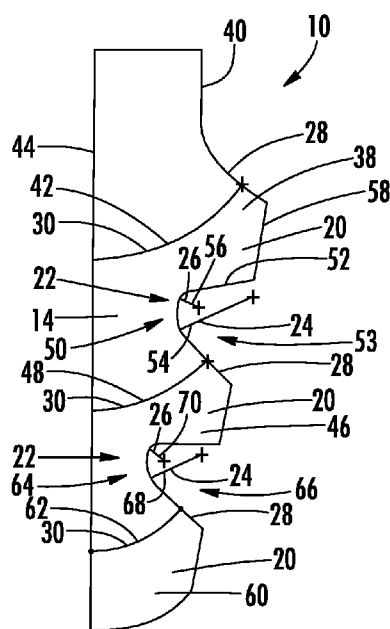




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(54) Title: ATTACHMENT SYSTEM FOR TURBINE ENGINE AIRFOIL

**FIG. 3**

(57) Abstract: An attachment system (10) for a turbine airfoil (12) including one or more roots (14) to attach the turbine airfoil (12) to a rotor is disclosed, whereby the roots (14) have teeth (20) configured with bearing surfaces positioned at different angles (42, 48, 62, 74, 92, 96, 104, 120) to increase the low cycle fatigue life of the root (14). As such, the low cycle fatigue life of a first side, first axially extending tooth (38) may be not more than 10 percent different than low cycle fatigue life of a first side, second axially extending tooth (46) to achieve balanced low cycle fatigue life and stress concentrations between the radially outer bearing surfaces (28) of the first side, first and second axially extending teeth. Such relationship increases the useful life of the airfoil (12). Other teeth (20) on the root (14) may have a similar relationship. The attachment system (10) may include compound fillet (22) between each set of adjacent teeth (20) and other elements to increase the useful life of the airfoil (12).

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ATTACHMENT SYSTEM FOR TURBINE ENGINE AIRFOIL

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

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5 Department of Energy, Contract No. DE-FC26-05NT42644. Accordingly, the United
States Government may have certain rights in this invention.

FIELD OF THE INVENTION

This invention is directed generally to airfoils usable in turbine engines, and
10 more particularly to a airfoil attachment systems.

BACKGROUND

Typically, gas turbine engines include a compressor for compressing air, a
combustor for mixing the compressed air with fuel and igniting the mixture, and a
15 turbine blade assembly for producing power. Combustors often operate at high
temperatures that may exceed 2,500 degrees Fahrenheit. Typical turbine combustor
configurations expose turbine vane and blade assemblies, to these high
temperatures. As a result, turbine airfoils, such as turbine vanes and blades must be
made of materials capable of withstanding such high temperatures. The turbine
20 blades are typically attached to a rotor via a root. The roots typically include a
plurality of teeth extending at an angle from two sides of the root to attach the root of
the turbine blade to an adjacent supporting disc. Currently, each of the teeth
extends from the root at the same angle relative to a radially extending axis. The
teeth extending from the root bear against corresponding surfaces in a supporting
25 disc. In conventional gas turbine power generation systems, the corresponding
surfaces of discs supporting the turbine blades may be subjected to substantial
centrifugal loads, such as about 40,000 tons. These high centrifugal loads wreak
havoc on the life of the roots of turbine blades and disc structures. Thus, a need
exists for an improved connection system for connecting turbine blades to a rotor.

30

SUMMARY OF THE INVENTION

An attachment system for a turbine airfoil including one or more roots to attach a turbine airfoil to a rotor is disclosed, whereby the roots have teeth configured with bearing surfaces positioned at different angles to increase the low cycle fatigue life of the root. As such, the low cycle fatigue life of a first side, first axially extending tooth may be not more than 10 percent different than low cycle fatigue life of a first side, second axially extending tooth to achieve balanced low cycle fatigue life and stress concentrations between the radially outer bearing surfaces of the first side, first and second axially extending teeth. Such relationship between the teeth increases the useful life of the airfoil. Other teeth on the root may have a similar relationship. The attachment system may also include one or more compound fillets between each set of adjacent teeth and other elements to increase the useful life of the airfoil. In at least one embodiment, the compound fillets between adjacent teeth may be formed from a major radius and a minor radius, whereby the major radius is larger than the minor radius. In at least one embodiment, the compound fillet between each set of adjacent teeth may be different such that the compound fillet becomes smaller moving radially inward.

In at least one embodiment, the attachment system for a turbine airfoil may include one or more roots configured to support a turbine airfoil within a turbine engine. The attachment system may include one or more teeth on a first side of the root and one or more teeth on a second side of the root. In at least one embodiment, the root may include, but is not limited to, an equal number of teeth on each side of the first and second sides of the root. For example, the root may include, but is not limited to, three or four teeth on each side of the first and second sides of the root. In at least one embodiment, the root may include another number of teeth. The teeth may extend generally laterally from the root at the same radial locations on the root.

More specifically, in at least one embodiment, the attachment system for a turbine airfoil may include one or more roots configured to support a turbine airfoil within a turbine engine. The root may include a first side first axially extending tooth extending from a first side of the root. A radially outer bearing surface of the first side first axially extending tooth may extend at a first acute angle inwardly relative to

a radially extending longitudinal axis of the root. A first side second axially extending tooth may extend from the first side and positioned radially inward of the first side first axially extending tooth. A radially outer bearing surface of the first side second axially extending tooth may extend at a second acute angle inwardly relative to the radially extending longitudinal axis of the root. An intersection between a radially inward surface of the first side first axially extending tooth and the radially outer bearing surface of the first side second axially extending tooth may be formed from a first compound fillet. The first compound fillet may be formed from a first major radius and a first minor radius. The first major radius may be larger than the first minor radius. The second acute angle of the first side second axially extending tooth may be less than the first acute angle of the first side first axially extending tooth.

The attachment system may include a first side third axially extending tooth extending from the first side and positioned radially inward of the first side second axially extending tooth. A radially outer bearing surface of the first side third axially extending tooth may extend at a third acute angle inwardly relative to the radially extending longitudinal axis of the root. An intersection between a radially inward surface of the first side second axially extending tooth and the radially outer bearing surface of the first side third axially extending tooth is formed from a second compound fillet. The second compound fillet may be formed from a second major radius and a second minor radius. The second major radius may be larger than the second minor radius. The second compound fillet may be different from the first compound fillet. At least one radius forming the second compound fillet may be less than at least one radius forming the first compound fillet. The second major radius may be less than the first major radius, and wherein the second minor radius may be less than the first minor radius. The third acute angle of the first side third axially extending tooth may be less than the second acute angle of the first side second axially extending tooth. The first side third axially extending tooth may be configured to contact a disk support structure such that the first side third axially extending tooth is lightly loaded with less than twenty percent of a total blade pull force during turbine engine operation.

The attachment system may include a first side fourth axially extending tooth extending from the first side and positioned radially inward of the first side third

axially extending tooth. A radially outer bearing surface of the first side fourth axially extending tooth may extend at a fourth acute angle inwardly relative to the radially extending longitudinal axis of the at least one root. An intersection between a radially inward surface of the first side third axially extending tooth and the radially outer bearing surface of the first side fourth axially extending tooth may be formed from a third compound fillet. The third compound fillet may be formed from a third major radius and a third minor radius. The third major radius may be larger than the third minor radius. The third compound fillet may be different from the first and second compound fillets. The one or more radii forming the third compound fillet may be less than at least one radius forming the second compound fillet. The third major radius may be less than the second major radius, and the third minor radius may be less than the second minor radius. The fourth acute angle of the first side fourth axially extending tooth may be less than the third acute angle of the first side third axially extending tooth. The first side fourth axially extending tooth may be configured to contact a disk support structure such that the first side fourth axially extending tooth is lightly loaded with less than fifteen percent of a total blade pull force during turbine engine operation. A fillet slope line extending tangentially relative to the first and second compound fillets may be positioned at an acute angle with a high slope greater than fifteen degrees. A fillet slope line extending tangentially relative to the first and second compound fillets may be positioned at an acute angle with a low slope less than thirteen degrees. The first side first axially extending tooth extending from the first side of the root may include a low stiffness and a low sliding angle which enhances stress flow at a top of a disc post.

The attachment system may include a one or more second side axially extending teeth extending from a second side of the root. The teeth on the second side may be a mirror image of the teeth on the first side of the root. In another embodiment, the teeth on the second side may be configured differently from the teeth on the first side of the root. A radially outer bearing surface of the second side first axially extending tooth may extend at a first acute angle inwardly relative to a radially extending longitudinal axis of the root. A second side second axially extending tooth may extend from the second side and may be positioned radially inward of the second side first axially extending tooth. A radially outer bearing

surface of the second side second axially extending tooth may extend at a second acute angle inwardly relative to the radially extending longitudinal axis of the root. An intersection between a radially inward surface of the second side first axially extending tooth and the radially outer bearing surface of the second side second axially extending tooth may be formed from a first compound fillet. The first compound fillet may be formed from a first major radius and a first minor radius. The first major radius may be larger than the first minor radius.

The attachment system may also include a second side third axially extending tooth extending from the second side and positioned radially inward of the second side second axially extending tooth. A radially outer bearing surface of the second side third axially extending tooth may extend at a third acute angle inwardly relative to the radially extending longitudinal axis of the root. An intersection between a radially inward surface of the second side second axially extending tooth and the radially outer bearing surface of the second side third axially extending tooth may be formed from a second compound fillet. The second compound fillet may be formed from a second major radius and a second minor radius. The second major radius may larger than the second minor radius.

An advantage of the attachment system is the angle of each tooth relative to a radially extending axis may be different to optimize the low cycle fatigue life of each tooth. In particular, the low cycle fatigue life of the teeth may be designed to be generally similar to each other, such as not more than 10 percent different between teeth, thereby creating balanced low cycle fatigue life and stress concentrations between the outer two teeth. Such relationship between the teeth increases the useful life of the airfoil. Other teeth on the root may have a similar relationship.

Another advantage of the attachment system is that because the angles of the radial outer bearing surfaces of each tooth on a side of a root may be different, the angle of the outermost tooth, referred to as a first axially extending tooth, and one or more other teeth may be greater than in conventional root designs, which enables the overall radial height of the root with the attachment system to be smaller than conventional root designs. In particular, the angles of the outermost teeth extending from the root may be less aligned with a radially extending axis. In at least one embodiment, a root with the attachment system may have 10 percent to 15

percent height reduction compared to conventional root designs. As such, the rim loading on a corresponding disc supporting the root with the attachment system is reduced compared to conventional root designs. The reduction in rim loading is significant considering the rim loading on a disc from a conventional airfoil of a gas turbine engine used in power generation is about 40,000 tons.

Yet another advantage of the attachment system is that because the angles of the radial outer bearing surfaces of each tooth on a side of a root may be different, each tooth may be positioned based upon the low cycle fatigue life, stress concentrations and the like of each tooth rather than based upon an analysis of the teeth taken globally.

Another advantage of the attachment system is that manufacturing an airfoil with a root having the attachment system will cost about the same as manufacturing costs for a conventional root.

Still another advantage of the attachment system is that the attachment system enables the teeth extending from a root to be individually optimized for better load management, rather than establishing a singular orientation of all teeth extending from a root.

Another advantage of the attachment system is that, in at least one embodiment, the teeth may be positioned at larger angles that become progressively smaller moving to the teeth positioned radially inward. As such, the angular gap between two radially adjacent teeth is greater than in conventional root configurations, which enables a larger fillet or compound fillet having a larger combined radius, thereby providing a larger stress reduction to the root than found in conventional root configurations.

These and other embodiments are described in more detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and form a part of the specification, illustrate embodiments of the presently disclosed invention and, together with the description, disclose the principles of the invention.

Figure 1 is a perspective view of an airfoil having features according to the instant invention.

Figure 2 is an exploded perspective view of the airfoil shown in Figure 1.

Figure 3 is a partial end view of a root with the attachment system including three teeth extending from a first side of the root.

Figure 4 is an end view of an embodiment of the root with the attachment
5 system including four teeth on each side of the root.

Figure 5 is an end view of another embodiment of the root with the attachment system engaged to a disc.

Figure 6 is an end view of yet another embodiment of the root with the
attachment system.

10 Figure 7 is an end view of another embodiment of the root with the attachment system including two teeth on each side of the root.

Figure 8 is an end view of yet another embodiment of the root with the attachment system.

15 Figure 9 is an end view of another embodiment of the root with the attachment system including two teeth on each side of the root and including stress-shielding holes.

Figure 10 is a partial end view of a root with another embodiment of the attachment system including three teeth extending from a first side of the root.

20 Figure 11 is an exploded perspective view of an alternative embodiment of the airfoil shown in Figure 1 with sloped radially outer bearing surfaces of the root sloped in the axial direction.

Figure 12 is an end view of yet another embodiment of the root shown in Figure 11 with sloped radially outer bearing surfaces of the attachment system.

25 DETAILED DESCRIPTION OF THE INVENTION

As shown in Figures 1-12, an attachment system 10 for a turbine airfoil 12 including one or more roots 14 to attach a turbine airfoil 12 to a rotor 18 is disclosed, whereby the roots 14 have teeth 20 configured with bearing surfaces 28 positioned at different angles 30 to increase the low cycle fatigue life of the root 14. As such,
30 the low cycle fatigue life of a first side, first axially extending tooth 38 may be not more than 10 percent different than low cycle fatigue life of a first side, second axially extending tooth 46 to achieve balanced low cycle fatigue life and stress

concentrations between the radially outer bearing surfaces 28 of the first side, first and second axially extending teeth 38, 46. Such relationship between the teeth 20 increases the useful life of the airfoil 12. Other teeth 20 on the root 14 may have a similar relationship.

5 The attachment system 10 may also include one or more compound fillets 22 between each set of adjacent teeth 20 and other elements to increase the useful life of the airfoil 12. In at least one embodiment, the compound fillets 22 between adjacent teeth 20 may be formed from a major radius 24 and a minor radius 26, whereby the major radius 24 is larger than the minor radius 26. In at least one
10 embodiment, the compound fillet 22 between each set of adjacent teeth 20 may be different such that the compound fillet 22 becomes smaller moving radially inward. The larger the compound fillet 22, the less the stress concentration at the fillet 22, thereby increasing the load limit that the root 14 can handle at the fillet 22. The compound fillet 22 may move a stress concentration away from the peak net-
15 section stress of the root 14, which increases the root life. The compound fillet 22 may be formed from two or more radii. For example, the compound fillet 22 may be formed from two, three or more radii, as shown in Figures 3 and 6. In embodiments with compound fillets 22 formed from multiple radii, such as, but not limited to three radii, there should be smooth transitions at the intersections between the adjacent
20 radii.

 In at least one embodiment, as shown in Figure 10, the attachment system 10 may also include a compound fillet 22 formed from a parameterized spline fit. The parameterized spline fit may be a non-uniform rational B-spline. The parameterized spline fit forming the surface of the compound fillet 22 may be curved such that the
25 ends of the parameterized spline fit join smoothly with the surfaces of the adjacent teeth 20 and without sharp points. The parameterized spline fit may be formed such that the surface of the compound fillet 22 starts and stops at two defined locations 164, 166, as shown in Figure 10. The parameterized spline fit may also be formed such that the surface of the compound fillet 22 passes through knot points 168, 170
30 that define the location of the surface of the compound fillet 22. The parameterized spline fit may also be formed such that the surface of the compound fillet 22 passes through knot points 168, 170 smoothly without sharp points.

In at least one embodiment, the attachment system 10 for a turbine airfoil 12 may include one or more roots 14 configured to support a turbine airfoil 12 within a turbine engine 36. The attachment system 10 may include one or more teeth 20 on a first side 40 of the root 14 and one or more teeth 20 on a second side 86 of the root 14. In at least one embodiment, the root 14 may include, but is not limited to, an equal number of teeth 20 on each side of the first and second sides 40, 86 of the root 14. For example, the root 14 may include, but is not limited to, three or four teeth 20 on each side of the first and second sides 40, 86 of the root 14. In at least one embodiment, the root 14 may include another number of teeth 20. The teeth 20 may extend generally laterally from the root 14 at the same radial locations on the root. Each tooth 20 may extend from the root 14 at different angles to achieve balanced low cycle fatigue life and stress concentrations while optimizing the loads carried by each tooth 20.

In at least one embodiment, the attachment system 10 may include one or more roots 14 including a first side first axially extending tooth 38 extending from a first side 40 of the root 14. As shown in Figures 3-6, a radially outer bearing surface 28 of the first side first axially extending tooth 38 may extend at a first acute angle 42 inwardly relative to a radially extending longitudinal axis 44 of the root 14. A first side second axially extending tooth 46 may extend from the first side 40 and may be positioned radially inward of the first side first axially extending tooth 38. A radially outer bearing surface 28 of the first side second axially extending tooth 46 may extend at a second acute angle 48 inwardly relative to the radially extending longitudinal axis 44 of the root 14. An intersection 50 between a radially inward surface 52 of the first side first axially extending tooth 38 and the radially outer bearing surface 28 of the first side second axially extending tooth 46 is formed from a first compound fillet 53. The first compound fillet 53 may be formed from a first major radius 54 and a first minor radius 56. The first major radius 54 may be larger than the first minor radius 56.

In at least one embodiment, the first side first axially extending tooth 38 may have a generally linear tip 58. Similarly, the first side second axially extending tooth 46 has a generally linear tip 58. In at least one embodiment, the tip 58 of the first side first axially extending tooth 38 or the tip 58 of the first side second axially

extending tooth 46, or both, may be nonorthogonal or nonparallel to the longitudinal axis 44 of the root 14. The tip 58 of the first side second axially extending tooth 46 may be positioned closer to the radially extending longitudinal axis 44 of the root 14 than the first side first axially extending tooth 38 such that each tip 58 of the teeth 20 moving radially inward is positioned closer to longitudinal axis 44 of the root 14 than teeth 20 positioned radially outward. In at least one embodiment, the second acute angle 48 of the first side second axially extending tooth 46 may be different than the first acute angle 42 of the first side first axially extending tooth 38. For example, the second acute angle 48 of the first side second axially extending tooth 46 may be less than the first acute angle 42 of the first side first axially extending tooth 38. The first side second axially extending tooth 46 and the first side first axially extending tooth 38 may extend at angles radially inward. The angular position of the first side first axially extending tooth 38, via the first acute angle 42, and the angular position of the first side second axially extending tooth 46, via the second acute angle 48, may be such that low cycle fatigue life of the first side, first axially extending tooth 38 is no more than 10 percent different than the low cycle fatigue life of the first side second axially extending tooth 46 to achieve balanced low cycle fatigue life and stress concentrations between the radially outer bearing surfaces 28 of the first side, first and second axially extending teeth 38, 46 to increase the life of the airfoil.

The attachment system 10 may include a first side third axially extending tooth extending 60 from the first side 40 and positioned radially inward of the first side second axially extending tooth 46. A radially outer bearing surface 28 of the first side third axially extending tooth 60 may extend at a third acute angle 62 inwardly relative to the radially extending longitudinal axis 44 of the root 14. An intersection 64 between a radially inward surface 52 of the first side second axially extending tooth 46 and the radially outer bearing surface 28 of the first side third axially extending tooth 60 may be formed from a second compound fillet 66. The second compound fillet 66 may be formed from a second major radius 68 and a second minor radius 70. In at least one embodiment, the second major radius 68 may be larger than the second minor radius 70. The second compound fillet 66 may be different from the first compound fillet 53. The radius forming the second compound fillet 66 may be less than at least one radius forming the first compound

fillet 53. The second major radius 68 may be less than the first major radius 54, and wherein the second minor radius 70 may be less than the first minor radius 70. The third acute angle 62 of the first side third axially extending tooth 60 may be less than the second acute angle 48 of the first side second axially extending tooth 46.

5 The first side third axially extending tooth 60 may be configured to contact a disk 84 such that the first side third axially extending tooth 60 is lightly loaded with less than twenty percent of a total blade pull force during turbine engine operation. In at least one embodiment, the first side third axially extending tooth 60 may be configured to contact a disk 84 such that the first side third axially extending tooth 60
10 is lightly loaded with between 15 percent and less than twenty percent of a total blade pull force during turbine engine operation.

 In another embodiment, as shown in Figures 4, 6 and 8, the attachment system 10 may include one or more first side fourth axially extending teeth 72 extending from the first side 40 and positioned radially inward of the first side third axially extending tooth 60. A radially outer bearing surface 28 of the first side fourth
15 axially extending tooth 72 may extend at a fourth acute angle 74 inwardly relative to the radially extending longitudinal axis 44 of the root 14. An intersection 76 between a radially inward surface 52 of the first side third axially extending tooth 60 and the radially outer bearing surface 28 of the first side fourth axially extending tooth 72
20 may be formed from a third compound fillet 78. The third compound fillet 78 may be formed from a third major radius 80 and a third minor radius 82. In at least one embodiment, the third major radius 80 may be larger than the third minor radius 82. The third compound fillet 78 may be different from the first and second compound fillets 53, 66. The radius forming the third compound fillet 78 may be less than at
25 least one radius forming the second compound fillet 66. In at least one embodiment, the third major radius 80 may be less than the second major radius 68, and the third minor radius 82 may be less than the second minor radius 70. The fourth acute angle 74 of the first side fourth axially extending tooth 72 may be less than the third acute angle 62 of the first side third axially extending tooth 60. The first side fourth
30 axially extending tooth 72 may be configured to contact a disk 84 such that the first side fourth axially extending tooth 72 may be lightly loaded with less than fifteen percent of a total blade pull force during turbine engine operation. In such

embodiment, the angular position of the first side second axially extending tooth 46, via the second acute angle 48, and the angular position of the first side third axially extending tooth 60, via the third acute angle 62, may be such that low cycle fatigue life of the first side, second axially extending tooth 46 is no more than 10 percent different than the low cycle fatigue life of the first side third axially extending tooth 60 to achieve balanced low cycle fatigue life and stress concentrations between the radially outer bearing surfaces 28 of the first side, second and third axially extending teeth 46, 60 to increase the life of the airfoil.

In at least one embodiment, the first side fourth axially extending tooth 72 may be configured to contact a disk 84 such that the first side fourth axially extending tooth 72 is lightly loaded with between 10 percent and less than fifteen percent of a total blade pull force during turbine engine operation. By configuring the first side fourth axially extending tooth 72 to be lightly loaded, the metal webbing between the third compound fillet 78 on the first and second sides 40, 86 of the root 14 may be kept thin. Lightly loading the first side fourth axially extending tooth 72 may also prevent crushing internal cooling channels within the root 14. In addition, lightly loading the first side fourth axially extending tooth 72 may enable the first side fourth axially extending tooth 72 to enable higher broach angles, which would reduce stress concentrations. The broach angle is the angle at which a root 14 of an airfoil 12 is positioned relative to a laterally extending longitudinal axis of the rotor 18 of the turbine engine 36. The broach angle is also the angle at which a root 14 of an airfoil 12 slides into the cavity in the disc relative to a laterally extending longitudinal axis of the rotor 18 of the turbine engine 36. The broach angle may be, but is not limited to being, between 0 and 20 degrees.

In at least one embodiment, the aspect ratio of the first, second or third compound fillets 53, 66, 78 or any combination thereof, may be greater than three. In another embodiment, the aspect ratio of the first, second or third compound fillets 53, 66, 78 or any combination thereof, may be greater than five. In yet another embodiment, the aspect ratio of the first, second or third compound fillets, 53, 66, 78 or any combination thereof, may be greater than ten.

The compound fillet aspect ratio of each fillet may be different. In at least one embodiment, the compound fillet aspect ratio of each fillet 22 may differ by at least

ten percent. In another embodiment, the compound fillet aspect ratio of each fillet 22 may differ by at least twenty five percent. The compound fillet aspect ratio may increase or decrease with tooth number.

5 The major radius 24 of each compound fillet may be different. In at least one embodiment, the major radius 24 between each compound fillet 22 may differ by at least ten percent. In another embodiment, the major radius 24 between each compound fillet 22 may differ by at least twenty five percent. The major radius 24 may increase or decrease with tooth number.

10 The angular orientation of the radially outer bearing surfaces 28 for each tooth 20 may be different. In particular, the angular orientation of the radially outer bearing surfaces 28 may differ by at least ten percent. In another embodiment, the angular orientation of the radially outer bearing surfaces 28 may differ by at least twenty five percent. The angular orientation of the radially outer bearing surfaces 28 may increase or decrease with tooth number.

15 In at least one embodiment, the tooth thickness may be different for each tooth 20. In at least one embodiment, the tooth thickness may differ by at least ten percent. In another embodiment, the tooth thickness may differ by at least twenty five percent. The tooth thickness may increase or decrease with tooth number.

20 In at least one embodiment, a fillet slope line 88 extending tangentially relative to the first and second compound fillets 53, 66 may be positioned at an acute angle with a high slope greater than fifteen degrees. In another embodiment, the high slope of the fillet slope line 88 may be greater than sixteen degrees. In yet another embodiment, the high slope of the fillet slope line 88 may be greater than seventeen degrees. The high slope of the fillet slope line 88 may reduce attachment mass and thus, the cost of metal casting. A fillet slope line 88 extending tangentially relative to
25 the first and second compound fillets 53, 66 may be positioned at an acute angle with a low slope less than thirteen degrees. In another embodiment, the low slope may be less than twelve degrees. In yet another embodiment, the high slope may be less than eleven degrees. The low slope can assist with package of root
30 attachments in a low pitch disk groove.

The first side first axially extending tooth 38 may extend from the first side 40 of the root 14 may include a low stiffness and a low sliding angle which enhances

stress flow at a top of a disc post. Stiffness may be measured by pull (Newtons) / displacement (millimeters). A top tooth, which may be the first side first axially extending tooth 38, may have a lower stiffness because the top section of the disk post has a smaller cross-sectional area than the lower disc posts, as shown in Figure

5 5. A smaller cross-sectional area equates to a higher net-section stress, which equates to a greater displacement per unit pull. The stiffness (N/mm) of the top tooth, such as the first side first axially extending tooth 38, may be about 25 percent lower than the middle teeth, which may be the first side second and third axially extending teeth 46, 60. In at least one embodiment, a bottom tooth, which may be
10 the first side third or fourth axially extending teeth 60, 72, may have the lowest stiffness because of the small cross-sectional area of the root 14 at the inward most tooth 60, or 72. A sliding angle may be an angle 30 of the radially outer bearing surface 28 of a tooth 20 relative to a radially extending longitudinal axis 44. In at least one embodiment, as shown in Figure 3, the first side first radially extending
15 tooth 38 may have a sliding angle 30 of about 64 degrees, the first side second radially extending tooth 46 may have a sliding angle 30 of about 51.3 degrees, the first side third radially extending tooth 60 may have a sliding angle 30 of about 48.3 degrees, and the first side fourth radially extending tooth 72 may have a sliding angle 30 of about 43.2 degrees. The sliding angles 30 of the teeth, 38, 46, 60 and 72 are
20 not limited to these angles but may have other numerical values. The root 14 may be configured such that the sliding angle of the first side first radially extending tooth 38 is greater than the sliding angle 30 of the first side second radially extending tooth 46, which may be greater than a sliding angle 30 of the first side third radially extending tooth 60, which may be greater than a sliding angle 30 of the first side
25 fourth radially extending tooth 72. As such, the first side first axially extending tooth 38 may extending from the first side 40 of the root 14 may include a low stiffness, such as at least 25 percent lower than the middle teeth, such as, but not limited to, the first side second and third axially extending teeth 46, 60. A low sliding angle may be a sliding angle 30 greater than about 54 degrees.

30 In at least one embodiment, as shown in Figures 11 and 12, the radially outer bearing surface 28 may be a sloped surface in an axial direction. As such, the radially outer bearing surface 28 at an upstream end 172 of the root 14 may be

radially outward further than the radially outer bearing surface 28 at a downstream end 174 of the root 14. The radially outer bearing surface 28 may be sloped in an effort to distribute the load placed on the radially outer bearing surface 28 by the disc during turbine engine operation more uniformly across the radially outer bearing surface 28. In conventional configurations, the loads are often not uniformly spread across the bearing surfaces of the teeth resulting in stress concentrations that reduce the useful life of the roots. The sloped radially outer bearing surfaces 28 shown in Figures 11 and 12 more uniformly distribute loads placed on the radially outer bearing surface 28. In at least one embodiment, the amount of slope on each tooth 20, specifically, the first side, first, second, third and fourth axially extending teeth, 38, 46, 60, 72 and second side, first, second, third and fourth axially extending teeth, 90, 94, 106, 118, may be equal to uniformly distribute loads placed on the radially outer bearing surfaces 28. Nonsloped radially outer bearing surfaces 28 may be shaped as rectangles. The sloped radially outer bearing surfaces 28 may be shaped as parallelograms.

The attachment system 10 may include one or more teeth 20 on a second side 86 of the root 14, as shown in Figures 4, 7 and 8. The teeth 20 on the second side 86 may be a mirror image of the teeth 20 on the first side 40 of the root 14. In another embodiment, the teeth 20 on the second side 86 may be configured differently from the teeth 20 on the first side 40 of the root 14. In at least one embodiment, the attachment system 10 may include a second side axially extending tooth 90 extending from a second side 86 of the root 14. A radially outer bearing surface 28 of the second side first axially extending tooth 90 may extend at a first acute angle 92 inwardly relative to a radially extending longitudinal axis 44 of the root 14. The attachment system 10 may include a second side second axially extending tooth 94 extending from the second side 86 and positioned radially inward of the second side first axially extending tooth 90. A radially outer bearing surface 28 of the second side second axially extending tooth 94 may extend at a second acute angle 96 inwardly relative to the radially extending longitudinal axis 44 of the root 14. An intersection 98 between a radially inward surface 52 of the second side first axially extending tooth 90 and the radially outer bearing surface 28 of the second side second axially extending tooth 94 is formed from a first compound fillet 53. The

first compound fillet 100 may be formed from a first major radius 102 and a first minor radius 104. The first major radius 102 may be larger than the first minor radius 104. In such embodiment, the angular position of the second side first axially extending tooth 90, via the first acute angle 92, and the angular position of the second side second axially extending tooth 94, via the second acute angle 96, may be such that low cycle fatigue life of the second side, first axially extending tooth 90 is no more than 10 percent different than the low cycle fatigue life of the second side second axially extending tooth 94 to achieve balanced low cycle fatigue life and stress concentrations between the radially outer bearing surfaces 28 of the second side, first and second axially extending teeth 90, 94 to increase the life of the airfoil.

A second side third axially extending tooth 106 may extend from the second side 86 and may be positioned radially inward of the second side second axially extending tooth 94. A radially outer bearing surface 28 of the second side third axially extending tooth 106 may extend at a third acute angle 108 inwardly relative to the radially extending longitudinal axis 44 of the root 14. An intersection 110 between a radially inward surface 52 of the second side second axially extending tooth 94 and the radially outer bearing surface 28 of the second side third axially extending tooth 106 may be formed from a second compound fillet 112. The second compound fillet 112 may be formed from a second major radius 114 and a second minor radius 116. The second major radius 114 may be larger than the second minor radius 116. The second compound fillet 112 of the second side 86 may be different from the first compound fillet 100 of the first side 40. The radius forming the second compound fillet 112 of the second side 86 may be less than at least one radius forming the first compound fillet 100. The second major radius 114 of the second side 86 may be less than the first major radius 102 of the second side 86, and the second minor radius 116 of the second side 86 may be less than the first minor radius 104 of the second side 86. The third acute angle 108 of the second side third axially extending tooth 106 may be less than the second acute angle 96 of the second side second axially extending tooth 94. The second side third axially extending tooth may be configured to contact a disk 84 such that the second side third axially extending tooth 106 may be lightly loaded with less than twenty percent of a total blade pull force during turbine engine operation. In at least one

embodiment, the second side third axially extending tooth 106 may be configured to contact a disk 84 such that the second side third axially extending tooth 106 is lightly loaded with between 15 percent and less than twenty percent of a total blade pull force during turbine engine operation.

5 In another embodiment, as shown in Figures 4, 7 and 8, the attachment system 10 may include a second side fourth axially extending tooth 118 extending from the second side 86 and positioned radially inward of the second side third axially extending tooth 106. A radially outer bearing surface 28 of the second side fourth axially extending tooth 118 may extend at a fourth acute angle 120 inwardly
10 relative to the radially extending longitudinal axis 44 of the root 14. An intersection 122 between a radially inward surface 52 of the second side third axially extending tooth 106 and the radially outer bearing surface 28 of the second side fourth axially extending tooth 118 may be formed from a third compound fillet 124. The third compound fillet 124 may be formed from a third major radius 126 and a third minor radius 128.
15 The third major radius 126 of the second side 86 may be larger than the third minor radius 128 of the second side 86. The third compound fillet 124 may be different from the first and second compound fillets 100, 112. A radius forming the third compound fillet 124 of the second side 86 may be less than at least one radius forming the second compound fillet 112 of the second side 86. The third major
20 radius 126 may be less than the second major radius 114 of the second side 86, and the third minor radius 128 may be less than the second minor radius 116 of the second side 86. The fourth acute angle 120 of the second side fourth axially extending tooth 118 may be less than the third acute angle 108 of the second side third axially extending tooth 106. The second side fourth axially extending tooth 118
25 may be configured to contact a disk 84 such that the second side fourth axially extending tooth 118 is lightly loaded with less than fifteen percent of a total blade pull force during turbine engine operation. In such embodiment, the angular position of the second side second axially extending tooth 94, via the second acute angle 96, and the angular position of the second side third axially extending tooth 106, via the
30 third acute angle 108, may be such that low cycle fatigue life of the second side, second axially extending tooth 94 is no more than 10 percent different than the low cycle fatigue life of the second side third axially extending tooth 106 to achieve

balanced low cycle fatigue life and stress concentrations between the radially outer bearing surfaces 28 of the second side, second and third axially extending teeth 94, 106 to increase the life of the airfoil.

As shown in Figure 9, the attachment system 10 may include one or more stress-shielding holes 154 extending from an upstream side 156 of the root 14 to a downstream side 158 of the root 14 and positioned radially between the radially outer bearing surface 28 of the first side first axially extending tooth 38 and a radially inward surface 52 of the first side first axially extending tooth 38 to reduce stress concentrations at the compound fillets 22, such as the first compound fillet 53. The stress-shielding hole 154 may be placed radially outward of a fillet 162 between teeth 20. At least a portion of the stress-shielding hole 154 may be inline with a radially extending axis 160 tangential with the fillet 162 between the first side first and second axially extending teeth 38, 46. In other embodiments, the stress-shielding hole 154 may be positioned not inline with the radially extending axis 160. In at least one embodiment, a vertical centerline 176 of the stress-shielding hole 154 may be aligned with the a radially extending axis 160. The stress-shielding hole 154 may also be positioned such that a horizontal centerline 178 of the stress-shielding hole 154 may be positioned such that a calculated minimum cross-sectional area of tooth 20 be equal above the stress-shielding hole 154 between the stress-shielding hole 154 and the radially outer bearing surface 28 and below the stress-shielding hole 154 between the stress-shielding hole 154 and the radially inward surface 52. The stress-shielding hole 154 should be no larger in diameter than a diameter of the stress-shielding hole 154 when the calculated minimum cross-sectional area of tooth 20 exists above the stress-shielding hole 154 between the stress-shielding hole 154 and the radially outer bearing surface 28 and the calculated minimum cross-sectional area of tooth 20 exists below the stress-shielding hole 154 between the stress-shielding hole 154 and the radially inward surface 52.

The stress-shielding hole 154 may have any appropriate cross-sectional area that may be shaped as a circle or other appropriate configuration. The stress-shielding hole 154 may have any appropriate diameter or size but should not be larger than a width of the root 14 between the first and second sides 40, 86. In at least one embodiment, the stress-shielding hole 154 may be between five

millimeters and 10 millimeters in diameter. The stress-shielding hole 154 may be manufactured in any appropriate manner, including, but not limited to, drilling, such as STEM drilling, EDM and the like.

In at least one embodiment, an airfoil 12 may extend radially outward from the
5 root 14. The airfoil 12 may be integrally formed with the root 14. In another
embodiment, the airfoil 12 may be a separate component forming a modular system.
The modular airfoil 12 may be coupled to the any appropriate way. In at least one
embodiment, the airfoil 12 may be formed from a generally elongated airfoil 140 with
an outer wall 142 having a leading edge 144, a trailing edge 146, a pressure side
10 148, and a suction side 150.

The foregoing is provided for purposes of illustrating, explaining, and
describing embodiments of this invention. Modifications and adaptations to these
embodiments will be apparent to those skilled in the art and may be made without
departing from the scope or spirit of this invention.

CLAIMS

We claim:

1. An attachment system (10) for a turbine airfoil (12), characterized in that:
 - at least one root (14) configured to support the turbine airfoil (12) within a turbine engine (36);
 - wherein the at least one root (14) includes a first side first axially extending tooth (38) extending from a first side (40) of the at least one root (14);
 - wherein a radially outer bearing surface (28) of the first side first axially extending tooth (38) extends at a first acute angle (42) inwardly relative to a radially extending longitudinal axis (44) of the at least one root (14);
 - a first side second axially extending tooth (46) extending from the first side (40) and positioned radially inward of the first side first axially extending tooth (38);
 - wherein a radially outer bearing surface (28) of the first side second axially extending tooth (46) extends at a second acute angle (48) inwardly relative to the radially extending longitudinal axis (44) of the at least one root (14);
 - wherein the second acute angle (48) of the first side second axially extending tooth (46) is different than the first acute angle (42) of the first side first axially extending tooth (38); and
 - wherein a configuration of the first acute angle (42) of the radially outer bearing surface (28) of the first side first axially extending tooth (38) and the second acute angle (48) of the radially outer bearing surface (28) of the first side second axially extending tooth (46) is such that when positioned in a turbine engine (36) and at operating conditions, low cycle fatigue life of the first side first axially extending tooth (38) is not more than 10 percent different than low cycle fatigue life of the first side second axially extending tooth (46) to achieve balanced low cycle fatigue life and stress concentrations between the radially outer bearing surfaces (28) of the first side (40), first and second axially extending teeth (38, 46).
2. The attachment system (10) of claim 1, characterized in that an intersection (50) between a radially inward surface (52) of the first side first axially

extending tooth (38) and the radially outer bearing surface (28) of the first side second axially extending tooth (46) is formed from a first compound fillet (53).

3. The attachment system (10) of claim 2, characterized in that the first compound fillet (53) is formed from a first major radius (54) and a first minor radius (56), and wherein the first major radius (54) is larger than the first minor radius (56).

4. The attachment system (10) of claim 2, characterized in that the first compound fillet (53) is formed from a parameterized spline fit.

5. The attachment system (10) of claim 1, characterized in that the radially outer bearing surface (28) of the first side first axially extending tooth (38) and the radially outer bearing surface (28) of the first side second axially extending tooth (46) are sloped radially.

6. The attachment system (10) of claim 1, characterized in that the second acute angle (48) of the first side second axially extending tooth (46) is less than the first acute angle (42) of the first side first axially extending tooth (38).

7. The attachment system (10) of claim 1, further characterized in that a first side third axially extending tooth (60) extending from the first side (40) and positioned radially inward of the first side second axially extending tooth (46), wherein a radially outer bearing surface (28) of the first side third axially extending tooth (60) extends at a third acute angle (62) inwardly relative to the radially extending longitudinal axis (44) of the at least one root (14) such that a configuration of the second acute angle (48) of the radially outer bearing surface (28) of the first side second axially extending tooth (46) and the third acute angle (62) of the radially outer bearing surface (28) of the first side third axially extending tooth (60) is such that when positioned in a turbine engine (36) and at operating conditions, low cycle fatigue life of the first side second axially extending tooth (46) is not more than 10 percent different than low cycle fatigue life of the first side third axially extending tooth (60) to achieve balanced low cycle fatigue life and stress concentrations

between the radially outer bearing surfaces (28) of the first side (40), second and third axially extending teeth (46, 60).

8. The attachment system (10) of claim 7, characterized in that an intersection (64) between a radially inward surface (52) of the first side second axially extending tooth (46) and the radially outer bearing surface (28) of the first side third axially extending tooth (60) is formed from a second compound fillet (66); wherein the second compound fillet (66) is formed from a second major radius (68) and a second minor radius (70); and wherein the second major radius (68) is larger than the second minor radius (70).

9. The attachment system (10) of claim 8, characterized in that the second compound fillet (66) is different from a first compound fillet (53) positioned at an intersection (50) between a radially inward surface (52) of the first side first axially extending tooth (38) and the radially outer bearing surface (28) of the first side second axially extending tooth (46).

10. The attachment system (10) of claim 9, characterized in that at least one radius forming the second compound fillet (66) is less than at least one radius forming the first compound fillet (53).

11. The attachment system (10) of claim 10, characterized in that the second major radius (68) of the second compound fillet (66) is less than a first major radius (54) of the first compound fillet (53), and wherein the second minor radius (70) of the second compound fillet (66) is less than a first minor radius (56) of the first compound fillet (53).

12. The attachment system (10) of claim 7, characterized in that the third acute angle (62) of the first side third axially extending tooth (60) is less than the second acute angle (48) of the first side second axially extending tooth (46).

13. The attachment system (10) of claim 7, characterized in that the first side third axially extending tooth (60) is configured to contact a disk support structure (34) such that the first side third axially extending tooth (60) is lightly loaded with less than twenty percent of a total blade pull force during turbine engine operation.

14. The attachment system (10) of claim 7, further characterized in that a first side fourth axially extending tooth (72) extending from the first side (40) and positioned radially inward of the first side third axially extending tooth (60); wherein a radially outer bearing surface (28) of the first side fourth axially extending tooth (72) extends at a fourth acute angle (74) inwardly relative to the radially extending longitudinal axis (44) of the at least one root (14).

15. The attachment system (10) of claim 14, characterized in that an intersection between a radially inward surface (52) of the first side third axially extending tooth (60) and the radially outer bearing surface (28) of the first side fourth axially extending tooth (72) is formed from a third compound fillet (78); wherein the third compound fillet (78) is formed from a third major radius (80) and a third minor radius (82); and wherein the third major radius (80) is larger than the third minor radius (82), wherein the third compound fillet (78) is different from the first and second compound fillets (53, 66), wherein at least one radius forming the third compound fillet (78) is less than at least one radius forming the second compound fillet (66), and wherein the third major radius (80) is less than a second major radius (68), and wherein the third minor radius (82) is less than a second minor radius (70), and wherein the fourth acute angle (74) of the first side fourth axially extending tooth (72) is less than the third acute angle (62) of the first side third axially extending tooth (60).

16. The attachment system (10) of claim 1, characterized in that a fillet slope line (88) extending tangentially relative to the first and second compound fillets (53, 66) is positioned at an acute angle with a high slope greater than fifteen degrees and wherein a fillet slope line (88) extending tangentially relative to the first and

second compound fillets (53, 66) is positioned at an acute angle with a low slope less than thirteen degrees.

17. The attachment system (10) of claim 1, further characterized in that at least one second side axially extending tooth (90) extending from a second side of the at least one root (14); wherein a radially outer bearing surface (28) of the second side first axially extending tooth (90) extends at a first acute angle (92) inwardly relative to a radially extending longitudinal axis (44) of the at least one root (14); a second side second axially extending tooth (94) extending from the second side (86) and positioned radially inward of the second side first axially extending tooth (90); wherein a radially outer bearing surface (28) of the second side second axially extending tooth (94) extends at a second acute angle (96) inwardly relative to the radially extending longitudinal axis (44) of the at least one root (14); wherein an intersection (98) between a radially inward surface (52) of the second side first axially extending tooth (90) and the radially outer bearing surface (28) of the second side second axially extending tooth (94) is formed from a first compound fillet (53); wherein the first compound fillet (53) is formed from a first major radius (102) and a first minor radius (104); and wherein the first major radius (102) is larger than the first minor radius (104).

18. The attachment system (10) of claim 17, further characterized in that a second side third axially extending tooth (106) extending from the second side (86) and positioned radially inward of the second side second axially extending tooth (94); wherein a radially outer bearing surface (28) of the second side third axially extending tooth (106) extends at a third acute angle (108) inwardly relative to the radially extending longitudinal axis (44) of the at least one root (14); wherein an intersection (110) between a radially inward surface (52) of the second side second axially extending tooth (94) and the radially outer bearing surface (28) of the second side third axially extending tooth (106) is formed from a second compound fillet (66); wherein the second compound fillet (66) is formed from a second major radius (114) and a second minor radius (116); and wherein the second major radius (114) is larger than the second minor radius (116).

19. The attachment system (10) of claim 1, further characterized in that at least one drilled stress-shielding hole (154) extending from an upstream side (156) of the at least one root (14) to a downstream side (158) of the at least one root (14) and positioned radially between the radially outer bearing surface (28) of the first side first axially extending tooth (38) and a radially inward surface (52) of the first side first axially extending tooth (38), and wherein at least a portion of the at least one drilled stress-shielding hole (154) is inline with a radially extending axis (160) tangential with a fillet (162) between the first side first and second axially extending teeth (38, 46).

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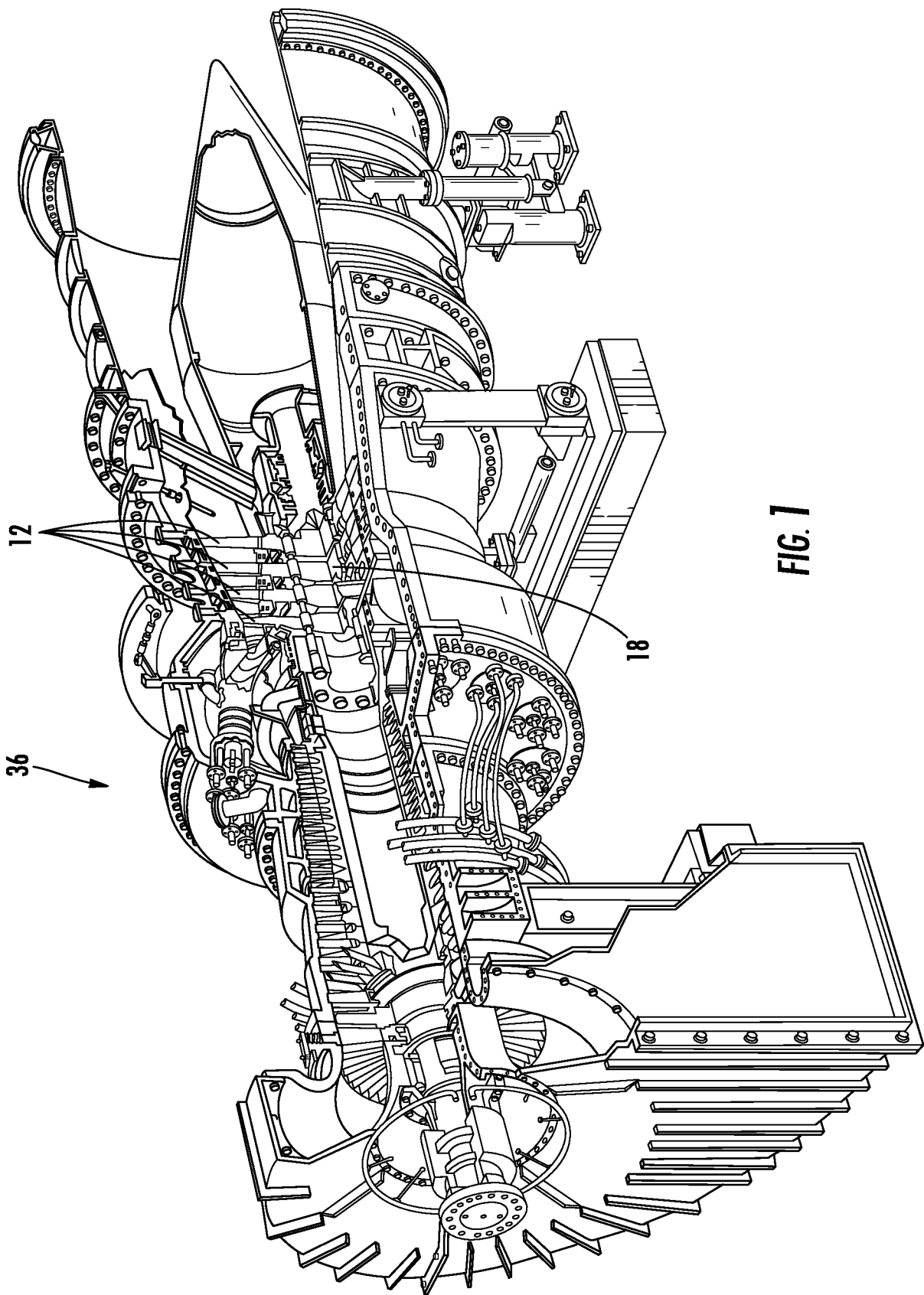


FIG. 1

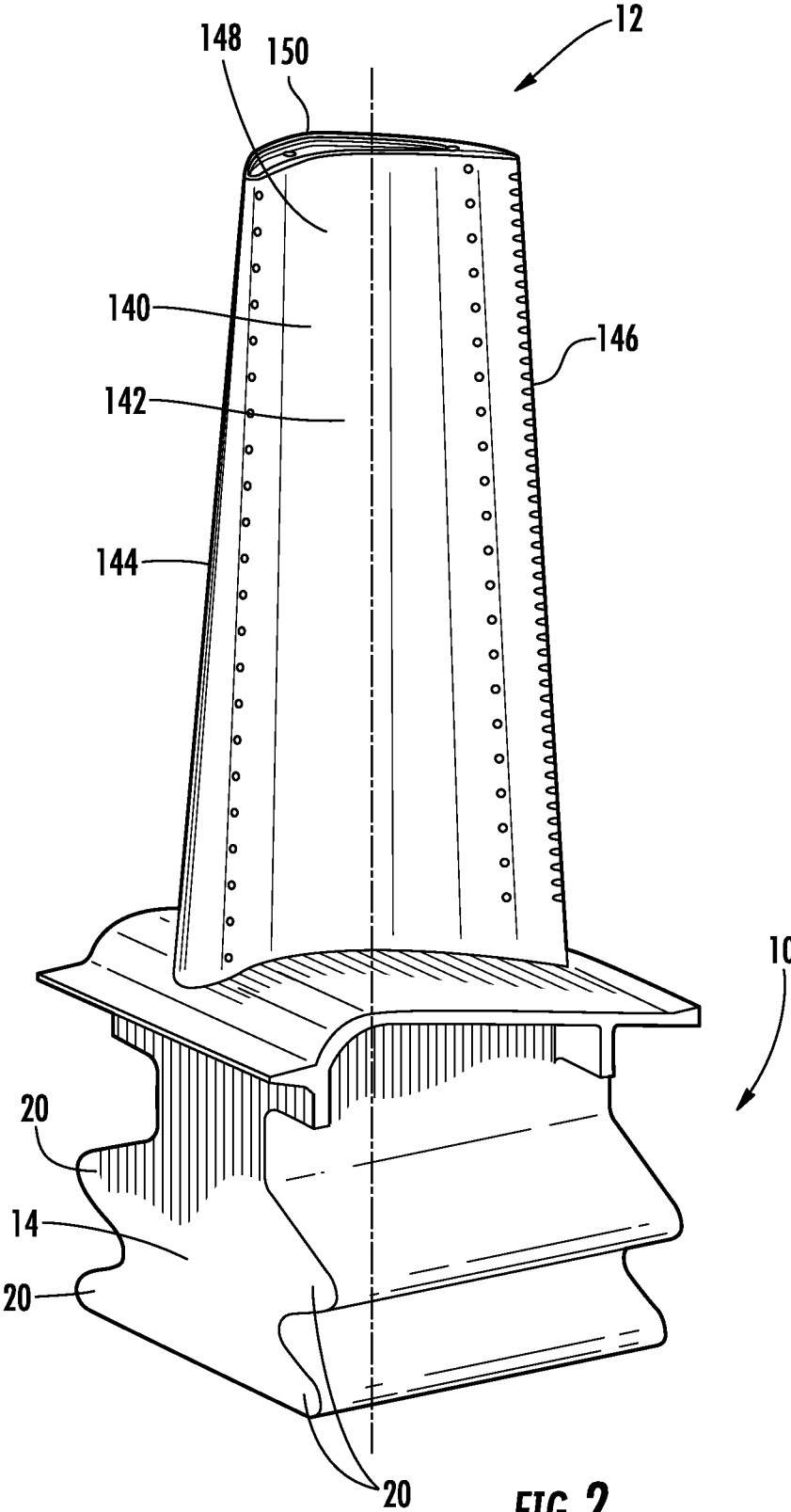


FIG. 2

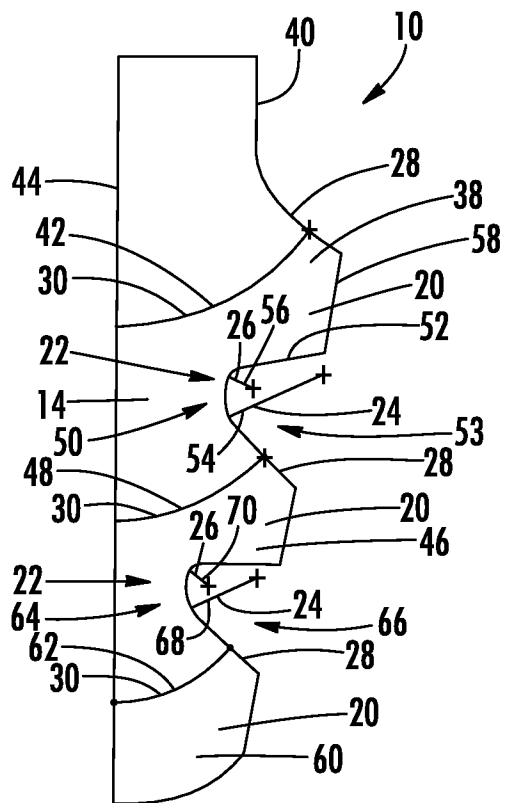


FIG. 3

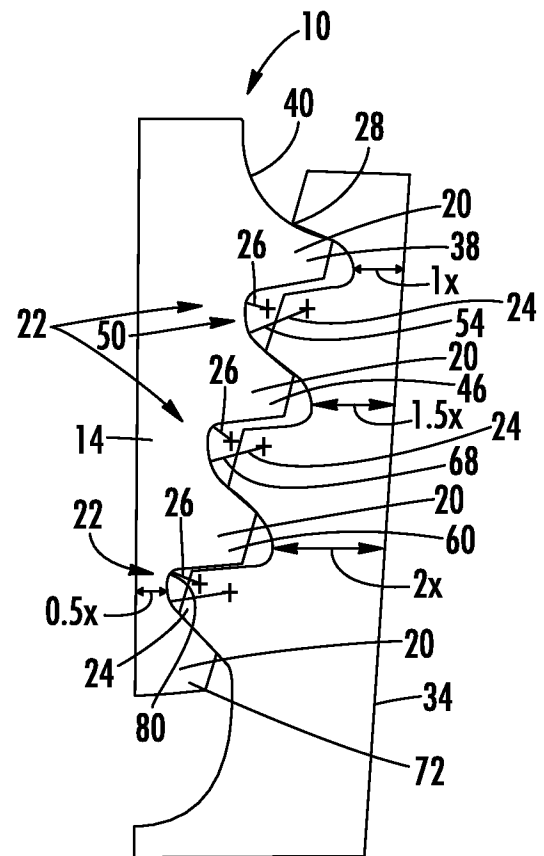


FIG. 5

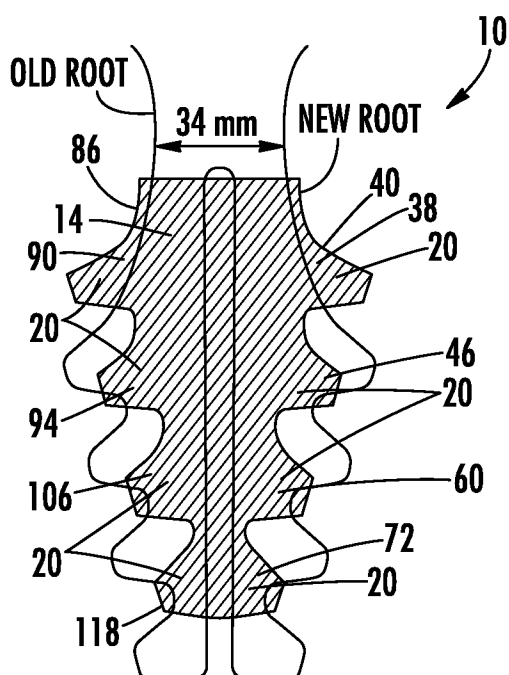


FIG. 4

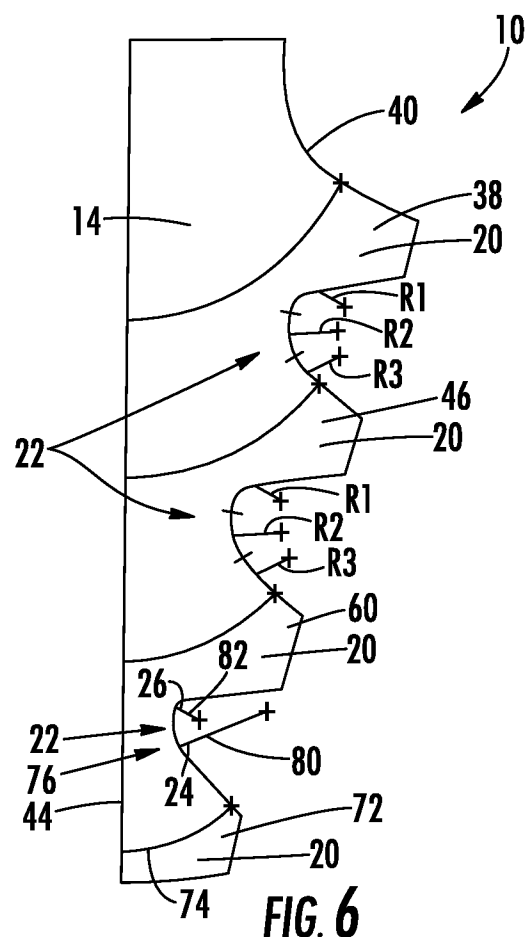


FIG. 6

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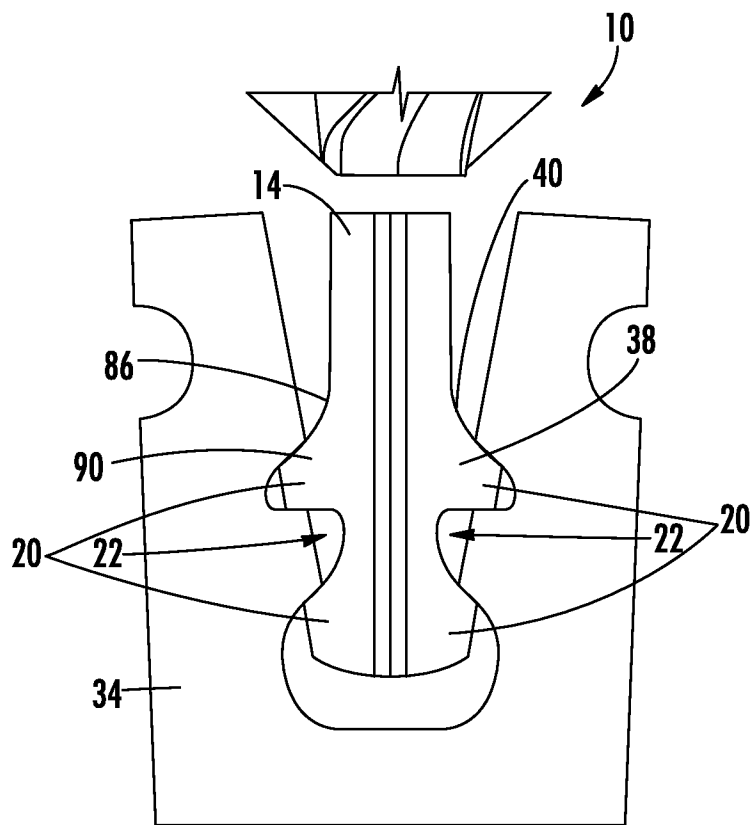


FIG. 7

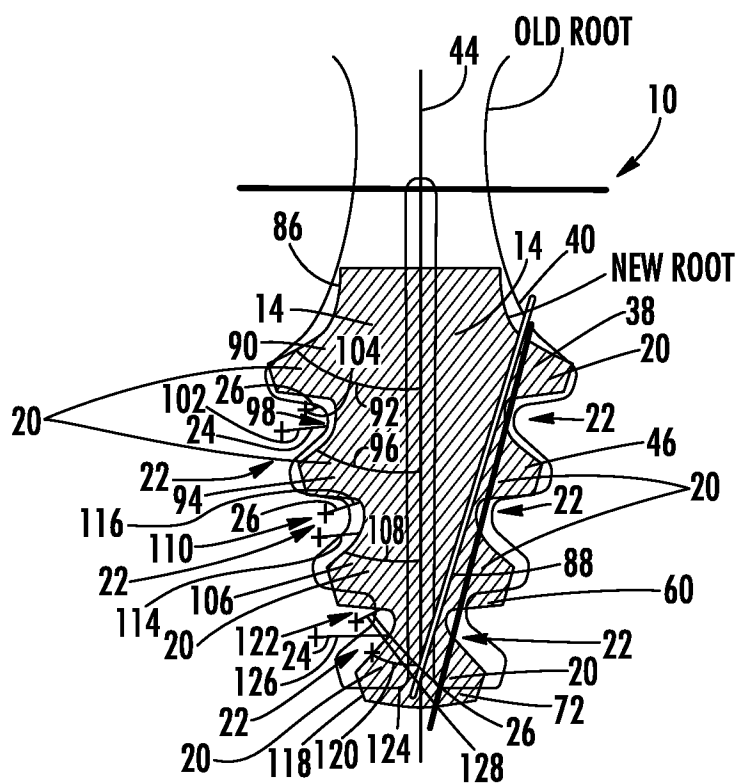


FIG. 8

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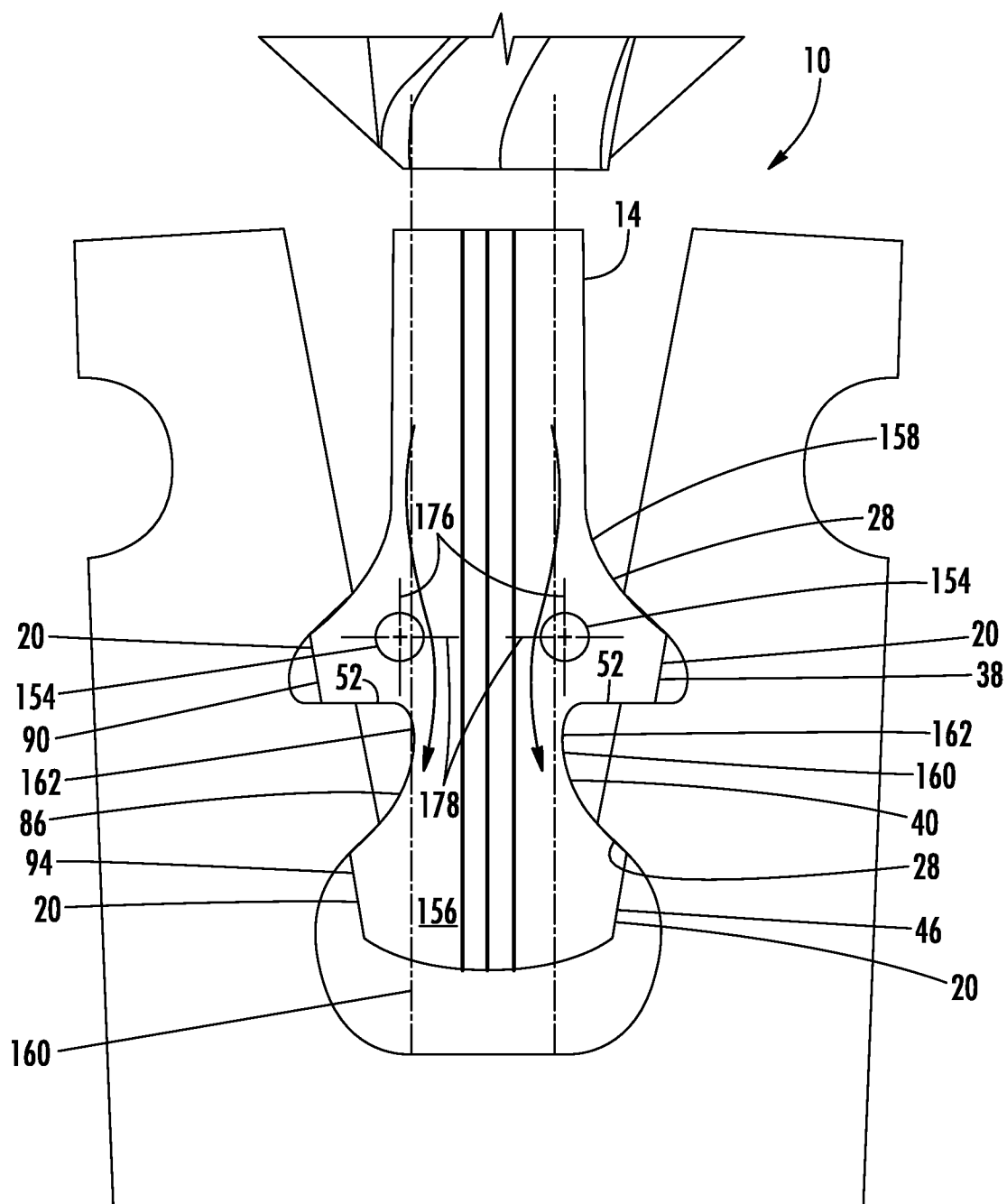


FIG. 9

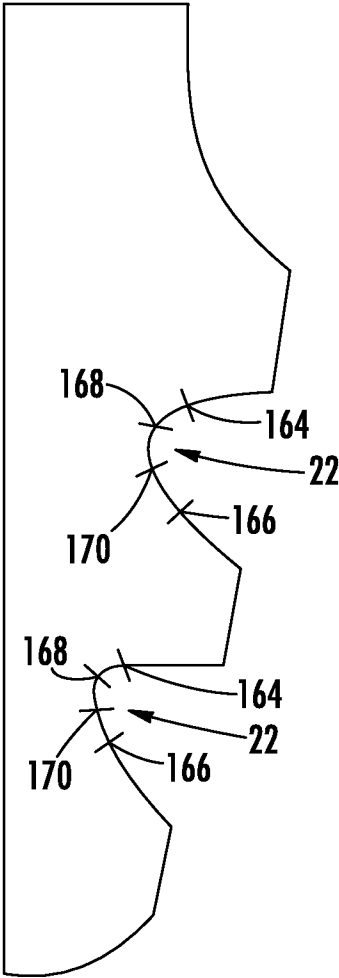
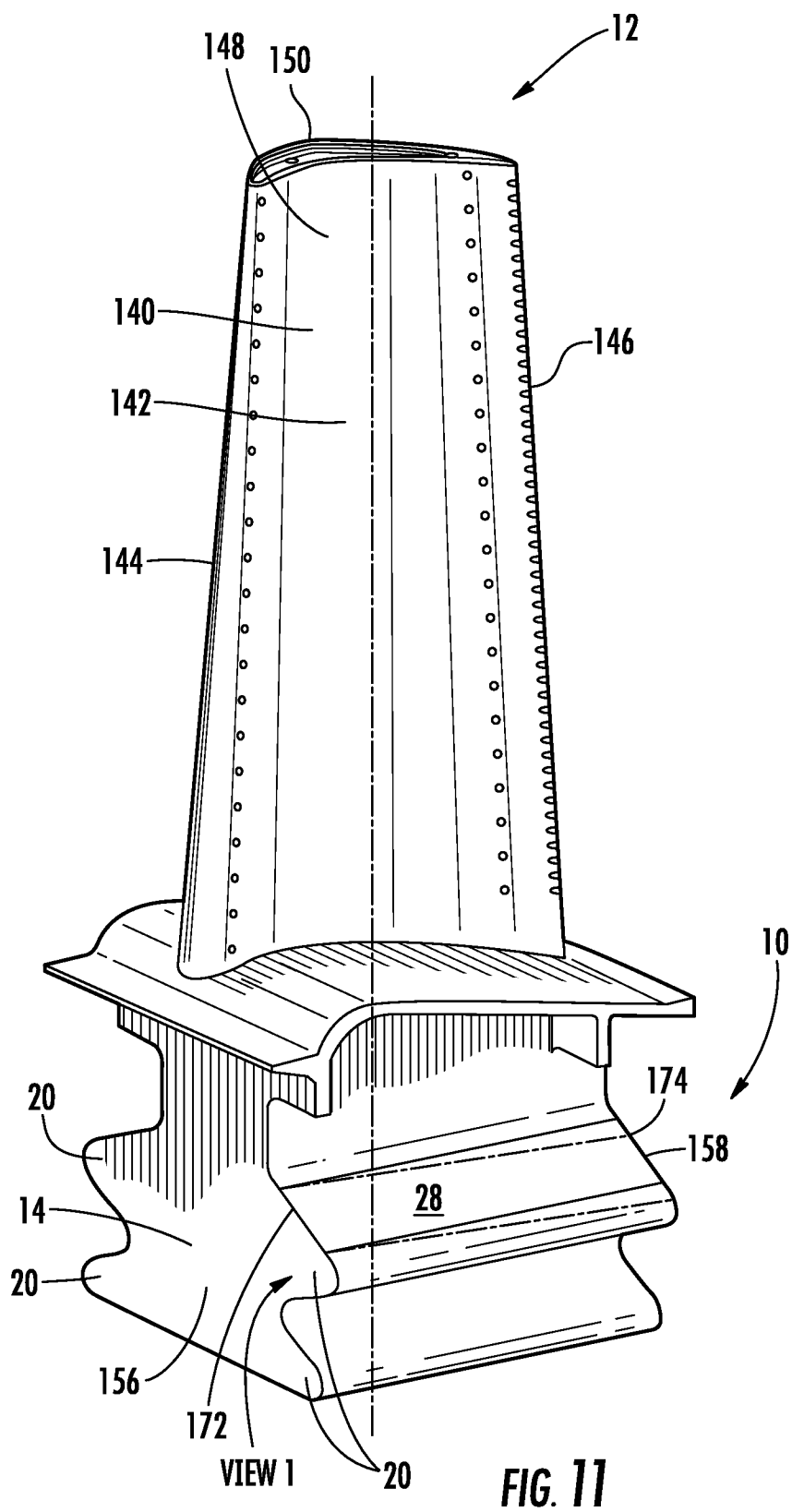


FIG. 10

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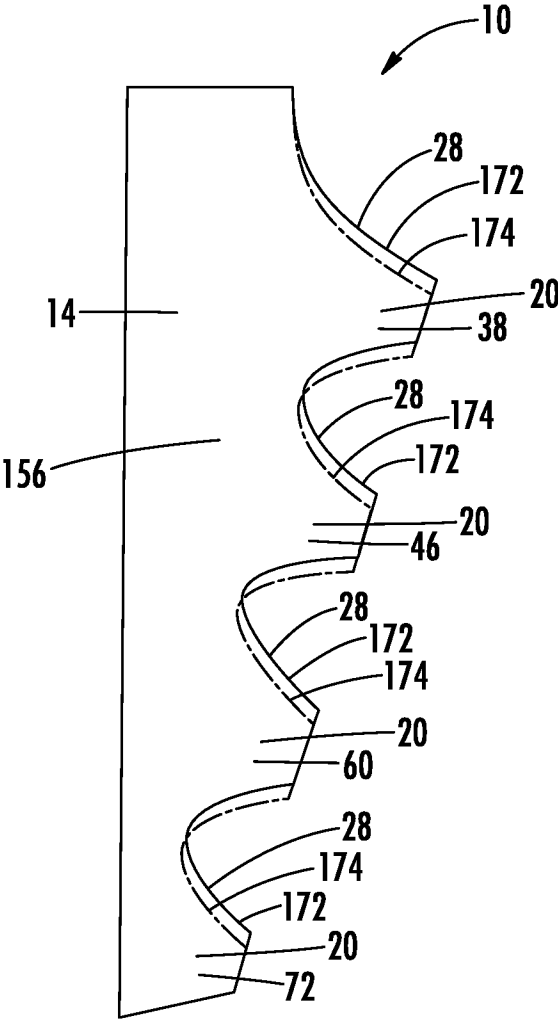


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2015/034135

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D5/30
ADD.

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/118358 A1 (SIEMENS AG [DE]) 7 August 2014 (2014-08-07)	1,4-6, 16,19
Y	figures 2, 3 page 19, line 34 - page 20, line 24 page 22, line 29 - page 24, line 17 -----	2,3,13, 17,18
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Y	figure 3 page 3, line 125 - page 4, line 14 -----	8-11, 13-15
Y	US 5 480 285 A (PATEL ASHOK T [US] ET AL) 2 January 1996 (1996-01-02) figures 1, 10, 11 column 8, line 54 - line 67 column 11, line 1 - line 25 ----- -/-	2,3, 8-11,14, 15,17,18



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

21 January 2016

Date of mailing of the international search report

29/01/2016

Name and mailing address of the ISA/

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Authorized officer

Lutoschkin, Eugen

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2015/034135

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2015/034135

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