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(54) **Rotor stage of a turbine**

(57) A rotor stage of a turbine has a rotational axis (XX), a shroud (35) and radially inward thereof a turbine blade (32) defined partly by a pressure side wall (38), a suction side wall (37) and a tip portion (46). The tip portion (46) has a pressure side tip rib (70) and a tip cavity floor (74) defining a tip cavity (76). The pressure side tip rib has a width W_{ps}, a height H_{ps} above the tip cavity and defines a tip gap G_{ps} with the shroud. The pressure side tip rib has a sloping side (78) joining the tip cavity floor and having an angle α_{ps} to a radial line ZZ. The width W_{ps} is in the range G_{ps} to $5G_{ps}$, the height H_{ps} is in the range $5G_{ps}$ to $15G_{ps}$ and the angle α_{ps} is in the range 20° to 70°.

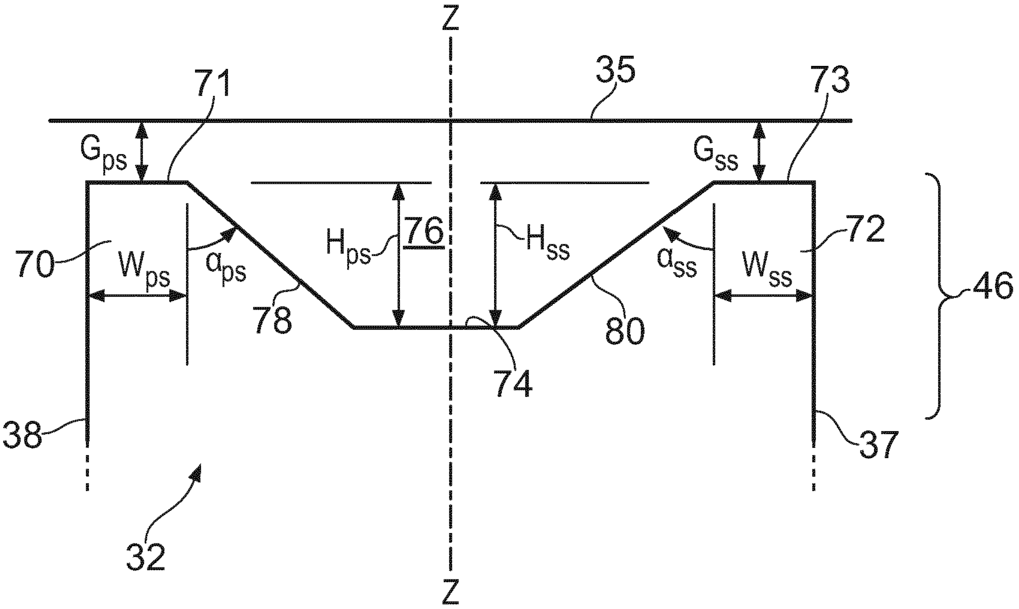

FIG. 8

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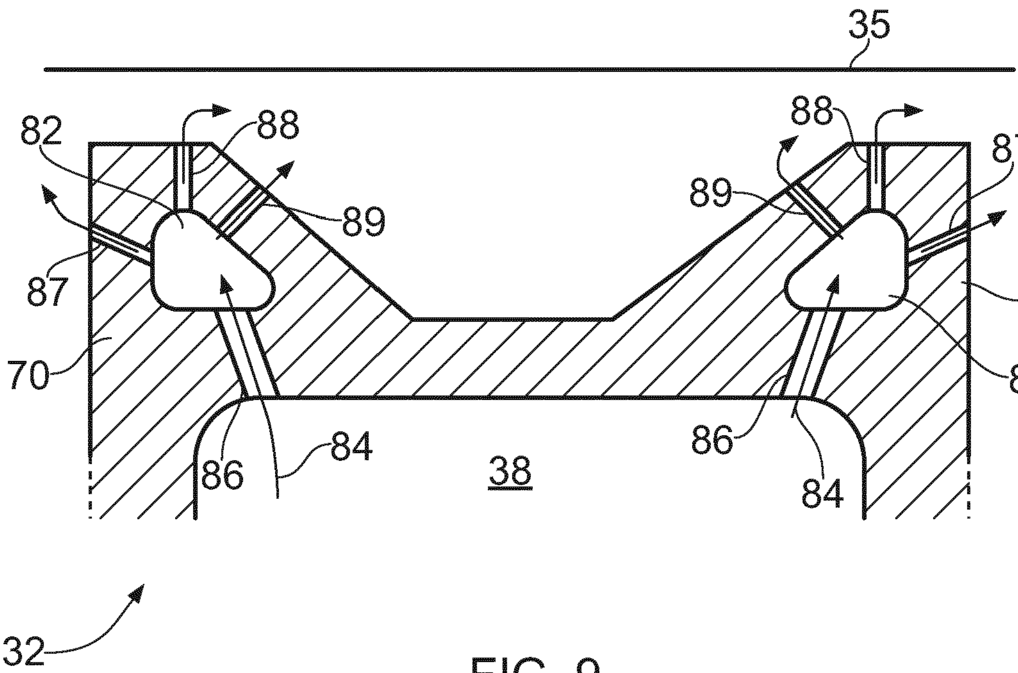


FIG. 9

Description

Technical Field

[0001] The present invention relates to an aerofoil structure, typically of a turbine blade for a gas turbine engine, and in particular a structure of the tip of the aerofoil.

Background

[0002] For turbine rotor blades and particularly high pressure (HP) turbine blades, there is an industry wide and an ever-important object to minimise over-tip leakage of hot working gases between a tip of the blades and a casing. In general, there are three types of tip geometry configurations which attempt to minimise over tip leakage: un-shrouded, partially shrouded and fully shrouded.

[0003] As shown in Figure 1, the simplest un-shrouded rotor blade tip 112 of a rotor blade 110 is a flat-tip arrangement having a generally planar radially outward facing surface. However, this flat-tip design is typically associated with considerable aerodynamic and heat losses due to the over-tip leakage flow of the main working gas. To reduce over-tip leakage, other blade tip configurations have been proposed. For example, in Figure 2 a 'squealer' blade 114 has a tip plate 116 extending over the pressure and suction surface walls. Tip rib, fins or fences 118, 120 extend from the tip plate 116 and define a tip cavity 122.

[0004] A further example is shown in Figure 3. This blade 124 is known as a 'winglet' type and comprises tip wings 126 and 128 that overhang the pressure and suction surfaces 130, 132 respectively. The tip wings 126 and 128 define a channel 134, which can have an inlet 136 and/or an outlet 138 at the leading and trailing edges respectively.

[0005] In either the squealer or winglet blade configurations, the function of the cavity 122 or channel 134 is to trap working gas that leaks over the peripheral wall on the pressure side of the blade. The trapped gas forms one or more vortices within the cavity or channel and/or over the outward surface of the tip fins 118, 120 or wings 126, 128. These vortices inhibit the over-tip leakage flow continuing to the suction side. These configurations serve to avoid losses in efficiency caused by working gas leakage over the turbine blade tips and also to avoid losses caused by flow disturbances set up by the leakage flow. However, a disadvantage of these configurations is that they are complex and as a result are difficult to manufacture. Furthermore, the increased surface area associated with these configurations leads to an increased heat load in the tip of the blade and it is difficult to achieve effective cooling of these blade configurations. Thus both designs are prone to degradation and short in-service life caused by high temperatures and severe thermal gradients.

[0006] A further disadvantage of the winglet configuration is the additional weight of the blade tip; this is a particular issue considering the very high centrifugal forces present in a modern gas turbine engine.

[0007] The squealer configuration particularly suffers from relatively high heat transfer into the blade and has limited cooling; therefore in-service life of the blade is compromised.

[0008] Figure 4 is a sectional view A-A shown on Figure 2. Considering the squealer configuration in more detail and with reference to Figure 4 where there is shown a surface 140 of a casing 142; the over-tip leakage 144 flows over the tip from a pressure surface 146 to a suction surface 148. An over-tip leakage gap G is defined between the tip outer surface 150 and the casing surface 140. To reduce the over-tip leakage flow, the squealer design relies on flow separation 154 at the pressure surface corner 152 of the squealer tip 120. The flow separation or vortex causes a blockage leading to a reduced overall discharge over the tip. This flow separation or vortex is more effective if the pressure surface squealer step is made thinner (i.e. with a smaller W). On the other hand, a thinner squealer will have a larger area-tovolume ratio and hence would be subject to higher specific heat load per unit volume. As a result, current squealer designs are mostly unable to explore the full aerodynamic potential of the squealer working mechanism due to the restrictions arisen from the enhanced heat transfer and the poor 'coolability'.

[0009] Thus the current squealer configuration leads to conflicting performance characteristics between the aerodynamics and heat transfer.

Statement of Invention

[0010] The present invention seeks to address the issues of minimizing over tip leakage and cooling the tips of blades.

[0011] In a first aspect of the invention there is provided a rotor stage of a turbine comprising a rotational axis, a shroud and radially inward thereof a turbine blade defined partly by a pressure side wall, a suction side wall and a tip portion, the tip portion has a pressure side tip rib and a tip cavity floor defining a tip cavity, the pressure side tip rib has a width W_{ps}, a height H_{ps} above the tip cavity and defines a tip gap G_{ps} with the shroud, the pressure side tip rib has a sloping side joining the tip cavity floor and having an angle α_{ps} to a radial line ZZ, the width W_{ps} is in the range G_{ps} to $5G_{ps}$, the height H_{ps} is in the range $5G_{ps}$ to $15G_{ps}$ and the angle α_{ps} is in the range 20° to 70°.

[0012] The sloping side provides more flexibility for the positioning of cooling chambers within the blade so as to achieve improved cooling of the blade tip.

[0013] An angle in the range of 20° to 70° is selected because this provides a balance between providing an increased space for cooling chambers within the blade tip and the need to ensure good aerodynamic performance. It has been found that with this angle range open type flow separation occurs over the rib, leading to a large vortical flow structure in the tip cavity, the above selected angle ensuring that there is a sufficiently large cavity volume to ensure such a vortical flow structure.

[0014] Aerodynamic performance has been found to be improved with a smaller width W_{ps}. However, a problem with squealer tips of the prior art is that a smaller width W_{ps} results in a higher specific heat load per unit volume, and hence increased problems of internal cooling. The present inventors have found that providing a sloping side enables the space within which a cooling cavity can be located to be increased compared to the prior art, so that cooling of the tip can be improved whilst having an aerodynamically beneficial width W_{ps}. In some cases it may be possible to reduce the width W_{ps} to a width narrower than the prior art.

[0015] The width W_{ps} may be in the range $2G_{ps}$ to $3G_{ps}$, the height H_{ps} may be in the range $7G_{ps}$ to $8G_{ps}$ and the angle α_{ps} may be in the range 40° to 60°. An angle between 40 to 60° increases the flexibility for the provision of cooling chambers, whilst maintaining a large tip cavity.

[0016] The width W_{ps} may be approximately $2.5G_{ps}$, the height H_{ps} may be approximately $7G_{ps}$ and the angle α_{ps} may be approximately 45°.

[0017] The sloping side may extend to a maximum radial extent of the turbine blade. That is, the pressure side tip rib may have a radially outer surface and the sloping side may extend directly between the radially outer surface and the tip cavity floor. For example, the pressure side tip rib could be considered to be trapezoidal in shape with the side of the trapezium on the pressure side of the turbine blade forming a right angle with what could be considered the base of the trapezium. Such an arrangement of the sloping side increases the volume of the pressure side tip rib which increases the flexibility for positioning and sizing of cooling chambers within the turbine blade.

[0018] The tip portion may have a suction side tip rib, the suction side tip rib may have a width W_{ss} and may define a tip gap G_{ss} with the shroud, the suction side tip rib may have a sloping side joining the tip cavity floor and having an angle α_{ss} to a radial line ZZ, the width W_{ss} may be in the range G_{ss} to $5G_{ss}$, the height H_{ss} may be in the range $5G_{ss}$ to $15G_{ss}$ and the angle α_{ss} may be in the range 20° to 70°. Such a construction and dimensions of the suction side tip rib has similar advantages to the pressure side tip rib, but on the suction side of the turbine blade.

[0019] The width W_{ss} may be in the range $2G_{ss}$ to $3G_{ss}$, the height H_{ss} may be in the range $7G_{ss}$ to $8G_{ss}$ and the angle α_{ss} may be in the range 40° to 60°.

[0020] The width W_{ss} may be approximately $2.5G_{ss}$, the height H_{ss} may be approximately $7G_{ss}$ and the angle α_{ss} may be approximately 45°.

[0021] The sloping side may extend to a maximum radial extent of the turbine blade. That is, the suction side tip rib may have a radially outer surface and the sloping side may extend directly between the radially outer surface and the tip cavity floor. For example, the suction side tip rib could be considered to be trapezoidal in shape with the side of the trapezium on the suction side of the turbine blade forming a right angle with what could be considered the base of the trapezium. Such an arrangement of the sloping side increases the volume of the suction side tip rib which increases the flexibility for positioning and sizing of cooling chambers within the turbine blade.

[0022] The turbine blade may comprise a rib that extends around the tip of the turbine blade, wherein the rib comprises the pressure side tip rib and the suction side tip rib.

[0023] The width of the tip rib, and/or the width W_{ps} of the pressure side tip rib and/or the width W_{ss} of the suction side tip rib may vary around the turbine blade. Such an arrangement permits the width of the rib(s) to be varied so that the width of the rib(s) can be reduced where the cooling requirements are less. For example, the width W_{ss} may be made thinner than the width W_{ps} because there are less cooling requirements on the suction side. Reducing the width W_{ss} advantageously reduces the weight of the turbine blade.

[0024] The rib that extends around the tip of the turbine blade may have a sloping side joining the tip cavity floor. The angle of the sloping side of the rib, and/or the angle α_{ps} of the pressure side tip rib and/or the angle α_{ss} of the suction side tip rib may vary around the turbine blade. For example, the angle α_{ps} of the pressure side tip rib may be approximately 40° and the angle α_{ss} of the pressure side tip rib may be approximately 60°. The angle may be selected to suit the local heat load at the respective position of the rib.

[0025] A cooling gallery may be defined at least partly within the tip rib (e.g. the pressure side tip rib, the suction side tip rib, and/or the entire tip rib that extends around the tip of the turbine blade and comprises the pressure side tip rib and the suction side tip rib). Extending the cooling gallery into the tip rib improves cooling of the blade tip. Improved cooling can contribute to extended blade life span. Furthermore, improving the cooling of the blade tip means that it is possible to further reduce the width W_{ps} so as to improve aerodynamic performance.

[0026] At least 30% of the cooling gallery may be defined in the tip rib. For example, at least 40% or at least 50% of the cooling gallery may be defined in the tip rib.

[0027] The blade may comprise an internal cooling passage. The blade may comprise a cooling hole extending from the internal cooling passage to the cooling gallery. Alternatively, the cooling gallery may be an extension of the internal cooling passage.

[0028] A cooling gallery may be defined wholly within the tip rib (e.g. the pressure side tip rib, the suction side tip rib, and/or the entire tip rib).

[0029] A cooling gallery may be located at least partly above the tip cavity floor. For example, the cooling gallery may extend into the tip rib in a radial direction by approximately a distance of at least one third of H_{ps} radially outward from (or above) the floor of the tip cavity, alternatively by a distance of at least one half of H_{ps}. The further the cooling gallery extends into the tip rib the greater the cooling of the tip rib.

[0030] At least a major portion of the cooling gallery may be situated radially outward of the floor of the cavity.

[0031] A cooling gallery may be located above or radially outwardly of the floor of the tip cavity, e.g. entirely above (or radially outward from) the tip cavity floor.

[0032] At least one cooling hole may extend from the cooling gallery to an external surface of the tip rib, an inlet of the cooling hole may be located radially outwardly of the floor of the tip cavity.

[0033] A first cooling hole may extend from the cooling gallery to the pressure side of the pressure side tip rib and a second cooling hole may extend to a position at or near a junction between an outer radial surface of the pressure side tip rib and the sloping side. In such an embodiment, the first and second cooling holes provide the function of film cooling, and the second cooling hole additionally contributes to controlling flow separation, which can further improve aerodynamic performance.

[0034] The cooling gallery may extend from the pressure side to the suction side.

[0035] The cooling gallery may be formed of an array of cooling sub-galleries.

[0036] The tip cavity may be defined by curved surfaces forming the outer surface of a wall of generally constant thickness.

Brief Description of the Drawings

[0037]

Figure 1 is a view of a tip portion of a known turbine blade having a flat tip surface,

Figure 2 is a view of a tip portion of a known turbine blade having a squealer tip configuration,

Figure 3 is a view of a tip portion of a known turbine blade having a winglet tip configuration,

Figure 4 is a sectional view A-A shown on Figure 2 and showing a known tip fin.

Figure 5 is a schematic longitudinal cross-section through a ducted fan gas turbine engine in which the present invention is incorporated,

Figure 6 is an isometric view of a typical single stage cooled turbine of the gas turbine described with reference to Figure 4,

Figure 7 shows a chord-wise cross-section through a high-pressure turbine blade incorporating the present invention,

Figure 8 is a schematic section of a tip portion and shroud of a rotor stage of a turbine; the tip portion includes an arrangement of tip ribs and is in accordance with the present invention,

Figure 9 is a schematic section of a tip portion of a blade and shroud of a rotor stage of a turbine; the tip portion includes a cooling scheme in accordance with the present invention,

Figure 10 is a schematic section of an alternative tip portion of a blade and shroud of a rotor stage of a turbine; the tip portion includes a cooling scheme in accordance with the present invention;

Figure 11 is a schematic section of an alternative pressure side tip portion of a blade;

Figure 12 is a schematic section of a further alternative pressure side tip portion of a blade; and

Figure 13 is a schematic section of a yet further alternative pressure side tip portion of a blade.

Detailed Description

[0038] With reference to Figure 5, a ducted fan gas turbine engine generally indicated at 10 has a principal and rotational axis X-X. The engine comprises, in axial flow series, an air intake 11, a propulsive fan 12, an intermediate pressure compressor 13, a high-pressure compressor 14, combustion equipment 15, a high-pressure turbine 16, and intermediate pressure turbine 17, a low-pressure turbine 18 and a core engine exhaust nozzle 19. A nacelle 21 generally surrounds the engine 10 and defines the intake 11, a bypass duct 22 and a bypass exhaust nozzle 23.

[0039] The gas turbine engine 10 works in a conventional manner so that air entering the intake 11 is accelerated by the fan 12 to produce two air flows: a first air flow A into the intermediate pressure compressor 13 and a second air flow B which passes through the bypass duct 22 to provide propulsive thrust. The intermediate pressure compressor 13 compresses the air flow A directed into it before delivering that air to the high pressure compressor 14 where further compression takes place.

[0040] The compressed air exhausted from the high-pressure compressor 14 is directed into the combustion equipment 15 where it is mixed with fuel and the mixture combusted. The resultant hot combustion products then expand through, and thereby drive the high, intermediate and low-pressure turbines 16, 17, 18 before being exhausted through the nozzle 19 to provide additional propulsive thrust. The high, intermediate and low-pressure turbines respectively drive the high and intermediate pressure compressors 14, 13 and the fan 12 by suitable interconnecting shafts.

[0041] The performance of gas turbine engines, whether measured in terms of efficiency or specific output, is improved by increasing the turbine gas temperature. It is therefore desirable to operate the turbines at the highest possible temperatures. For any engine cycle compression ratio or bypass ratio, increasing the turbine entry gas temperature produces more specific thrust (e.g. engine thrust per unit of air mass flow). However as turbine entry temperatures increase, the life of an un-cooled turbine falls, necessitating the development of better materials and the introduction of internal air cooling.

[0042] In modern engines, the high-pressure turbine gas temperatures are hotter than the melting point of the material of the blades and vanes, necessitating internal air-cooling of these airfoil components. During its passage through the engine, the mean temperature of the gas stream decreases as power is extracted. Therefore, the need to cool the static and rotary parts of the engine structure decreases as the gas moves from the high-pressure stage(s), through the intermediate-pressure and low-pressure stages, and towards the exit nozzle.

[0043] Figure 6 shows an isometric view of a typical single stage cooled high-pressure turbine. The present tip arrangement can also be applied to other turbine or even compressor stages of a gas or steam turbine, whether for an aero, industrial or marine engine. Cooling air-flows are indicated by arrows.

[0044] Internal convection and external coolant films are the prime methods of cooling the gas path components such as aerofoils 36, platforms 34, shrouds 33 and casing shroud segments 35 etc. High-pressure turbine nozzle guide vanes 31 (NGV) consume the greatest amount of cooling air on high temperature engines. High-pressure blades 32 typically use about half of the NGV coolant flow. The intermediate-pressure and low-pressure stages downstream of the HP turbine use progressively less cooling air.

[0045] The high-pressure turbine airfoils are cooled by using high-pressure air from one of the compressors that has by-passed the combustor and is therefore relatively cool compared to the gas temperature. Typical cooling air temperatures are between 800 and 1000 K, while gas temperatures can be in excess of 2100 K.

[0046] The cooling air from the compressor that is used to cool the hot turbine components is not used fully to extract work from the turbine. Therefore, as extracting coolant flow has an adverse effect on the engine operating efficiency, it is important to use the cooling air as effectively as possible.

[0047] Ever increasing gas temperature levels combined with a drive towards flatter combustion radial temperature profiles, in the interests of reduced combustor emissions, have resulted in an increase in local gas temperature experienced by the extremities of the blades and vanes, and the working gas annulus end-walls.

[0048] Referring to Figures 6 and 7, a turbine blade 32 has a longitudinally extending aerofoil portion 36 with facing suction side 37 and pressure side 38 walls. The aerofoil portion 36 extends across the working gas annulus, with the longitudinal direction of the aerofoil portion being arranged generally along a radial direction of the engine. The turbine blade 32 has a root portion 44 radially inward of the aerofoil and a tip portion 46 radially outward of the aerofoil. The suction side 37 and pressure side 38 walls meet at a leading edge 48 and a trailing edge 50. The root portion engages a rotor disc 52 via complimentary dovetail or in this example, fir-tree fixtures 54. Radially outward of the tip portion 46 is the casing shroud 35. The blade, disc and casing shroud form a rotor stage 56.

[0049] In this exemplary embodiment, a multi-pass cooling passage 38 is fed cooling air 42 by a feed passage 40 formed in the root portion 44 of the blade. A second cooling air feed 60 can supply additional coolant for the trailing edge 50 of the blade that can be particularly prone to thermal erosion. Cooling air leaves the multi-pass cooling passage through effusion holes 62, 64 in the aerofoil surfaces and particularly in the leading and trailing edges 48, 50 of the blade to create a film of cooling air over the aerofoil surfaces 37, 38. The block arrows in Figure 6 show the general direction of cooling airflow. The arrows in Figure 7 show in more detail the internal cooling flow directions in this multipass cooling passage system.

[0050] Radially outwardly of the turbine blade is the casing shroud segment 35 and partially shown a tip clearance control arrangement 66 capable of cooling or heating the shroud segment 35 to dilate or contract the shroud segments to maintain a desired position relative to the blade tip. As is well known in the tip clearance control field cooling or heating fluid can be fed via holes 68 to impinge onto the shroud segment. Other mechanical tip clearance control systems, whether active or scheduled, can be used and are well known in the art.

[0051] Referring now to Figures 8 and 9, the turbine blade 32 is defined partly by the pressure side wall 38, the suction side wall 37 and the tip portion 46. The tip portion 46 has a pressure side tip rib 70 and a tip cavity floor 74 partly defining a tip cavity 76. The pressure side tip rib 70 has a radially outer surface 71 having a width W_{ps}, a height H_{ps} above the tip cavity floor and defines the tip gap G_{ps} with the shroud segment 35. The pressure side tip rib has a sloping side 78 joining the tip cavity floor 76 and the radially outer surface 71. The sloping side 78 has an angle α_{ps} to the radial line ZZ.

[0052] The problems of known blade tip configurations as described in the background section, are greatly resolved by the present tip configuration by a tip rib having the width W_{ps} in the range G_{ps} to $5G_{ps}$, the height H_{ps} is in the range $5G_{ps}$ to $10Gp_s$ and the angle α_{ps} is in the range 20° to 60°.

[0053] A particularly effective envelope of the pressure side tip rib dimensions is considered to be that the width W_{ps} is in the range $2G_{ps}$ to $5G_{ps}$, the height H_{ps} is in the range $7G_{ps}$ to $15G_{ps}$ and the angle α_{ps} is in the range 40° to 60°. One example of a tip rib has its dimensions where the width W_{ps} is approximately $2.5G_{ps}$, the height H_{ps} is approximately $7G_{ps}$ and the angle α_{ps} is approximately 45°.

[0054] The gap G_{ps} is a nominal gap size at an engine or a rotor stage design point. This design point is can be at a number of engine or rotor operational conditions such as at cruise or take-off. During a normal flight cycle the engine and rotor stage are usually at the cruise condition for the longest period of time and therefore the design point is chosen here to provide the greatest efficiency. The design point can also be at take-off where the engine is producing its greatest thrust and therefore the working gas is at its hottest and greatest flow. Thus at take-off conditions it can be advantageous to design the gap G_{ps} to occur. As is well known, tip clearance control systems can be used in an attempt to maintain the gap G_{ps} to its design point.

[0055] Of primary importance is the above defined pressure side tip rib; however, the suction side tip rib is also instrumental in reducing over tip leakage and heat loading in to the blade. Thus the presently described blade comprises the tip portion 46 having a suction side tip rib 72. The suction side tip rib has a width W_{ss} and defines a tip gap G_{ss} with the shroud 35. The suction side tip rib 72 has a sloping side 80 joining the tip cavity floor 74 with its radially outer surface 73. The sloping side 80 has an angle α_{ss} to a radial line ZZ. In general, the width W_{ss} is in the range G_{ss} to $5G_{ss}$, the height H_{ss} is in the range $5G_{ss}$ to $10G_{ss}$ and the angle α_{ss} is in the range 20° to 70°.

[0056] A particularly effective envelope of the suction side tip rib dimensions is considered to be that the width W_{ss} is in the range $2G_{ss}$ to $3G_{ss}$, the height H_{ss} is in the range $7G_{ss}$ to $15G_{ss}$ and the angle α_{ss} is in the range 40° to 60°. One example of a tip rib has its dimensions where the width W_{ss} is approximately $2.5G_{ss}$, the height H_{ss} is approximately $7G_{ss}$ and the angle α_{ss} is approximately 45°.

[0057] The pressure side tip rib 70 described above can be used in conjunction with a conventional rectangular tip rib on the suction side or the above described suction side tip rib 72. The suction side tip rib 72 described above can also be used in conjunction with a conventional rectangular tip rib on the pressure side.

[0058] The sloping side of the suction side rib may be angled at a different angle α_{ss} to the angle α_{ps} of the sloping side of the pressure side rib. For example, the angle α_{ps} may be 40° and the angle α_{ss} may be 60°, or any other angle within the range specified, the angle being selected to suit local heat loading. The angle of the sloping side may continuously vary around the aerofoil to further tune the sloping sides to local heat loading. In alternative embodiments the angle α_{ps} of the sloping side of the pressure side rib may be equal to the angle α_{ss} of the sloping side of the suction side rib.

[0059] The dimensions of the tip ribs 70, 72 may be constant along the chord of the blade from the leading to the trailing edge. Alternatively, the dimensions of the tip ribs 70, 72 may vary in any one of more of their dimensions for the best possible aerodynamic shape to minimise over tip leakage. Any variation in the dimensions can be because of the curvature of the blade between leading and trailing edges and/or the direction of the working gases and/or the mass flow of the over tip leakage flow. Further, varying the dimensions of the tip rib can reduce the weight of the blade.

[0060] A further and important aspect of the above described dimensions of the tip ribs is that their cross-sectional profile lends itself to improved cooling or coolability over conventional tip ribs. As can be seen in Figures 7 and 9, a cooling gallery 82 is defined at least partly within the tip rib 70 itself. Preferably, at least a major part of the cooling gallery 82 is situated radially outward of the floor of the cavity 76. With certain tip rib configurations, the whole of the cooling gallery 82 is positioned radially outwardly of the floor of the tip cavity. The cooling holes 87, 88, 89 can be arranged such that their inlets are located radially outward of the floor of the cavity 76.

[0061] Coolant 84 is fed from one of the main multipass cooling passages 38 through a supply passage 86 and into the tip rib cooling gallery 82. The gallery 82 can supply any one or more cooling holes 87, 88, 89 that can be provided which in turn then supply any one or more of the external surfaces of the tip rib with coolant. Not only can the coolant in the gallery 82 remove heat by convection from the bulk mass of the blade tip rib, but also the coolant passing through the supply passage 86 can impinge on a surface of the gallery to reduce heat load. The cooling holes 87, 88, 89 can form a film of coolant over the surrounding surface to help prevent hot gases directly impinging on the surface and can also locally add to and cool the hot working gases which spill over the tip.

[0062] The gallery 82 can extend part of or all the chord length of the blade between leading edge to the trailing edge. The gallery can extend around the leading edge and/or trailing edge so that it forms a single gallery. Alternatively, the blade can include a number of galleries 82', 82", 82'" aligned in the tip rib and supplied with different sources of coolant as can be seen in Figure 7. The galleries 82', 82", 82'" can be supplied coolant from different sources or parts of the multipass passage 38 and blade coolant supplies 42, 60 via supply passages 86', 86", 86"' respectively.

[0063] The gallery 82 is shown having a cross-sectional profile generally corresponding to the profile of the tip rib so that the walls have an approximately similar thickness; however, other cross-sectional profiles can be used such as circular or elliptical.

[0064] Figure 10 shows an alternative blade 32 where the galleries 82 are now extensions of the main coolant passage 38 arranged within the main aerofoil of the blade. This embodiment has common features as described with reference to Figure 8. The relevant angles of the surfaces 78 and 80 can be equated with the dashed lines 90, 92 which represent approximate centre-lines of the wall defining these surfaces. The same cooling holes 87, 88, 89 as shown in Figure 9, can supply coolant to the external surfaces of the tip ribs 70, 72 in similar manner.

[0065] This alternative blade also has a tip cavity 76 defined by curved surfaces 78, 74 and 80 that can help prevent localised recirculation of hot gases that spill over the tip ribs. The curved surface also helps to reduce stress at otherwise sharp geometric changes between sloping surfaces 78, 80 and the tip cavity floor.

[0066] The wall forming the tip cavity floor 74 and the surfaces 78, 80 can be formed having a generally constant thickness T. Advantageously, the aerofoil can be lighter, less complex to manufacture and can result in lower pressure loss for the coolant and supply of coolant through cooling holes 87, 88, 89.

[0067] Referring to Figure 11 a portion of a further alternative blade is shown. Similarly to the blade shown in Figure 10, the cooling gallery 82 is an extension of the coolant passage 38. However, in the embodiment shown in Figure 11 the sides of the tip are substantially straight angled sides, instead of curved sides. In the present embodiment, the cooling gallery 82 substantially follows the profile of the tip. However, in alternative embodiments the cooling gallery may take any suitable form.

[0068] Referring to Figures 12 and 13 a further alternative configuration of cooling gallery is shown. In the examples shown in Figures 12 and 13 the cooling gallery is elliptical. In the embodiment shown in Figure 12, one cooling passage 87 is shown extending to the pressure side of the turbine blade to provide the function of film cooling. In Figure 13 a further passage 89 is shown. Said further passage is located at a position where the radially outer surface connects with the sloping side. The further passage 89 provides both film cooling and contributes to flow separation control.

Claims

1. A rotor stage of a turbine comprising
a rotational axis (XX),
a shroud (35) and radially inward thereof
a turbine blade (32) defined partly by a pressure side wall (38), a suction side wall (37) and a tip portion (46),
the tip portion (46) has a pressure side tip rib (70) and a tip cavity floor (74) defining a tip cavity (76),
the pressure side tip rib has a width W_{ps}, a height H_{ps} above the tip cavity and defines a tip gap G_{ps} with the shroud,
the pressure side tip rib has a sloping side (78) joining the tip cavity floor and having an angle α_{ps} to a radial line ZZ,
the width W_{ps} is in the range G_{ps} to $5G_{ps}$,
the height H_{ps} is in the range $5G_{ps}$ to $15G_{ps}$ and
the angle α_{ps} is in the range 20° to 70°.

2. A rotor stage of a turbine as claimed in claim 1, wherein
the width W_{ps} is in the range $2G_{ps}$ to $3G_{ps}$,
the height H_{ps} is in the range $7G_{ps}$ to $8G_{ps}$ and
the angle α_{ps} is in the range 40° to 60°.

3. A rotor stage of a turbine as claimed in claim 1 or 2, wherein the pressure side tip rib has a radially outer surface and the sloping side directly extends between the radially outer surface and the tip cavity floor.

4. A rotor stage of a turbine as claimed in any previous claim, wherein the tip portion (46) has a suction side tip rib (72),
the suction side tip rib has a width W_{ss} and defines a tip gap G_{ss} with the shroud,
the suction side tip rib has a sloping side (80) joining the tip cavity floor and having an angle α_{ss} to a radial line ZZ,
the width W_{ss} is in the range G_{ss} to $5G_{ss}$,
the height H_{ss} is in the range $5G_{ss}$ to $15G_{ss}$ and
the angle α_{ss} is in the range 20° to 70°.

5. A rotor stage of a turbine as claimed in claim 4, wherein
the width W_{ss} is in the range $2G_{ss}$ to $3G_{ss}$,
the height H_{ss} is in the range $7G_{ss}$ to $8G_{ss}$ and
the angle α_{ss} is in the range 40° to 60°.

6. A rotor stage of a turbine as claimed in any one of the previous claims, comprising a tip rib, wherein the tip rib comprises the pressure side tip rib, and wherein a cooling gallery (82) is defined at least partly within a tip rib.

7. A rotor stage of a turbine as claimed in claim 6, wherein a major portion of the cooling gallery is situated radially outward of the tip cavity floor (74).

8. A rotor stage of a turbine as claimed in claim 6 or 7, wherein the blade comprises an internal cooling passage (38, 60) and the cooling gallery (82) is an extension of the internal cooling passage.

9. A rotor stage of a turbine as claimed in claim 8, wherein the tip cavity is defined by curved surfaces forming the outer surface of a wall of generally constant thickness (T).

10. A rotor stage of a turbine as claimed in claim 6 or 7, wherein a cooling gallery (82) is defined wholly within the tip rib.

11. A rotor stage of a turbine as claimed in any one of claims 6 to 10, wherein a cooling gallery (82) is located above the tip cavity floor.

12. A rotor stage of a turbine as claimed in any one of claims 6 to 11, wherein at least one cooling hole (87, 88, 89) extends from the cooling gallery (82) to an external surface of the pressure side tip rib, an inlet

of the cooling hole is located radially outwardly of the floor of the tip cavity.

13. A rotor stage of a turbine as claimed in any one of claims 6 to 12 as dependent on claim 4 or 5, wherein the tip rib comprises the suction side rib and the cooling gallery is defined at least partly within the suction side tip rib.

14. A rotor stage of a turbine as claimed in claim 13, wherein the cooling gallery (82) extends from the pressure side to the suction side.

15. A rotor stage of a turbine as claimed in any one of claims 6 to 14, wherein the cooling gallery (82) is formed of an array of cooling sub-galleries.

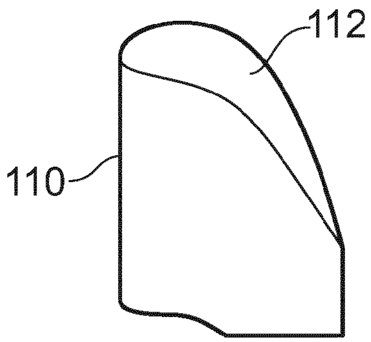


FIG. 1

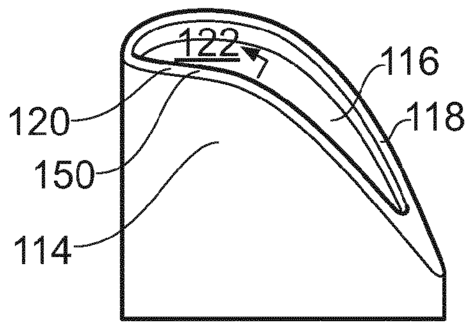


FIG. 2

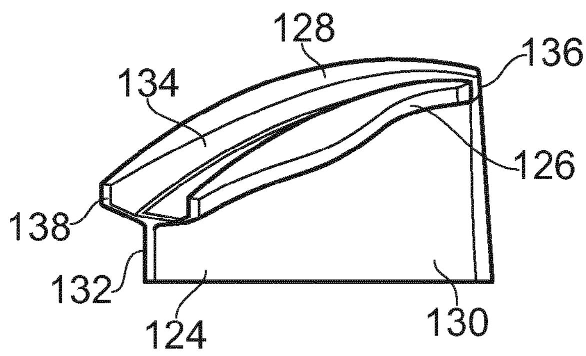
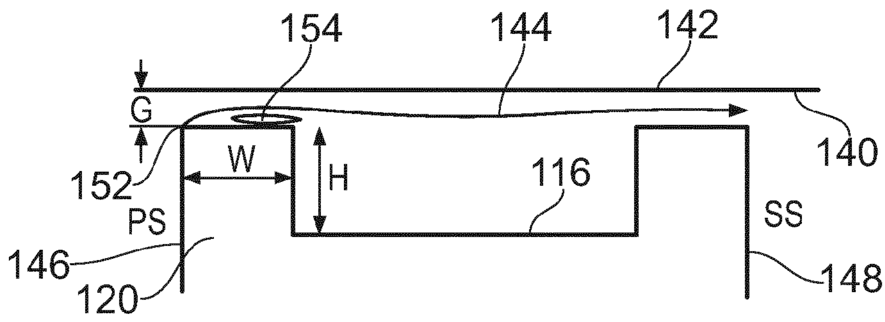


FIG. 3



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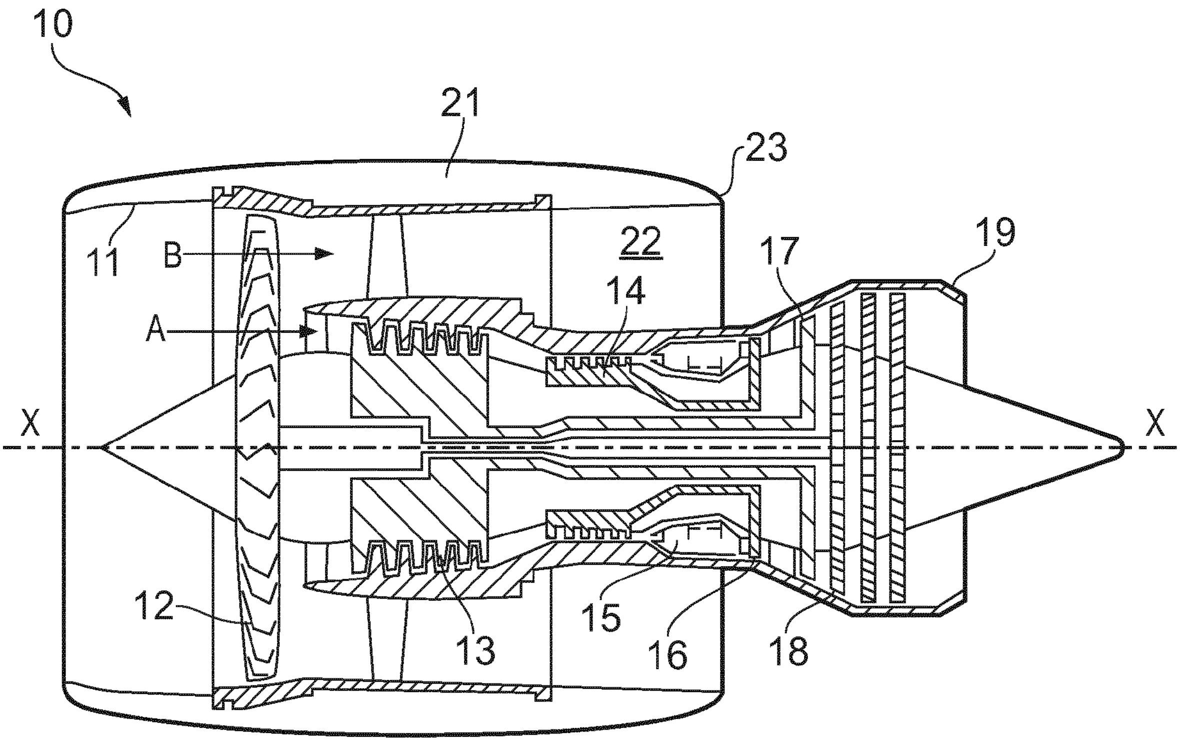
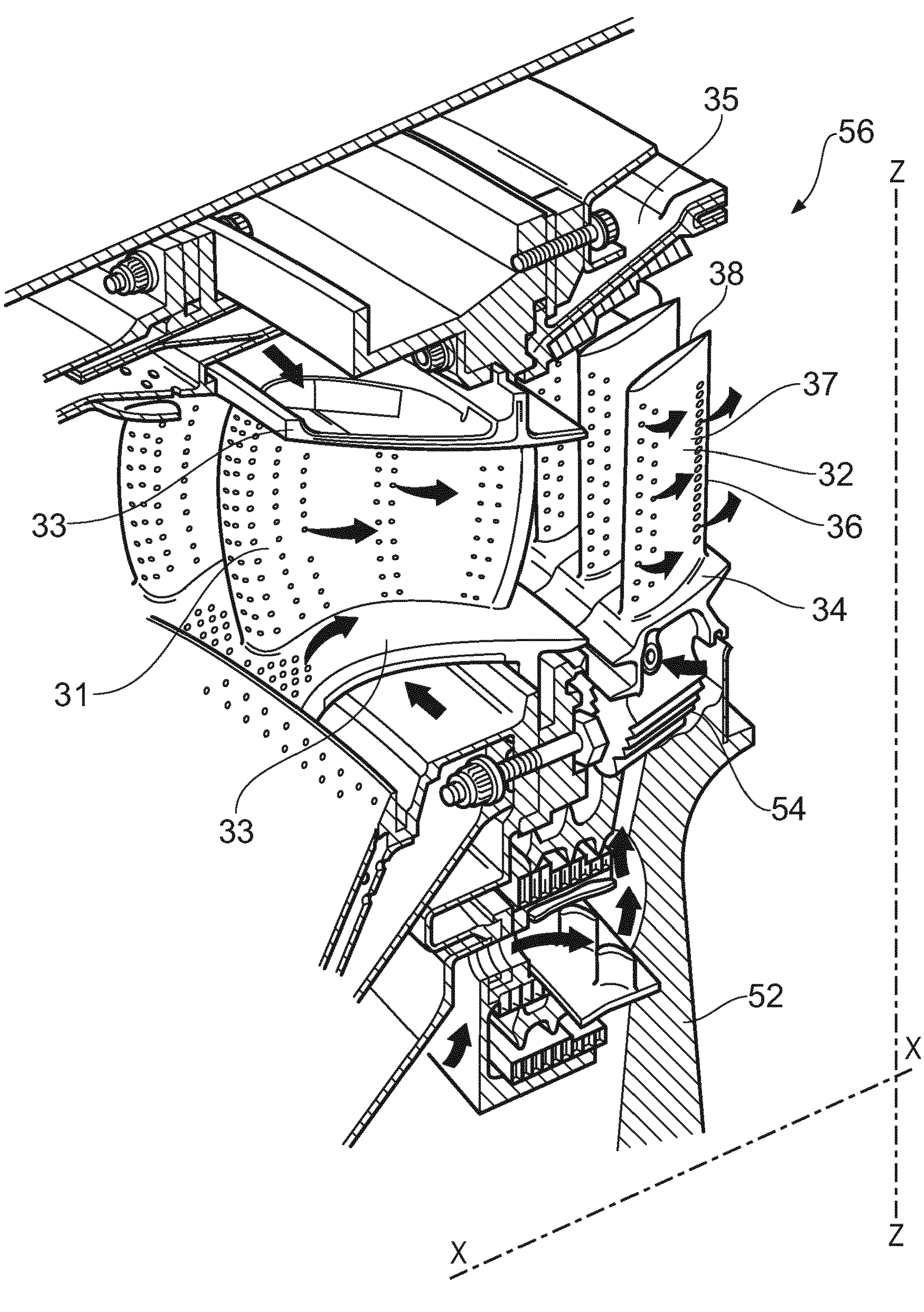


FIG. 5



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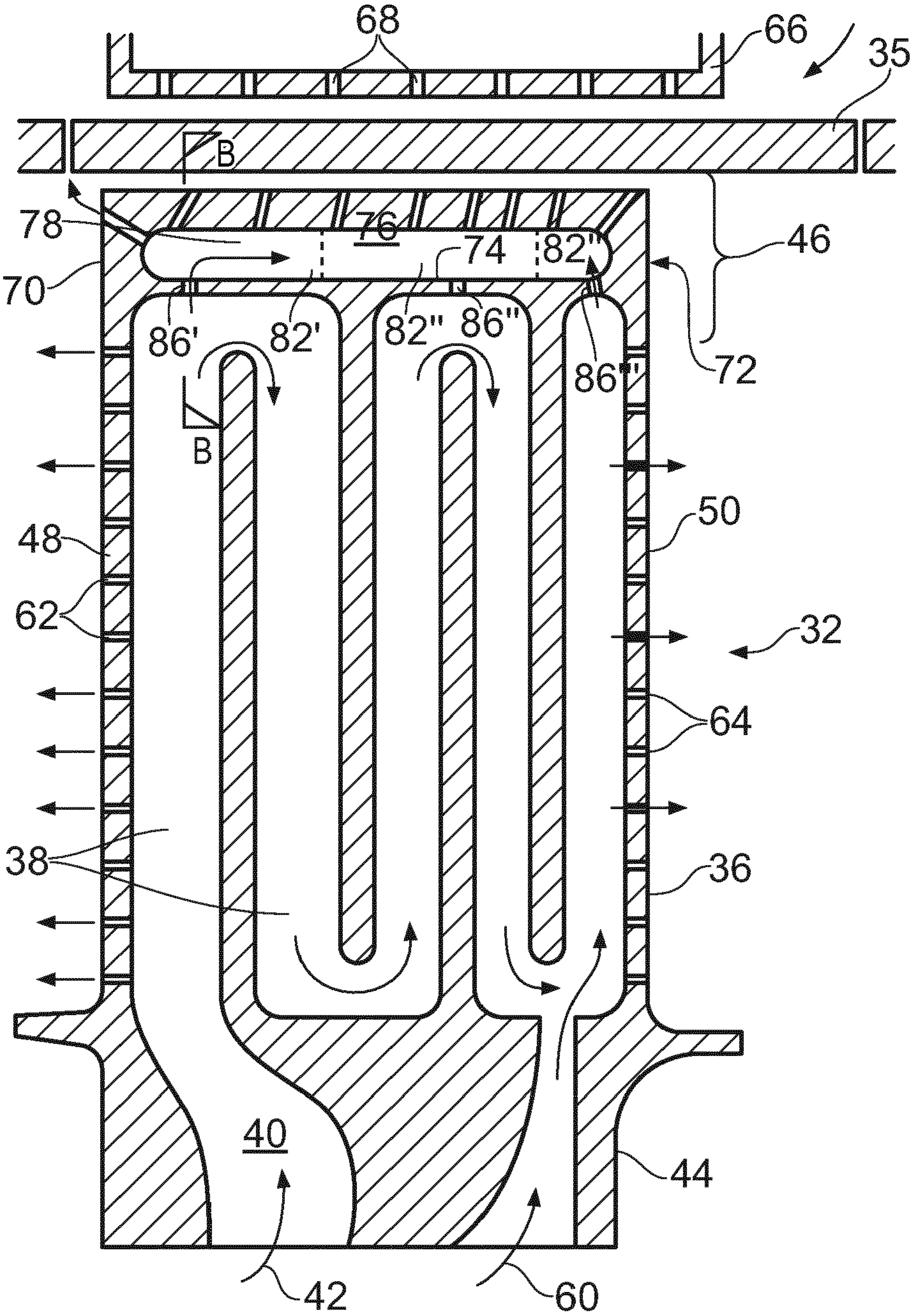
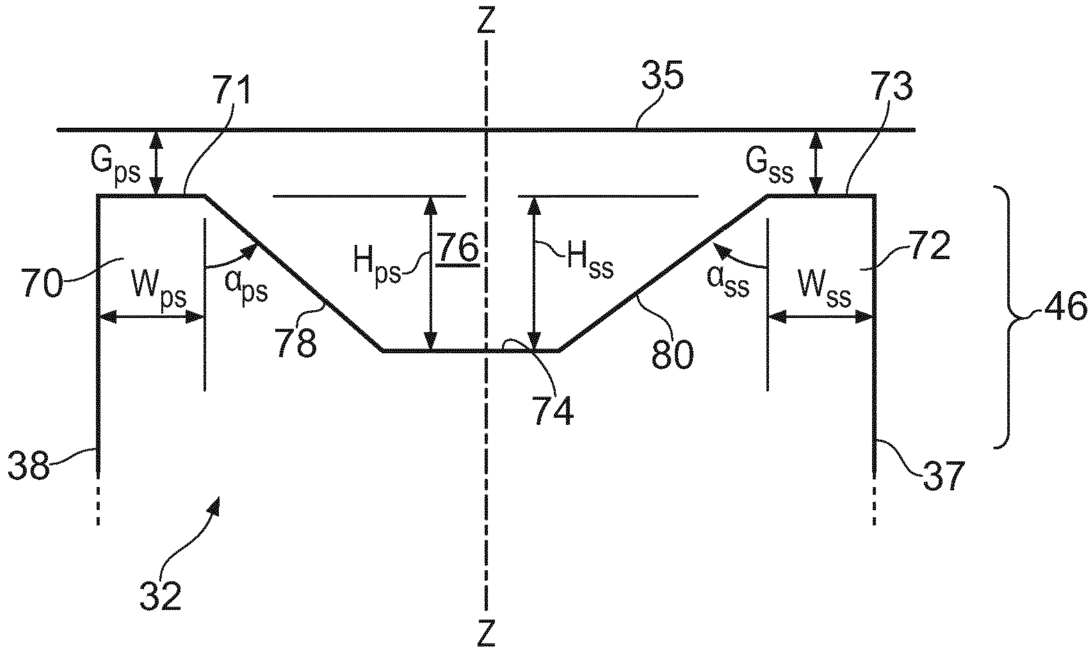

68
66
35
B
46
78
76
74
82'''
70
72
86'
82'
82''
86''
86'''
B
48
50
62
32
64
38
36
40
44
42
60

FIG. 7


Z
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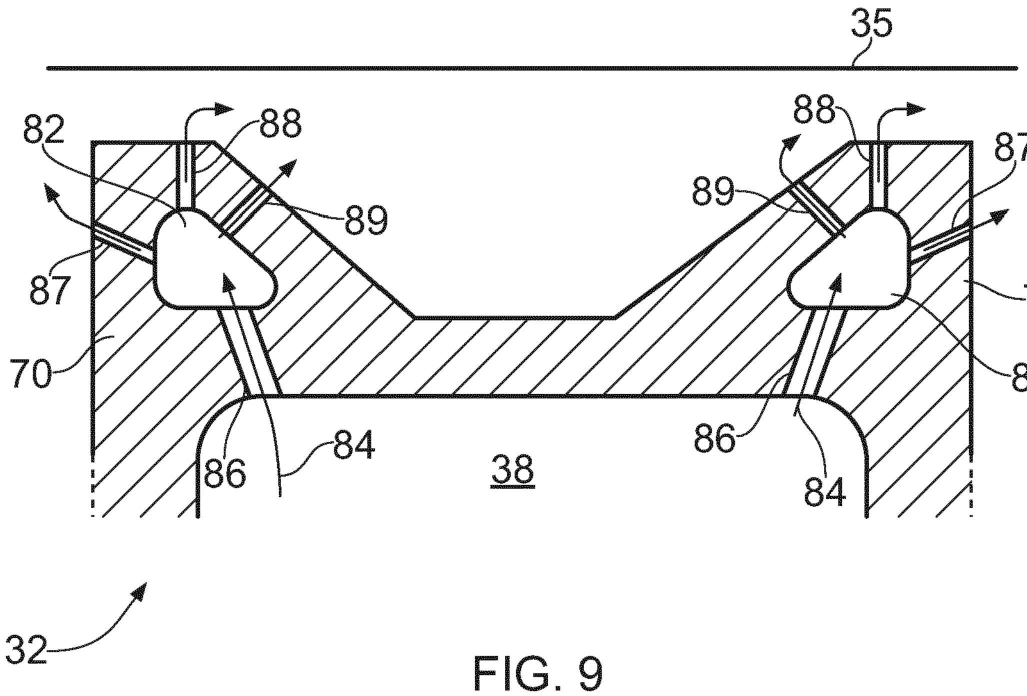
35
73
G_{ps}
G_{ss}
76
H_{ps}
H_{ss}
70
W_{ps}
α_{ps}
α_{ss}
72
W_{ss}
46
78
80
74
38
37
32
Z

FIG. 8


35
82
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72
70
82
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84
38
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84
32

FIG. 9

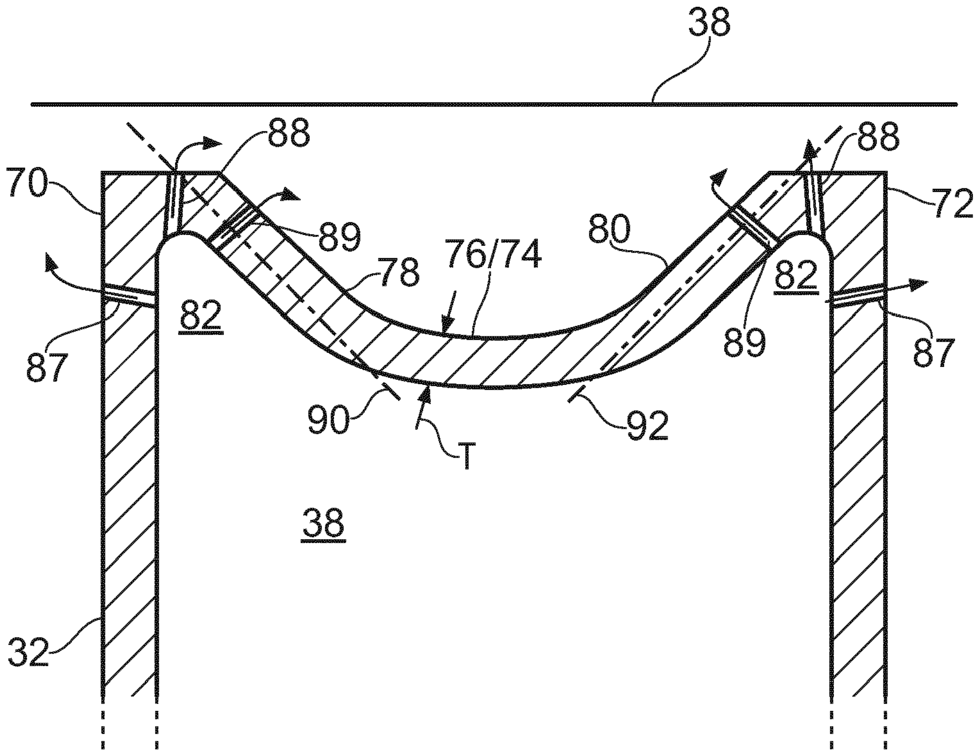

FIG. 10

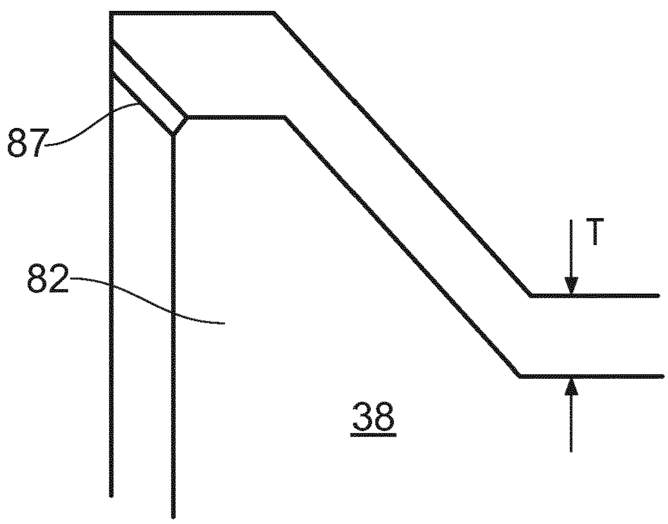

FIG. 11

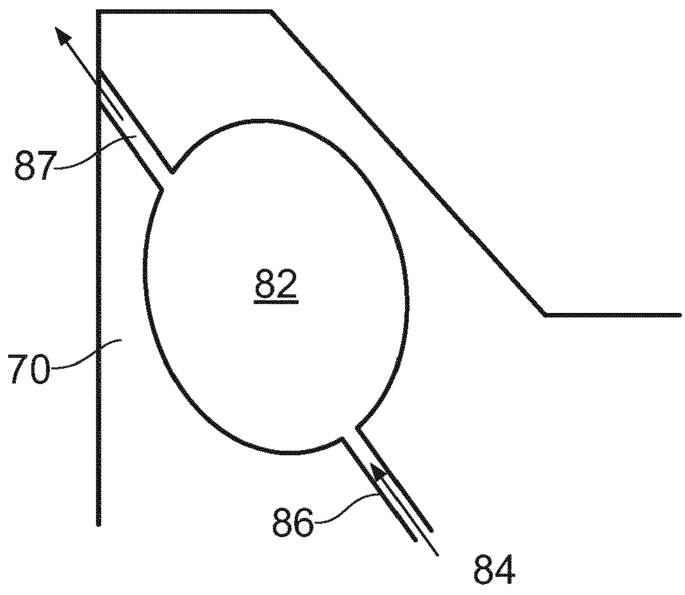

FIG. 12

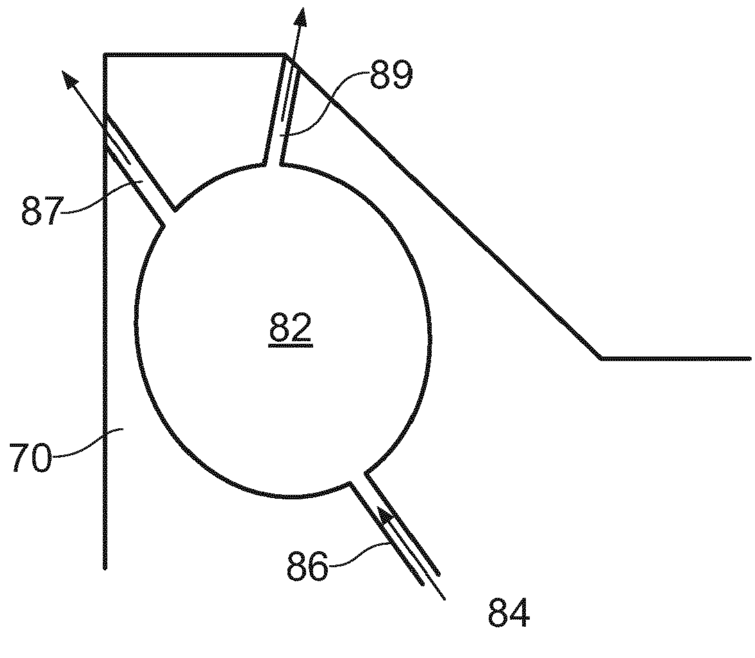

FIG. 13

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EUROPEAN SEARCH REPORT

Application Number
EP 13 19 6186

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 2010/047057 A1 (KOPMELS MICHIEL [GB]) 25 February 2010 (2010-02-25) * figures *	1-5	INV. F01D5/20
X	US 2009/092500 A1 (BOURY JACQUES AUGUSTE AMEDEE [FR] ET AL) 9 April 2009 (2009-04-09) * paragraph [0034]; figures *	1-5	
X	KR 2012 0048439 A (UNIV SOGANG IND UNIV COOP FOUN [KR]) 15 May 2012 (2012-05-15) * figures *	1-5	
X	US 2004/179940 A1 (LIANG GEORGE [US]) 16 September 2004 (2004-09-16) * figures 3,4 *	1-15	
X	US 2005/111979 A1 (LIANG GEORGE [US]) 26 May 2005 (2005-05-26) * figures *	1-15	TECHNICAL FIELDS SEARCHED (IPC)
X	US 5 660 523 A (LEE CHING-PANG [US]) 26 August 1997 (1997-08-26) * figures *	1-15	F01D
X	US 5 738 491 A (LEE CHING-PANG [US] ET AL) 14 April 1998 (1998-04-14) * figure 6 *	1-15	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	19 February 2014	Raspo, Fabrice

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19-02-2014

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010047057 A1	25-02-2010	EP 2141327 A2	06-01-2010
		GB 2461502 A	06-01-2010
		US 2010047057 A1	25-02-2010
US 2009092500 A1	09-04-2009	EP 1736636 A1	27-12-2006
		FR 2887581 A1	29-12-2006
		US 2009092500 A1	09-04-2009
KR 20120048439 A	15-05-2012	NONE	
US 2004179940 A1	16-09-2004	US 2004179940 A1	16-09-2004
		US 2006029497 A1	09-02-2006
US 2005111979 A1	26-05-2005	NONE	
US 5660523 A	26-08-1997	NONE	
US 5738491 A	14-04-1998	NONE	

EPO FORM P0459

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