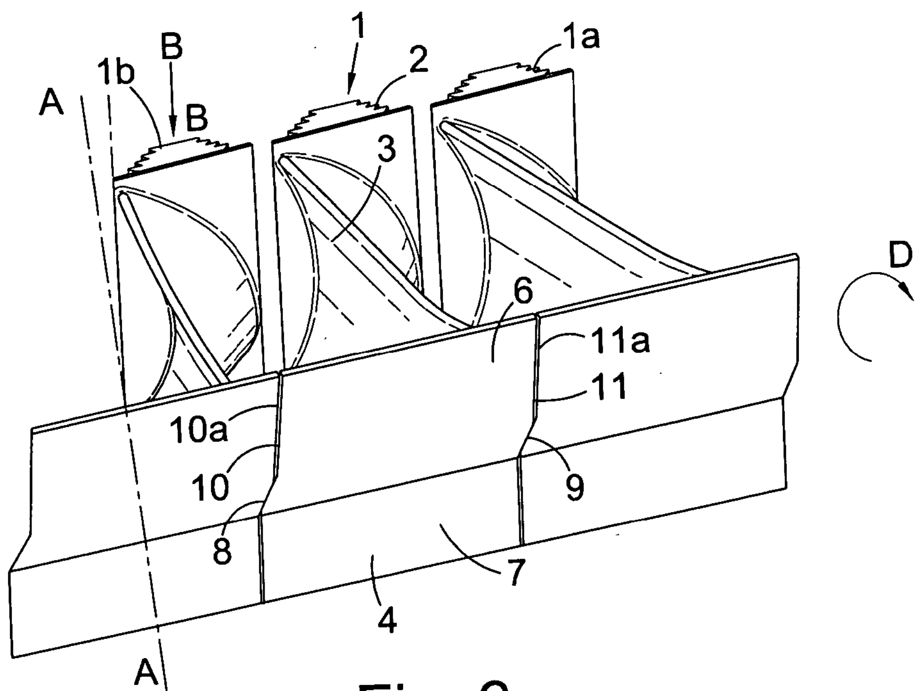


Fig. 3

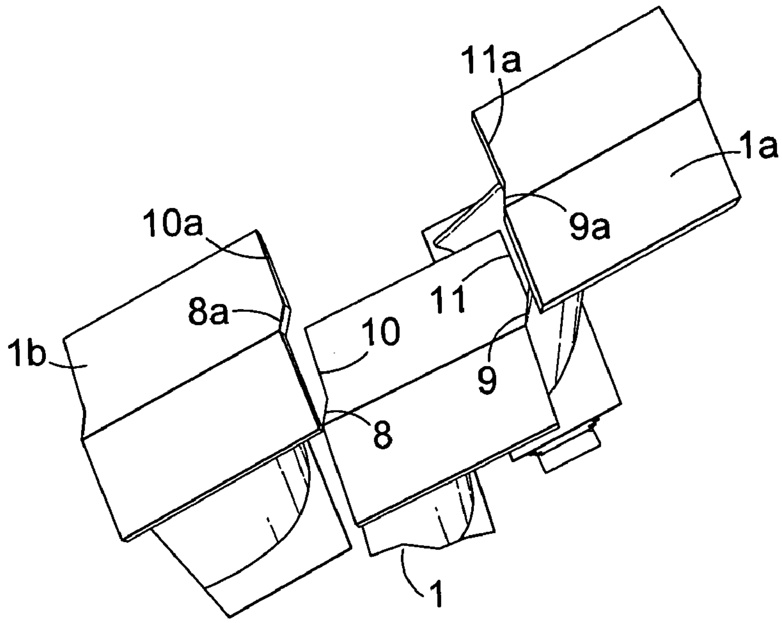


Fig. 4

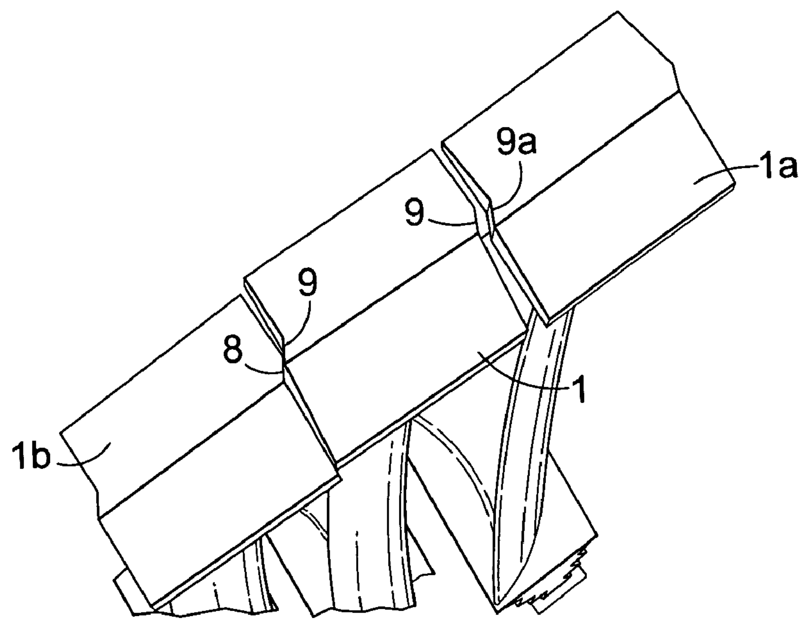


Fig. 5

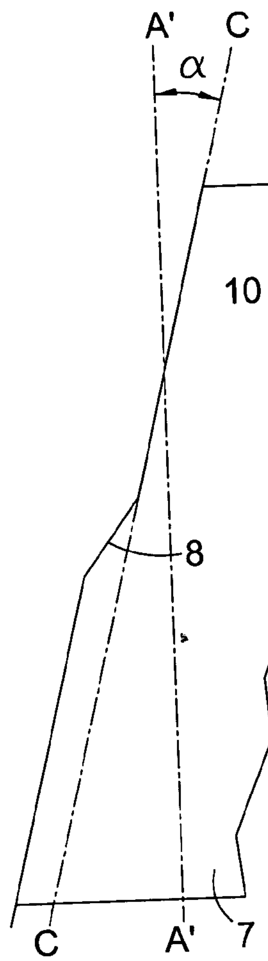


Fig.6

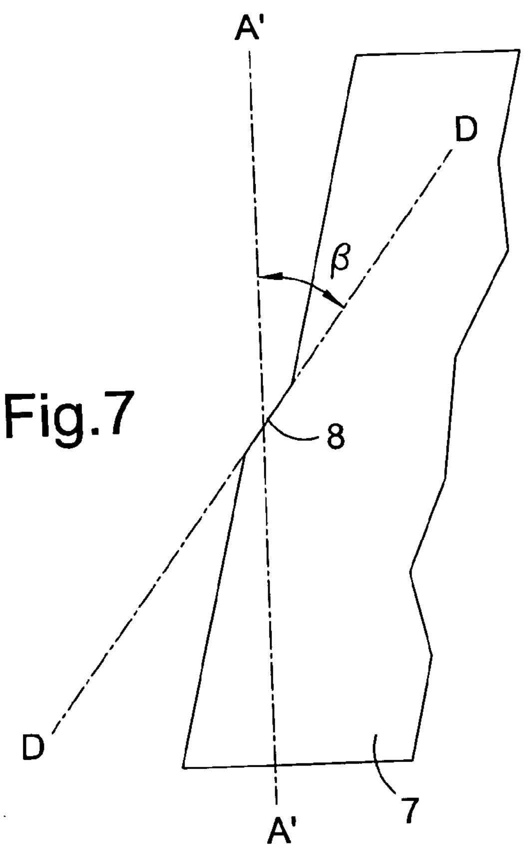


Fig.7

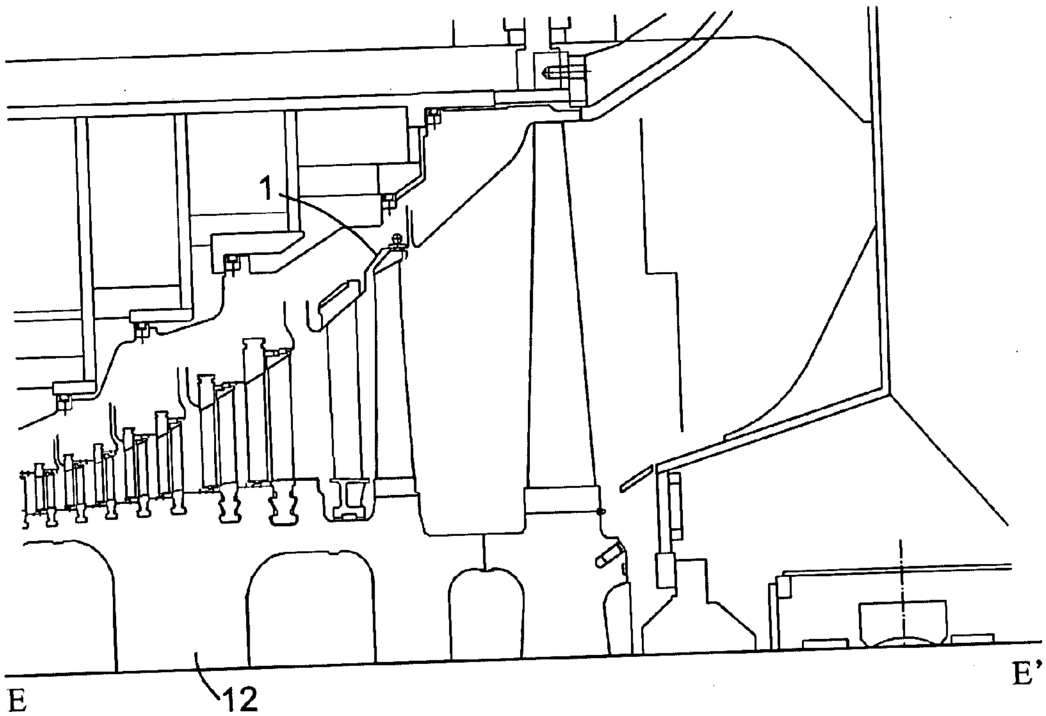


Fig.8

TURBINE AND TURBINE BLADE

[0001] The present invention relates to a turbine and a turbine blade for a turbine. The present invention also relates to a method of assembling a turbine.

[0002] The present invention is particularly concerned with turbines of the type in which the turbine blades include a root for insertion into a turbine shaft, an aerofoil section and a shroud section at the radially outer end of the aerofoil section. The individual shroud sections of the turbine blades lie adjacent to one another defining an annular shroud in the complete turbine for reducing the drag caused by vortex separation at the blade tips. In particular, this type of blade is commonly used in steam turbines.

[0003] There are a number of designs of root which allow the turbine blades to be fixed to the turbine shaft. The present invention is particularly concerned with root forms in which the turbine blades are inserted into locking formations in the shaft in a direction which is nearly parallel to the shaft and which has substantially no radial component.

[0004] A particularly important type of root design is the so-called fir tree root. This is a formation which is named after its resemblance to an inverted fir tree and which is designed to engage in corresponding formation in the turbine shaft.

[0005] During assembly of a turbine having this type of blade root, the turbine blades are inserted one after another in sequence into the turbine shaft until all but one of the turbine blades have been inserted. Particular problems can be encountered during insertion of the last turbine blade. In particular, excessive frictional blocking at the shroud contact surfaces may be encountered as the blades already in the rotor are forced apart to allow the last turbine blade to be inserted between the two adjacent blades. This may particularly be a problem where a pre-twist is applied to the blades, so that they are provided with a torque which resists rotation of the blades in use under the effect of centrifugal forces.

[0006] In addition, during operation of the turbine there may be a temperature differential between the shroud and the root. This can lead to high hoop stresses in the shroud, or blocking, unless the shroud design is able to permit sliding on the surface in contact with the adjacent blade. Thermal expansion of the shroud in the tangential direction can also lead to hoop stresses in the shrouds. Blocking can lead to residual stresses on departure from normal operating regime and consequential natural frequency scatter. Sliding of the contact surfaces can only occur if the angle on the contact surfaces is sufficiently away from the axial direction.

[0007] One solution is to arrange the insertion direction of the roots into the turbine shaft, so that they are not axial.

[0008] In this case, the side surfaces of the shroud sections of the individual turbine blades are designed to be parallel to the insertion direction.

[0009] If the angle between the insertion axis and the axial direction is of the order of 30° or more, the blocking problem can be effectively overcome.

[0010] However, it is sometimes desirable that the angle between the insertion direction and the axial direction is significantly less than 30°, and preferably less than 20°. For example, the insertion direction, which is defined by the angle of the root fixing, may need to be optimised for the root profile design and best aerodynamics. Further, the angle of the root fixing slot may be selected to resist movement in use of the blade in the tangential direction.

[0011] In such cases, the blocking problem remains.

[0012] The present invention sets out to provide a turbine in which the turbine blades are designed so that they can be inserted effectively during assembly of the turbine and can avoid blocking during turbine operation even if the insertion direction is close to the axial direction.

[0013] The present inventors have realised that a turbine blade can be made with an insertion direction which is close to the axial direction, the shroud section having at least two separate lateral surface sections, one surface section being for contacting adjacent contact surface sections of adjacent shrouds and being configured at an angle to the axial direction of about 20° to 50°, which allows easy insertion, the second surface section comprising a free surface which is spaced from adjacent free surfaces of adjacent shroud sections. The free surface can have an angle which is substantially parallel to the insertion direction, and is not more than 30° to the axial direction, blocking being avoided by the spacing between free surfaces.

[0014] Accordingly, the present invention provides a turbine having a turbine shaft defining an axial direction, a plurality of blades mounted in the turbine shaft, each blade comprising a root for insertion into the turbine shaft along an insertion axis, the insertion axis being at an angle of not more than 30° to the axial direction, an aerofoil section and a shroud section, each shroud section having lateral surfaces each comprising a contact surface section and a free surface section, the contact surface sections of adjacent shroud sections contacting one another, the free surface sections of adjacent shroud sections being spaced from one another, each contact surface section lying at an angle in the range 20° to 50° to the axial direction of the shaft, each free surface section lying at an angle to the axial direction of not more than 30°, each contact surface section lying at a greater angle to the axial direction of the shaft than the corresponding free surface section.

[0015] The present invention further provides a turbine blade comprising a root for insertion into the shaft of a turbine, an aerofoil section and a shroud section, which turbine has an axial direction, the blade being for insertion along an insertion axis which is at angle at not more than 30° to the axial direction, each shroud section having lateral surfaces each comprising a contact surface section and a free surface section, the contact surface sections being for contacting adjacent contact surface sections of adjacent shroud sections when assembled into the turbine and the free surface sections being spaced from adjacent free surface sections of adjacent shroud sections when assembled into the turbine, each contact surface section lying at an angle in the range 20° to 50° to the axial direction of the shaft, each free surface section lying at an angle of not more than 30° to the axial direction, each contact surface section lying at a greater angle to the axial direction than the corresponding free surface section.

[0016] The present invention further provides a method of assembling a turbine comprising the steps of inserting a plurality of turbine blades into a turbine shaft, the turbine shaft defining an axial direction, each blade comprising a root which is inserted into the shaft along an insertion axis which is at an angle of less than 30° to the axial direction, an aerofoil section and a shroud section, each shroud section having lateral surfaces each comprising a contact surface section and a free surface section, each contact surface lying at an angle of from 20° to 50° to the axial direction, each free surface section ling at an angle to the axial direction of not more than 30°, each contact surface section lying at a greater angle to the axial direction than the corresponding free surface section, adjacent turbine blades being inserted so that their respective contact sections contact one another and so that their respective free surface sections are spaced from one another.

[0017] The present invention may be used with any type of turbine, including gas turbines, air turbines or steam turbines, but is particularly suitable for steam turbines.

[0018] The turbine may be of the impulse type, reaction type or combination of the two. The aerofoil section of each turbine blade will be designed accordingly in a manner which is known to the person skilled in the art.

[0019] In a turbine blade according to the present invention, the skilled person will be able to determine the axial direction from a knowledge of the configuration of the turbine blade. In any case, in a turbine blade according to the present invention, each root will define an insertion axis along which it is insertable into the turbine shaft, the free surface sections of the shroud section being substantially parallel to the insertion axis and the contact surface section of each shroud section being at an angle to the insertion axis.

[0020] In practice, the insertion axis of the root and the axial direction of the shaft are defined by lines which do not cross one another. However, the angle between the lines may be defined to be the angle between the projections of the lines onto a notional common surface in a direction normal to the notional surface. Equally, the angle between the insertion axis and the axial direction may be determined by a reference plane which contains the axial direction, the angle being the angle between the axial direction and a projection of the insertion axis onto the reference plane in a direction normal to the reference plane.

[0021] Similarly, the contact surface sections and the free surface sections are not intersected by the axial direction. As the free surface sections and the contact surface sections normally comprise substantially radially oriented surfaces, the angle between these surfaces and the axial direction may be taken to be the angle between the projection of the respective surface and the projection of the axial direction onto to a notional common surface in a direction normal to the notional surface. Equally, the angle may be determined by a reference plane which contains the axial direction, the angle being the angle between a projection of the free surface section or contact surface section onto the reference plane in a direction normal to the reference plane

[0022] If the contact surface section or free surface section is not substantially radially disposed, the angle may be determined by reference to a line which extends from the leading edge to the trailing edge of the surface and which bisects the surface.

[0023] When considering angles between two lines, of course, two angles are in fact formed, one greater and one smaller, the angles adding up to 180°. In the present application, the angle referred to is always the smaller of the two angles.

[0024] The design of the root and any structure on the shaft for engaging the root may be any suitable known design in which the insertion axis is parallel, nearly parallel or at an angle to the axial direction of the shaft, having substantially no radial component. The present invention is for use where the insertion axis is nearly axial, being at an angle of not more than 30° to the axial direction, preferably not more than 20° to the axis and preferably less than 15°. A suitable angle is 13.5°.

[0025] The present invention is particularly suitable for use with the inverted fir tree root design.

[0026] An additional advantage of the present invention is that the contact surfaces of adjacent turbine blades are small and clearly defined, so that they can be properly defined and designed.

[0027] Apart from the lateral surfaces of the shroud sections, the other surfaces of the shroud sections may define any conventional shape. For example, the leading surface, trailing surface and top and bottom surfaces of the shroud section may be any conventional design. Suitably, the bottom surface (which contacts the aerofoil section) is inclined with respect to the axial direction. In this way, the flow cross-section over the aerofoil increases in the flow direction in a conventional manner.

[0028] Suitably, the top surface of the shroud section (the surface opposite to the aerofoil section) comprises a first surface which is inclined with respect to the axial direction and a second surface which is substantially parallel to it.

[0029] In this case, the contact surface section of the lateral surface may be located in the first surface or the second surface, preferably the first surface.

[0030] The lateral surfaces may comprise a first, free surface section followed by a second, contact surface section, followed by a third, free surface section.

[0031] The shroud section may be of any conventional dimensions.

[0032] The free surface sections are preferably substantially parallel to the insertion axis of the root. The free surface sections are preferably configured so that they are spaced apart from one another by distance in the range 0.5-5.0 mm, preferably 0.5-2 mm, preferably around 1 mm. Preferably, the spacing is kept relatively small to prevent leakage of the working fluid. However, sufficient spacing must be provided to allow assembly in accordance with the invention.

[0033] The shroud sections will suitably have two lateral surfaces which correspond in shape to one another.

[0034] Preferably, the contact surface section is smaller than the free surface section, the contact surface section being suitably 50% or less in length compared to the free surface section, preferably 40% or less, more preferably 25% less and most preferably 20% or less. Where there are two or more free surface sections in one lateral surface, the total length is considered.

[0035] The contact surface sections and free surface sections are preferably contiguous, forming a smooth lateral surface with no step in it.

[0036] The contact surface direction may preferably form an angle with the axial direction in the range 25-40°, preferably around 35°.

[0037] Preferably, a pre-twist is applied to the turbine blades. That is, they are inserted in such a manner that, when the turbine is complete, each shroud section is twisted compared to the root, untwisting being resisted by contact between adjacent contact surface sections. For example, the turbine blade may be pre-twisted in such a way that, when the turbine is running and the blades are exposed to centrifugal forces, the pre-twist will resist any twisting due to centrifugal forces. Contact surface sections are accordingly preferably arranged to resist the pre-twisting forces.

[0038] In order to allow the turbine blades to be installed particularly easily and to allow them to be designed to resist pre-twist forces, if present, the shroud edges are preferably arranged so that there is no step when moving from the free surface section to the corresponding contact surface section. In this case, a step is formed if the angle between the axial direction and the free surface section and the angle between the axial direction and the contact surface section lie on different sides of the axial direction. That is, a step is formed if there is effectively a reverse of the slope of the lateral surface of the shroud. As noted above, it is desired to avoid a step.

[0039] The method of the invention preferably further comprises the steps of inserting all but one of the turbine blades into the turbine shaft, forcing apart the turbine blades adjacent the position of the final turbine blade, inserting the final turbine blade into the turbine shaft between the two forced apart turbine blades and removing the force on the two forced apart turbine blades. A jack may be used to force the blades apart.

[0040] The present invention will be further described by way of example with reference to the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWING

[0041] **FIG. 1** is an isometric view of a turbine according to the present invention, seen from the downstream side.

[0042] **FIG. 2** is an isometric view of a turbine blade according to the present invention, seen from the upstream side.

[0043] **FIG. 3** is a sketch isometric view of three turbine blades according to the present invention in the configuration in which they would be mounted in a turbine shaft.

[0044] **FIG. 4** is a sketch isometric view of a first stage of insertion of the last turbine blade into a turbine shaft in the method of the invention.

[0045] **FIG. 5** is a sketch isometric view of the penultimate stage in the insertion of the last turbine blade into the turbine shaft in the method of the present invention.

[0046] **FIG. 6** is a sketch plan view of one lateral surface of the shroud **7** of **FIG. 1**, showing the angle between the free surface section and the axial direction.

[0047] **FIG. 7** is a sketch plan view of the lateral surface of the shroud **7** of **FIG. 1**, showing the angle between the contact surface section and the axial direction.

[0048] **FIG. 8** is a schematic cross sectional view of part of a turbine incorporating a turbine blade according to the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0049] **FIG. 1** is an isometric view of a turbine blade according to the present invention, generally designated **1**, seen from the downstream side,

[0050] It comprises a root **2** for insertion into a turbine shaft. The root is an inverted fir-tree type root which is designed for insertion into a corresponding formation in the turbine shaft along an insertion axis which extends at an angle of about 13.5° to the axial direction of the turbine shaft.

[0051] The turbine blade further comprises an aerofoil section **3** of conventional design and a shroud section **4**, which will be further described below.

[0052] **FIG. 2** shows another sketch isometric view of the turbine blade **1**, from the upstream direction.

[0053] **FIG. 3** shows a sketch isometric view of three turbine blades according to the present invention adjacent to one another in the configuration in which they would be mounted in a turbine shaft. The turbine shaft itself is not shown, for clarity.

[0054] Line A-A shows the axial direction of the turbine shaft.

[0055] The line B-B shows the insertion direction of each turbine blade into the turbine shaft. The insertion direction in this case forms an angle of 13.5° with respect to the axial direction AA.

[0056] Each turbine blade is identical to the adjacent turbine blades.

[0057] One turbine blade **1** will be described in further detail.

[0058] The root **2** and aerofoil section **3** are of standard design and will not be described further.

[0059] The shroud section **4** is defined by a lower surface **5** which is in contact with the working fluid and which lies at an angle to the axial direction, in a manner known in the art. The top surface of the shroud section comprises a first surface component **6** and a second surface component **7**. The first surface component **6** has lateral surfaces comprising first and second contact surface sections **8**, **9** located on either side of the surface component **6**. As shown in **FIG. 3**, when assembled, these contact sections **8** and **9** are in close contact with the contact sections of adjacent turbine blades.

[0060] The turbine blade **1** can be inserted with a pre-twist acting in the sense shown by the arrow D, to resist centrifugal twisting in the opposite sense during operation of the turbine. The contact surfaces **8** and **9** resist the pre-twist force.

[0061] The surface component **6** further comprises free surface sections **10**, **11** which are contiguous with the respective contact surface sections **8** and **9** and which, when assembled, lie parallel to the free surface sections **10***a* and **11***a* of adjacent turbine blades **1***b*, **1***a* and spaced therefrom by 1 mm. It can be seen that the free surface sections **10**, **11** are parallel to the insertion axis BB and lie at an angle of about 13.5° to the axial direction AA of the turbine shaft. However, the contact surface sections **8** and **9** form a much larger angle, of about 35°, with the axial direction AA. This is shown in more detailed in **FIGS. 6 and 7**.

[**0062**] **FIG. 6** is a sketch plan view of one lateral surface section of the shroud **7**. The line A'A' denotes the axial direction of the shaft. The line C C denotes a projection onto a plane which contains the axial direction A'A', normal to that plane, of the free surface section **10**. The smallest angle is denoted a and is 13.5°. **FIG. 7** shows a sketch plan view of the same section of lateral surface of the shroud **7**. In this case, the dotted line A'A' denotes the axial direction and the line D D denotes a projection of the contact surface section **8** onto a reference plane which contains the axial direction A'A', from a direction normal to that plane. The smallest angle is denoted β and is 25°. It should be noted that the angle β is formed on the same side of the axial direction A'A' as the angle α. Accordingly, the lateral surface of the shroud **7** has a smooth shape without a step, thus easing insertion during assembly of the turbine.

[**0063**] **FIG. 4** is a schematic isometric view of a step in the construction of a turbine according to the present invention.

[**0064**] In previous steps (not shown), all but one of the turbine blades have been inserted into a turbine shaft (not shown for clarity), side by side leaving a gap of one turbine blade's width between the turbine blades **1***a* and **1***b*. The space between the turbine blades **1***a* and **1***b* is designed to exactly accommodate the final turbine blade **1**, but with the shroud section twisted slightly with respect to the root section **2**. **FIG. 4** shows the twist applied to the already inserted blades compared to the last blade. In order to insert the turbine blade **1**, a jack is used to space the turbine blades **1***a* and **1***b* further apart to allow the blade **1** to be inserted. In practice, there is a limit to the jacking amount which can be safely carried out. When the jacking force is released, the final blade will take up the same twist as the already inserted blades.

[**0065**] However, locking and frictional resistance to insertion of shroud section **4** between the free surface sections **10** and **10***a* and **11** and **11***a* does not occur in the present invention, because of the slight additional space between the free surface sections. Further, blocking does not occur between the contact surface sections **8** and **9** and corresponding surfaces **8***a* and **9***a*, because of the relatively high angle to the axial direction of these surface sections. Accordingly, the turbine blade **1** can be inserted smoothly between the turbine blade **1***a* and **1***b* to the position shown in **FIG. 5**. Once the turbine blades are in the position shown in **FIG. 5**, the jack can be released so that the turbine blades **1**, **1***a* and **1***b* move to a configuration in which the respective contact surface sections **8***a*, **8**, **9**, **9***a* are in firm contact with one another and the free surface sections **10**, **11** are spaced apart from one another by a distance of about 1 mm.

[**0066**] **FIG. 6** is a schematic view of part of a turbine according to the present invention. Only part of the turbine is shown, which is axially symmetrical about its axis EE'. The turbine is of conventional design and will not be explained in detail. A turbine blade **1** according to **FIGS. 1 and 2** is shown inserted in the shaft **12** of the turbine.

[**0067**] The present invention has been described above purely by way of example and modifications can be made within the spirit of the invention, which extends to equivalents of the features described. The invention also consists in any individual features described or implicit herein or shown or implicit in the drawings or any combination of any such features or any generalisation of any such features or combination.

1. A turbine blade, comprising:

a root for insertion along an insertion axis into the shaft of a turbine, which turbine has an axial direction, the insertion axis being at an angle of not more than 30° to the axial direction of the shaft, the turbine blade further comprising an aerofoil section, and a shroud section, each shroud section having lateral surfaces each comprising a contact surface section and a free surface section, the contact surface section being for contacting adjacent contact surface sections of adjacent shroud sections when assembled into the turbine and the free surface sections being spaced from adjacent free surface sections of adjacent shroud sections when assembled into the turbine, each contact surface section lying at an angle of from 20° to 50° to the axial direction, each free surface section lying at an angle of not more than 30° to the axial direction, each contact surface section lying at a greater angle to the axial direction than the corresponding free surface section.

2. The turbine blade according to claim 1, wherein the root comprises a fir tree root.

3. The turbine blade according to claim 1, wherein the bottom surface of the shroud section is inclined with respect to the axial direction.

4. The turbine blade according to claim 1, wherein the top surface of the shroud section comprises a first surface which is inclined with respect to the axial direction and a second surface which is substantially parallel to the axial direction.

5. The turbine blade according to claim 4, wherein the contact surface section of the lateral surface is located in the first surface.

6. The turbine blade according to claim 1, wherein the lateral surface comprises a first, free surface section, followed by a second, contact surface section, followed by a third, free surface section.

7. The turbine blade according to claim 1, wherein the contact surface section is 50% or less in length compared to the free surface section, preferably 40% or less, more preferably 25% or less.

8. A turbine, having a turbine shaft defining an axial direction and a plurality of turbine blades according to claim 1, inserted in the turbine shaft.

9. A turbine, having:

a turbine shaft defining an axial direction,

a plurality of turbine blades mounted in the shaft, each blade comprising:

a root for insertion into the shaft along an insertion axis which is at an angle of the less than 30° to the axial direction,

an aerofoil section, and

a shroud section, each shroud section having lateral surfaces each comprising a contact surface section and a free surface section, the contact surface sections of adjacent shroud sections contacting one another and the free surface sections of adjacent shroud sections being spaced from one another,

each contact surface section lying at an angle of from 20° to 50° to the axial direction, each free surface section lying at an angle of not more than 30° to the axial direction,

each contact surface lying at a greater angle to the axial direction of the shaft than the corresponding free surface section.

10. A turbine according to claim 6, wherein the free surface sections of adjacent turbine blades are spaced apart from one another by a distance in the range 0.5-5.0 mm.

11. A turbine according to claim 8, wherein the turbine blades are provided with a pre-twist.

12. A method of assembling a turbine comprising the steps of inserting a plurality of turbine blades into a turbine shaft, the turbine shaft defining an axial direction, the blades being inserted along an insertion axis which is at an angle of less than 30° to the axial direction, each blade comprising a root which is inserted into the shaft, an aerofoil section and a shroud section, each shroud section having lateral surfaces each comprising a contact surface section and a free surface section, the contact surface sections lying at an angle of from 20° to 50° to the axial direction when assembled and the free surface sections lying at an angle of not more than 30° to the axial direction when assembled, the contact surface section lying at a greater angle to the axial direction than the corresponding free surface section, adjacent turbine blades being inserted so that their respective contact sections contact one another and so that their respective free surface sections are spaced from one another.

13. A method according to claim 12, further comprising the steps of inserting all but one of the turbine blades into the turbine shaft, forcing apart the turbine blades adjacent the position of the final turbine blade, inserting the final turbine blade into the turbine shaft between the two forced apart turbine blades and removing the force on the two forced apart turbine blades.

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