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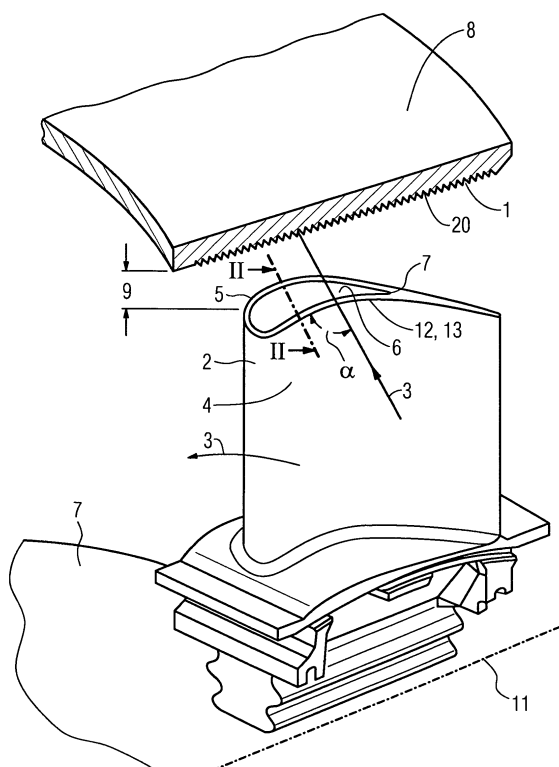
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(54) **Rotary machine**

(57) The invention relates to Rotary machine comprising at least one rotor (7) and at least one casing (8), whereby blades (2) are mounted to the rotor, whereby a clearance (9) between the radial outer first end of the blades (2) and a radially opposing facing first surface (1) of the casing (8) is provided, whereby the first surfaces (1) is provided with at least one radial protrusion, which is extending in circumferen-

tial direction (11) of the rotation of the rotor (7). The radial clearance (9) causes pressure losses and reduces the efficiency. The invention proposes to provide the blades (2) at the respective first ends with at least one rib (10) which rib (10) extends in the height radially outwards and has a longitudinal extending, which forms an angle a bigger than 0° with the circumferential direction (11) of the rotation of the rotor.

FIG 1



Description

[0001] This invention relates to a rotary machine comprising at least one rotor and at least one casing, whereby blades are mounted to the rotor and a clearance between the radial outer end of the blades and the radially opposite facing first surface of the casing is provided, whereby the first surface is provided with at least one radial protrusion, which is extending in circumferential direction of the rotation of the rotor.

[0002] The preferred technical field of application of the invention are rotary machines, in particular gas turbines and steam turbines comprising rotating blades mounted to a rotor, which blades do not comprise shrouds. Due to the increasing shortage of fossil energy resources and the growing awareness to emissions, which are affecting the world climate, the efficiency of machines, which are converting the fossil energy resources to mechanical or electrical power, becomes very important. The majority of power plants are still using steam turbines or gas turbines or a combination of these turbines. A typical rotary machine according to the invention comprises blades mounted to a rotor and comprises a stationary casing with a surface facing the blade tips. The rotating blades in general have a blade profile with a pressure side and a suction side and due to the dynamic pressure difference between pressure side and suction side an impulse drives the rotor. The rotating blades do therefore have an optimized angle, which is formed by the rotor axis and the longitudinal extension of the blade profile - also called stagger angle - under which they are mounted to the rotor. This angle optimum depends on the gas, respectively steam conditions, the pressure difference over the entire blading-stage and the orientation of the gas-flow - respectively steam-flow direction before it enters the blading stage.

[0003] A very complex flow distribution is always established at the blade tip, where the flow through the clearance between the blade tip and the opposing surface of the casing can be considered as a pressure-loss and has direct negative consequences for the efficiency. A similar problem is encountered in the aviation technology where for example winglets are installed at the end of the wings of an airplane to reduce the loss of the pressure difference between the pressure side and the suction side of the wing.

[0004] In the technical field of rotary machines respectively turbines numerous approaches were made to minimize the pressure loss through the clearance at the tip of the blade. One example are shrouds at the tip of the blade, which forms together with the other blades of one stage in the assembled condition a closed ring, which itself has a sealing surface, which corresponds to an opposing sealing surface of the casing. Shrouds do have the disadvantage that their mass causes additional tensile stress in the blade due to centrifugal forces resulting from the mass of the shroud under a high rotational speed. Therefore, radially long blades mounted on a

large diameter of the rotor cannot be equipped with shrouds due to constraints from the material.

[0005] One solution to minimize the bypass flows through the clearance at the tip of the blades is known from the patent US 4,239,452 which proposes to equip the surface of the casing, which is facing the blade tips, with seal strips or radial protrusions, which protrusions are extending in a circumferential direction with respect to the rotation of the turbine rotor. While these seal strips respectively protrusions avoid a flow in the axial direction of the turbine a flow in the circumferential direction is not affected.

[0006] Another solution for sealing of free standing blade tips to the casing is the minimization of the radial clearance between the tip and the corresponding casing surface. Due to thermal radial expansion under the heat of the gas respectively the steam is especially during transient thermal conditions the clearance can be reduced and rubbing between the blades' tips and the corresponding casing surface might damage the turbine due to vibration excitation or excessive heat generation. To avoid this, it was suggested to apply an abradable coating, which means a coating that is capable of being rubbed off, to the blades' tips or to the whole blade, which on the one hand minimizes the radial clearance and on the other hand is worn away when contacting the casing surface without causing any serious damage to other turbine components. The disadvantage of this solution is that the abradable coating is also worn away without any contact to the opposing surface after a longer period of operation by the gas flow so that the efficiency advantage is lost with time.

[0007] One object of the invention is to overcome the above mentioned problems and disadvantages and to seal the radial clearance between the blade tip and the opposing casing surfaces to obtain a higher efficiency over the total time of operation without decreasing the operational safety.

[0008] According to the present invention the blades of a rotary machine of the initial mentioned type are provided at the respective first ends with at least one rib respectively fin, which rib extends in the height radially outwards and has a longitudinal extending, which forms an angle α bigger than 0 with the circumferential direction of the rotation.

[0009] The rib on the blade tip is orientated in a direction which crosses the direction of the circumferential protrusions. This arrangement causes an unexpected high pressure drop, which results in an exceptional good sealing of the radial clearance between the blades tip and the corresponding casing surface.

[0010] The pressure drop from the pressure side to the suction side through the radial clearance can be enlarged when the height of the rib is selected in such a way that during operation the rib gets into contact with at least one protrusion at least at the first operations start. One big advantage of the arrangement according to the invention is, that the protrusions of the casing get in contact with

the ribs of the blades only at a certain point, which minimizes the contact surface and therefore the heat and the forces generated by this rubbing contact. According to the invention the rib is designed in such a way, that the heat energy and the forces caused by rubbing do not exceed critical limits and therefore do not damage parts of the turbine. On the other hand the rib is designed strong enough to cope with the pressure difference between suction side and pressure side and that it is not totally destroyed by rubbing.

[0011] The best sealing effect can be obtained when the height of the rib is designed in such a way, that material abrasion occurs on the rib caused by the circumferential protrusion.

[0012] The typical expansion behavior of a turbine synergistically increases the advantages of the solution according to the invention. At the beginning of the expansion process during the first (10 minutes of operation intensive radial expansion of the blade air foil can be observed and the blade tip gets into contact with the opposing surface of the stator. In a second stage between (30 minutes and one hour from a turbine start radial and axial displacement of the stator follows during which the blade tip loses the contact to the corresponding surface of the stators casing, which results in an opening of the radial clearance. In a third stage after approximately three hours from the start of the turbine radial and axial displacement of the rotor, in particular of the shaft, follows, which closes the radial clearance again. The first radial expansion of the rotor is caused by the blades thermal expansion and the rotors disks' radial elongation due to the centrifugal load. The thermal expansion of the shaft is the last step before thermal equilibrium is established due to the shaft's mass. The unexpected big advantage of the invention with respect to the expansion process is, that the relative axial position of the blades tips to the opposing surface of the casing respectively to the circumferential protrusions are the same in the first stage and the last respectively the third stage, when the radial clearance is closed due to centrifugal elongation respectively thermal expansion. Due to the fact, that each protrusion only contacts a point of each respective rib, the abrasion occurs mainly at this point of the rib and not at the circumferential protrusion of the casing, which leads to a cut or a recess in the rib at a special axial position of the protrusion. Therefore, the local abrasion of the rib at the blade's tip caused by the circumferential protrusion does always occur at the same position. Hence the circumferential protrusions fit almost exactly in the abrasion recesses of the ribs, which results in an ideal sealing of the radial clearance.

[0013] The rib can be an inserted seal strip at the tip of the blade but also can be one piece of material with the blade. A characteristic feature of the transition between the blade and the rib is a tapering resulting in a shoulder at least on one side of the rib, respectively the pressure side or the suction side.

[0014] Preferred embodiment of the invention is given

by a rib, which extends along the circumference of parallel to the circumference of the profile of the blade. The form of the rib on the blades tip can be compared to a crown on the blades tip. This comparison especially becomes valid, where the protrusions caused recesses in the rib due to material abrasion resulting from radial contact.

[0015] To further increase the tightness of the sealing of the radial clearance more than one rib, preferably several ribs can be provided on the blades tip.

[0016] The above mentioned attributes and other features and advantages of this invention and the manner of attaining them, will become more apparent and the invention itself will be better understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawing, wherein:

Figure 1 shows a schematic three-dimensional drawing of an arrangement comprising a blade and a surface facing the blade tip,

Figure 2 shows a cross section through the blade according to reference position B of figure (1,

Figure 3 a schematic drawing of a blade and the corresponding opposing surface of the casing, during operation, wherein an abradable coating had been applied to tip of the blade,

Figure 4 a blade and a corresponding opposing surface of the casing according to the invention during operation,

Figure 5 a blade and a corresponding opposing surface according to the invention before operation,

Figure 6 a blade and a corresponding opposing surface according to the invention after operation,

Figure 7 a blade and a corresponding opposing surface according to the invention before operation,

Figure 8 a detailed depiction of a part of figure (7, in which these details are indicated with reference position I.

[0017] Figure 1 shows a three-dimensional schematic drawing of an arrangement comprising a turbine blade 2 and a surface 1 of a turbine casing 8, which is extending in a circumferential direction 3 indicated by an arrow and which is facing the blade 2 tips 6. This arrangement belongs to a turbine, wherein the blade 2 is mounted to a rotor 7, which is not shown and which rotates around a longitudinal not shown central axis 11 of the rotor. The

blades 2 belong to a group of blades 2 which group is not shown in the drawings, and each blade 2 is mounted in a not shown manner to the rotor 7, so that a ring of blades 2 in a circumferential direction of the rotor 7 is arranged around the rotor.

[0018] The blade has a pressure side 4 and a suction side 5, so that a pressure difference establishes from the pressure side 4 to the suction side 5. At the tip 6 of the blade 2 the blade 2 faces the surface 1 of the casing 8. The pressure difference between pressure side 4 and suction side 5 leads to a tendency of a fluid or a gas to flow through a clearance 9 between each blade 2 tip 6 and the surface 1 of the casing 8. This flow results in a partial loss of the pressure difference, which drives the rotor 7 in the turbine and therefore this loss results in a loss of turbine efficiency. In order to minimize this flow, the radial clearance 9 is designed in a way, which increases the pressure drop from the pressure side 4 to the suction side 5 of the blade 2. According to the invention the tip 6 of the blade 2 is equipped with a rib 10, which extends in the height radially outwards and has a longitudinal extending, which forms an angle α with the circumferential direction 11 of the rotation, which angle α is bigger than 0.

[0019] Figure 1 shows a preferred embodiment, wherein the rib 10 extends along the circumference 12 of a blade profile 13 at the tip 6 of the blade 2. The form of the rib 10 can be compared to a crown on the top of the tip 6 of the blade 2.

[0020] The surface 1 is provided with radial protrusions 20, which are extending in circumferential direction 3 of the rotation of the rotor.

[0021] Figure 2 shows the blades tip 6 as a cross section and as indicated by position B in figure 1. Figure 2 shows a hollow blade 2 being closed at the blade tip 14 and having trapezium formed ribs 10, which form a crown on the top of the blade 2 tip 6.

[0022] Figure 3 and 4 show the arrangement of figure 1 during operation. Figure 3 shows an example of an embodiment according to the state of the art, where an abradable coating was applied to the blade 2 and which is wasted away during operation to a certain degree after turbine start, so that the radial clearance 9 is minimized. This coating is worn away during operation totally.

[0023] Figure 5 shows the design of the blade 2 tip 14 and the surface 1 of the turbine casing 8 according to the invention and during operation. The pressure drop over the clearance 9 is increased due to the rib 10 at the tip 14 of the blade 2, which got into contact with the protrusions of the surface 1 and became abraded at the locations of the protrusions, so that the form of the rib 10 became a negative image of the form of the surface 1 with the protrusions. Since the protrusions have only a point contact to the rib 10 the heat energy generated during the rubbing is low and so are the forces during the rubbing within the first start up of the turbine.

[0024] Figure 5 and 6 show the arrangement according to the invention before operation and after operation. Be-

fore operation the rib 10 did not have contact to the protrusions of the surface 1 and after operation the protrusion of surface 1 abraded locally the rib 10 so that recesses 16 were machined into the rib 10.

[0025] A closer look at the arrangement according to the invention in figure 7 and 8 shows a preferred embodiment of the protrusions, which are of a trapezium form (view I).

Claims

1. Rotary machine comprising at least one rotor (7) and at least one casing (8),
whereby blades (2) are mounted to the rotor, whereby a clearance (9) between the radial outer first end of the blades (2) is and a radially opposing facing first surface (1) of the casing (8) is provided, whereby the first surfaces (1) is provided with at least one radial protrusion, which is extending in circumferential direction (11) of the rotation of the rotor (7),
characterized in that
the blades (2) at the respective first ends are provided with at least one rib (10),
which rib (10) extends in the height radially outwards and has a longitudinal extending, which forms an angle α bigger than 0° with the circumferential direction (11) of the rotation of the rotor.
2. Rotary machine according to claim 1,
characterized in that
the height of the rib (10) is selected in such a way, that during operation the rib (10) gets into contact with at least one protrusion (20) at least during the first operation start.
3. Rotary machine according to claim 1 or 2,
characterized in that
the protrusion (20) is designed as a seal strip.
4. Rotary machine according to claim 1, 2 or 3,
characterized in that
the first surface (1) is provided with a plurality of radial protrusions (20) which are extending in circumferential direction (11) of the rotation of the rotor.
5. Rotary machine according to claim 1, 2, 3 or 4, **characterized by** an angle α between $(10^\circ$ and 90° .
6. Rotary machine according to one of the preceding claims,
characterized in that
the protrusion (20) forms at each point of its extension an angle α between $(10^\circ$ and 90° with the rib (10).
7. Rotary machine according to one of the preceding claims,

characterized in that

the height of the ribs (10) is between 5mm and 3mm.

8. Rotary machine according to one of the preceding claims,

5

characterized in that

the protrusion (20) has a height between point 0.5mm and 5mm.

1 surface	10
2 blade	
3 circumferential direction	
4 pressure side	
5 suction side	
6 tip	15
7 rotor	
8 casing	
9 clearance	
10 ribs	
11 central axis	20
12 circumference of a blade	
13 blade profile	
16 recesses	
20 radial protrusion	
α α	25

30

35

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FIG 1

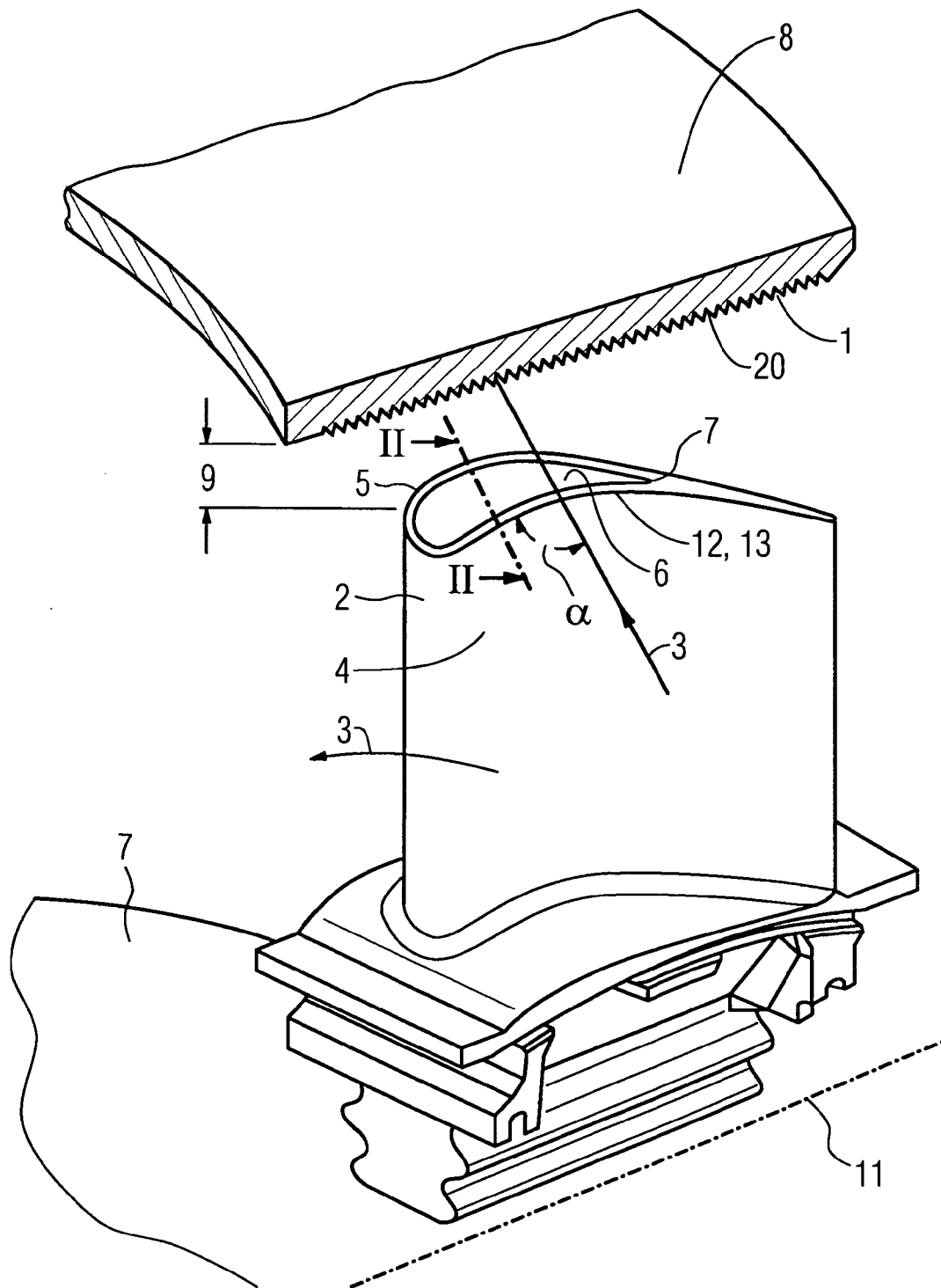


FIG 2

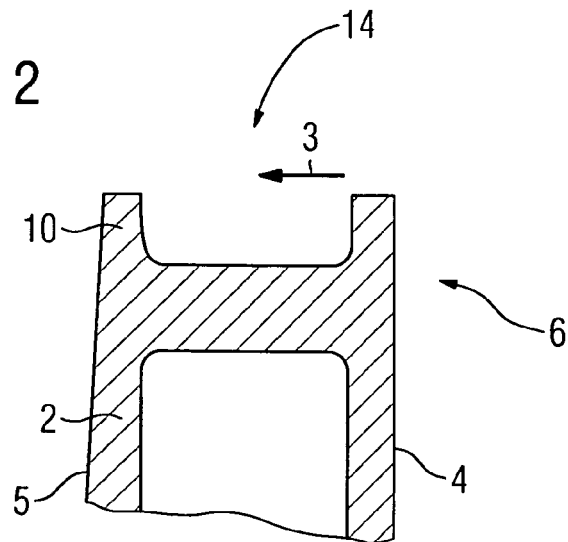


FIG 3

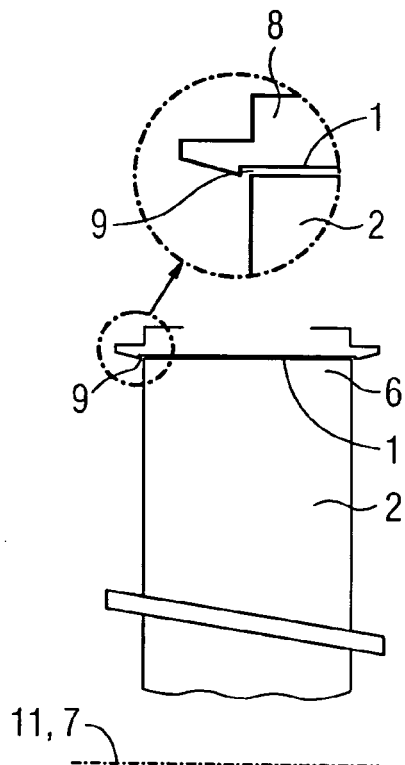


FIG 4

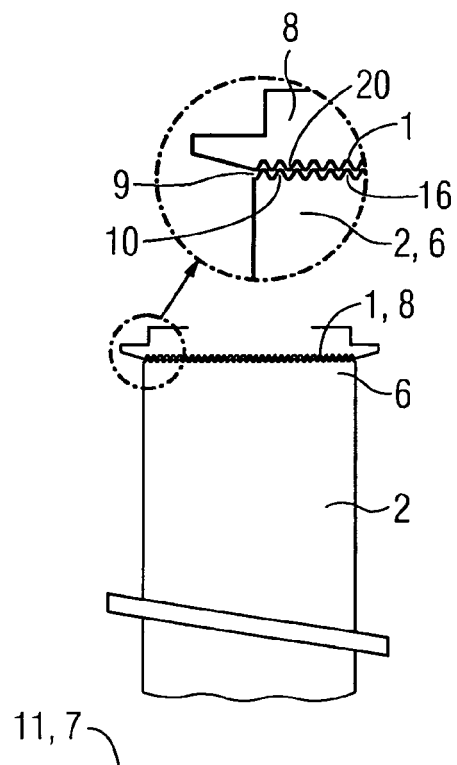


FIG 5

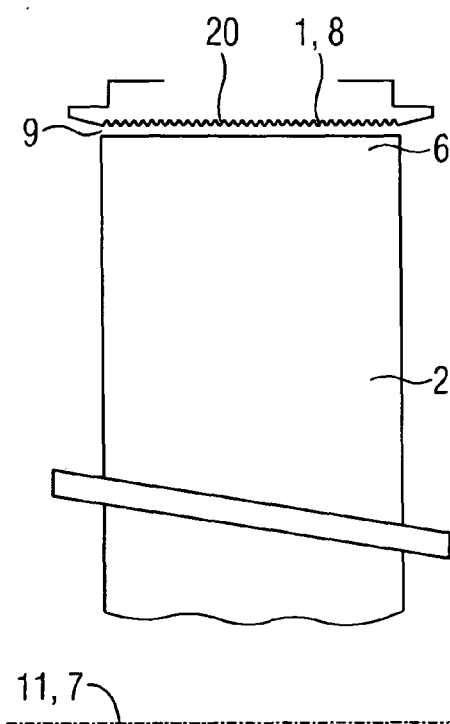


FIG 6

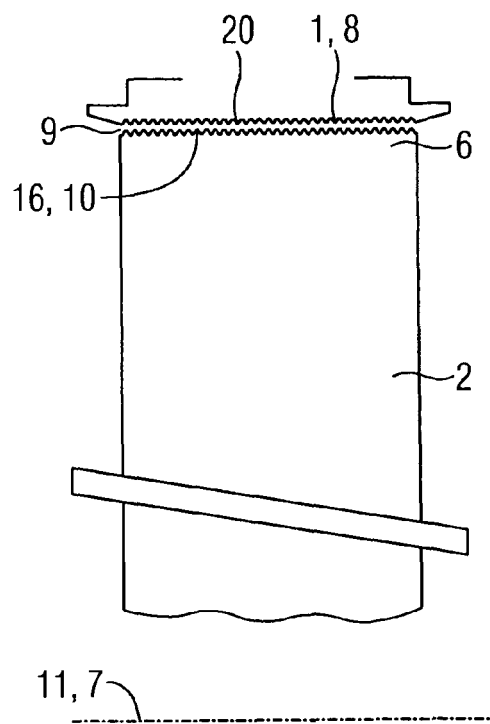


FIG 7

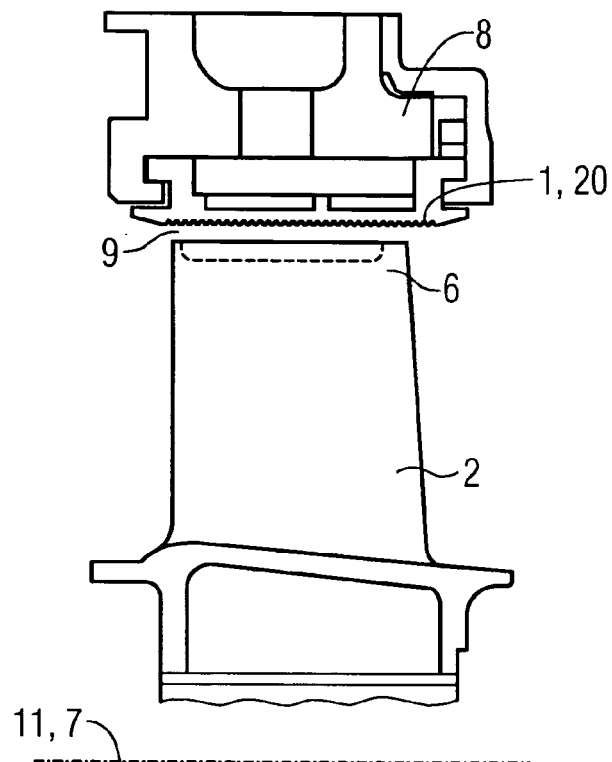
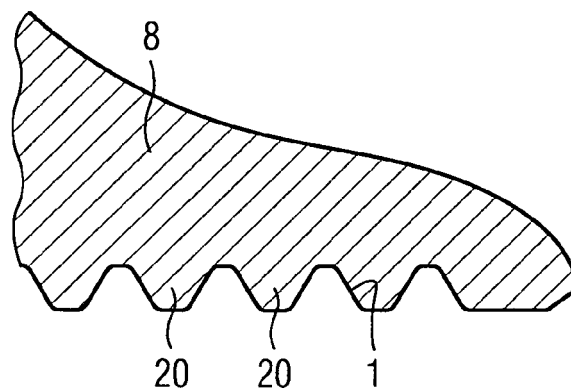


FIG 8





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 07 00 8551

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2003/175116 A1 (LE BIEZ PHILIPPE [FR] ET AL) 18 September 2003 (2003-09-18) * paragraphs [0040] - [0045]; figures 3,5,7,8 *	1-8	INV. F01D5/20 F01D11/02 F01D11/12
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			TECHNICAL FIELDS SEARCHED (IPC)
			F01D
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 21 September 2007	Examiner OECHSNER DE CONINCK
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EPO FORM 1503 03.82 (P04C01)

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

EP 07 00 8551

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21-09-2007

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REFERENCES CITED IN THE DESCRIPTION

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