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FIG. 4

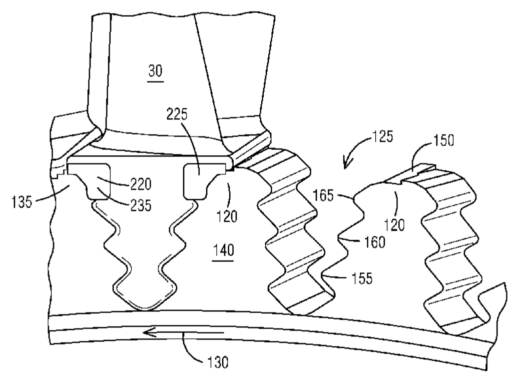
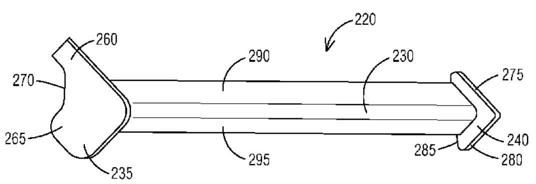


FIG. 7



(57) Abstract: A turbine (10) includes a disk (25) having a plurality of protrusions (120) arranged such that any two adjacent protrusions (120) define an axial entry fir tree space (125), each protrusion (120) defining an outermost lobe (165) having an outermost surface (150) and an axial length. A turbine blade (30) includes an airfoil (170), a platform (175), and a blade root (180) having a fir tree arranged to engage a leading protrusion (135) and a trailing protrusion (140). The blade root (180) and the leading protrusion (135) cooperate to define a leading gap (200), and the blade root (180) and the trailing protrusion (140) cooperate to define a trailing gap (215). A leading plug (220) is disposed in the leading gap (200) and a trailing plug (225) is disposed in the trailing gap (215). Each of the leading plug (220) and the trailing plug (225) have a plug (220) length that is at least as great as the axial length.

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TURBINES AND CORRESPONDING METHOD OF DAMPENING

TECHNICAL FIELD

[0001] The present disclosure is directed, in general, to a blade attachment system for attaching a turbine blade to a rotor, and more specifically to a blade attachment system for attaching a turbine blade to a rotor of a small energy recapturing turbine.

BACKGROUND

[0002] Industrial processes such as fluid catalytic cracking (FCC) often produce discharge streams of gas at very high temperatures (e.g., 1000 degrees F (538 degrees C) or greater) and at high pressures. Throttle valves can be used to reduce the pressure and discharge velocity of these gasses. However, using a throttle valve wastes the available energy in the gas stream. Energy recovery turbines can be used to recapture the energy from these gas discharges to make the overall industrial process more efficient.

SUMMARY

[0003] A turbine includes a disk having a plurality of protrusions arranged such that any two adjacent protrusions define an axial entry fir tree space, each protrusion defining an outermost lobe having an outermost surface and an axial length. A turbine blade includes an airfoil, a platform, and a blade root having a fir tree arranged to engage a leading protrusion and a trailing protrusion. The blade root and the leading protrusion cooperate to define a leading gap, and the blade root and the trailing protrusion cooperate to define a trailing gap. A leading plug is disposed in the leading gap and a trailing plug is disposed in the trailing gap. Each of the leading plug and the trailing plug have a plug length that is at least as great as the axial length.

[0004] In another construction, a turbine includes a disk having a plurality of protrusions arranged to define a plurality of fir tree spaces and an axial length, and a turbine blade including an airfoil, a platform, and a blade root, the blade root including a fir tree arranged to fit within

one of the fir tree spaces and cooperating with a leading protrusion of the plurality of protrusions to define a leading gap and a trailing protrusion of the plurality of protrusions to define a trailing gap. A leading plug has a length at least as great as the axial length and includes an upstream cap having an upstream perimeter, a downstream cap having a downstream perimeter, and a body extending therebetween and having a body perimeter, each of the upstream perimeter and the downstream perimeter are larger than and fully enclosing the body perimeter at their respective interfaces.

[0005] In another construction, a turbine includes a plurality of protrusions arranged to define a plurality of axial entry fir tree spaces with each axial entry fir tree space formed between two adjacent protrusions. The turbine includes a plurality of turbine blades, each turbine blade including an airfoil, a platform, and a blade root that defines an axial length, the blade root including a fir tree having a leading pocket and a trailing pocket. A plurality of leading plugs is arranged with each leading plug at least partially disposed in the leading pocket of an associated blade of the plurality of blades. Each leading plug has a length at least as great as the axial length and includes an upstream cap, a downstream cap, and a body extending between the caps. Each turbine blade engages one of the axial entry fir tree spaces and one of the leading plugs, and wherein the upstream cap completely covers the leading pocket of the associated blade.

[0006] In another construction, a method of dampening the vibration of a blade installed in a blade root formed in a turbine rotor includes providing a clearance between the blade and the blade root to allow relative movement therebetween when the turbine rotor is not in operation, installing a leading plug between the blade and the turbine rotor, the leading plug including a first surface that selectively engages the blade and a second surface that selectively engages the turbine rotor, and operating the turbine rotor, wherein operation of the turbine rotor moves the blade into engagement with the blade root to inhibit relative movement therebetween, and wherein the first surface frictionally engages the blade and the second surface engages the rotor to fix the position of the leading plug and to dampen the vibration of the blade with respect to the turbine rotor.

[0007] The foregoing has outlined rather broadly the technical features of the present disclosure so that those skilled in the art may better understand the detailed description that follows.

Additional features and advantages of the disclosure will be described hereinafter that form the subject of the claims. Those skilled in the art will appreciate that they may readily use the conception and the specific embodiments disclosed as a basis for modifying or designing other structures for carrying out the same purposes of the present disclosure. Those skilled in the art will also realize that such equivalent constructions do not depart from the spirit and scope of the disclosure in its broadest form.

[0008] Also, before undertaking the Detailed Description below, it should be understood that various definitions for certain words and phrases are provided throughout this specification and those of ordinary skill in the art will understand that such definitions apply in many, if not most, instances to prior as well as future uses of such defined words and phrases. While some terms may include a wide variety of embodiments, the appended claims may expressly limit these terms to specific embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Fig. 1 is a partially broken away perspective view of an energy recovery turbine including a rotor, a disk, and a plurality of rotating blades.

[0010] Fig. 2 is a perspective view of the disk of Fig. 1 including a portion of the rotating blades installed on the disk.

[0011] Fig. 3 is a perspective top view of the disk and blades of Fig. 1 arranged such that a longitudinal axis of the turbine is vertical.

[0012] Fig. 4 is an enlarged upstream side perspective view of one of the blades installed in the disk and including a leading plug and a trailing plug.

[0013] Fig. 5 is an enlarged downstream side perspective view of one of the blades installed in the disk and including the leading plug and the trailing plug.

[0014] Fig. 6 is a perspective view of a blade root arranged to receive the leading plug and the trailing plug of Fig. 4.

[0015] Fig. 7 is a perspective view of a leading plug of Fig. 4.

[0016] Fig. 8 is a perspective section view taken along line 8-8 of Fig. 7.

[0017] Fig. 9 is a perspective section view taken along line 9-9 of Fig. 7.

[0018] Fig. 10 is a top view of the leading plug of Fig. 7.

[0019] Fig. 11 is an end view of a blade installed in the disk with the leading plug and trailing plug removed.

[0020] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting.

DETAILED DESCRIPTION

[0021] Various technologies that pertain to systems and methods will now be described with reference to the drawings, where like reference numerals represent like elements throughout. The drawings discussed below, and the various embodiments used to describe the principles of the present disclosure in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the disclosure. Those skilled in the art will understand that the principles of the present disclosure may be implemented in any suitably arranged apparatus. It is to be understood that functionality that is described as being carried out by certain system elements may be performed by multiple elements. Similarly, for instance, an element may be configured to perform functionality that is described as being carried out by multiple elements. The numerous innovative teachings of the present application will be described with reference to exemplary non-limiting embodiments.

[0022] Also, it should be understood that the words or phrases used herein should be construed broadly, unless expressly limited in some examples. For example, the terms “including,” “having,” and “comprising,” as well as derivatives thereof, mean inclusion without limitation.

The singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. Further, the term “and/or” as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. The term “or” is inclusive, meaning and/or, unless the context clearly indicates otherwise. The phrases “associated with” and “associated therewith,” as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, or the like.

[0023] Also, although the terms "first", "second", "third" and so forth may be used herein to refer to various elements, information, functions, or acts, these elements, information, functions, or acts should not be limited by these terms. Rather these numeral adjectives are used to distinguish different elements, information, functions or acts from each other. For example, a first element, information, function, or act could be termed a second element, information, function, or act, and, similarly, a second element, information, function, or act could be termed a first element, information, function, or act, without departing from the scope of the present disclosure.

[0024] In addition, the term "adjacent to" may mean: that an element is relatively near to but not in contact with a further element; or that the element is in contact with the further portion, unless the context clearly indicates otherwise. Further, the phrase “based on” is intended to mean “based, at least in part, on” unless explicitly stated otherwise. Terms “about” or “substantially” or like terms are intended to cover variations in a value that are within normal industry manufacturing tolerances for that dimension. If no industry standard as available a variation of twenty percent would fall within the meaning of these terms unless otherwise stated.

[0025] Fig. 1 illustrates an energy recovery turbine 10 that includes a housing 15, a rotor 20, a disk 25, a plurality of blades 30, and a bearing 35. Turbines 10 of this type are often used to recover energy from exhaust gases in industrial processes. For example, turbines 10 of this type are often installed in both fluid catalytic cracking (FCC), and residue fluid catalytic cracking (RFCC) systems to capture energy from high temperature flue gas. The flue gas drives the rotor 20 which in turn drives a generator to generate electricity or another device. The generator could be a synchronous generator or a multi-speed alternator with each generating usable electricity.

In other constructions, the rotor 20 drives another device such as a fan, a catalyst regenerator main air blower, a pump, a compressor, or some other device. The actual device being driven can be any rotatable device that might be useful in a particular application.

[0026] Operation in a flue gas environment does provide unique challenges for the turbine 10. The operating environment can include extreme high temperatures (e.g., greater than 1000 ^{o}F, 538 ^{o}C) chemical corrosion, and kinetic erosion caused by the hot, particulate laden flue gas, high speed operation, etc. Significant and rapidly applied thermal differentials can also create substantial stress on the components of the turbine 10.

[0027] Returning to Fig. 1, the housing 15 defines an inlet 40 and an outlet 45 and provides structural support for both the rotor 20 and the bearing 35. The inlet 40 includes a flange 50 that receives flue gas from a source. A plurality of aerodynamic struts 55 support a central cone 60 that cooperates with the flange 50 to define an annular flow area 65. The annular flow area 65 leads to a series of stationary vanes or inlet guide vanes 70 that receive the flow of flue gas and turn that flow of gas into a desired direction. An exhaust portion 75 of the housing 15 surrounds the disk 25 and an exhaust cone 80 (sometimes referred to as a diffuser) and is arranged to collect the flue gas and discharge it through the outlet 45 after the energy has been extracted from the gas.

[0028] The disk 25 includes an upstream side 85 and a downstream side 90 and is supported immediately downstream of the guide vanes 70. The disk 25 supports the plurality of blades 30 in a position where the flue gas exiting the guide vanes 70 engages the plurality of blades 30. The blades 30 are arranged to provide flow paths 95 therebetween that provide for the expansion of the flue gas, thereby converting a portion of the energy carried by the flue gas to torque which is applied to the disk 25. The torque causes rotation of the disk 25 and the blades 30 about a longitudinal axis 100. The exhaust cone 80, or diffuser extends from the blades 30 and defines an expanding annular flow path 105 that allows for further expansion and efficient deceleration of the flue gas as it is collected in the exhaust portion 75 of the housing 15.

[0029] The rotor 20 is coupled to the disk 25 such that any torque applied to the disk 25 is transferred to the rotor 20. The rotor 20 is also coupled to the generator or to another device to be driven and transfers torque to that device. The generator, in turn generates electricity for use as desired. In the illustrated construction, the exhaust portion 75 of the housing 15 is annular, and the bearing 35 is positioned within a space 110 defined by the exhaust portion 75. This arrangement provides for a short axial length for the energy recovery turbine 10.

[0030] It should be understood that Fig. 1 illustrates one example of an energy recovery turbine 10 with many different designs and arrangements being possible. For example, other energy recovery turbines could include multiple rotating stages and multiple disks. Other arrangements could include a linear flow path with no ninety degree turns. Still other arrangements could drive devices other than the generator. The disk 25, the blade 30, and the attachment system described herein are equally applicable to many different designs and should not be limited by the arrangement of the energy recovery turbine 10.

[0031] Figs. 2 and 3 illustrate the disk 25 with a few of the plurality of blades 30 installed. The disk 25 includes an attachment arrangement 115 at its center that is arranged to attach to the rotor 20 or to the device being driven by the disk 25. Many different attachment arrangements are possible and can be used as desired.

[0032] An outer circumference of the disk 25 includes a plurality of protrusions 120 that cooperate to define a plurality of axial entry fir tree roots or fir tree spaces 125. When viewing the disk 25 from the upstream or inlet side 85, the disk 25 rotates in a rotation direction 130 that is counterclockwise. Thus, each fir tree space 125 is defined by a leading protrusion 135 and a trailing protrusion 140 with the leading protrusion 135 being the first of the two protrusions 135, 140 to rotate past a fixed point during operation. Each protrusion 135, 140 is a leading protrusion 135 for one blade 30 and a trailing protrusion 140 for the blade 30 immediately in front of that blade 30. With reference to Fig. 3, the protrusions 120 are arranged to define an oblique angle 145 with respect to the longitudinal axis 100 of the turbine 10. Thus, the fir tree space 125 defined is an inclined or angled fir tree space 125 with straight or curved fir tree spaces also being possible.

[0033] Fig. 4 better illustrates the protrusions 120 as including three lobes on either side of the protrusion 120 and an outermost surface 150. A first lobe 155 is positioned at the smallest diameter, followed by a second lobe 160 outside of the first lobe 155, and a third lobe 165 outside of the second lobe 160. The outermost surface 150 is defined outside of the third lobe 165.

[0034] As illustrated in Fig. 6, each blade 30 includes an airfoil 170, a platform 175, and a root 180 arranged to engage the disk 25. The airfoils 170 are arranged such that the airfoils 170 of adjacent blades 30 cooperate to define the converging flow path 95 for the flue gas (best illustrated in Fig. 3). Each airfoil 170 extends radially outward from the platform 175 which is positioned radially outward from the root 180. The root 180 includes a fir tree arrangement sized and shaped to engage the fir tree spaces 125 defined by the protrusions 120. Specifically, each blade 30 includes three lobes 185 on either side of the root 180 that each engage one of the lobes 155, 160, 165 of the leading protrusion 135 and the trailing protrusion 140 associated with that blade 30. Each blade 30 also defines a leading pocket 190 between a radially outermost lobe 185a and the platform 175. The leading pocket 190 is a space in which the root profile of the blade 30 does not closely follow the profile defined by the protrusions 120. A similar trailing pocket 195 is defined on the trailing side of the blade 30.

[0035] When the blade 30 is installed, the blade root 180, the leading protrusion 135, and the platform 175 define and substantially surround a leading gap 200 (best illustrated in Fig. 11) that includes the leading pocket 190. The term “substantially surround” as used in this context means that the blade root 180, the leading protrusion 135, and the platform 175 make up or define at least eighty percent of the perimeter surrounding the leading gap 200 with each end (an upstream end 205 and a downstream end 210) being completely open or uncovered. The blade root 180, the trailing protrusion 140, and the platform 175 cooperate to define a trailing gap 215 (best illustrated in Fig. 11) that includes the trailing pocket 195. The trailing gap 215 is a substantial (i.e., within typical manufacturing tolerances) mirror image of the leading gap 200.

[0036] Figs. 7-10 illustrate a leading plug 220 that is sized and shaped to at least partially fill the leading gap 200. A trailing plug 225 is sized and shaped to at least partially fill the trailing gap 215. Before describing the leading plug 220 in detail, it should be noted that the trailing plug 225 is a substantial mirror image of the leading plug 220 and will not be described in detail. However, the details described with regard to the leading plug 220 are equally applicable to the trailing plug 225.

[0037] The leading plug 220 includes a body portion 230, an upstream cap 235, and a downstream cap 240. The body portion 230 includes a substantially triangular cross section (filleted corners) that extends from the upstream cap 235 along a path that is obliquely-angled with respect to a normal to the upstream cap 235. The body portion 230 extends to the downstream cap 240 which is positioned to be parallel to the upstream cap 235 as is illustrated in Fig. 10.

[0038] As discussed, the body portion 230 includes a cross-sectional shape that is triangular with filleted corners. The cross-sectional shape defines a body perimeter 245 as illustrated in Figs. 8 and 9. The upstream cap 235 includes an upstream perimeter 250 that is larger than the body perimeter 245 and that surrounds the body perimeter 245 at the intersection of the body portion 230 and the upstream cap 235 as is best illustrated in Fig. 8. Similarly, the downstream cap 240 includes a downstream perimeter 255 that is larger than the body perimeter 245 and that surrounds the body perimeter 245 at the intersection of the body portion 230 and the downstream cap 240 as is best illustrated in Fig. 9.

[0039] The leading plug 220 and the trailing plug 225 are sized and shaped to fit within the leading gap 200 and the trailing gap 215 as best illustrated in Figs. 4 and 5. Fig. 4 is a view of the disk 25 from the upstream side 85 with one of the blades 30 attached to the disk 25. The leading plug 220 and the trailing plug 225 are positioned such that the upstream cap 235 for each of the plugs 220, 225 fully covers the upstream end 205 of the leading gap 200 and the trailing gap 215. In this position, during operation, the upstream caps 235 function to limit or inhibit the entry of flue gas into the leading gap 200 and the trailing gap 215. The upstream caps 235 are significantly larger than the open upstream ends 205 of the leading gap 200 and the trailing gap 215 such that the upstream caps 235 also act as stops that inhibit the passage of the leading plugs 220 or the trailing plugs 225 through the leading gaps 200 or the trailing gaps 215.

[0040] Fig. 5 illustrates the blade 30, the leading plug 220, the trailing plug 225, and the disk 25 from the downstream side 90 of the disk 25. As can be seen, the downstream cap 240 is smaller than the upstream cap 235 and does not cover the downstream end 210 of the leading gap 200 or the trailing gap 215 to the extent that the upstream cap 235 covers the upstream end 205 of the leading gap 200 or the trailing gap 215.

[0041] As illustrated in Fig. 8, the upstream cap 235 includes a first portion 260 that is substantially rectangular with a long end extending substantially circumferentially and a second portion 265 that is substantially rectangular and extends in a radial direction. A large chamfer 270 connects the first portion 260 and the second portion 265 at an inner corner. The first portion 260 is arranged to sit radially inside the platform 175 and extends from an interior portion of the blade root 180 to an interior portion of the adjacent protrusion 120. The second portion 265 extends from radially inside the platform 175 to a point radially inward of the third lobe 165 of the associated protrusion 120. Thus, the upstream cap 235 completely covers the open upstream end 205 of the leading gap 200 or the trailing gap 215 associated with the plug 220, 225. The size and shape of the upstream cap 235 is also selected to assure that no matter the position of the plug 220, 225 in the associated gap 200, 215, the upstream cap 235 cannot pass through the gap 200, 215, thus preventing further axial movement of the plug 220, 225 in the flow direction (i.e., from the upstream side 85 of the disk 25 toward the downstream side 90 of the disk 25). It should be noted that other shapes and sizes could be employed for the upstream cap 235 so long as the upstream cap 235 covers the open upstream end 205 of the associated leading gap 200 or the trailing gap 215. Therefore, the plugs 220, 225 should not be limited to the particular shape or size illustrated for the upstream caps 235.

[0042] The downstream cap 240, illustrated in Fig. 9 includes a first side 275, a second side 280, and a third side 285 arranged in a triangular shape. Each of the three sides 275, 280, 285 of the triangle are spaced a parallel non-zero distance outside of the edge defined by the intersection of the body portion 230 and the downstream cap 240 such that the downstream perimeter 255 completely surrounds and encloses the body perimeter 245. A first surface 290 and a second surface 295 of the body portion 230 engage the platform 175 and the blade root 180 respectively for installation. In this position, a third surface 300 of the plug 220, 225 remains spaced apart from the adjacent protrusion 120, thereby allowing passage of the blade 30 into the fir tree space 125. The third side 285 of the downstream cap 240 adjacent the third surface 300 is positioned close to the third surface 300 to assure that the downstream cap 240 can pass through the fir tree space 125 during installation. Once the blade 30 is installed, the downstream cap 240 inhibits unwanted axial movement of the plug 220, 225. It should be noted that other shapes or sizes could be employed for the downstream cap 240 so long as the cap 240 is capable of passing through the associated leading gap 200 or the trailing gap 215 during installation. Therefore, the plugs 220, 225 should not be limited to the particular shape or size illustrated for the downstream caps 240.

[0043] As discussed above, the blades 30, the disk 25, the leading plugs 220, and the trailing plugs 225 are subject to a challenging environment during operation. The high temperature and often corrosive gas generally require that the blades 30, the disk 25, the leading plugs 220, and the trailing plugs 225 be made from stainless steels, nickel-based alloys, or other high temperature corrosion resistant alloys. In one construction, the leading plugs 220 and the trailing plugs 225 are formed using an additive manufacturing process such as selective laser melting (SLM) and the like. These processes allow for the selection of materials more suited to the actual operating environment. Of course, more conventional machining, welding, forging, or casting techniques could be employed depending upon the operating temperature, environment, and materials selected for the particular application.

[0044] To assemble the turbine 10, the blades 30 must be installed on the disk 25. With reference to Fig. 5, the installer first positions the leading plug 220 and the trailing plug 225 in position within the leading pocket 190 and the trailing pocket 195. With the leading plug 220 and trailing plug 225 positioned adjacent and abutting the blade 30 in the respective leading pocket 190 and trailing pocket 195, the three parts can be slid axially within the axial fir tree space 125. More specifically, the body portion 230 of the leading plug 220 and the trailing plug 225 is smaller than the leading gap 200 and the trailing gap 215. Once the blade 30 is slid into position, a locking pin (not shown) engages a locking tail 305 (shown in Fig. 5) to inhibit unwanted axial movement of the blade 30 with the engaged blade root 180 and fir tree space 125 limiting radial and circumferential movement of the blade 30 with respect to the disk 25. The blade root 180, the fir tree space 125, the leading plug 220, and the trailing plug 225 are sized to provide a slightly loose fit that allows the blades 30 to move slightly in the radial direction. More specifically, some embodiments include a clearance of between 0.005-0.020 inches (0.12 mm – 0.51 mm) on all three sides 290, 295, 300 of the plug 220, 225.

[0045] During operation, the centrifugal force generated by the rotation of the disk 25 forces the blade root 180 to engage the adjacent protrusions 120 and locks the blade 30, the leading plug 220, and the trailing plug 225 in place. In addition to filling the leading gap 200 and the trailing gap 215, the leading plug 220 and the trailing plug 225 also provide additional vibration dampening for the blade 30 during operation. The dampening is achieved through a combination of the relatively a loose fit, the relatively large contact area, and the triangle/wedge shape that firmly applies friction due to centrifugal loads and relative blade/disc motion. During operation, the first surface 290 and the third surface 300 are actively, frictionally engaged by the blade 30 and disk 25 respectively. The second surface 295 generally maintains clearance during operation. A fillet radius between the first surface 290 and the third surface 300 contacts the blade 30 and keeps the first surfaces 290 engaged with the blade 30 and the third surface 300 engaged with the disk 25.

[0046] The upstream caps 235 cover the upstream ends 205 of the leading gaps 200 and the trailing gaps 215 to inhibit the unwanted entry of flue gas during operation.

[0047] Although an exemplary embodiment of the present disclosure has been described in detail, those skilled in the art will understand that various changes, substitutions, variations, and improvements disclosed herein may be made without departing from the spirit and scope of the disclosure in its broadest form.

[0048] None of the description in the present application should be read as implying that any particular element, step, act, or function is an essential element, which must be included in the claim scope: the scope of patented subject matter is defined only by the allowed claims. Moreover, none of these claims are intended to invoke a means plus function claim construction unless the exact words "means for" are followed by a participle.

CLAIMS

What is claimed is:

1. A turbine comprising:

a disk including a plurality of protrusions arranged such that any two adjacent protrusions define an axial entry fir tree space, each protrusion defining an outermost lobe having an outermost surface and an axial length;

a turbine blade including an airfoil, a platform, and a blade root, the blade root including a fir tree arranged to engage a leading protrusion and a trailing protrusion, the blade root and the leading protrusion cooperating to define a leading gap, and the blade root and the trailing protrusion cooperating to define a trailing gap;

a leading plug disposed in the leading gap; and

a trailing plug disposed in the trailing gap, each of the leading plug and the trailing plug having a plug length that is at least as great as the axial length.

2. The turbine of claim 1, wherein the turbine has an axial direction, and wherein each of the protrusions of the plurality of protrusions is arranged at an oblique angle with respect to the axial direction such that each of the axial entry fir tree spaces is arranged at the oblique angle with respect to the axial direction.

3. The turbine of claim 1, wherein the blade root, the platform, and the leading protrusion substantially surround the leading gap, and the blade root, the platform, and the trailing protrusion substantially surround the trailing gap.

4. The turbine of claim 3, wherein the leading plug includes a body portion having a body perimeter that defines a substantially triangular cross section, an upstream cap having an upstream perimeter that surrounds and encloses the body perimeter at their intersection, and a downstream cap having a downstream perimeter that surrounds and encloses the body perimeter at their intersection.

5. The turbine of claim 4, wherein the leading gap includes an upstream opening and a downstream opening and wherein the upstream cap completely covers the upstream opening.

6. The turbine of claim 4, wherein the downstream cap is sized to fit within the leading gap when the body portion abuts the blade root.

7. The turbine of claim 1, wherein the trailing plug is a mirror image of the leading plug.

8. A turbine comprising:

a disk including a plurality of protrusions arranged to define a plurality of fir tree spaces and an axial length;

a turbine blade including an airfoil, a platform, and a blade root, the blade root including a fir tree arranged to fit within one of the fir tree spaces and cooperating with a leading protrusion of the plurality of protrusions to define a leading gap and a trailing protrusion of the plurality of protrusions to define a trailing gap; and

a leading plug having a length at least as great as the axial length and including an upstream cap having an upstream perimeter, a downstream cap having a downstream perimeter, and a body extending therebetween and having a body perimeter, each of the upstream perimeter and the downstream perimeter being larger than and fully enclosing the body perimeter at their respective interfaces.

9. The turbine of claim 8, wherein the turbine has an axial direction, and wherein each of the protrusions of the plurality of protrusions is arranged at an oblique angle with respect to the axial direction such that each of the axial entry fir tree spaces is arranged at the oblique angle with respect to the axial direction.

10. The turbine of claim 8, wherein the blade root, the platform, and the leading protrusion substantially surround the leading gap, and the blade root, the platform, and the trailing protrusion substantially surround the trailing gap.

11. The turbine of claim 10, wherein the body of the leading plug defines a substantially triangular cross section.

12. The turbine of claim 11, wherein the leading gap includes an upstream opening and a downstream opening and wherein the upstream cap completely covers the upstream opening.

13. The turbine of claim 11, wherein the downstream cap is sized to fit within the leading gap when the body portion abuts the blade root.

14. The turbine of claim 8, further comprising a trailing plug, wherein the trailing plug is a mirror image of the leading plug.

15. A turbine including a plurality of protrusions arranged to define a plurality of axial entry fir tree spaces each axial entry fir tree space formed between two adjacent protrusions, the turbine comprising:

a plurality of turbine blades, each turbine blade including an airfoil, a platform, and a blade root that defines an axial length, the blade root including a fir tree having a leading pocket and a trailing pocket; and

a plurality of leading plugs, each leading plug at least partially disposed in the leading pocket of an associated blade of the plurality of blades, each leading plug having a length at least as great as the axial length and including an upstream cap, a downstream cap, and a body extending therebetween, wherein each turbine blade engages one of the axial entry fir tree spaces and one of the leading plugs, and wherein the upstream cap completely covers the leading pocket of the associated blade.

16. The turbine of claim 15, wherein the turbine has an axial direction, and wherein each of the protrusions of the plurality of protrusions is arranged at an oblique angle with respect to the axial direction such that each of the axial entry fir tree spaces is arranged at the oblique angle with respect to the axial direction.

17. The turbine of claim 15, further comprising a plurality of trailing plugs, wherein each trailing plug is a mirror image of one of the leading plugs.

18. The turbine of claim 17, wherein each trailing plug is at least partially disposed in the trailing pocket of one of the plurality of blades, and wherein each turbine blade engages one of the axial entry fir tree roots, one of the leading plugs, and one of the trailing plugs.

19. The turbine of claim 15, wherein the leading pocket of each of the plurality of turbine blades is substantially surrounded by the blade root, the platform, and a leading protrusion to define a leading gap, and the trailing pocket of each of the plurality of turbine blades is substantially surrounded by the blade root, the platform, and a trailing protrusion to define a trailing gap.

20. The turbine of claim 19, wherein each leading gap includes an upstream opening and a downstream opening and wherein each upstream cap completely covers one of the upstream openings.

21. The turbine of claim 20, wherein each downstream cap is sized to fit within one of the leading gaps when the leading plug abuts the blade root.

22. The turbine of claim 15, wherein each upstream cap defines an upstream perimeter, each downstream cap defines a downstream perimeter and each body portion defines a body perimeter, and wherein the upstream perimeter and the downstream perimeter are each larger than and fully enclose the body perimeter at their respective interfaces.

23. A method of dampening the vibration of a blade installed in a blade groove formed in a turbine rotor, the method comprising:

providing a clearance between the blade and the blade groove to allow relative movement therebetween when the turbine rotor is not in operation;

installing a leading plug between the blade and the turbine rotor, the leading plug including a first surface that selectively engages the blade and a second surface that selectively engages the turbine rotor; and

operating the turbine rotor, wherein operation of the turbine rotor moves the blade into engagement with the blade groove to inhibit relative movement therebetween, and wherein the first surface frictionally engages the blade and the second surface engages the rotor to fix the position of the leading plug and to dampen the vibration of the blade with respect to the turbine rotor.

24. The method of claim 23, further comprising installing a trailing plug between the blade and the turbine rotor, the trailing plug including a third surface that selectively engages the blade and a fourth surface that selectively engages the turbine rotor.

25. The method of claim 24, wherein operation of the turbine rotor frictionally engages the third surface and the blade and frictionally engages the second surface and the rotor to fix the position of the trailing plug and to dampen the vibration of the blade with respect to the turbine rotor.

26. The method of claim 23, wherein the turbine rotor includes a disk and the blade grooves are formed in the disk.

FIG. 1

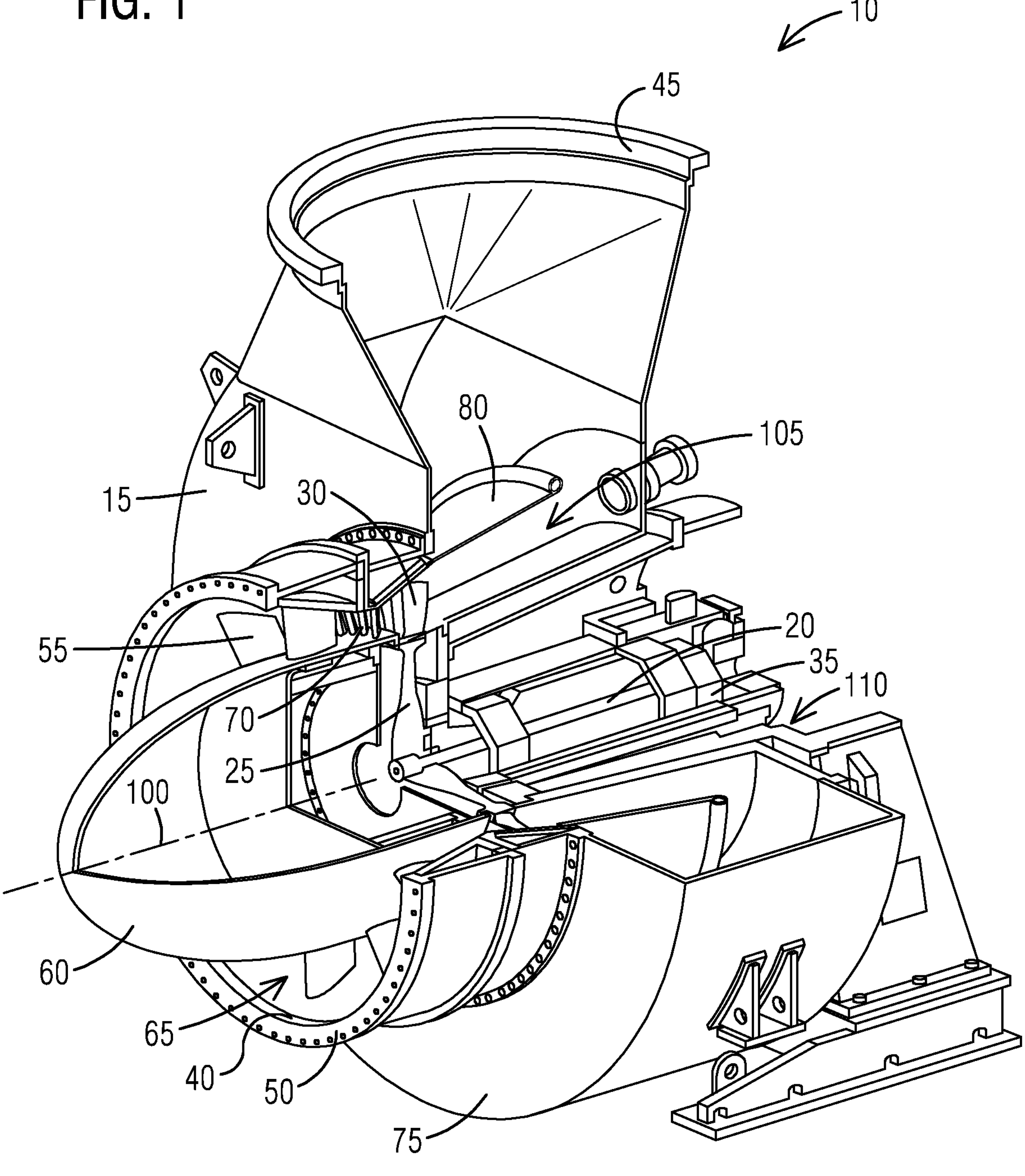

FIG. 2

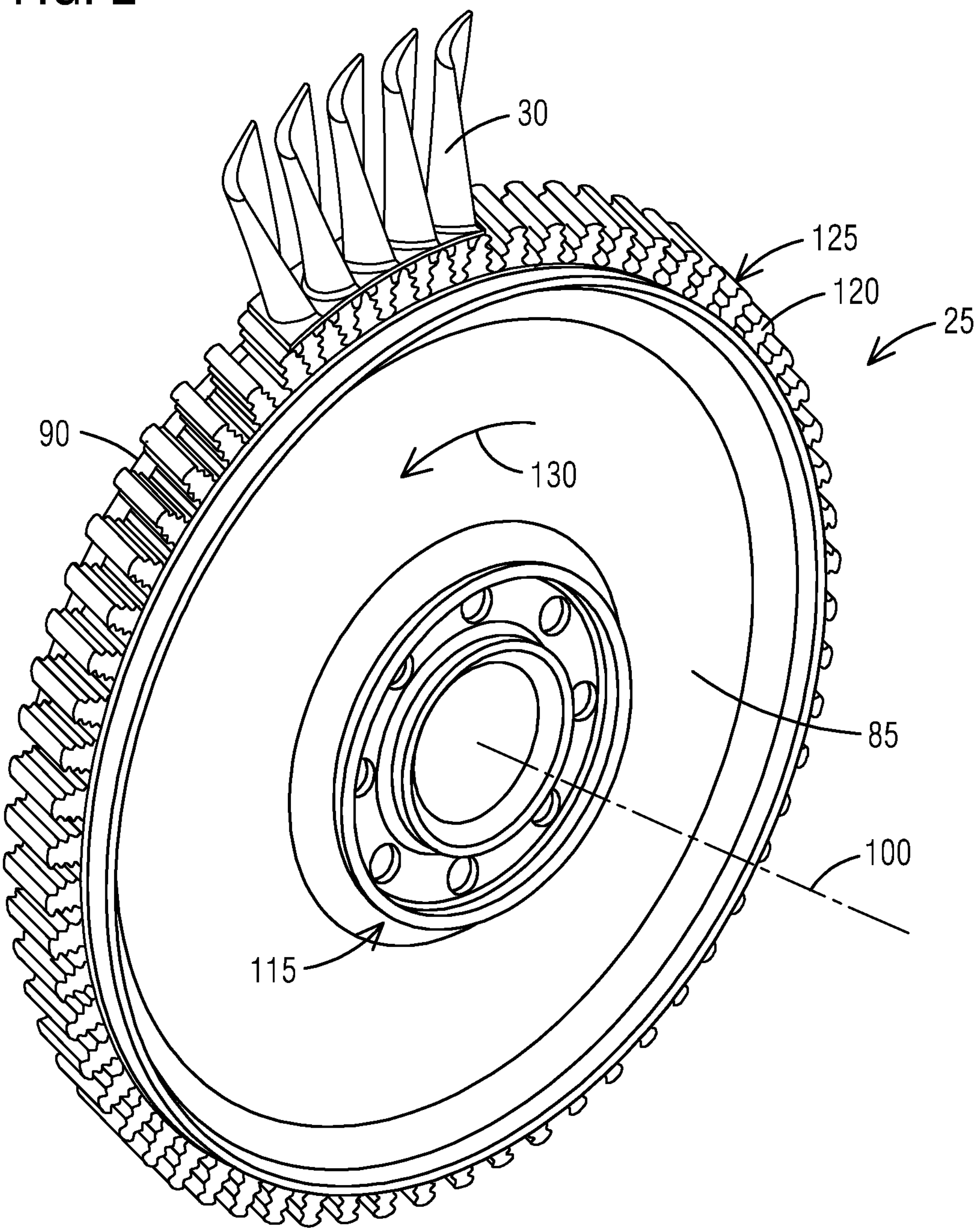

FIG. 3

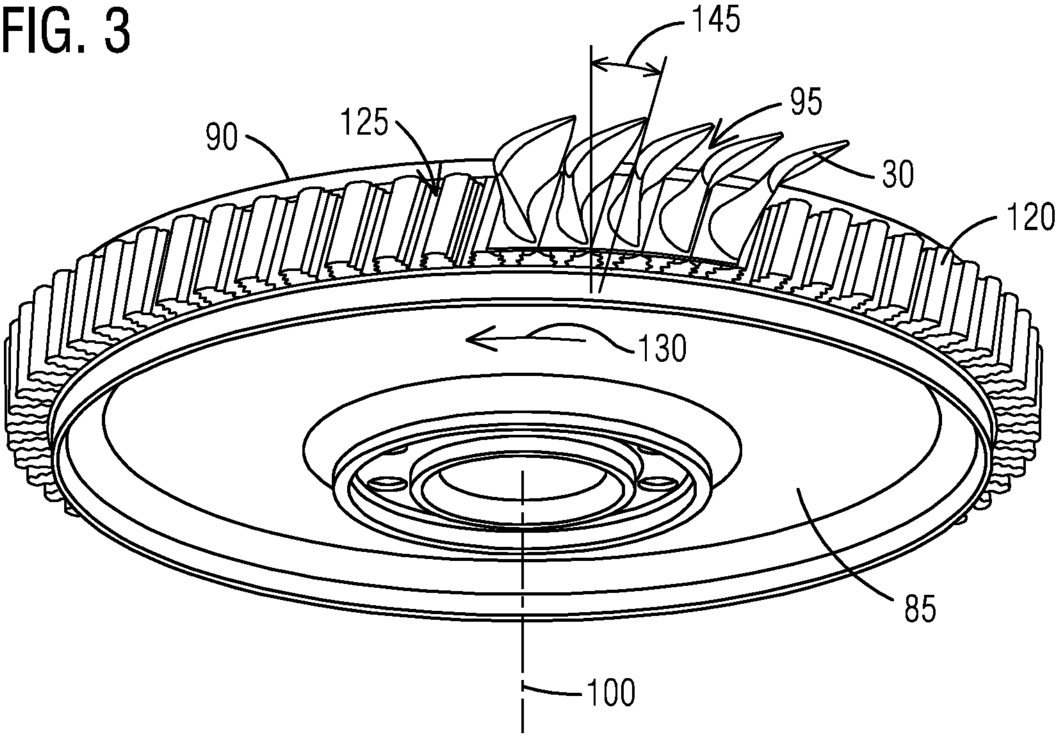
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FIG. 4

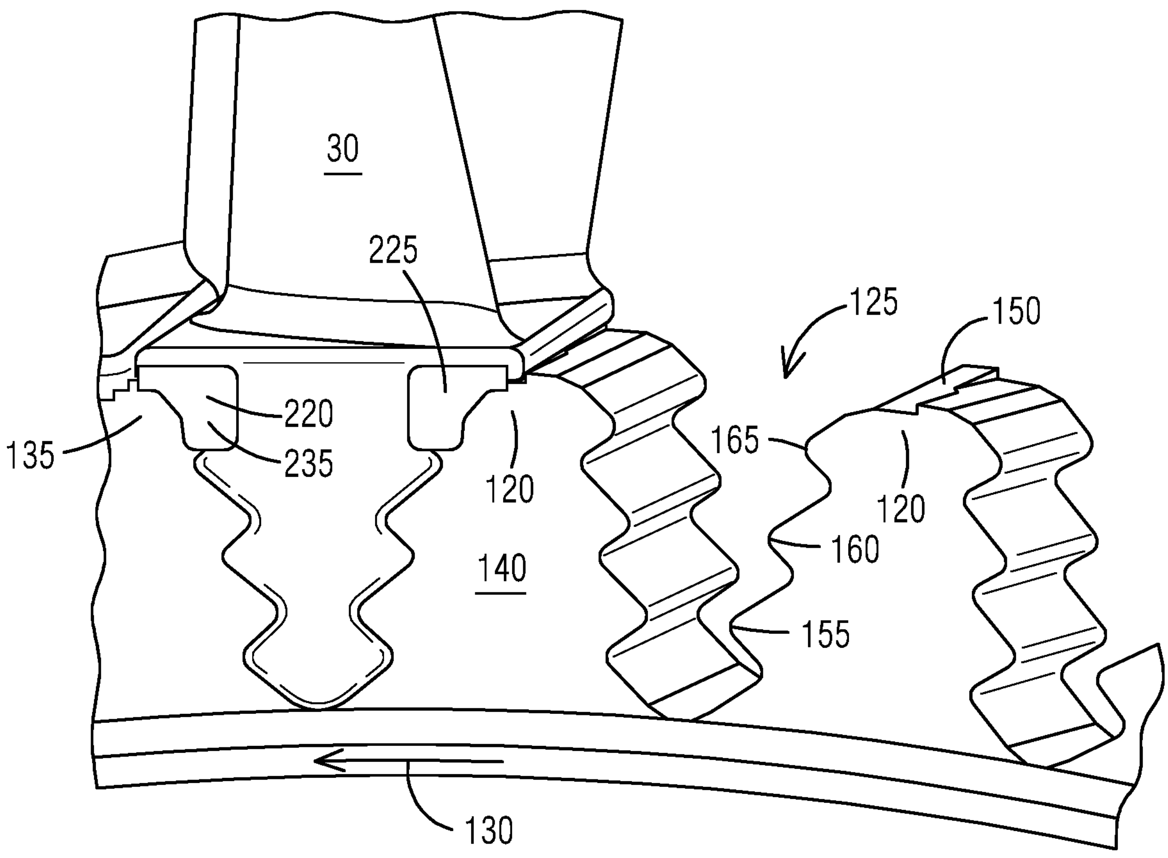
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FIG. 5

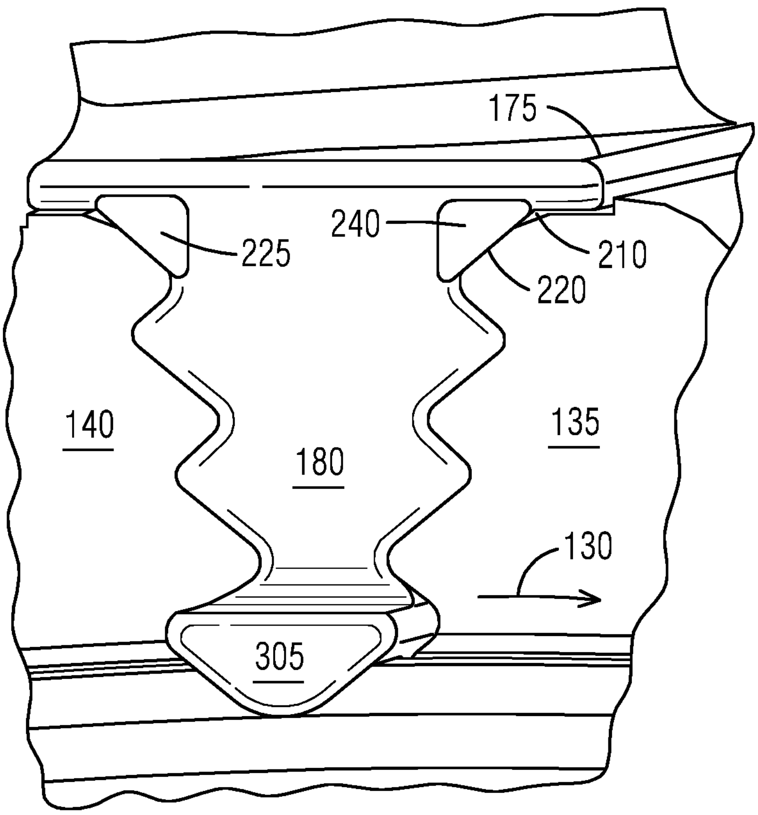
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FIG. 6

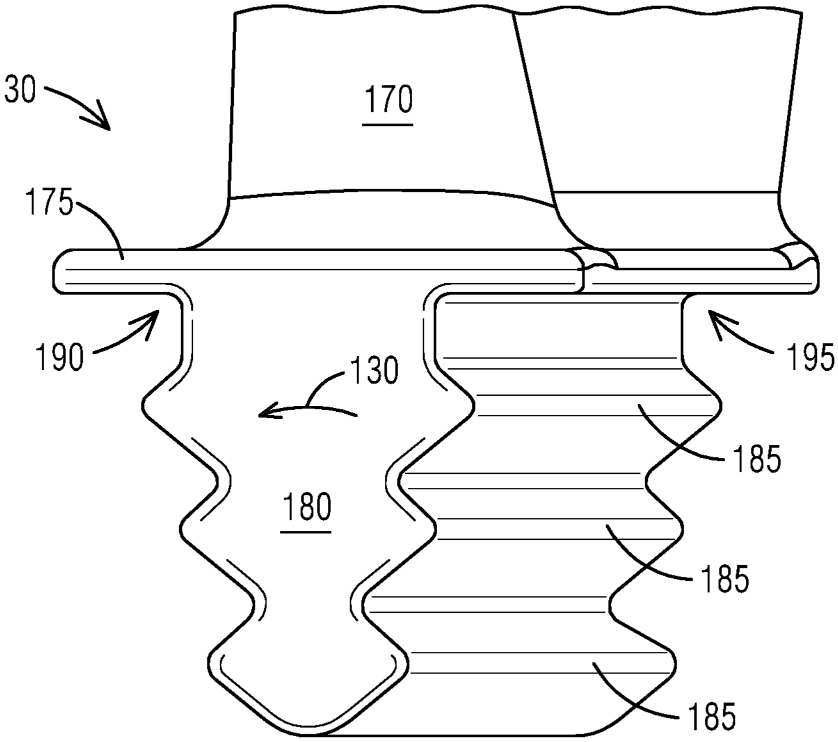
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FIG. 7

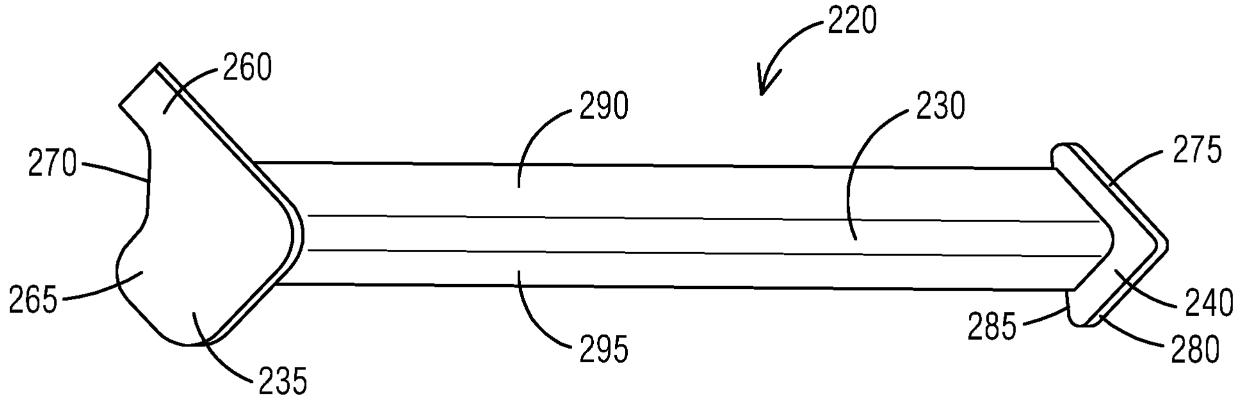


FIG. 8

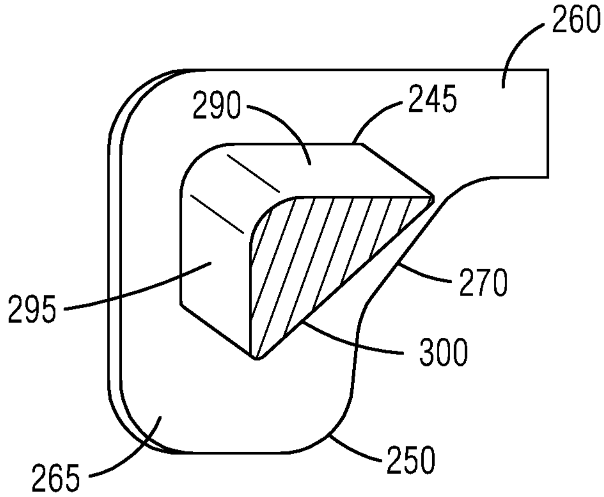


FIG. 9

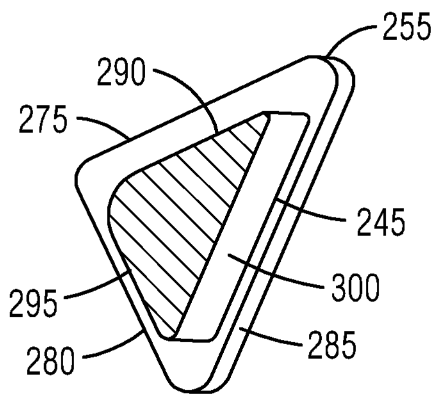


FIG. 10

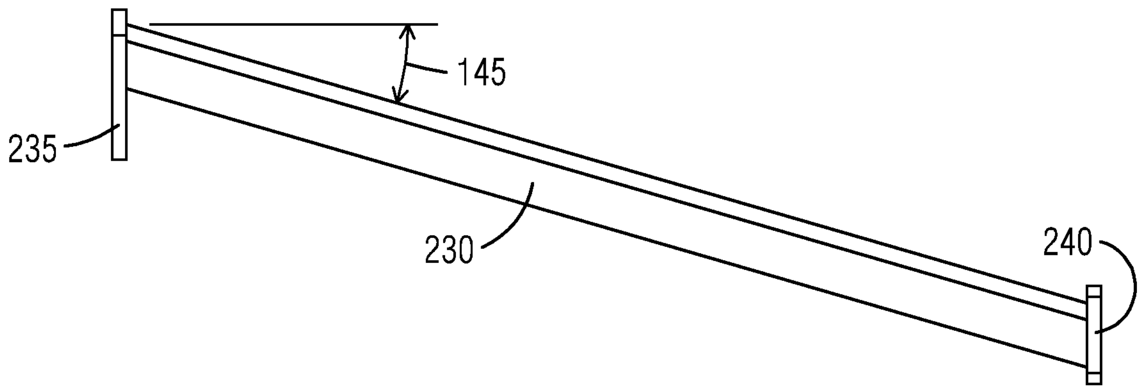
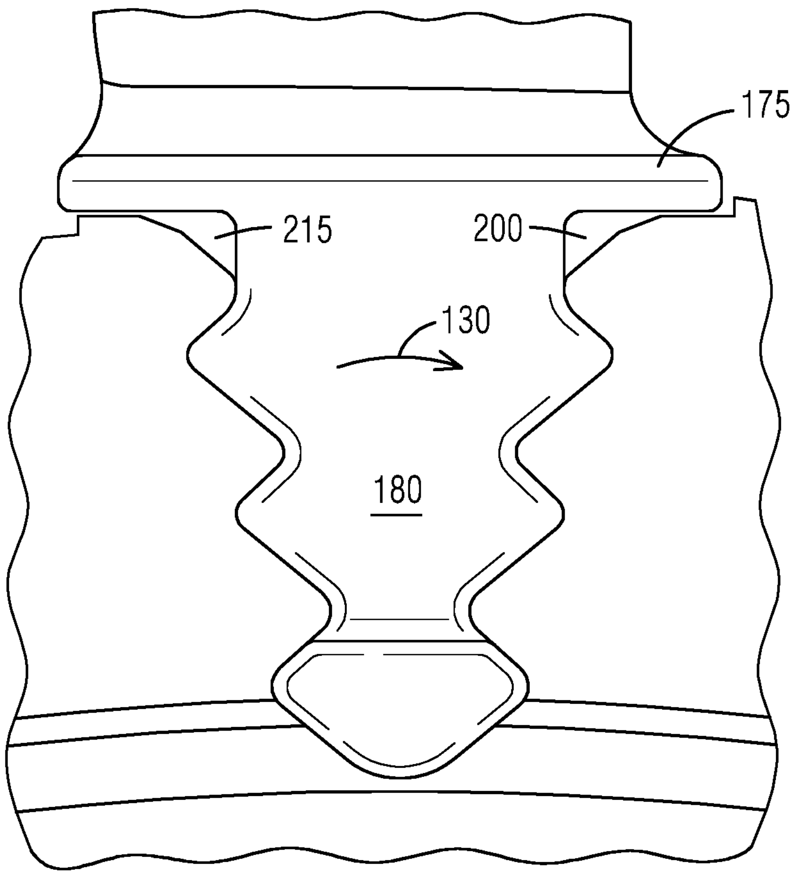


FIG. 11



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/022901

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D5/22
ADD. F01D11/00 F01D5/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 671 960 A (BRISTOL AEROPLANE CO LTD) 14 May 1952 (1952-05-14) figures	1-26
X	US 5 478 207 A (GEN ELECTRIC [US]) 26 December 1995 (1995-12-26)	1-4, 6-11,13, 14,23-26
A	figures	5,12, 15-22
X	US 2014/119917 A1 (TARCZY JEFFREY EUGENE [US] ET AL) 1 May 2014 (2014-05-01)	1-3, 8-10, 23-26
A	figures	4-7, 11-22

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 November 2019	20/11/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Raspo, Fabrice

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/323031 A1 (ZHANG QINGXUAN MICHAEL [US] ET AL) 5 December 2013 (2013-12-05)	1-3, 8-10, 23-26
A	figures	4-7, 11-22

X	US 8 425 194 B2 (LIOTTA GARY C [US]; WARD JR JOHN D [US]; GEN ELECTRIC [US]) 23 April 2013 (2013-04-23)	1,2,7-9, 14-18, 22-26
A	figures	3-6, 10-13, 19-21

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2019/022901

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			US	2009022592	A1	22-01-2009