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(54) ANGLED TIP RODS USED TO CAST HOLES IN TIPS OF BLADE CORES OF AIRFOILS

STÄBE MIT ABGEWINKELTER SPITZE ZUM GIESSEN VON LÖCHERN IN DIE SPITZEN DER SCHAUFELKERNE VON SCHAUFELN

TIGES À POINTE INCLINÉE POUR COULER DES TROUS DANS LES EXTRÉMITÉS DES NOYAUX D'AUBES.

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Description

BACKGROUND

[0001] Exemplary embodiments of the present invention relate generally to gas turbine engines and, in one embodiment, to angled tip rods used to cast holes in tips of blade cores of airfoils.

[0002] Airfoils are present in many aerodynamic applications including, but not limited to, turbines of gas turbine engines. These turbine airfoils each have a root, a tip, pressure and suction surfaces that extend from root to tip and leading and trailing edges at leading and trailing sides of the pressure and suction surfaces. In a turbine, the turbine airfoils or turbine blades can aerodynamically interact with high temperature and high pressure fluids to cause a rotor to rotate.

[0003] During operations, gas turbine engines ingest dirt and this dirt travels through the compression system and the combustor and into the cores of the turbine blades where the dirt and air is flung or pumped to the outer diameters or tips of the turbine blades. Typically, the majority of the dirt particles are extremely fine and flows within the cooling air streams that are used to cool the internals of the turbine blades. However, in some cases, the dirt particles are too large to make the abrupt turns inside the internal passages of the turbine blades and they adhere to the outermost surfaces of the turbine blade internals. This can result in an accumulation of dirt on those outermost surfaces and, at given temperatures, can cause premature metallurgical degradation as well as create unwanted insulated areas within the airfoil. The accumulation of dirt can also tend to increase the tip pull of the turbine blades thus reducing the structural integrity of the blade root and disk lugs and altering the expected structural and vibration responses of the turbine blade.

[0004] Therefore, it is common practice to have at least one relatively large hole at the tip of the core of each turbine blade. This hole allows entrained relatively large dirt particles to escape out of the turbine blade and into the gas path and out the back of the gas turbine engine.

[0005] The holes are typically cast using alumina or quartz rods.

[0006] During turbine blade investment casting processes, the alumina or quartz rods can also be used as core position control features to assist in casting. Cores of turbine blades (or blade cores) shift around during the casting process so it is necessary to provide tip features that allow control of blade core shift in all directions. This is especially important in multi-core blade designs where both hot and cold walls and internal blade core ribs must be protected. Tip rods can be used as blade core locators to control radial, axial and tangential shifts of blade cores. When one blade core has multiple tip rods extending out of the tip, they are often connected by a tip plenum that extends outside of the final machined part. The tip plenum helps to provide core stability by controlling internal blade core ribs and can also be used as a blade core locator in conjunction with the tip rods.

[0007] Blade core leaching is also a concern in complex blade core designs with multiple dead end cavities. Alumina or quartz rods can be used to assist by being embedded into dead end cavities and extending outside of the finished casting. This creates a path for the ceramic blade core to exit the part during leaching. If rods cannot be used, internal core ties are often required that connect multiple blade core cavities together that would alter the cooling scheme of the turbine blade and, due to sizing requirements, may negatively impact part durability.

[0008] Alumina and quartz tip rods should meet specific sizing requirements in order to ensure cast-ability. These requirements include meeting a minimum rod diameter (e.g., about 0.035" (0.089 cm) for quartz rods), meeting a maximum unsupported length (e.g., about 1.5x the rod diameter) and the fact that rods should be embedded into blade core material by a minimum distance (e.g., about 0.065" - 0.100" (0.165 - 0.254 cm)). In addition, rods must be surrounded by .025" (0.063 cm) of blade core thickness

[0009] In turbine blade airfoils with a sweep at the tip, radially oriented rods often do not meet producible tip rod sizing criteria, such as specifically embedded length and core thickness requirements, due to the curvature of the blade cores at the tip. The tip rods that are incorporated and that do not meet sizing criteria are highly likely to break during casting causing increased scrap.

[0010] Accordingly, it is necessary to devise tip rod geometry that can be used in turbine blades with an airfoil sweep that meets producible tip rod sizing criteria.

[0011] EP 3 808 941 A1 discloses prior art angled tip rods in a casting core for a turbine blade.

[0012] US 2021/154729 A1 discloses a turbine blade casting with a strongback core.

BRIEF DESCRIPTION

[0013] According to a first aspect of the present invention, there is provided an airfoil as set forth in claim 1.

[0014] According to a further aspect of the present invention, there is provided a method of forming an airfoil of a blade structure as set forth in claim 11.

[0015] Further embodiments are provided as set forth in claims 2 to 10 and 12.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

FIG. 1 is a partial cross-sectional view of a gas turbine engine;

FIG. 2 is a perspective view of a turbine blade of a turbine section of a gas turbine engine in accordance with embodiments;

FIG. 3 is an enlarged perspective view of a tip shelf in accordance with further embodiments;

FIG. 4 is a perspective view of a core for fabricating an airfoil of the turbine blade of FIGS. 2 and 3 in accordance with embodiments;

FIG. 5 is an enlarged, schematic side view of a portion of the core of FIG. 4 in accordance with embodiments;

FIG. 6 is a flow diagram illustrating a method of assembling a core for fabricating a blade in accordance with embodiments;

FIG. 7 is a front view of a portion of a blade structure during an investment casting process to form an airfoil of the turbine blade of FIGS. 2 and 3 in accordance with embodiments;

FIG. 8 is a flow diagram illustrating a method of forming an airfoil of a blade structure in accordance with embodiments; and

FIG. 9 is a graphical depiction of tip solidity of an airfoil in accordance with embodiments.

[0017] These and other advantages and features will become more apparent from the following description taken in conjunction with the drawings.

DETAILED DESCRIPTION

[0018] A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

[0019] FIG. 1 schematically illustrates a gas turbine engine 20. The gas turbine engine 20 is disclosed herein as a two-spool turbofan that generally incorporates a fan section 22, a compressor section 24, a combustor section 26 and a turbine section 28. Alternative engines might include other systems or features. The fan section 22 drives air along a bypass flow path B in a bypass duct, while the compressor section 24 drives air along a core flow path C for compression and communication into the combustor section 26 and then expansion through the turbine section 28. Although depicted as a two-spool turbofan gas turbine engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with two-spool turbofans as the teachings may be applied to other types of turbine engines including three-spool architectures.

[0020] The exemplary gas turbine engine 20 generally includes a low speed spool 30 and a high speed spool 32 mounted for rotation about an engine central longitudinal axis A relative to an engine static structure 36 via several bearing systems 38. It should be understood that various bearing systems 38 at various locations may alternatively or additionally be provided, and the location of bearing systems 38 may be varied as appropriate to the application.

[0021] The low speed spool 30 generally includes an inner shaft 40 that interconnects a fan 42, a low pressure compressor 44 and a low pressure turbine 46. The inner shaft 40 is connected to the fan 42 through a speed change mechanism, which in exemplary gas turbine engine 20 is illustrated as a geared architecture 48 to drive the fan 42 at a lower speed than the low speed spool 30. The high speed spool 32 includes an outer shaft 50 that interconnects a high pressure compressor 52 and high pressure turbine 54. A combustor 56 is arranged in the gas turbine engine 20 between the high pressure compressor 52 and the high pressure turbine 54. The engine static structure 36 is arranged generally between the high pressure turbine 54 and the low pressure turbine 46. The engine static structure 36 further supports the bearing systems 38 in the turbine section 28. The inner shaft 40 and the outer shaft 50 are concentric and rotate via bearing systems 38 about the engine central longitudinal axis A which is collinear with their longitudinal axes.

[0022] The core airflow is compressed by the low pressure compressor 44 and then the high pressure compressor 52, is mixed and burned with fuel in the combustor 56 and is then expanded over the high pressure turbine 54 and the low pressure turbine 46. The high and low pressure turbines 54 and 46 rotationally drive the low speed spool 30 and the high speed spool 32, respectively, in response to the expansion. It will be appreciated that each of the positions of the fan section 22, compressor section 24, combustor section 26, turbine section 28, and fan drive gear system 48 may be varied. For example, geared architecture 48 may be located aft of the combustor section 26 or even aft of the turbine section 28, and the fan section 22 may be positioned forward or aft of the location of geared architecture 48.

[0023] The gas turbine engine 20 in one example is a high-bypass geared aircraft engine. In a further example, the gas turbine engine 20 bypass ratio is greater than about six (6), with an example embodiment being greater than about ten (10), the geared architecture 48 is an epicyclic gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3 and the low pressure turbine 46 has a pressure ratio that is greater than about five. In one disclosed embodiment, the gas turbine engine 20 bypass ratio is greater than about ten (10:1), the fan diameter is significantly larger than that of the low pressure compressor 44, and the low pressure turbine 46 has a pressure ratio that is greater than about five 5:1. Low pressure turbine 46 pressure ratio is pressure measured prior to inlet of low pressure turbine 46 as related to the pressure at the outlet of the low pressure turbine 46 prior to an exhaust nozzle. The geared architecture 48 may be an epicycle gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3:1. It should be understood, however, that the above parameters are only exemplary of one embodiment of a geared architecture engine and that the present disclosure is applicable to other gas turbine engines including direct drive turbofans.

[0024] A significant amount of thrust is provided by the bypass flow B due to the high bypass ratio. The fan section 22 of the gas turbine engine 20 is designed for a particular flight condition--typically cruise at about 0.8 Mach and about 35,000 feet (10,688 meters). The flight condition of 0.8 Mach and 35,000 ft (10,688 meters), with the engine at its best fuel consumption--also known as "bucket cruise Thrust Specific Fuel Consumption ('TSFC')"--is the industry standard parameter of lbm of fuel being burned divided by lbf of thrust the engine produces at that minimum point. "Low fan pressure ratio" is the pressure ratio across the fan blade alone, without a Fan Exit Guide Vane ("FEGV") system. The low fan pressure ratio as disclosed herein according to one non-limiting embodiment is less than about 1.45. "Low corrected fan tip speed" is the actual fan tip speed in ft/sec divided by an industry standard temperature correction of $[(\text{Tram °R})/(518.7\ \text{°R})]^{0.5}$. The "Low corrected fan tip speed" as disclosed herein according to one non-limiting embodiment is less than about 1150 ft/second (350.5 m/sec).

[0025] As will be described below, a tip rod geometry is provided for use in turbine blades with an airfoil sweep that meets producible tip rod sizing criteria. The tip rods are made of alumina or quartz and are located at the tip of a blade core at an angle. In locations where embedded rod lengths can be met but core thicknesses around the rod are not met, additional core support features, such as bumpers, can be used to meet producibility criteria and to add additional wall thickness controls.

[0026] With reference to FIGS. 2 and 3, a turbine blade 201 is provided for use in at least the compressor section 24 and the turbine section 28 of the gas turbine engine 20 of FIG. 1.

[0027] The turbine blade 201 includes a root 210 with a dovetail or fir tree cross-section, an airfoil 220 and a platform 240 that is radially interposed between the root 210 and the airfoil 220. The airfoil 220 extends radially outwardly from the platform 240 and includes a pressure surface 221, a suction surface 222 opposite the pressure surface 221, leading and trailing edges 223 and 224 extending along leading and trailing ends of the pressure and suction surfaces 221 and 222 and a tip shelf 225 at a distal, radially outboard end of the airfoil 220. The tip shelf 225 has a first sweep configuration 701, which is characterized as a sweep of the tip shelf 225 relative to the rest of the airfoil 220 (see FIG. 7), and a wall 226. The airfoil 220 is formed to define internal channels 702 (see FIG. 7), which will be described below, and the wall 226 is formed to define obliquely-angled through-holes 301 (see FIG. 3), which will also be described below. The obliquely-angled through-holes 301 are defined at an oblique angle α (see FIG. 7) relative to a normal angle of the wall 226.

[0028] In accordance with embodiments, the angle α can be about 5 degrees or slightly less, 5-12 degrees inclusive or about 12 degrees or slightly more.

[0029] As shown in FIG. 3, the tip shelf 225 can be curved to maintain a substantially uniform depth of about 0.03" (0.76 mm) or the tip shelf 225 can be flat or straight with a maximum depth of about 0.030" (0.76 mm) and a minimum depth of 0.033" (0.83 mm) at a central point in the tip shelf 225, a maximum depth of about 0.035" (0.89 mm) and a minimum depth of 0.024" (0.061 cm) at the leading edge 223 and a maximum depth of about 0.026" (0,66 mm) and a minimum depth of 0.015" (0.38 mm) at the trailing edge 224. In any case, the tip shelf 225 is formed to define a squealer pocket 302 with an optional 0.01" (0.25 mm) step. The obliquely-angled through-holes 301 can be defined adjacent to a wall 310 surrounding the squealer pocket 302 and along the pressure surface 221. The wall 310 extends radially outwardly from the tip shelf 225 and delimits a periphery of the squealer pocket 302.

[0030] In accordance with embodiments, the wall 310 at the pressure surface 221 can have a substantially uniform thickness T1 (of about 0.03" (0.76 mm) nominal, 0.02" (0.51 mm) minimal) from an upstream portion 311 thereof, which is disposed axially between the through-holes 301 and the leading edge 223, to a downstream portion 312 thereof, which is disposed axially between the through-holes 301 and the trailing edge 224. To achieve this substantially uniform thickness T1, the wall 310 curves inwardly into the squealer pocket 302 around each of the through-holes 301 to form notched or convex sections 313. The wall 310 can also include a straight or flat section 314 between the notched or convex sections 313.

[0031] In accordance with further embodiments, while the wall 310 has the substantially uniform thickness T1 from the upstream portion 311 to the downstream portion 312, the wall 310 can continue around an entirety of the squealer pocket 302 and can have varying thicknesses at several different sections. For example, the wall 310 can have a slightly increased thickness at or near the leading edge 223 and a significantly increased thickness at or near the trailing edge 224. In addition, the wall 310 at the suction surface 222 can have varying thicknesses T2 that each exceed the magnitude of the substantially uniform thickness T1. In some cases, the wall 310 can have a wedge-shape 315 (see FIG. 7) at the suction surface 222. The wedge-shape 315 allows for more material to be provided to the wall 310 during installing and initial operations. At a base of the wedge-shape 315, the wall 310 can have a thickness of about 0.03" (0.76 mm) nominal or about 0.02" (0.51 mm) minimum

[0032] Notably, when blades and blade outer air seals (BOAS) interact, a goal is for the BOAS to lose material and the blades to remain intact. However, if the blade is too solid at the tip, there will be too much material to cool during engine operation and the tip will oxidize. Due to the tip bow and squealer pocket design in this case, there is more material at the tip during initial engine operation (when the blades and BOAS "break in") but less material to cool on the blade tips once any rub has occurred.

[0033] With continued reference to FIGS. 2 and 3 and with additional reference to FIG. 4, a core 401 is provided for use in fabricating an airfoil of a blade, such as the turbine blade 201 of FIGS. 2 and 3, to include the features of the airfoil 220 described above using casting processes which will be described below. The core 401 includes channel sections 410 and tip rods 420. The channel sections 410 are configured to form the internal channels 702 (see FIG. 7) within the airfoil 220 by the casting processes. The tip rods 420 are disposed to extend from respective portions of the channel sections 410 that are located proximate to a location of the tip shelf 225 once the tip shelf 225 is eventually formed by the casting processes. That is, the tip rods 420 extend radially outwardly from distal ends of the respective portions of the channel sections 410. The respective portions of the channel sections 410 have a second sweep configuration 430 that corresponds to the first sweep configuration 701 (see FIG. 7). The tip rods 420 are configured to extend from the respective portions of the channel sections 410 or the internal channels 702 (see FIG. 7) and through the wall 226 once the tip shelf 225 and the wall 226 are eventually formed by the casting processes at the oblique angle α (i.e., about 5 degrees) relative to a normal angle of the wall 226 during the casting processes. The tip rods 420 cause the obliquely-angled through-holes 301 to form in the wall 226.

[0034] In accordance with embodiments, thickness of the tip shelf 225 can vary. For example, the thickness of the tip shelf 225 at or around the obliquely-angled through-holes 301 can be about 0.05" (1.27 mm) and the thickness of the tip shelf 225 within the squealer pocket 302 can be about 0.038" (0.96 mm) maximum, to about 0.022" (0.56 mm) minimum at the leading edge 223 or about 0.035" (0.89 mm) minimum at the trailing edge 224.

[0035] In addition to the obliquely-angled through-holes 301, the tip shelf 225 can be further formed to define additional holes 320 within the squealer pocket 302. These holes 320 can be provided for permitting fluid communication, e.g, a flow of coolant outwardly from an interior of the airfoil 220 or, more particularly, from one or more of the internal channels 702 to the squealer pocket 302 as shown in FIG 7. The additional holes 320 can be arranged in various formations including, but not limited to, the formation 321 that is illustrated in FIG. 3. The additional holes 320 have a linear grouping of additional holes 320 that become increasingly staggered with increasing distance from the trailing edge 224, at least one or more additional hole 320 located between the notched or convex sections 313 and at least one or more additional hole 320 proximate to the leading edge 223.

[0036] In accordance with embodiments, the tip rods 420 can include at least one or more of alumina and quartz.

[0037] In accordance with further embodiments, the channel sections 410 can include a bumper 430 proximate to an internal end of at least one of the tip rods 420.

[0038] With reference to FIG. 5, a plenum body 501 can be provided and external ends 502 of the tip rods 420 can be coupled to the plenum body 501.

[0039] With continued reference to FIGS. 2-5 and with additional reference to FIG. 6, a method of assembling the core 401 (see FIG. 4) is provided. As shown in FIG. 6, the method includes forming the channel sections 410 such that the channel sections 410 are configured to form the internal channels 702 (see FIG. 7) within the airfoil 220 by casting processes (block 610), disposing the tip rods 420 to extend from the respective portions of the channel sections 410 proximate to the location of the tip shelf 225 (block 620) and executing the casting processes to cast the blade whereby the tip rods 420 extend from the internal channels 702 and through the wall 226 at the oblique angle α relative to the normal angle of the wall 226 to form the obliquely-angled through-holes 301 in the wall 226 (block 630). The method can further include forming the squealer pocket 302 in the tip shelf 225 (block 640).

[0040] The executing of the casting processes of block 630 can include executing an investment casting process to cast the blade around the core 401 and to subsequently remove the core 401 from the blade once the blade is cast. This can be achieved by known methods and processes for casting and results in the definition and the formation of the airfoil 220 and the internal channels 702. The method can further include removing the tip rods 420 from the blade via the obliquely-angled through-holes 301 in the wall 226 upon completion of the investment casting process (block 650).

[0041] In accordance with embodiments, the method can also include forming the bumper 430 proximate to the internal end of at least one of the tip rods 420 and coupling the external ends of the tip rods 420 to the plenum body 501.

[0042] Except as provided herein, the squealer pocket 302 of FIG. 3 and the wall 310 can be formed by various additional or alternative processes. These include, but are not limited to, electro-dynamic machining (EDM). In some cases, where the squealer pocket 302 is formed by EDM, the additional holes 320 can be formed by cast processes or by further EDM processing.

[0043] With reference to FIG. 7, a blade structure 700 is provided. The blade structure 700 is essentially an intermediate stage structure which exists during the casting processes and includes the tip rods 420 and the airfoil 220 as each is described above. The airfoil 220 has the first sweep configuration 701 and is formed to define the internal channels 702. Here, the core 401 has already been removed by the completion of the investment casting process noted above with the airfoil 220 left remaining and intact whereby the core 401 includes the wall 226 as well as external passage wall components 710 and internal passage wall components 711 that were formed by the channel sections 410. The tip rods 420 extend from the internal channels 702 and through the wall 226 at the oblique angle α relative to the normal angle of the wall 226 to thus form the obliquely-angled through-holes 301 during the casting processes and are removable via the obliquely-angled through-holes 301.

[0044] With the tip rods 420 extending through the wall 226 at the oblique angle α, distances between the tip rods 420 and the external and internal passage wall components 710 and 711 can be maintained at or above minimum required distances with the tip rods 420 still having reliably producible dimensions and sizes of the obliquely-angled through-holes 301 being maintained at or above minimum required sizes.

[0045] In accordance with embodiments, at least one or more of the internal passage wall components 711 proximate to the internal end of at least one of the tip rods 420 can be formed to define a divot 712. The divot results from the investment casting process and the formation of the bumper 430 (see FIG. 4). To an extent the internal end of the at least one of the tip rods 420 is excessively close to the internal passage wall component 711, the divot 712 serves to recapture the minimum required distance.

[0046] With reference to FIG. 8, a method of forming an airfoil of a blade structure as described above is provided. The method includes casting the airfoil to include pressure and suction surfaces, leading and trailing edges extending along the pressure and suction surfaces and a tip shelf with a sweep configuration at an outboard airfoil end (801), executing the casting such that the airfoil defines internal channels and the tip shelf defines obliquely-angled through-holes (802) and machining a squealer pocket into the tip shelf with a remainder of the tip shelf forming a wall extending radially outwardly to delimit a periphery of the squealer pocket and with the obliquely-angled through-holes being adjacent to the wall (803). In accordanc with embodiments, the machining of operation 803 can include electro-dynamic machining (EDM).

[0047] With reference to FIG. 9, tip solidity of the airfoil 201 described herein can vary along the chord line of the airfoil 201 as shown in the graph.

[0048] Benefits of the features described herein allows for the use of tip rods to produce holes for internal cavity dirt purge, core position control and casting in blades with an airfoil sweep.

[0049] The term "about" is intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application.

[0050] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element components, and/or groups thereof.

[0051] While the present disclosure has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this present disclosure, but that the present disclosure will include all embodiments falling within the scope of the claims.

Claims

1. An airfoil (220), comprising:

pressure and suction surfaces (221, 222);
leading and trailing edges (223, 224) extending along the pressure and suction surfaces (221, 222);
a tip shelf (225) with a sweep configuration (701) at an outboard airfoil end; and
a wall (226, 310) extending radially outwardly from the tip shelf (225) to delimit a periphery of a squealer pocket (302) at the tip shelf (225),
wherein the airfoil (220) defines internal channels (702),
the tip shelf (225) defines obliquely-angled through-holes (301) adjacent to the wall (226, 310),
the wall (226, 310) comprises notched sections (313) that curve around the obliquely-angled through-holes (301, 802), **characterised in that** the tip shelf (225) defines additional holes (320) within the squealer pocket (302) to provide fluid communication between the internal channels (702) and the squealer pocket (302), and
the additional holes (320) are arranged in a linear grouping becoming increasingly staggered with increasing distance from the trailing edge (224) with at least one of the additional holes (320) being located between the notched sections (313) and with at least one of the additional holes (320) proximate to the leading edge (223).

2. The airfoil (220) according to claim 1, wherein the tip shelf (225) is curved to maintain a substantially uniform depth.

3. The airfoil (220) according to claim 1, wherein the tip shelf (225) is flat or straight with a maximum depth of 0.030" (0.76mm) and a minimum depth of 0.033" (0.84mm) at a central point in the tip shelf (225), a maximum depth of about 0.035" (0.89mm) and a minimum depth of 0.024" (0.61mm) at the leading edge (223) and a maximum depth of about 0.026" (0.66 mm) and a minimum depth of 0.015" (0.38 mm) at the trailing edge (224).

4. The airfoil (220) according to any of claims 1 to 3, wherein the obliquely-angled through-holes (301) are angled at about 5-12 degrees inclusive.

5. The airfoil (220) according to any preceding claim, wherein the wall (226, 310) has a substantially uniform thickness (T1) along the pressure surface (221).

6. The airfoil (220) according to claim 5, wherein the wall (226, 310) has a thickness (T2) along the suction surface (222) that exceeds the substantially uniform thickness (T1) along the pressure surface (221).

7. The airfoil (220) according to any preceding claim, wherein the wall (226, 310) further comprises a flat section (314) between the notched sections (313).

8. The airfoil (220) according to any preceding claim, wherein a thickness (T2) of the wall (226, 310) along the suction surface (222) varies.

9. The airfoil (220) according to any preceding claim, wherein the wall (226, 310) has a wedge shape (315) at the suction surface (222).

10. The airfoil (22) according to claim 9, wherein the wall (226, 310) at a base of the wedge shape (315) has a minimum thickness of 0.02" (0.51mm).

11. A method of forming an airfoil (220) of a blade structure (700), the method comprising:

casting the airfoil (220) to comprise pressure and suction surfaces (221, 222), leading and trailing edges (223, 224) extending along the pressure and suction surfaces (221, 222) and a tip shelf (225) with a sweep configuration (701) at an outboard airfoil end (801);
executing the casting such that the airfoil (220) defines internal channels (702) and the tip shelf (225) defines obliquely-angled through-holes (301); and
machining a squealer pocket (302) into the tip shelf (225) with a remainder of the tip shelf (225) forming a wall (226, 310) extending radially outwardly to delimit a periphery of the squealer pocket (302) and with the obliquely-angled through-holes (301) being adjacent to the wall (226, 310),
wherein the wall (226, 310) comprises notched sections (313) that curve around the obliquely-angled through-holes (301, 802),
the tip shelf (225) defines additional holes (320) within the squealer pocket (302) to provide fluid communication between the internal channels (702) and the squealer pocket (302), and
the additional holes (320) are arranged in a linear grouping becoming increasingly staggered with increasing distance from the trailing edge (224) with at least one of the additional holes (320) being located between the notched sections (313) and with at least one of the additional holes (320) proximate to the leading edge (223.

12. The method according to claim 11, wherein the machining comprises electro-dynamic machining.

Patentansprüche

1. Schaufel (220), umfassend:

Druck- und Saugflächen (221, 222);
Vorder- und Hinterkanten (223, 224), die sich entlang der Druck- und Saugflächen (221, 222) erstrecken;
ein Spitzendeckband (225) mit einer Pfeilkonfiguration (701) an einem äußeren Schaufelende; und
eine Wand (226, 310), die sich radial nach außen von dem Spitzendeckband (225) erstreckt, um einen Umfang einer Anstreiftasche (302) an dem Spitzendeckband (225) abzugrenzen,
wobei die Schaufel (220) innere Kanäle (702) definiert,
das Spitzendeckband (225) schräg abgewinkelte Durchgangslöcher (301) benachbart zu der Wand (226, 310) definiert,
die Wand (226, 310) gekerbte Abschnitte (313) umfasst, die um die schräg abgewinkelten Durchgangslöcher (301, 802) herum gekrümmt sind, **dadurch gekennzeichnet, dass**
das Spitzendeckband (225) zusätzliche Löcher (320) innerhalb der Anstreiftasche (302) aufweist, um eine Fluidverbindung zwischen den internen Kanälen (702) und der Anstreiftasche (302) herzustellen, und
die zusätzlichen Löcher (320) in einer linearen Gruppierung angeordnet sind, die mit zunehmendem Abstand von der Hinterkante (224) zunehmend versetzt ist, wobei sich mindestens eines der zusätzlichen Löcher (320) zwischen

den gekerbten Abschnitten (313) befindet und mindestens eines der zusätzlichen Löcher (320) in der Nähe der Vorderkante (223) liegt.

2. Schaufel (220) nach Anspruch 1, wobei das Spitzendeckband (225) gekrümmt ist, um eine im Wesentlichen gleichmäßige Tiefe aufrechtzuerhalten.

3. Schaufel (220) nach Anspruch 1, wobei das Spitzendeckband (225) flach oder gerade ist und an einem zentralen Punkt in dem Spitzendeckband (225) eine maximale Tiefe von 0,030" (0,76 mm) und eine minimale Tiefe von 0,033" (0,84 mm), an der Vorderkante (223) eine maximale Tiefe von etwa 0,035" (0,89 mm) und eine minimale Tiefe von 0,024" (0,61 mm) und an der Hinterkante (224) eine maximale Tiefe von etwa 0,026" (0,66 mm) und eine minimale Tiefe von 0,015" (0,38 mm) aufweist.

4. Schaufel (220) nach einem der Ansprüche 1 bis 3, wobei die schräg abgewinkelten Durchgangslöcher (301) in einem Winkel von einschließlich etwa 5-12 Grad abgewinkelt sind.

5. Schaufel (220) nach einem der vorhergehenden Ansprüche, wobei die Wand (226, 310) entlang der Druckfläche (221) eine im Wesentlichen gleichmäßige Dicke (T1) aufweist.

6. Schaufel (220) nach Anspruch 5, wobei die Wand (226, 310) entlang der Saugfläche (222) eine Dicke (T2) aufweist, die die im Wesentlichen gleichmäßige Dicke (T1) entlang der Druckfläche (221) übersteigt.

7. Schaufel (220) nach einem der vorhergehenden Ansprüche, wobei die Wand (226, 310) ferner einen flachen Abschnitt (314) zwischen den gekerbten Abschnitten (313) umfasst.

8. Schaufel (220) nach einem der vorhergehenden Ansprüche, wobei eine Dicke (T2) der Wand (226, 310) entlang der Saugfläche (222) variiert.

9. Schaufel (220) nach einem der vorhergehenden Ansprüche, wobei die Wand (226, 310) an der Saugfläche (222) eine Keilform (315) aufweist.

10. Schaufel (22) nach Anspruch 9, wobei die Wand (226, 310) an einer Basis der Keilform (315) eine Mindestdicke von 0,02" (0,51 mm) aufweist.

11. Verfahren zum Bilden einer Schaufel (220) einer Schaufelstruktur (700), wobei das Verfahren Folgendes umfasst:

Gießen der Schaufel (220), um Druck- und Saugflächen (221, 222), Vorder- und Hinterkanten (223, 224), die sich entlang der Druck- und Saugflächen (221, 222) erstrecken, und ein Spitzendeckband (225) mit einer Pfeilkonfiguration (701) an einem äußeren Schaufelende (801) zu umfassen;
Ausführen des Gießens derart, dass die Schaufel (220) innere Kanäle (702) definiert und das Spitzendeckband (225) schräg abgewinkelte Durchgangslöcher (301) definiert; und
maschinelles Einarbeiten einer Anstreiftasche (302) in das Spitzendeckband (225), wobei ein Rest des Spitzendeckbands (225) eine Wand (226, 310) bildet, die sich radial nach außen erstreckt, um einen Umfang der Anstreiftasche (302) abzugrenzen, und wobei die schräg abgewinkelten Durchgangslöcher (301) benachbart zu der Wand (226, 310) liegen,
wobei die Wand (226, 310) gekerbte Abschnitte (313) umfasst, die um die schräg abgewinkelten Durchgangslöcher (301, 802) herum gekrümmt sind,
das Spitzendeckband (225) zusätzliche Löcher (320) innerhalb der Anstreiftasche (302) aufweist, um eine Fluidverbindung zwischen den internen Kanälen (702) und der Anstreiftasche (302) herzustellen, und
die zusätzlichen Löcher (320) in einer linearen Gruppierung angeordnet sind, die mit zunehmendem Abstand von der Hinterkante (224) zunehmend versetzt ist, wobei sich mindestens eines der zusätzlichen Löcher (320) zwischen den gekerbten Abschnitten (313) befindet und mindestens eines der zusätzlichen Löcher (320) in der Nähe der Vorderkante (223) liegt.

12. Verfahren nach Anspruch 11, wobei das maschinelle Einarbeiten eine elektrodynamische Bearbeitung umfasst.

Revendications

1. Profil aérodynamique (220) comprenant :

des surfaces de pression et d'aspiration (221, 222) ;
des bords d'attaque et de fuite (223, 224) se prolongeant le long des surfaces de pression et d'aspiration (221, 222) ;
un plateau de pointe (225) avec une configuration de balayage (701) à une extrémité extérieure du profil aérodynamique ; et
une paroi (226, 310) se prolongeant radialement vers l'extérieur à partir du plateau de pointe (225) pour délimiter une périphérie d'une poche d'indicateur de fuite audible (302) au niveau du plateau de pointe (225),
dans lequel le profil aérodynamique (220) définit des canaux internes (702),

le plateau de pointe (225) définit des trous traversants selon un angle oblique (301) adjacents à la paroi (226, 310),

la paroi (226, 310) comprend des sections entaillées (313) qui s'incurvent autour des trous traversants selon un angle oblique (301, 802), **caractérisé en ce que**

le plateau de pointe (225) définit des trous supplémentaires (320) à l'intérieur de la poche d'indicateur de fuite audible (302) pour assurer une communication fluidique entre les canaux internes (702) et la poche d'indicateur de fuite audible (302), et

les trous supplémentaires (320) sont disposés selon un groupement linéaire devenant de plus en plus décalé à mesure que la distance par rapport au bord de fuite (224) augmente, avec au moins l'un des trous supplémentaires (320) étant situé entre les sections entaillées (313) et avec au moins l'un des trous supplémentaires (320) à proximité du bord d'attaque (223).

2. Profil aérodynamique (220) selon la revendication 1, dans lequel le plateau de pointe (225) est incurvé pour maintenir une profondeur sensiblement uniforme.

3. Profil aérodynamique (220) selon la revendication 1, dans lequel le plateau de pointe (225) est plat ou droit avec une profondeur maximale de 0.030" (0,76 mm) et une profondeur minimale de 0.033" (0,84 mm) au niveau d'un point central du plateau de pointe (225), une profondeur maximale d'environ .0.35" (0,89 mm) et une profondeur minimale de 0.024" (0,61 mm) au niveau du bord d'attaque (223) et une profondeur maximale d'environ 0.026" (0,66 mm) et une profondeur minimale de 0.015" (0,38 mm) au niveau du bord de fuite (224).

4. Profil aérodynamique (220) selon l'une quelconque des revendications 1 à 3, dans lequel les trous traversants selon un angle oblique (301) sont inclinés à environ 5 à 12 degrés inclus.

5. Profil aérodynamique (220) selon une quelconque revendication précédente, dans lequel la paroi (226, 310) présente une épaisseur (T1) sensiblement uniforme le long de la surface de pression (221).

6. Profil aérodynamique (220) selon la revendication 5, dans lequel la paroi (226, 310) a une épaisseur (T2) le long de la surface d'aspiration (222) qui dépasse l'épaisseur (T1) sensiblement uniforme le long de la surface de pression (221).

7. Profil aérodynamique (220) selon une quelconque revendication précédente, dans lequel la paroi (226, 310) comprend également une section plate (314) entre les sections entaillées (313).

8. Profil aérodynamique (220) selon une quelconque revendication précédente, dans lequel une épaisseur (T2) de la paroi (226, 310) le long de la surface d'aspiration (222) varie.

9. Profil aérodynamique (220) selon une quelconque revendication précédente, dans lequel la paroi (226, 310) présente une forme de coin (315) au niveau de la surface d'aspiration (222).

10. Profil aérodynamique (22) selon la revendication 9, dans lequel la paroi (226, 310) au niveau d'une base de la forme en coin (315) présente une épaisseur minimale de 0.02" (0,51 mm).

11. Procédé de formation d'un profil aérodynamique (220) d'une structure de pale (700), le procédé comprenant :

le moulage du profil aérodynamique (220) pour comprendre des surfaces de pression et d'aspiration (221, 222), des bords d'attaque et de fuite (223, 224) se prolongeant le long des surfaces de pression et d'aspiration (221, 222) et un plateau de pointe (225) avec une configuration de balayage (701) à une extrémité extérieure du profil aérodynamique (801) ;

l'exécution du moulage de telle sorte que le profil aérodynamique (220) définisse des canaux internes (702) et le plateau de pointe (225) définisse des trous traversants selon un angle oblique (301) ; et

l'usinage d'une poche d'indicateur de fuite audible (302) dans le plateau de pointe (225) avec un reste du plateau de pointe (225) formant une paroi (226, 310) se prolongeant radialement vers l'extérieur pour délimiter une périphérie de la poche d'indicateur de fuite audible (302) et avec les trous traversants selon un angle oblique (301) étant adjacents à la paroi (226, 310),

dans lequel la paroi (226, 310) comprend des sections entaillées (313) qui s'incurvent autour des trous traversants selon un angle oblique (301, 802),

le plateau de pointe (225) définit des trous supplémentaires (320) à l'intérieur de la poche d'indicateur de fuite audible (302) pour assurer une communication fluidique entre les canaux internes (702) et la poche d'indicateur de fuite audible (302), et

les trous supplémentaires (320) sont disposés selon un groupement linéaire devenant de plus en plus décalé à mesure que la distance par rapport au bord de fuite (224) augmente, avec au moins l'un des trous supplémentaires (320) étant situé entre les sections entaillées (313) et avec au moins l'un des trous supplémentaires (320) à proximité du bord d'attaque (223).

12. Procédé selon la revendication 11, dans lequel l'usinage comprend l'usinage électrodynamique.

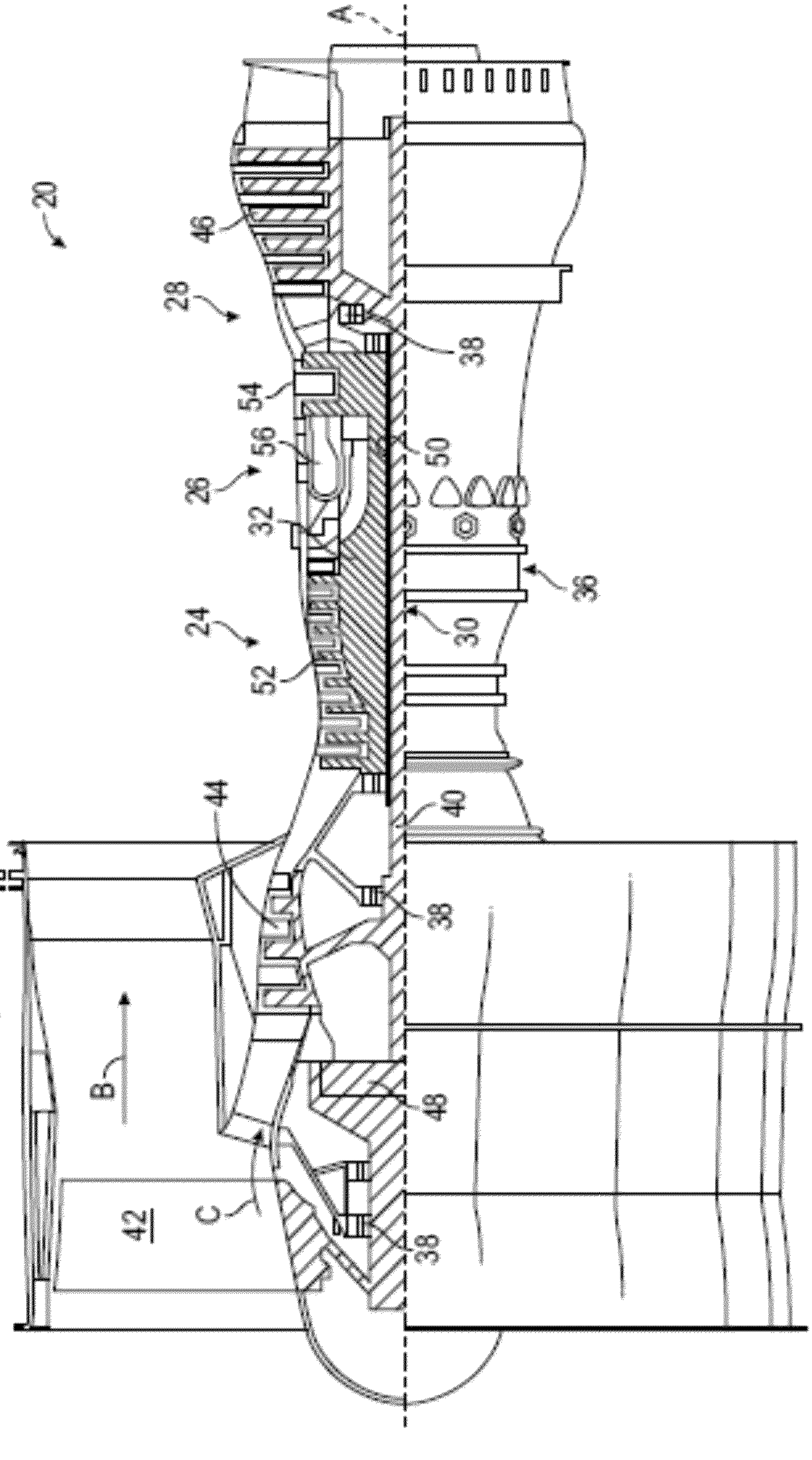


FIG. 1

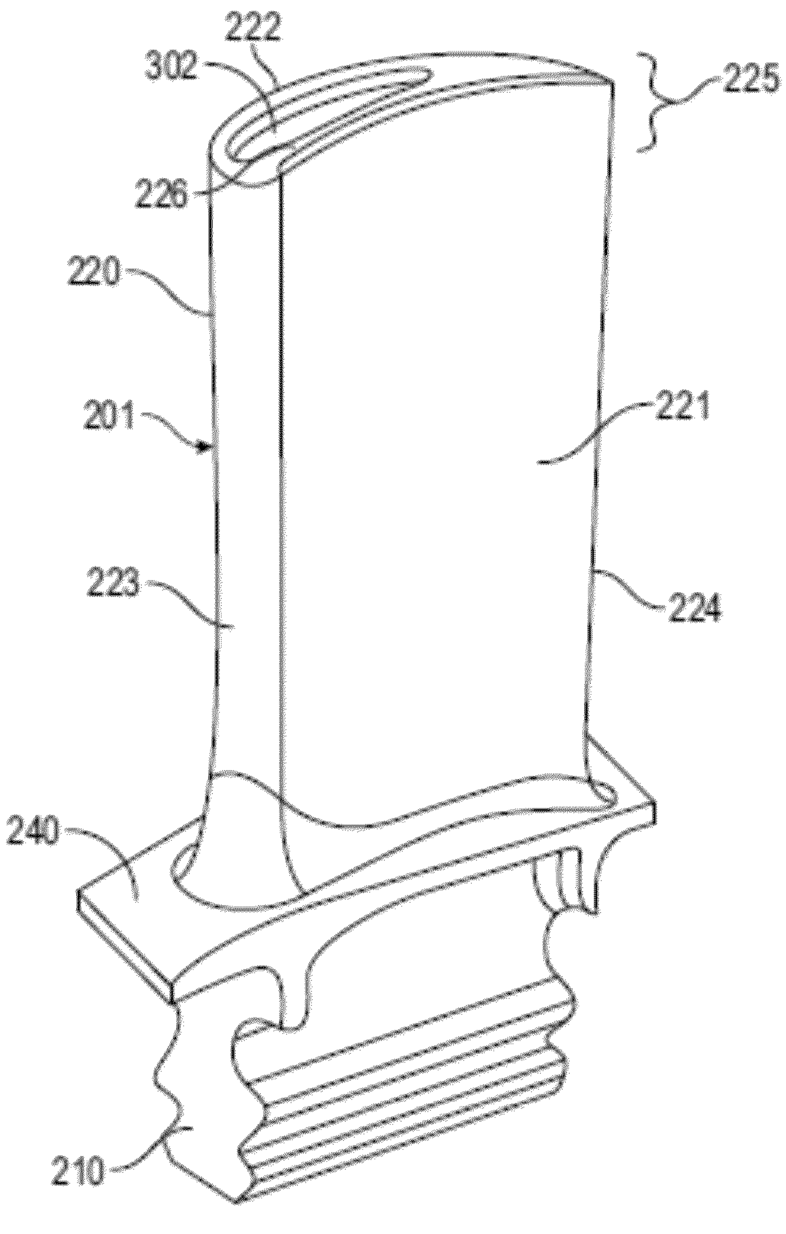


FIG. 2

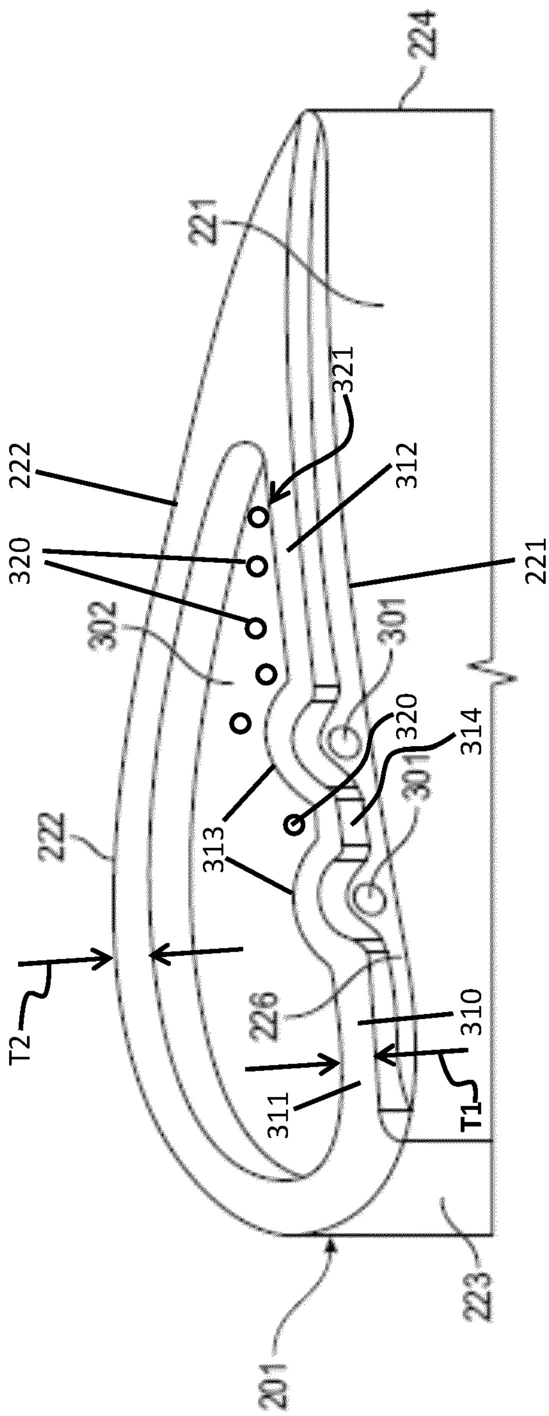

224
221
321
312
222
320
221
302
301
320
314
313
301
222
226
310
T2
311
T1
223
201

FIG. 3

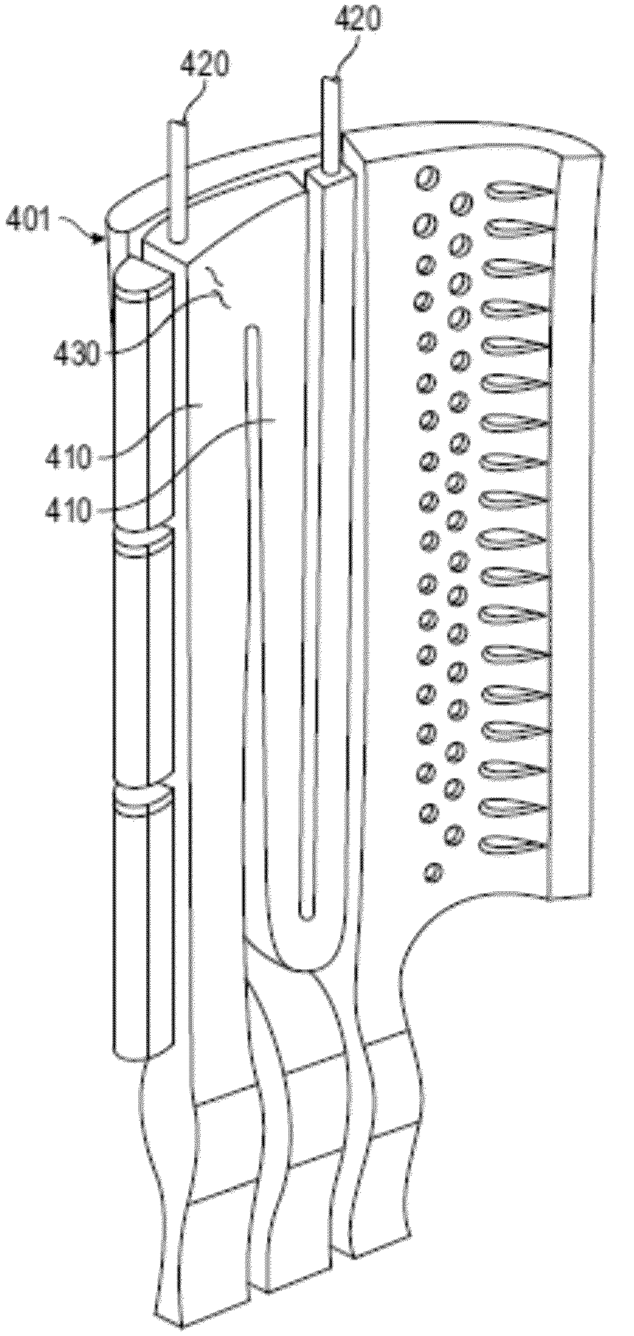


FIG. 4

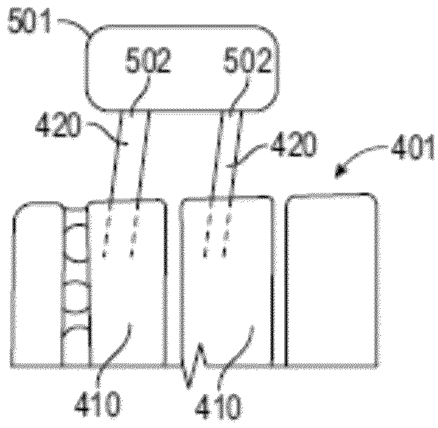

501
502
502
420
420
401
410
410

FIG. 5

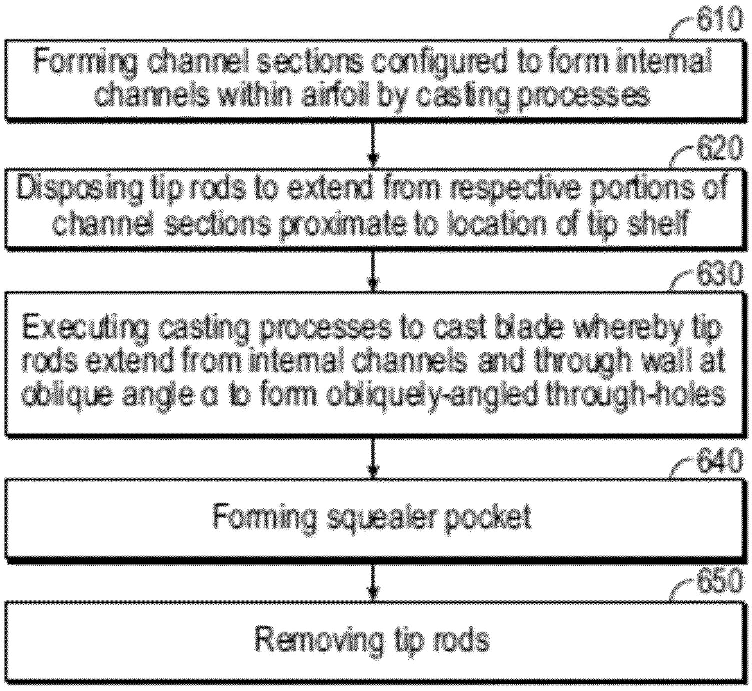

610
Forming channel sections configured to form internal channels within airfoil by casting processes
620
Disposing tip rods to extend from respective portions of channel sections proximate to location of tip shelf
630
Executing casting processes to cast blade whereby tip rods extend from internal channels and through wall at oblique angle α to form obliquely-angled through-holes
640
Forming squealer pocket
650
Removing tip rods

FIG. 6

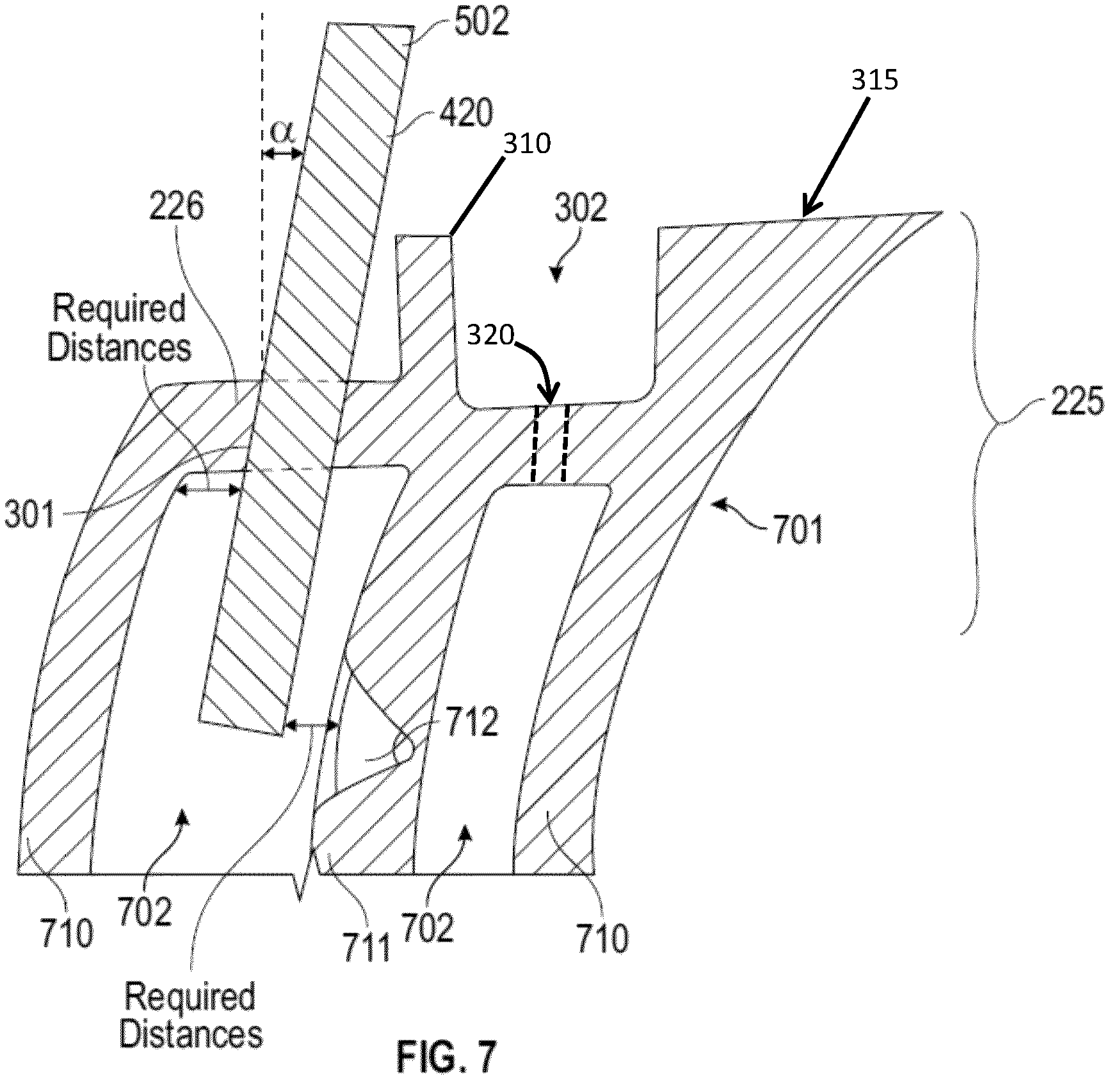

502
420
α
310
315
302
226
Required Distances
320
225
301
701
712
710
702
711
702
710
Required Distances

FIG. 7

FIG. 8

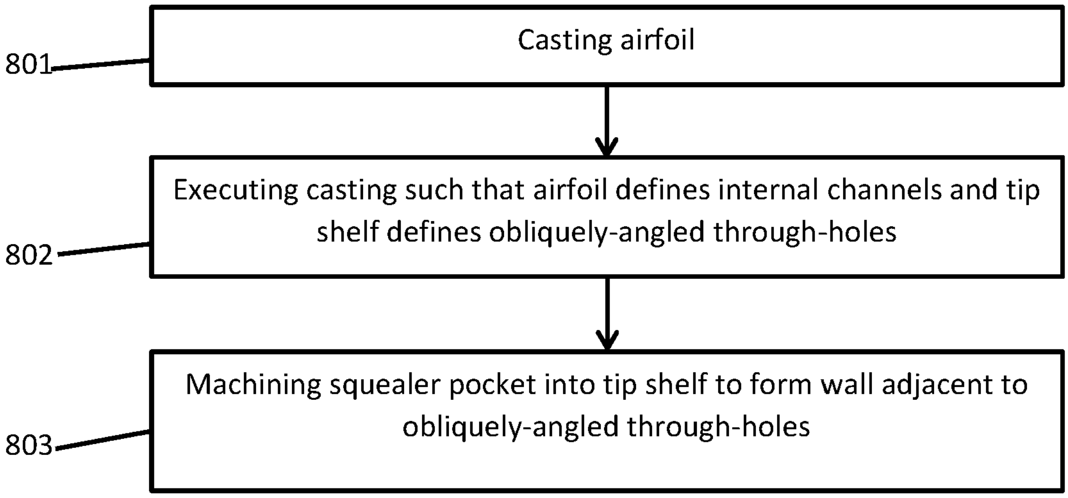
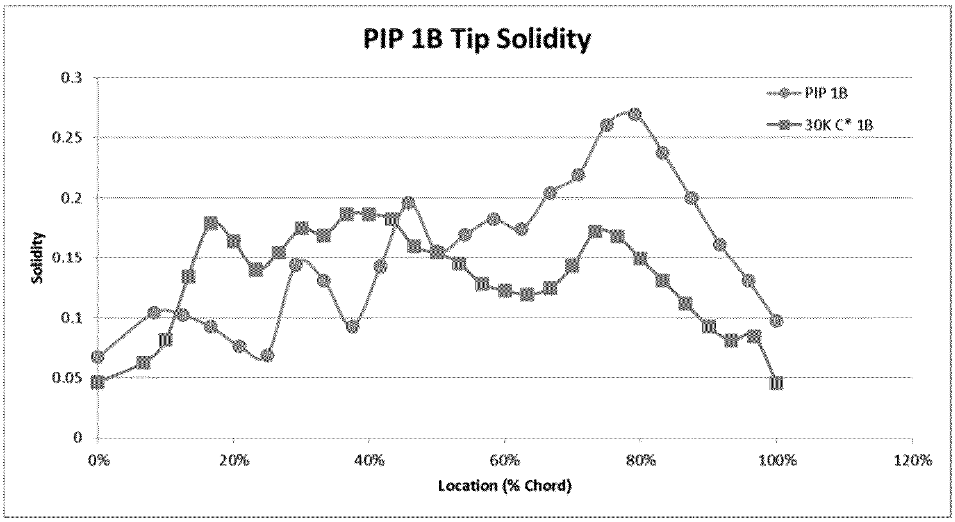

801
Casting airfoil
802
Executing casting such that airfoil defines internal channels and tip shelf defines obliquely-angled through-holes
803
Machining squealer pocket into tip shelf to form wall adjacent to obliquely-angled through-holes

FIG. 9


PIP 1B Tip Solidity
PIP 1B
30K C* 1B
Solidity
0
0.05
0.1
0.15
0.2
0.25
0.3
0%
20%
40%
60%
80%
100%
120%
Location (% Chord)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 3808941 A1 **[0011]**
- US 2021154729 A1 **[0012]**