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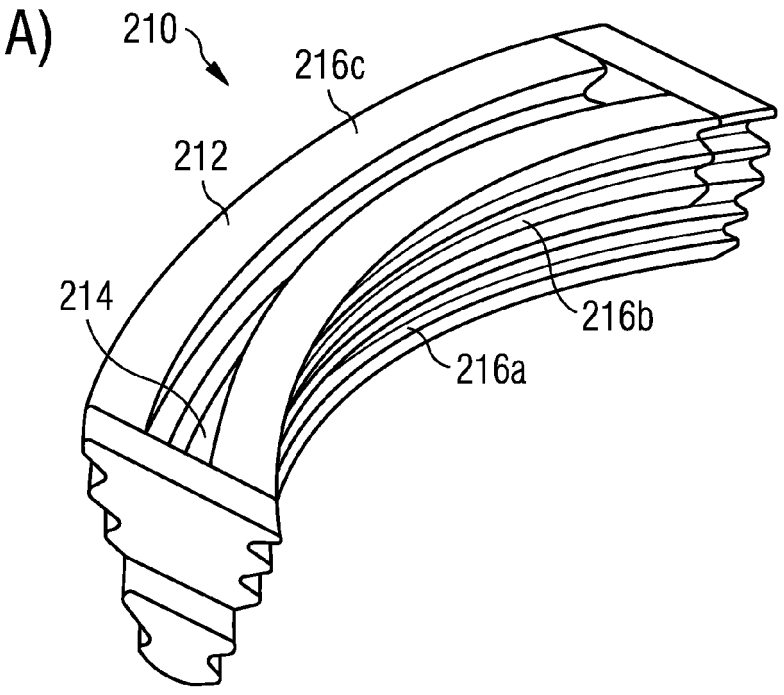
Remarks:
Amended claims in accordance with Rule 137(2) EPC.

(54) Root adapting device and method of attaching a blade in a recess of a rotatable shaft of a steam turbine

(57) A root adapting device (210) for attaching a blade in a recess of a rotatable shaft of a steam turbine comprises a body (212) configured for being accommodated in the recess of the shaft, and a recess (214) formed in the body (212) and configured for accommodating the blade.

FIG 2



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Description

Field of invention

[0001] The invention relates to a root adapting device for attaching a blade in a recess of a rotatable shaft of a steam turbine.

[0002] Further, the invention relates to a method of attaching a blade in a recess of a rotatable shaft of a steam turbine.

[0003] Further, the invention relates to a steam turbine.

Art Background

[0004] It is commonly known that power generation may be based on the usage of steam turbines.

[0005] In general, a steam turbine comprises a casing in which a rotatable shaft is mounted. The steam turbine further comprises blades which are mounted in one or more rows in respective recesses arranged along a circumference of the shaft. The shaft is connected with a generator configured for generating electrical energy based on a rotational movement of the shaft. In operation of the steam turbine, pressurized and heated steam generated by combusting, for example, natural gas, oil, or biomass drives the blades such that the shaft rotates around its rotational axis. The rotational energy generated by the rotational movement of the shaft is converted by the generator into electrical energy which is supplied to a utility grid.

[0006] Only recently, blades for a steam turbine may be manufactured by composite alloys instead of a steel material. Such composite alloys may have different material properties, for example, a lower density, compared to a steel material. Accordingly, a usage of composite materials for blades for a steam turbine comes along with new blade designs. For example, a length of a composite blade may be increased compared to a length of a steel blade such that the area of the blade on which the pressurized and heated steam may act may accordingly be increased, thereby increasing the efficiency of the steam turbine.

[0007] Thus, retrofitting of a steel blade mounted on a shaft of an already operational steam turbine may offer the possibility of increasing the efficiency of the steam turbine. In particular, a steel blade of a steam turbine may be replaced which may or may not show fatigue owing to a previous operation of the steam turbine.

[0008] However, material properties of a steel blade and a composite blade are different from one another and may require a modified root design of a blade root of a steel blade and a composite blade. In particular, retrofitting a composite blade for a steel blade may be a complicated task, since a connection between the blade root of the composite blade and a respective recess of the shaft of the steam turbine may pose high demands on reliability of the connection.

Summary of the Invention

[0009] It may be an object of the invention to provide an improved connection between a blade root of a blade and a recess of a shaft of a steam turbine.

[0010] In order to achieve the object defined above, a root adapting device for attaching a blade in a recess of a rotatable shaft of a steam turbine, a method of attaching a blade in a recess of a rotatable shaft of the steam turbine, and a steam turbine according to the independent claims are provided. According to an exemplary aspect of the invention, a root adapting device for attaching a blade in a recess of a rotatable shaft of a steam turbine is provided, the root adapting device comprising a body configured for being accommodated in the recess of the shaft, and a recess formed in the body and configured for accommodating the blade.

[0011] According to another exemplary aspect of the invention, a method of attaching a blade in a recess of a rotatable shaft of a steam turbine is provided, the method comprising accommodating a root of the blade in a recess of a root adapting device as defined above, and accommodating the root adapting device in the recess of the shaft.

[0012] According to another exemplary aspect of the invention, a steam turbine is provided, the steam turbine comprising a blade, a rotatable shaft comprising a recess configured for accommodating the blade, and a root adapting device configured for attaching the blade in the recess of the shaft as defined above.

[0013] In the context of this application, the term "root adapting device" may particularly denote a device which may act as a "plug" configured for being plugged into (particularly a recess of) an object and may act as a support structure configured for accommodating a respective plug which may be plugged into (particularly a recess of) the root adapting device. In particular, the object may be a shaft of a steam turbine, and the plug to be plugged into the root adapting device may be (particularly a blade root of) a blade of the steam turbine.

[0014] The term "blade root" of a blade may particularly denote an ending portion of a blade which may be mounted in a recess of a rotatable shaft of a steam turbine for fixing the blade in the shaft. In particular, a root length may be measured along a length extension of a blade which may comprise the root, a root width may be measured along a width extension of the blade which may comprise the root, and/or a root thickness may be measured along a thickness extension of the blade which may comprise the root.

[0015] According to the exemplary aspects of the invention, a connection between a blade root of a blade and a recess of a rotatable shaft of a steam turbine may be accomplished by utilizing a root adapting device which may comprises a recess in which the blade root of the blade is accommodated and which may itself be accommodated in a recess of the shaft.

[0016] Thus, the root adapting device may provide an

easily accomplished connection between the recess of the shaft and the blade root in that the recess of the root adapting device may be shaped according to a respective blade root of a blade to be accommodated in the root adapting device and the outer shape of the root adapting device may be formed according to a recess shape of the recess of the shaft.

[0017] Further, the connection between the blade root and the shaft may be particularly strong and timely reliable despite a usage of a further device interposed between the blade root and the shaft, since the recess of the root adapting device and the outer shape of the root adapting device may be designed in a precisely tailored way. In particular, a usage of glue, bolts or a weld for accomplishing the connection between the blade root and the recess of the shaft may be omitted during accommodating the blade root in the shaft which may weaken the connection between the blade root and the shaft. In particular, a later occurring loosing of the blade during the operation of the steam turbine may be prevented, since a strength of the connection between the root of the blade and the recess of the shaft may depend on the root adapting device, particularly on the design and the material of the root adapting device, but not on the used glue, bolts or a weld connection.

[0018] Further, retrofitting of blades, particularly blades made of a composite material, may be facilitated, since the root adapting device may account for different root designs without requiring an alternation of a recess shape of the recess of the shaft. In particular, a recess shape of the recess formed according to a root design of a standard blade root may be maintained.

[0019] Further, conventional manufacturing tools for manufacturing the recess of the shaft may be used when manufacturing the shaft of the steam turbine, since the recess shape may be unchanged despite another blade root design.

[0020] Further, maintenance costs of the steam turbine arising from retrofitting of a blade may be low, since the recess shape of the recess of the shaft may not need to be modified during the retrofitting process.

[0021] Further, a conventionally designed rotor of a steam turbine may be maintained while retrofitting blades of different materials and/or designs, since the root adapting device may enable a connection between a standard recess of a shaft of the conventionally designed rotor and blade roots of any kind of blades.

[0022] Further, when particularly retrofitting blades made of a composite material, the efficiency of the steam turbine may be improved, since the different material properties of the retrofitted blade may be used for increasing the efficiency of the steam turbine. In particular, a blade length of a composite blade which may be to be retrofitted may be increased compared to a length of a steel blade such that a greater area on which the pressurized steam may act for driving the shaft of the steam turbine may be provided while maintaining a conventional width of a steel blade.

[0023] Next, further exemplary embodiments of the root adapting device for attaching a blade of a steam turbine in a recess of a rotatable shaft of the steam turbine will be explained. However, these embodiments also apply to the respective method and the respective steam turbine.

[0024] The body may comprise an elongated shape, wherein the recess may extend along a length extension of the body. Thus, the connection between the root adapting device and the shaft may be further improved, since the elongated body of the root adapting device may provide a large connection area towards the shaft. Thus, forces acting on the root adapting device during an operation of the steam turbine may be uniformly distributed along the length extension of the body. Further, the connection between the blade root and the root adapting device may be further improved, since a large connection area towards the blade root may be provided by the length extension of the recess. Thus, forces acting on the blade root during an operation of the steam turbine may be uniformly distributed along a length extension of the body.

[0025] The recess may be formed as an elongated groove, particularly as an elongated hole (which may comprise rounded transverse front sides). In particular, the recess may comprise a bent or curved shape. In particular, the recess may extend from a transverse side of the body into an interior of the body or may be completely accommodated in the body without contacting surfaces of transverse sides of the body. Thus, the shape of the recess of the root adapting device may be precisely tailored with respect to a flat, strait (and bent) shape of the blade and thus the blade root.

[0026] The recess may comprise, when seen along a depth extension of the recess, a broadened shape or a uniform width. In particular, in a case of a broadened shape of the recess the blade root may not slide out of the recess of the root adapting device during operation of the steam turbine, since the blade root may be securely fixed in the recess. In particular, in a case of a uniform width of the recess, the recess of the root adapting device may be easily manufactured. Further, forces acting on sides of the blade root may be sufficiently high to securely fix the blade root in the recess of the root adapting device, since the connection area between the root blade and the root adapting device may be larger compared, for example, to a tapered shape of the recess when seen along the depth extension of the recess.

[0027] The recess may comprise, when seen along a depth extension of the recess, a fir tree-like shape, a wedge-like shape or a hammer-like shape. In particular, a width extension of the fir tree-like shaped recess may be uniform or may be increasing along the depth extension of the recess. In particular, in a case in which the recess may comprise a fir-tree like shape, surfaces of the recess may comprise a zig-zac-pattern when seen along a depth extension of the recess and/or at least one section of the recess may comprise a wedge-like shape.

In particular, the wedge-like shaped recess may comprise a broadened shape. Thus, the fir tree-like shaped recess, the wedge-like shaped recess, or the hammer-like shaped recess may comprise a sufficiently large surface of the recess, in order to distribute forces acting between the recess surface and the surface of the blade root during an operation of the steam turbine such that the stability of the connection between the blade root and the recess of the root adapting device may be further improved.

[0028] In particular, the fir tree-like shaped recess may comprise "branches" or sections each of which comprising two projections arranged on each opposite surface sides of the recess and projecting towards an interior of the recess.

[0029] In particular, the wedge-like shaped recess may be comprise (per wedge-like shaped section of the recess) on each opposite surface sides of the recess one notch and two projections arranged adjacent to the notch and projecting towards an interior of the recess.

[0030] In particular, the recess may be (essentially) symmetrically formed with respect to a depth extension of the recess, thus accounting for symmetrically formed blade roots with respect to a length extension of the blade root.

[0031] In particular, a length extension of the recess may be between (about) 90 mm and (about) 110 mm, particularly between (about) 120 mm and 140 mm, further particularly between (about) 150 mm and (about) 170 mm, a depth of the recess may be between (about) 21 and (about) 23 mm, particularly between (about) 24 mm and (about) 26 mm, further particularly between (about) 27 mm and (about) 29 mm, and a width or thickness of the recess may be between (about) 14 mm and (about) 16 mm, particularly between (about) 17 mm and (about) 19 mm, further particularly between (about) 20 mm and (about) 22 mm. In particular, the above mentioned values of the length, depth and width of the recess may be combined in any suitable manner. Thus, blade roots of different dimensions may be accommodated in the recess of the root adapting device.

[0032] The body may comprise two members, wherein a portion of the recess may be formed in a first member of the body, wherein a remaining portion of the recess may be formed in a second member of the body. Consequently, the recess may be divided into two portions formed in different members in a not assembled state of the root adapting device. In particular, such a root adapting device may account for (particularly non uniform) length, width and/or thickness shape changes of the blade root, since the portions of the recess formed in the first and second members may comprise different shapes. Such shape changes may be, for example, curvature changes of the blade root or thickness steps. In particular, manufacturing costs of the root adapting device may be very low owing to the low number of body members. Further, accommodating the blade root in the recess of the body of the root adapting device may be very easily accomplished in that, for example, one transverse ending portion or both transverse, opposite ending portions of the blade root may be introduced into the portion of the recess which may be formed in the first member of the body or into respective portions of the recess which may be formed in the first and second members of the body, respectively, and afterwards the first member and/or the second member of the body may be moved towards the another one.

[0033] A side of each of the first and second members from which the respective portion of the recess may extend to an interior of the respective one of the first and second members may comprise a flat shape. Thus, an accurate fit of the transverse sides of the first and second members facing to one another in an assembled state of the root adapting device may be accomplished. In particular, the root adapting device may comprise a compact designs in an assembled state.

[0034] In particular, the side of each of the first and second members may be inclined (particularly with respect to a plane being perpendicular to another (particularly longitudinal) side of the first and second side members and/or with respect to one another in an assembled state of the root adapting device) and/or may run parallel to one another. In particular, an inclination angle of the sides of the first and second members may be opposite to one another. In particular, inclined surfaces may account for different (particularly non uniform) length, width and/or thickness shape changes of the first and second surfaces of the blade root to be accommodated in the recess of the root adapting device. In particular, an absolute value of an inclination angle of the side of each of the first and second members may depend on a design of a blade root to be accommodated and may be between (about) 33° and (about) 37°, particularly between (about) 23° and (about) 27°, further particularly between (about) 13° and (about) 17°.

[0035] The body may comprise three members, wherein a center member of the body may comprise first and second side elements and a connection element extending transverse (particularly perpendicular) to the first and second side elements, wherein first and second side members of the body may be accommodatable between the first and second side elements and on the connection element. In particular, the center member of the body may comprise a U-type shape. In particular, a three-pieced body may account for (particularly non uniform) length, width and/or thickness shape changes of the blade root, for example, curvature changes of the blade root or thickness steps of the blade root, since longitudinal and transverse sides of the center member and first and second side members may be formed according to a design of the blade root. In particular, outer sides of the first and second side elements may coincide with transverse sides of the connection element. In particular, an outer side of at least one of the first and second side elements may be backwardly displaced with respect to a respective transverse side of the connection element.

Thus, the body of the root adapting device may comprise a respective projection on which an additional securing measure, for example, a securing plate, may be placed for facilitating a mounting of the root adapting device in the recess of the shaft and/or for fixing a root adapting device in the recess of the shaft. In particular, the recess of the root adapting device may be defined by inner sides of the first and second side elements and the inner sides of the first and second side members. Thus, the first and second side elements of the center member may serve for positioning the blade root along a width extension of the blade root, and in particular, in a mounted state of the blade in the shaft, for axially positioning of the blade root with respect to a longitudinal or axial extension of the shaft. Further, the first and second side members may distribute forces acting between the blade root and the recess of the shaft when the blade root may be accommodated in the recess of the root adapting device. Consequently, the root adapting device may have a simple, stable and compact design and may be particularly easily manufactured. Further, accommodating the blade root in the recess of the root adapting device may be simplified by arranging the blade root along a length extension of the connection element of the center element and between the side elements of the center member, and arranging the side members on respective sides of the blade root in contact with inner sides of the first and second side members and/or the upper side of the connection element. In particular, since the side members may be securely held particularly by frictionally engaging with side surfaces of the side elements of the center member, no additional welding step may be required when assembling the root adapting device.

[0036] An inner side of the first side element and an inner side of the second side element which may face to one another may be inclined with respect to one another. In particular, (outer transverse) sides of the first and second side members may be inclined with respect to one another, wherein an inclination of the sides of the first and second side elements and an inclination of the respective first and second side members may be adapted to one another. Such a root adapting device may be configured for accommodating blade roots comprising a curvature along its width extension. Further, assembling the root adapting device may be facilitated in that the side elements have different shapes owing to the inclined sides and may only fit in the center member in a unique way. In particular, accommodating the blade root in the recess of the root adapting device may be accomplished in that a first side member comprising a smaller length extension compared to the second side member may be arranged between the first and second side elements and on the connection element of the center member, the root blade may be arranged next to the first side member in the center member, and the second member may be arranged next to the root blade in the center member.

[0037] Alternatively, an inner side of the first side element and inner side of the second side element may run parallel to one another. In particular, (outer transverse) sides of the first and second side members may be flat and may run parallel to one another, particularly wherein, in an assembled state of the root adapting device, the inner sides of the first and second side elements and the (outer transverse) sides of the first and second side member may run parallel to one another. Such a root adapting device may be manufactured in an easy and cost-effective way.

[0038] The body may comprise a rectangular shape or an elongated bent shape. In particular, a rectangular shaped body may provide a very compact, self contained root adapting device and/or may allow for accommodating blades having small width extension of the blade root. In particular, an elongated bent shaped body may enable the root adapting device to accurately match along a circumferential shape of the shaft and/or may allow for accommodating a blade root having a large width extension.

[0039] The body may comprise, when seen along a height extension of the body, a tapered shape or a uniform width. In particular, the body may comprise a fir tree-like shape, a T-shape, a double-T-shape or a threefold T-shape. In particular, a T-shaped body may comprise a form of a T comprising a center element and an element arranged transversely, particularly perpendicularly, compared to the center element and located centrically on the center element. In particular, a double-T-shaped body may comprise a form of a T as detailed above and a further element arranged transversely, particularly perpendicularly, compared to the center element and located centrically at the center element opposite to the element arranged on top of the center element. In particular, a threefold-T-shaped body may comprise a double-T-shaped element and a T-shaped element, wherein the T-shaped element may be concentrically connected to one of the transversely arranged elements of double-T-shaped element via an ending portion of the center element of the T-shaped element at a location opposite to a connection of the center element of the T-shaped element with the transversely arranged element of the T-shaped element. In particular, heights of broader longitudinal ending portions of the double-T shaped body or the threefold-T-shaped body and of a broader longitudinal middle portion of the threefold-T-shaped body may be different to one another. In particular, the double-T shaped body or the threefold-T-shaped body may taper towards an ending portion of the body to be mounted in an interior of the recess. In particular, in a case in which the body comprises a fir tree-like shape, outer longitudinal surfaces of the body may comprise a zig-zac-pattern when seen along a height extension of the body and/or at least one section of the recess may comprise a wedge-like shape. In particular, the fir tree-like shaped body may comprise "branches" or sections each of which comprising two projections arranged on each opposite surface sides of the body and projecting towards outwards. In particular, a T-shaped body may comprise sufficient

mass to securely hold a blade, particularly a blade arranged at a downstream portion of the shaft of the steam turbine. In particular, a double-T-shaped body may comprise a reduced mass compared to, for example, a similarly designed T-shaped body, thereby enabling a cost-effective production of the root adapting device. Thus, accommodating the body in a recess of a shaft in terms of laterally inserting the body in the recess of the shaft may be easily accomplished.

[0040] In particular, the body may be symmetrically formed when seen along a height extension of the body, thus being adapted to a symmetrical shape of the recess of the shaft.

[0041] In particular, a length extension of the body may be between (about) 110 mm and (about) 130 mm, particularly between (about) 140 mm and between (about) 160 mm, further particularly between (about) 170 mm and (about) 190 mm, a height of the body may be between (about) 24.8 mm and (about) 26.8 mm, particularly between (about) 27.8 mm and (about) 29.8 mm, further particularly between (about) 30.8 mm and (about) 32.8 mm, and a width or thickness of the body may be between about 19.8 mm and (about) 21.8 mm, particularly between (about) 22.8 mm and (about) 24.8 mm, further particularly between (about) 25.8 mm and (about) 27.8 mm. In particular, the above mentioned values of the length, height and width of the body may be combined in any suitable manner. Thus, the root adapting device may be configured to be accommodated in recesses of different dimensions of the shaft.

[0042] The body may comprise metal, particularly at least one of stainless steel, further particularly x5, x10, x12 and/or x20 stainless steel, titanium, and a titanium alloy. In particular, the material of the root adapting device may be selected according to the material and the shape of the blade and/or the shaft. In particular, the members of the root adapting device may be made of the same material or of different materials. In particular, at least two of the first and second side members and the center member may be made of the same material. Thus, manufacturing costs of the root adapting device and/or maintainance costs of the steam turbine may be low owing to the kind of the material. Further, the root adapting device may have a long lifetime owing to the kind of the material.

[0043] Next, further exemplary embodiments of the steam turbine may be explained. However, these embodiments also apply to the respective root adapting device and the respective method.

[0044] In particular, the recess of the shaft may comprise a groove, particularly a standard (particularly existing) groove of the shaft which may be used in connection with conventional steel blades.

[0045] In particular, the blade may be made of a composite material, particularly of a composite alloy.

[0046] In particular, the recess of the shaft may be formed in a downstream portion of the shaft, particularly in a most downstream portion of the shaft of the steam turbine. Here, the term "downstream portion of the shaft" may particularly denote a portion of the shaft with respect to a flow direction of a pressurized steam used during an operation of the steam turbine. Thus, the root adapting device may be used for attaching particularly large blades, thereby being configured for withstanding high aerodynamic demands.

[0047] The aspects defined above and further aspects of the present invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited.

Brief Description of the Drawing

[0048]

Fig. 1A, B illustrate perspective views of a steel blade and a composite blade usable in a steam turbine.

Fig. 2A illustrates a perspective view of a root adapting device according to an exemplary embodiment of the invention in an assembled state.

Fig. 2B-D illustrate perspective views of members of the root adapting device in Fig. 2A.

Fig. 2E-I illustrate steps of a method of attaching a blade in a recess of a rotatable shaft of a steam turbine according to an exemplary embodiment of the invention.

Fig. 3A, B illustrates a perspective view and a top view of a root adapting device according to another exemplary embodiment of the invention in an assembled state.

Fig. 3C, D illustrate a perspective view and a front view of a member of the root adapting device in Fig. 3A, B.

Fig. 3E-G illustrate steps of a method of attaching a blade in a recess of a rotatable shaft of a steam turbine according to another exemplary embodiment of the invention.

Fig. 4A illustrates an exploded view of a root adapting device according to another exemplary embodiment of the invention.

Fig. 4B illustrates a perspective view of the root adapting device in Fig. 4A in an assembled state.

Fig. 4C, D illustrate perspective views of members of the root adapting device in Fig. 4A, B.

Fig. 5A illustrates an exploded view of a root adapting

device according to another exemplary embodiment of the invention.

Fig. 5B illustrates a cross-sectional view of the root adapting device in Fig. 5A taken along a line A-A.

Detailed Description

[0049] The illustration in the drawing is schematic. It is noted that in different figures, similar or identical elements are provided with the same reference signs or with reference signs, which are different from the respective reference signs only within the first digit.

[0050] Referring to Fig. 1A, B, a blade 100a made of a steel material and a blade 100b made of a composite material both usable in a steam turbine is illustrated, respectively. Each of the blades 100a, b comprises a flat body 102a, b of an elongated, twisted shape. A blade root 104a, b of the blade 100a, b is bent along a width extension of the blade root 104a, b. Here, the blade root 104b is defined as an end portion of the blade 100a, b to be mounted in a recess of a shaft of the steam turbine.

[0051] The blade root 104a of the steel blade 100a comprises a fir tree-like shape tapering towards an ending portion 106a of the root 104a. When seen along a length extension of the blade root 104a, the blade root 104a comprises five sections 108a-e each of which comprises two projections arranged at opposite sides and projecting towards outwards. A tip of each of the projections is rounded. Each of the sections 108a-e has a different thickness compared to the other sections 108a-e.

[0052] For comparison, the blade root 104b of the composite blade 100b is also fir tree-like shaped but comprises a uniform width. Further, the blade root 104b comprises two sections 109a, b each of which comprising two projections arranged on opposite sides and projecting towards outwards. Each of the sections 109a, b broadens towards the ending portion 106b of the blade root 106b and is wedge-like shaped when seen along length extension of the blade 104b.

[0053] In order to retrofit the blade 100b for the blade 100a in a steam turbine, a root adapting device 210 according to an exemplary embodiment of the invention is provided. The root adapting device 210 allows for attaching the blade root 104b of the composite blade 100b in a standard groove-like recess of a rotatable shaft of the steam turbine which is manufactured according to an outer surface shape of the blade root 104a of the steel blade 100a.

[0054] Referring to Fig. 2A-E, a constructive design of the root adapting device 210 will be explained in more detail. In an assembled state of the root adapting device 210, the root adapting device 210 comprises an elongated bent body 212 and a recess 214 in the form of a groove formed in a surface of the body 212 and extending inwardly (Fig. 2A).

[0055] The root adapting device 210 is composed of three members 216a-c. A center member 216a comprises an elongated, bent U-type shape and is made of a connection element 218a and first and second side elements 218b, c (Fig. 2B-D). The connection element 218a extends perpendicular to a length extension of the first and second side elements 218a, b. The first side element 218b is mounted on a first ending portion 220a of the connection element 218a, and the second side element 218c is mounted on a second ending portion 220b of the connection element 216a. Alternatively, the first and second side elements 218b, c and the connection element 218a are integrally manufactured. An outer front side 222a of the first side element 218b and a first front side 224a of the connection element 218c are flat and coincide, whereas an outer front side 222b of the side element 218c and a second front side 224b of the connection element 218a are flat but are displaced relative to one another such that a respective ending portion of the center member 216a comprises a step-like projection 226. An inner front side 228a of the first side element 218b and an inner front side 228b of the second side element 218c are flat and run parallel to the respective outer front sides of the first and second side elements 218b, c.

[0056] The center member 216a tapers towards a longitudinal ending portion 229a of the connection element 218a. When seen along a height extension of the center member 216a, the center member 216a comprises a fir tree-like shape and comprises five sections 230a-e of different thicknesses. Each of the sections 230a-e comprises two oppositely arranged projections projecting towards outwards and having tip-like shapes. The connection element 218a comprises the sections 230a, b, and the side elements 218b, c comprise the sections 230c-e. The projections of the section 230e coincide with an upper surface of the side elements 222a, b.

[0057] The first and second side members 216b, c are designed as elongated bent members with identical curvatures and small thicknesses. A cross section of the first and second side members 216b, c tapers towards longitudinal ending portions 232a, b of the first and second side members 216b, c and comprises a zig-zag-like pattern with five projections 234a-e, 236a-e. The projections 234a, c, e, 236a, c, e and the projections 234b, d, 236b, d are directed in opposite directions, respectively. Longitudinal ending portions 238a, b of the first and second side members 216b, c are flat with edges of the ending portions 238a, b comprising the projections 234d, e, 236d, e. Front sides 240a, b, 242a, b of the side members 216a, b are designed in a flat way and run parallel to one another. Inner surfaces 244a, b and outer surfaces 246a, b of the first and second side members 216b, c comprise an identical curvature. The shape of the outer surfaces 246a, b of the first and second side members 216b, c is identical to the edge characteristic of the fir tree-like side elements 218b, c.

[0058] In the assembled state of the root adapting device 210 illustrated in Fig. 2A, the side members 216b, c are frictionally engaged in the connection element 216a in that the front sides 240a, b of the side member 216b

engage with the inner front sides 228a, b of the side elements 218b, c of the center member 216a and the front sides 242a, b of the side member 216c engage with the inner front sides 228a, b of the side elements 218b, c of the center member 216a.

[0059] The outer shape of the root adapting device 210 and in inner shape of the groove-like recess of the shaft in which the root adapting device 210 is to be accommodated comprise similar dimensions. For example, a length extension of the groove-like recess of the shaft is about 120 mm, a depth of the groove-like recess of the shaft is about 28 mm, and a width or thickness of the groove-like recess of the shaft is about 21 mm. Outer dimensions of the root adapting device 210 are approximately similar to the dimensions of the recess of the shaft such that the root adapting device 210 tightly fits into the groove-like recess of the shaft.

[0060] The center member 216a and the side members 216b, c of the root adapting device 210 are made of X5 stainless steel material. Alternatively, the root adapting device 210 may be manufactured from x10 stainless steel or x20 stainless steel. Alternatively, the root adapting device may be made of any material having a sufficient stiffness and stability, for example, titanium or a titanium-based alloy.

[0061] Referring to Fig. 2E-I, a method of attaching the blade 104b in a recess of a rotatable shaft of a steam turbine according to an exemplary embodiment of the invention will be explained. Here, the root adapting device 210 is used.

[0062] The blade root 104b of the blade 100b is arranged on a top surface 248 of the connection element 218a (Fig. 2E). The side members 216b, c are placed in contact with lateral sides 249a, b of the blade root 104b in that the inner front sides 228a, b of the side elements 218b, c of the center member 216a and the front sides 232a, b, 234a, b of the first and second side members 216b, b frictionally engage with one another. Fig. 2F-H illustrate an assembled state of the root adapting device 210 with the blade root 104b being accommodated in the root adapting device 210. Next, the assembled root adapting device 210 is axially slided in a groove-like recess 250 of a shaft 252 of the steam turbine. A length extension of the root adapting device 210 runs essentially parallel to an axial extension of the shaft 252. A thin securing plate 253 of a fir tree like shape is inserted at an ending portion of the recess 252 such that the securing plate 253 rests on the projection 226 of the root adapting device 210. Fig. 2I illustrates a mounted state of the blade 104b in the shaft 252. For comparison, steel blades 100a are illustrated whose blade roots 104a are accommodated in respective recesses 254 of the shaft 252. The recesses 250, 254 are identically designed to one another and are manufactured in accordance with the dimensions of the recess of the shaft, as detailed above.

[0063] Referring to Fig. 3A-D, a root adapting device 310 according to another exemplary embodiment of the invention will be explained.

[0064] Fig. 3A, B illustrates a perspective view and a front view of the root adapting device 310 in an assembled state. The root adapting device 310 comprises a rectangular body 312 of a double-T-shape in which a recess 314 is formed. The body 312 comprises a uniform thickness w with upper and lower longitudinal ending portions 356a, b of the body 312 being broader compared to a central portion 358 of the body 312 and comprising different heights h1, h2. Here, the height h1 of the upper longitudinal ending portion 356a is smaller than the height h2 of the lower longitudinal ending portion 356b. Edges between the central portion 358 and the upper and lower longitudinal ending portions 356a, b are rounded. The lower longitudinal ending portion 356b comprises longitudinal outer edges being inclined with respect to a lower surface 360a of the root adapting device 310. The recess 314 extends from an upper surface 360a of the body 316 towards an interior of the body 312 and is designed as an elongated bent groove. The upper surface 360a and a lower surface 360b of the root adapting device 310 are flat.

[0065] The root adapting device 310 comprises two members 316a, b which are mirror-invertedly designed (Fig. 3B). A first member 316a comprises a first portion 362a of the recess 314, and a second member 316b comprises a second portion 362b of the recess 314. The recess 314 is arranged symmetrically with respect to inner transverse front sides 364a, b of the first and second members 316a, b in that a length extension of the portion 362a, b of the recess 314 of the respective first and second member 316a, b are identical to one another (Fig. 3B). The transverse inner front sides 364a, b and transverse outer front sides 366a, b of the first and second members 316a, b are formed in a flat way and run parallel to one another.

[0066] Fig. 3C, D illustrates a perspective view and a front view of the member 316b. When seen along a depth extension of the recess 314, the recess 314 broadens towards to an interior of the body 312 (Fig. 3D). A shape of the recess 314 is identical to the shape of the recess 214. The recess 314 comprises a fir tree-like shape with two wedge-like shaped sections 368a, b formed along longitudinal surfaces 369a, b of the recess 314. A bottom surface 369c of the recess 314 is flat and runs parallel to the lower surface 360b of the body 312. Accordingly, the surfaces 369a, b comprise a zig-zac-pattern when seen along a depth extension of the recess 314. Each of the sections 368a, b comprises on each of the surfaces 369a, b one notch 370a, b, 371a, b and two projections 372a, b, 373a, b, 374a, b adjacent to the notch 370a, b, 371a, b and projecting into an interior 376 of the recess 314. The projections 373a, b belong to the both sections 368a, b, and the projections 374a, c correspond to edges of the upper surface 360b of the body 314.

[0067] The first member 316a of the root adapting device 310 is made of X5 stainless steel material, and the second member 316b of the root adapting device 310 is made of X10 stainless steel material.

[0068] Referring to Figs. 3E-G, a method of attaching the blade 100b in a recess of a rotatable shaft of a steam turbine according to another exemplary embodiment will be explained. Here, the root adapting device 310 is used.

[0069] First, a first ending portion of the blade root 104b is completely inserted into the portion 362b of the recess 314 formed in the second member 316b. Next, another ending portion 382 of the blade root 104b is partially inserted in the portion 362a of the recess 314 formed in the first member 316a. Afterwards, the first and second members 316a, b are pushed together such that the front surfaces 364a, b of the first and second members 316a, b abut against one another. Fig. 3F, G illustrate a mounted state of the blade 100b in the root adapting device 310. Next, the root adapting device 310 is inserted into the groove-like recess of the shaft, as explained with reference to Fig. 2I.

[0070] Alternatively, the ending portion 382 of the blade root 104b is completely inserted into the portion 362a of the recess 314 formed in the first member 316a. The another ending portion of the blade root 104b is then partially inserted in the portion 362b of the recess 314 formed in the second member 314a, and the first and second members 316a, b are pushed together.

[0071] Alternatively, both ending portions 382 of the blade root 104b are simultaneously partially introduced into respective portions 362a, b of the recess 314 and the first and second members 316a, b are pushed together.

[0072] Referring to Figs. 4A-D, a root adapting device 410 according to another exemplary embodiment of the invention will be explained. The root adapting device 410 is similarly constructed compared with the root adapting device 210 illustrated in -J. However, a body 412 of the root adapting device 410 is rectangular shaped. A center member 416a of the root adapting device 410 comprises a U-type shape with a connection element 418a and two side elements 418b, c. The connection element 418a and the side elements 418b, c are integrally designed. Outer front sides 422a, b of the side elements 418b, c and front sides 424a, b of the connection element 418b are flat and coincide with one another. Further, inner front sides 428a, b of the side elements 418a, b are inclined with respect to one another in an opposite way. For example, an inclination angle measured with respect to a plane parallel to the outer front sides 422a, b of the side elements 418b, c is about 35°. The side elements 418a, b and the connection element 418a taper towards a flat ending portion 429a of the center member 416a. The first and second side elements 418b, c and the connection element 418a comprise a fir tree-like shape when seen along a height extension of the center member 416a. Further, the center member 416a comprises four sections 430a-d with each section 430a-d comprising two projections arranged at opposite sides and projection towards outwards. The connection element 418a comprises the sections 430a, b and a lower portion of the section 430c. The side elements 418b, c comprise the section 430d and an upper portion of the section 430c. The projections of the section 430d correspond to an upper longitudinal ending portion 429b of the center member 416a and comprise a step-like shape. The projections of the sections 430a-c comprise a tip-like shape.

[0073] Further, the side members 416b, c of the root adapting device 410 comprise flat, oppositely inclined front sides 440a, b, 442a, b and bent inner surfaces 444a, b with a curvature of the inner surfaces 444a, b of the side members 416b, c being identical to one another. Outer surfaces 446a, b of the side members 416a, b are flat and run parallel to one another in an assembled state of the root adapting device 410.

[0074] When seen along a height extension of the side members 416b, c, the side members 416b, c tapers towards a longitudinal ending portion 432a, b of the side members 416b, c. The inner surfaces 444a, b of the side members 416b, c are identically shaped compared to the inner surfaces 244a, b of the side members 216b, b and comprise a fir tree-like shape. Thus, the inner surfaces 344a, b comprise one notch and two projections located adjacent to the notch and projecting towards an interior of the recess 414. The outer surfaces 446a, b of the side members 416b, c also comprise a fir tree-like shape comprising two projections projecting towards outwards. A first projection corresponds to an upper longitudinal ending portion 438a, b of the side members 416b, c and comprises a step-like shape. A second projection corresponding to the lower ending portion 432a, b of the side members 416b, c comprises a tip.

[0075] The center member 416a of the root adapting device 410 is made of x5 stainless steel, and the side members 416b, c of the root adapting device 410 are made of x20 stainless steel material.

[0076] During a method of attaching a blade 104b in a recess of a shaft of a steam turbine according to another exemplary embodiment of the invention, the side member 416b is laterally moved along the upper surface 448 of the connection element 418a such that the inclined front sides 440a, b of the side members 416b, c abut against the inner front sides 428a, b of the side elements 418a, b of the center member 416a. Next, the blade root 104b is laterally moved towards the inner surface 444a of the side member 416b along the upper surface 448 of the connection element 418a. Next, the side member 416c is laterally introduced into the center member 416a until the inner surface 444b of the side member 416c abuts against the blade root 104a. Hence, the front sides 442a, b of the side member 416c abut against the inner transverse sides 428a, b of the side elements 418a, b of the center member 416a. Next, the root adapting device 410 comprising the blade 104b is laterally slided into the recess of the shaft of the steam turbine, as explained with reference to Fig. 2I.

[0077] Alternatively, the side member 416a may be introduced vertically into the center member 416a instead of being laterally introduced into the center member 416a.

[0078] Referring to Figs. 5A, B, a root adapting device 510 according to another exemplary embodiment of the invention will be explained. Fig. 5A illustrates an exploded view of the root adapting device 510, and Fig. 5B illustrates a cross-sectional view of the root adapting device 510 taken along the line A-A in Fig. 5A.

[0079] The root adapting device 510 is identical to the root adapting device 410 illustrated in Figs. 4A-D except for the design of the recess 514 defined by inner sides 544a, b of side members 516b, c and inner front sides 528a, b of the side elements 518b, c of a center member 516a. The recess 514 comprises a wedge-like shape in that each of the inner surfaces 544a, b of the side members 516b, c comprises a notch 580a, b arranged close to an upper surface 548 of the connection element 518a and two projections 582a, b, 584a, b located adjacent to the notch 580a, b and projecting towards an interior 576 of the recess 514.

[0080] The center member 516a of the root adapting device 510 is made of x5 stainless steel, the side member 516b of the root adapting device 510 is made of x10 stainless steel material, and the side member 516c of the root adapting device 510 is made of x20 stainless steel material.

[0081] A method of attaching a blade in a recess of a shaft of a steam turbine according to another exemplary embodiment of the invention is executed as described with reference to Fig. 4A-D. However, the root adapting device 510 is used instead of the root adapting device 410.

[0082] It should be noted that the term "comprising" does not exclude other elements or steps and the use of articles "a" or "an" does not exclude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

Claims

1. A root adapting device (210, 310, 410, 510) for attaching a blade (104b) in a recess (250) of a rotatable shaft (252) of a steam turbine, the root adapting device (210, 310, 410, 510) comprising

- a body (212, 312, 412, 512) configured for being accommodated in the recess (250) of the shaft (252), and
- a recess (214, 314, 414, 514) formed in the body (212, 312, 412, 512) and configured for accommodating the blade (104b).

2. The root adapting device (210, 310, 410, 510) according to claim 1, wherein the body (212, 312, 412, 512) comprises an elongated shape, wherein the recess (214, 314, 414, 514) extends along a length extension of the body (212, 312, 412, 512).

3. The root adapting device (210, 310, 410, 510) according to claim 1 or 2, wherein the recess (214, 314, 414, 514) is formed as an elongated groove.

4. The root adapting device (210, 310, 410, 510) according to anyone of claims 1 to 3, wherein the recess (214, 314, 414, 514) comprises, when seen along a depth extension of the recess (214, 314, 414, 514), a broadened shape or a uniform width.

5. The root adapting device (210, 310, 410, 510) according to anyone of claims 1 to 4, wherein the recess (214, 314, 414, 514) comprises, when seen along a depth extension of the recess (214, 314, 414, 514), a fir tree-like shape, a wedge-like shape or a hammer-like shape.

6. The root adapting device (310) according to anyone of claims 1 to 5, wherein the body (312) comprises two members (316a, b), wherein a portion (362a) of the recess (314) is formed in a first member (316a) of the body (312), wherein a remaining portion (362b) of the recess (314) is formed in the second member (316b) of the body (312).

7. The root adapting device (310) according to claim 6, wherein a side (364a, b) of each of the first and second members (316a, b) from which the respective portion of the recess (314) extends to an interior of the respective one of the first and second members (316a, b) comprises a flat shape.

8. The root adapting device (210, 410, 510) according to anyone of claims 1 to 5, wherein the body (212, 412, 512) comprises three members (216a-c, 416a-c, 516a-c), wherein a center member (216a, 416a, 516a) of the body (212, 412, 512) comprises first and second side elements (218b, c, 418b, c, 518b, c,) and a connection element (218a, 418a, 518a) extending transverse to the first and second side elements (218b, c, 418b, c, 518b, c,), wherein first and second side members (216b, c, 416b, c, 516b, c,) of the body (212, 412, 512) are accommodatable between the first and second side elements (218b, c, 418b, c, 518b, c,) and on the connection element (218a, 418a, 518a).

9. The root adapting device (210, 410, 510) according to claim 8, wherein an inner side (228a, 428a, 528a) of the first side element (218b, 418b, 518b) and an inner side (230b, 430b, 530b) of the second side element (218c, 418c, 518c) which face to one another are inclined with respect to one another.

10. The root adapting device (210, 310, 410, 510) according to anyone of claims 1 to 9, wherein the body (212, 312, 412, 512) comprises a rectangular shape or an elongated bent shape.

11. The root adapting device (210, 310, 410, 510) according to anyone of claims 1 to 10, wherein the body (212, 312, 412, 512) comprises a tapered shape or a uniform width.

12. The root adapting device (210, 310, 410, 510) according to anyone of claims 1 to 11, wherein the body (212, 312, 412, 512) comprises metal, particularly at least one of stainless steel, titanium, and a titanium alloy.

13. A method of attaching a blade (104b) in a recess (214, 314, 414, 514) (250) of a rotatable shaft (252) of a steam turbine, the method comprising

- accommodating a root of the blade (104b) in a recess (214, 314, 414, 514) of a root adapting device (210, 310, 410, 510) according to anyone of claims 1 to 12, and
- accommodating the root adapting device (210, 310, 410, 510) in the recess (250) of the shaft (252).

14. A steam turbine, the steam turbine comprising

- a blade (104b),
- a rotatable shaft (252) comprising a recess (250) configured for accommodating the blade (104b), and
- a root adapting device (210, 310, 410, 510) configured for attaching the blade (104b) in the recess (250) of the shaft according to anyone of claims 1 to 12.

15. The steam turbine according to claim 14, wherein the recess (250) of the shaft (252) is formed in a downstream portion of the shaft (252).

Amended claims in accordance with Rule 137(2) EPC.

1. A root adapting device (210, 310, 410, 510) for attaching a blade (104b) in a recess (250) of a rotatable shaft (252) of a steam turbine, the root adapting device (210, 310, 410, 510) comprising

- a body (212, 312, 412, 512) configured for being accommodated in the recess (250) of the shaft (252), and
- a recess (214, 314, 414, 514) formed as an elongated groove in the body (212, 312, 412, 512) and configured for accommodating the blade (104b),

wherein the body (212, 312, 412, 512) comprises an elongated shape configured for running essentially along the axial extension of the shaft (252) and providing a large connection area,
wherein the recess (214, 314, 414, 514) extends along a length extension of the body (212, 312, 412, 512),
wherein the body (312) comprises two members (316a, b), wherein a portion (362a) of the recess (314) is formed in a first member (316a) of the body (312),
wherein a remaining portion (362b) of the recess (314) is formed in the second member (316b) of the body (312).

2. The root adapting device (210, 310, 410, 510) according to claim 1, wherein the recess (214, 314, 414, 514) comprises, when seen along a depth extension of the recess (214, 314, 414, 514), a broadened shape or a uniform width.

3. The root adapting device (210, 310, 410, 510) according to anyone of claims 1 or 2, wherein the recess (214, 314, 414, 514) comprises, when seen along a depth extension of the recess (214, 314, 414, 514), a fir tree-like shape, a wedge-like shape or a hammer-like shape.

4. The root adapting device (310) according to anyone of claims 1 to 3, wherein a side (364a, b) of each of the first and second members (316a, b) from which the respective portion of the recess (314) extends to an interior of the respective one of the first and second members (316a, b) comprises a flat shape.

5. The root adapting device (210, 410, 510) according to anyone of claims 1 to 4, wherein the body (212, 412, 512) comprises three members (216a-c, 416a-c, 516a-c), wherein a center member (216a, 416a, 516a) of the body (212, 412, 512) comprises first and second side elements (218b, c, 418b, c, 518b, c,) and a connection element (218a, 418a, 518a) extending transverse to the first and second side elements (218b, c, 418b, c, 518b, c,), wherein first and second side members (216b, c, 416b, c, 516b, c,) of the body (212, 412, 512) are accommodatable between the first and second side elements (218b, c, 418b, c, 518b, c,) and on the connection element (218a, 418a, 518a).

6. The root adapting device (210, 410, 510) according to claim 5, wherein an inner side (228a, 428a, 528a) of the first side element (218b, 418b, 518b) and an inner side (230b, 430b, 530b) of the second side element (218c, 418c, 518c) which face to one another are inclined with respect to one another.

7. The root adapting device (210, 310, 410, 510) according to anyone of claims 1 to 6, wherein the body (212, 312, 412, 512) comprises a rectangular shape or an elongated bent shape.

8. The root adapting device (210, 310, 410, 510) according to anyone of claims 1 to 7, wherein the body (212, 312, 412, 512) comprises a tapered shape or a uniform width.

9. The root adapting device (210, 310, 410, 510) according to anyone of claims 1 to 8, wherein the body (212, 312, 412, 512) comprises metal, particularly at least one of stainless steel, titanium, and a titanium alloy.

10. A method of attaching a blade (104b) in a recess (214, 314, 414, 514) (250) of a rotatable shaft (252) of a steam turbine, the method comprising

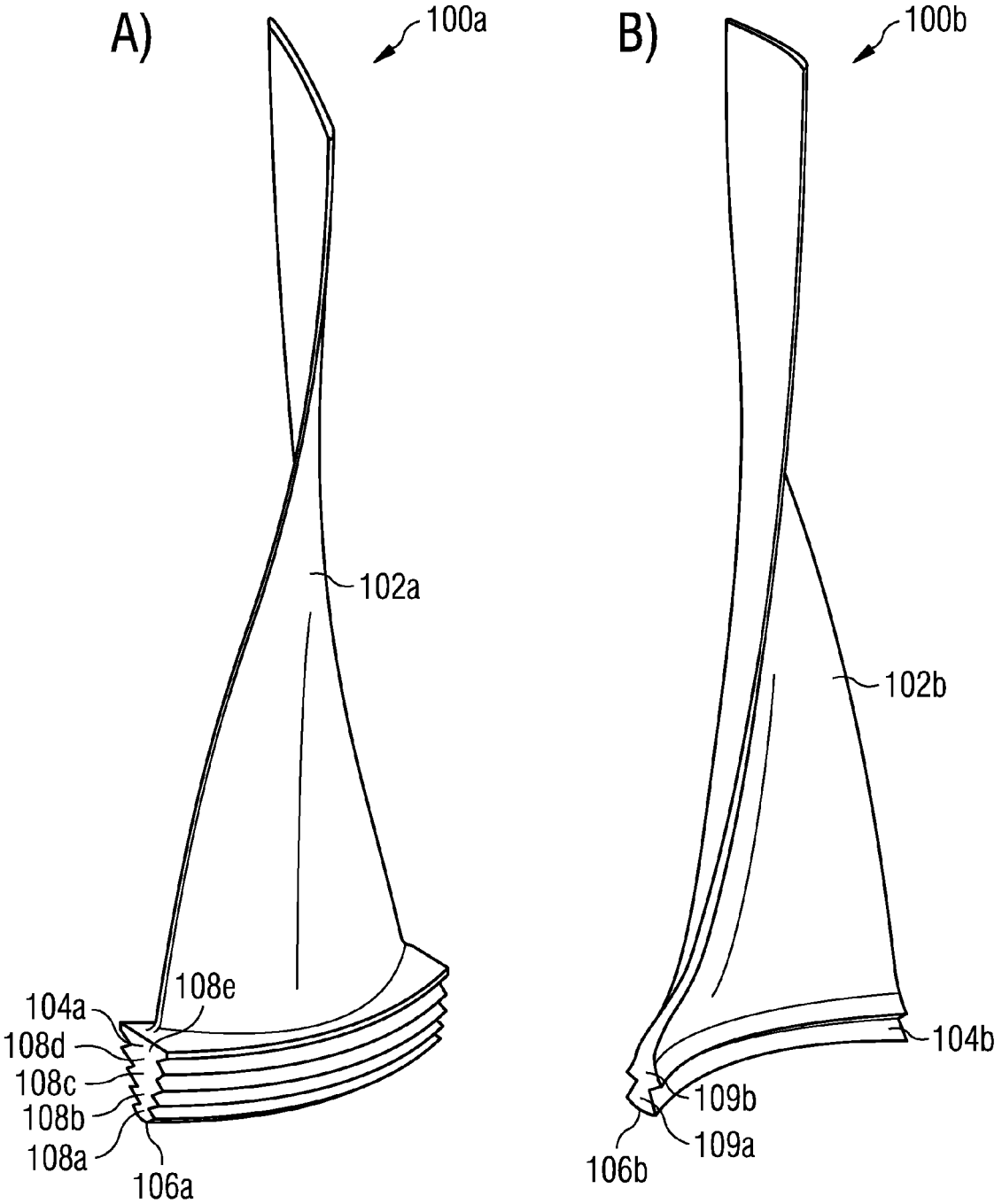
- accommodating a root of the blade (104b) in a recess (214, 314, 414, 514) of a root adapting device (210, 310, 410, 510) according to anyone of claims 1 to 9, and
- accommodating the root adapting device (210, 310, 410, 510) in the recess (250) of the shaft (252).

11. A steam turbine, the steam turbine comprising

- a blade (104b),
- a rotatable shaft (252) comprising a recess (250) configured for accommodating the blade (104b), and
- a root adapting device (210, 310, 410, 510) configured for attaching the blade (104b) in the recess (250) of the shaft according to anyone of claims 1 to 9.

12. The steam turbine according to claim 11, wherein the recess (250) of the shaft (252) is formed in a downstream portion of the shaft (252).

FIG 1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108c
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B)
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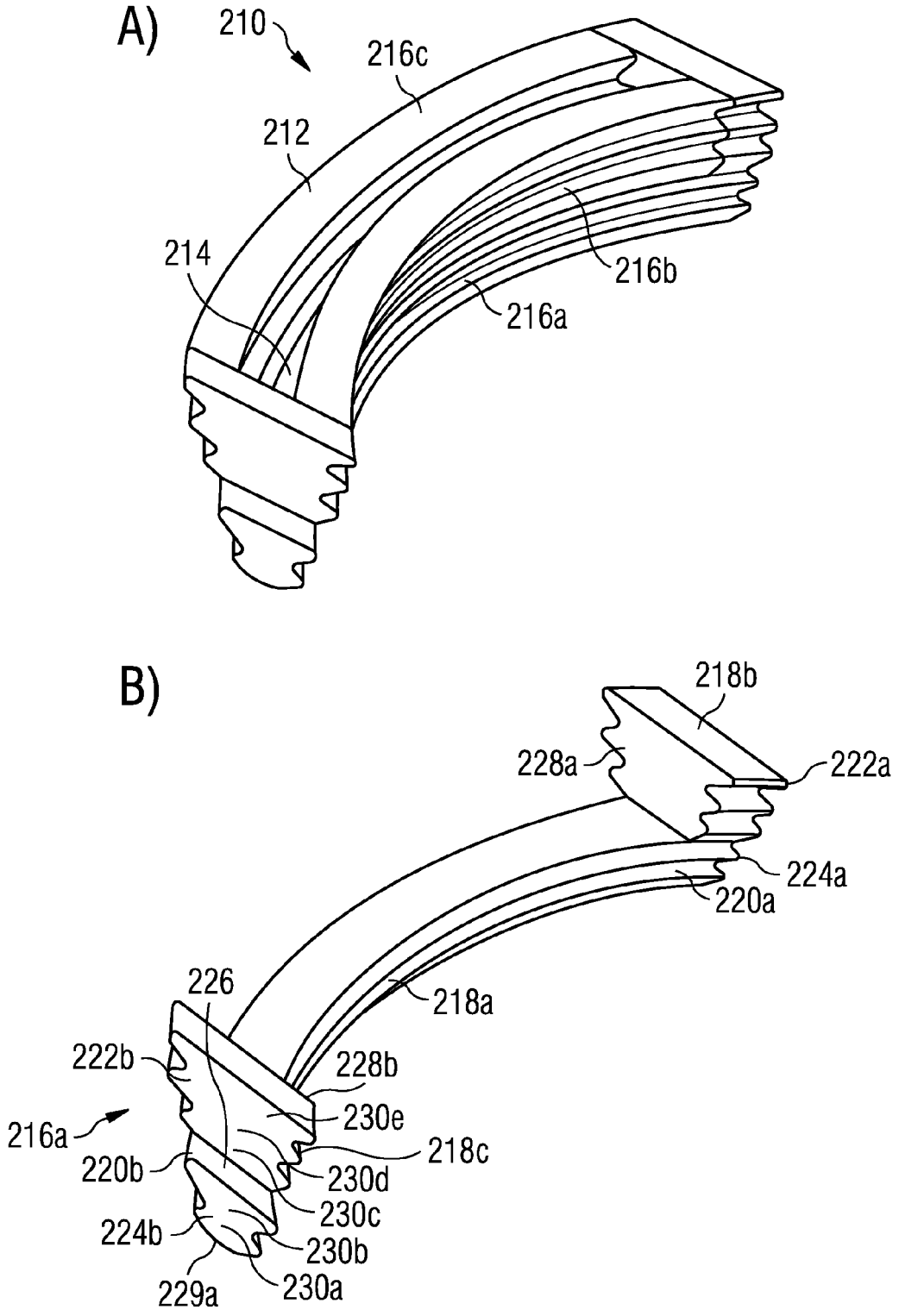
106b

FIG 2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212
214
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B)
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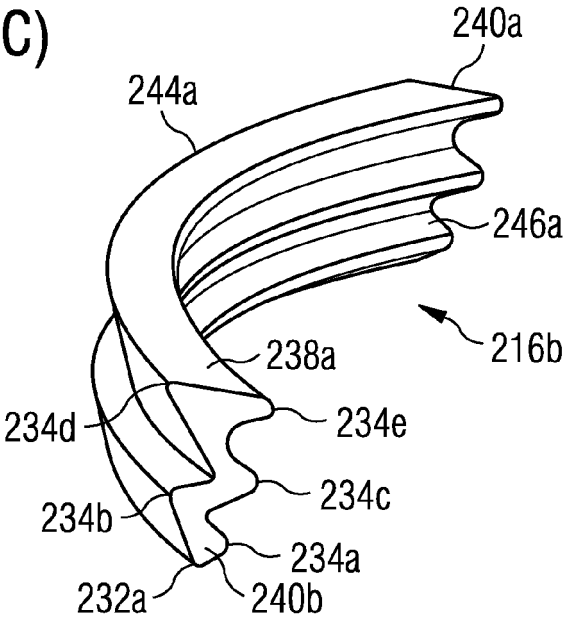
229a
230a

FIG 2

C)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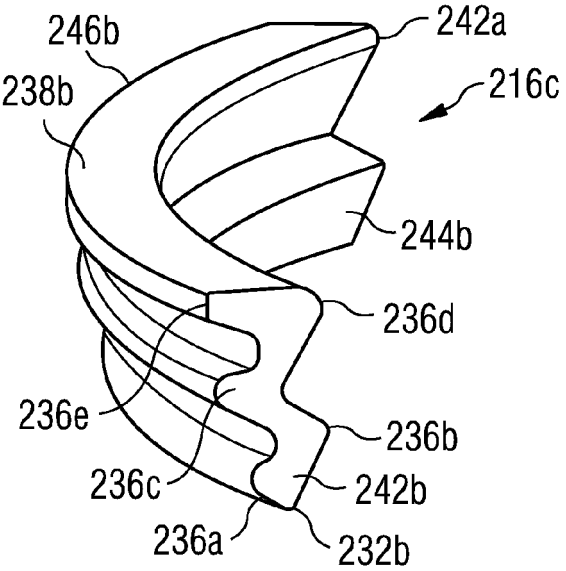
234a
232a
240b

D)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242b
236a
232b

FIG 2

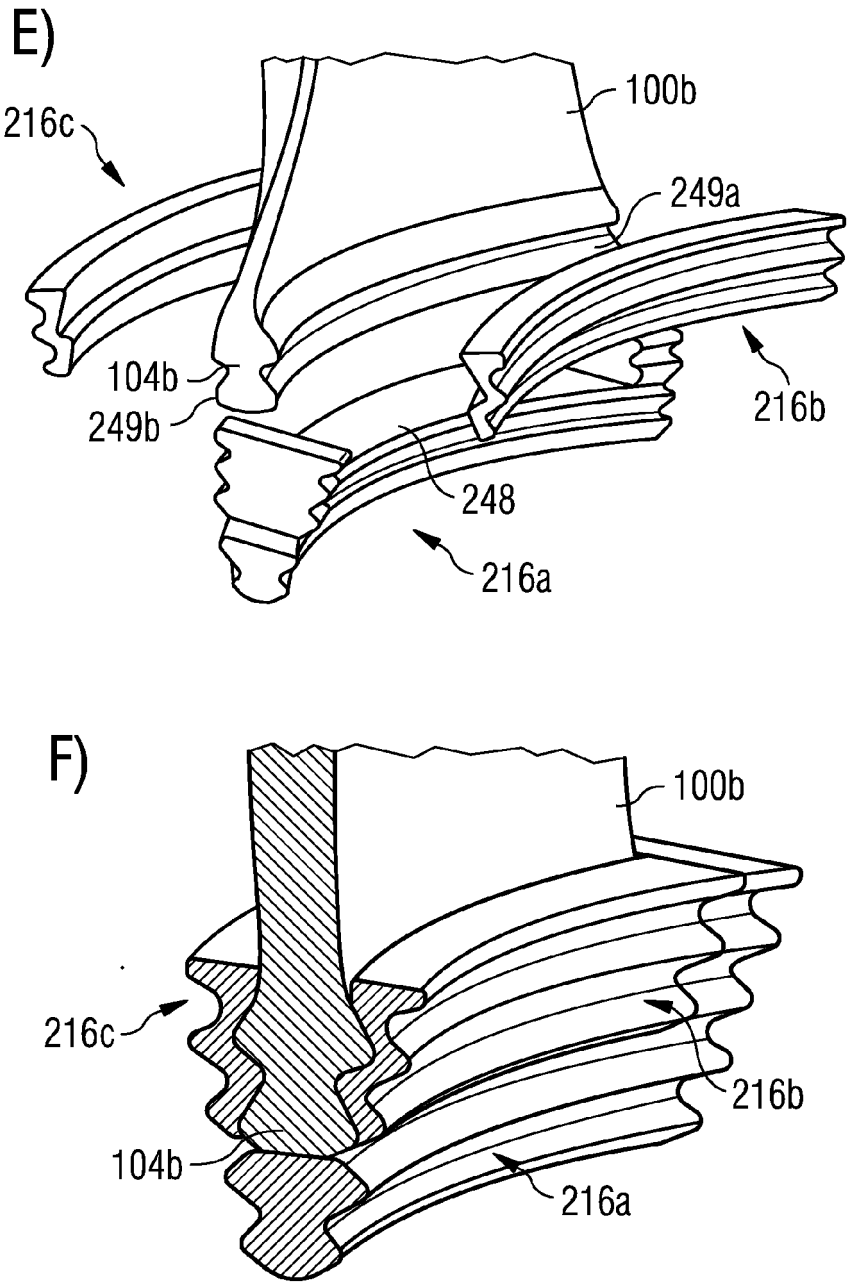
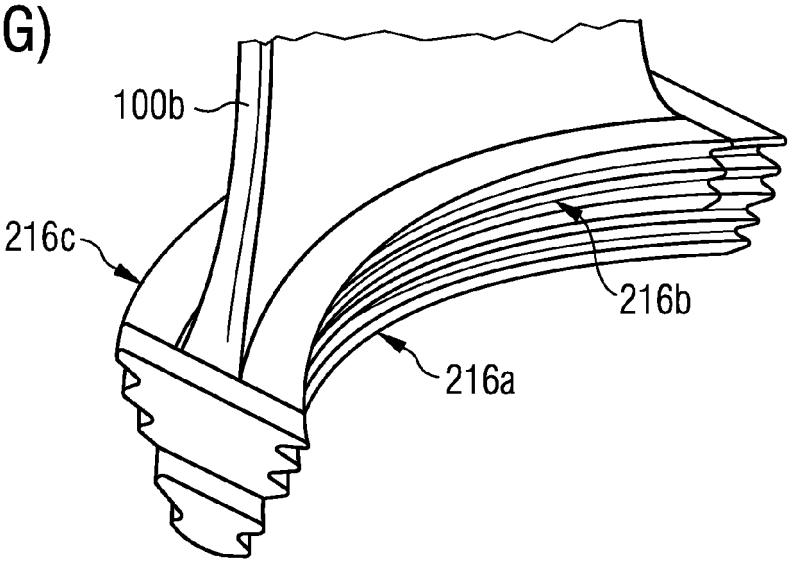

E)
216c
100b
249a
104b
249b
216b
248
216a
F)
100b
216c
216b
104b
216a

FIG 2

G)



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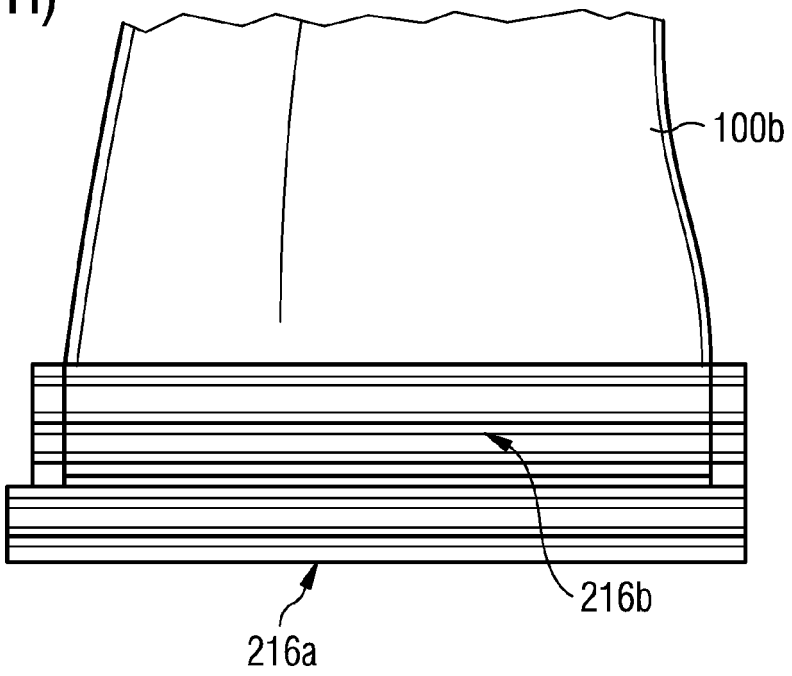


FIG 2

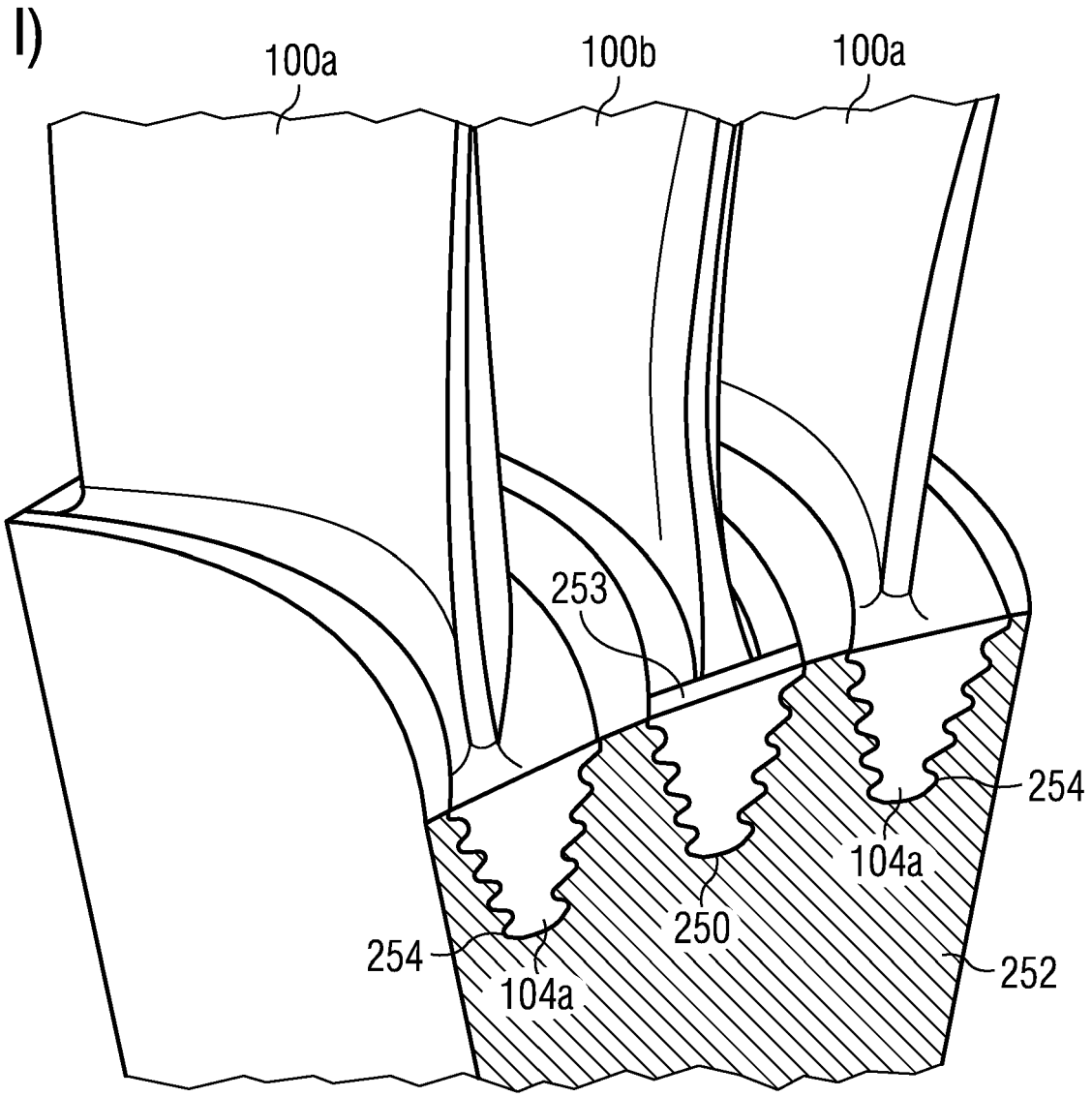


FIG 3

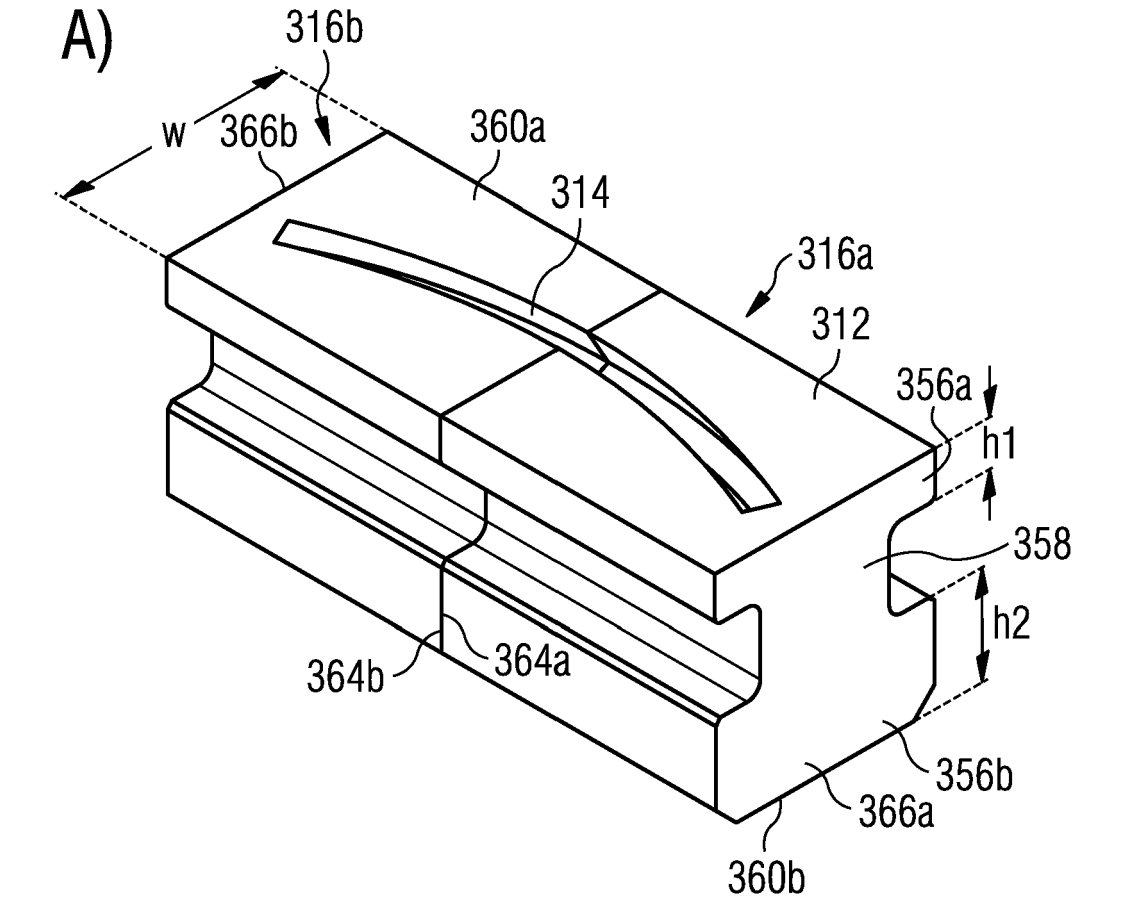
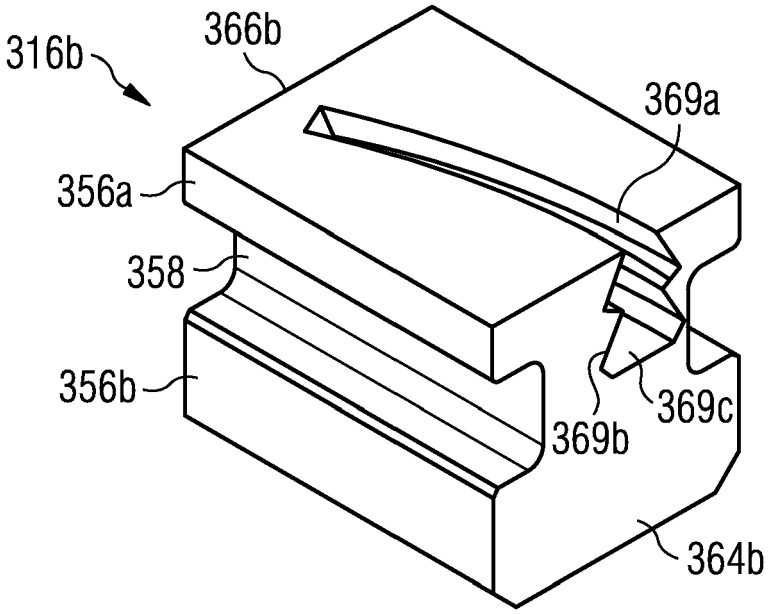

A)
316b
w
366b
360a
314
316a
312
356a
h1
358
h2
364b
364a
356b
366a
360b
B)
312
314
316b
316a
362b
362a

FIG 3

C)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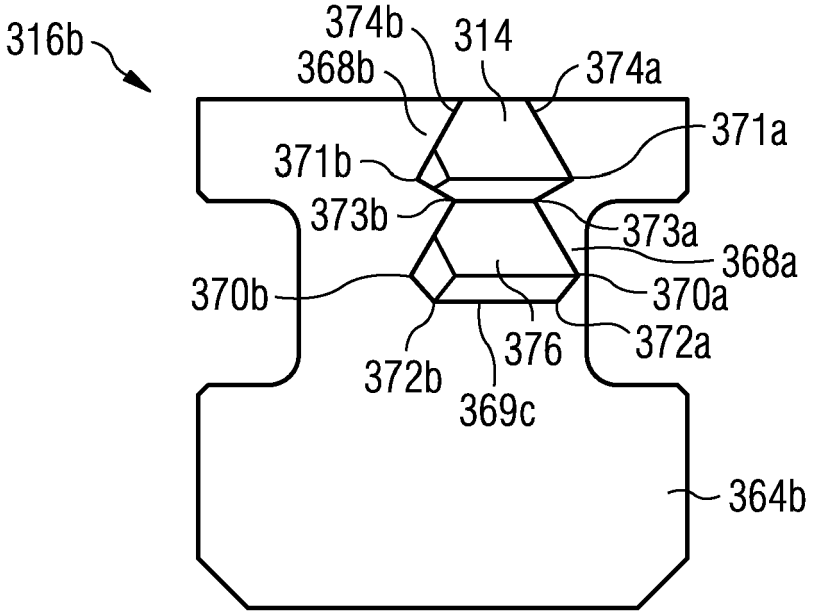
356a
358
356b
369b
369c
364b

D)


316b
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370a
376
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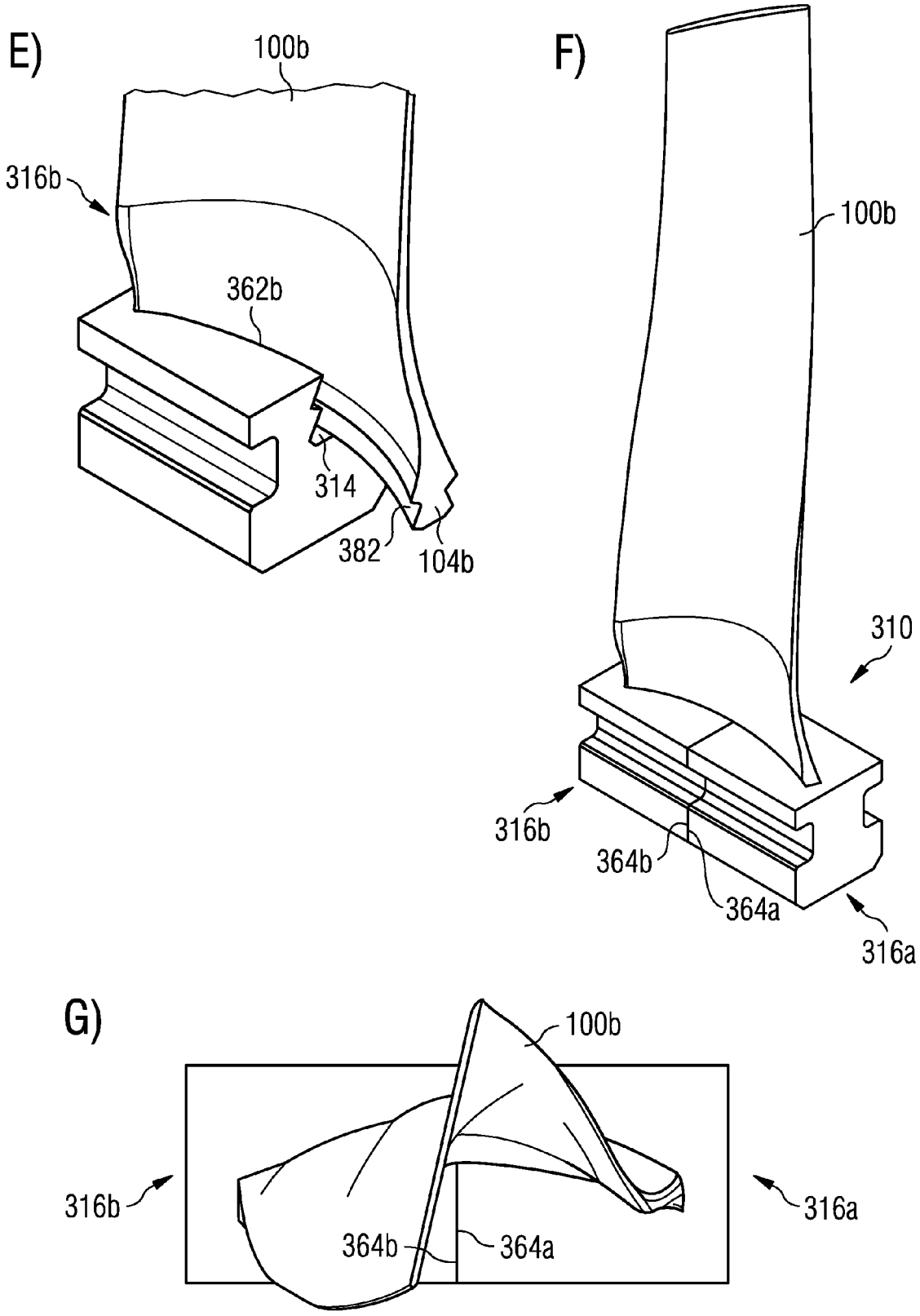
372b
369c
364b

FIG 3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100b
316b
362b
314
382
104b
F)
100b
310
316b
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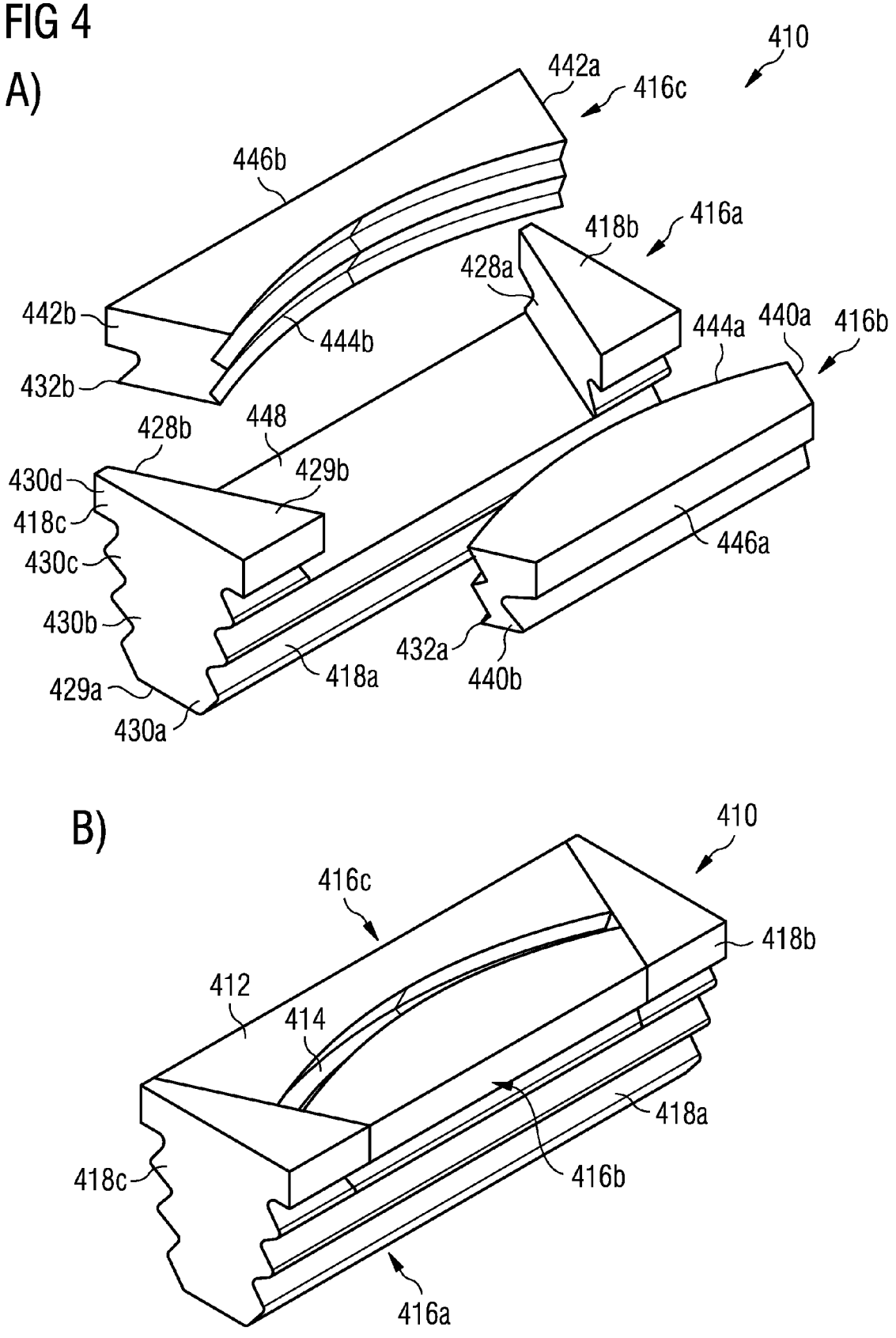
364b
364a
316a

FIG 4


A)
410
442a
416c
446b
418b
416a
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442b
444b
444a
440a
416b
432b
448
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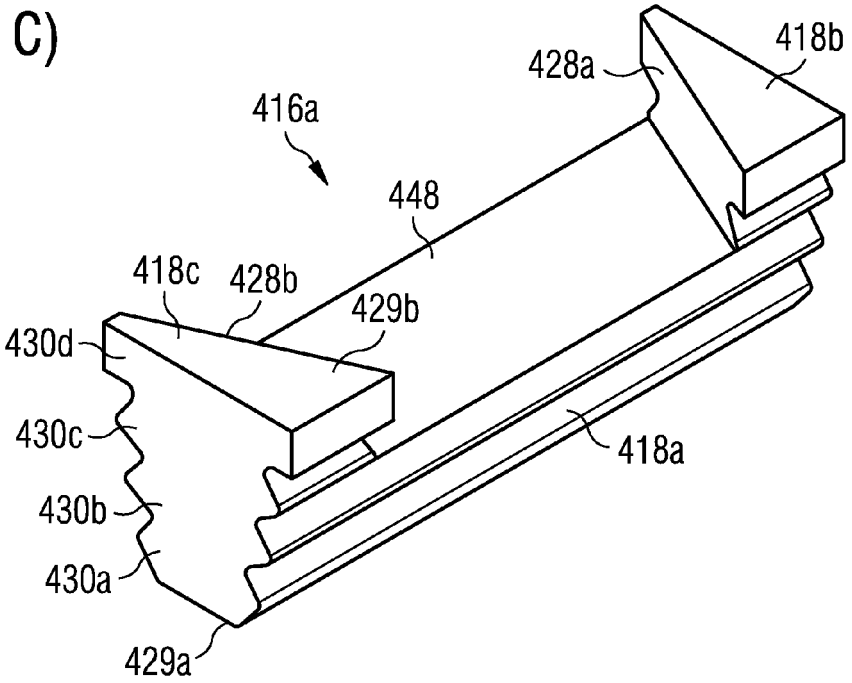
429b
430d
418c
430c
430b
429a
430a
418a
432a
440b
446a
B)
410
416c
418b
412
414
418a
418c
416b
416a

FIG 4

C)


418b
428a
416a
448
418c
428b
429b
430d
430c
418a
430b
430a
429a

D)

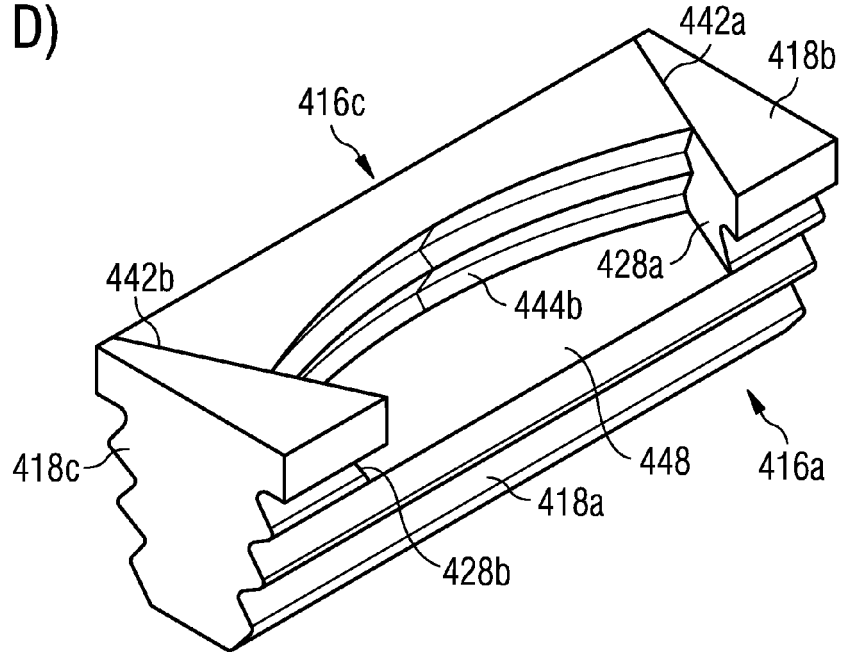
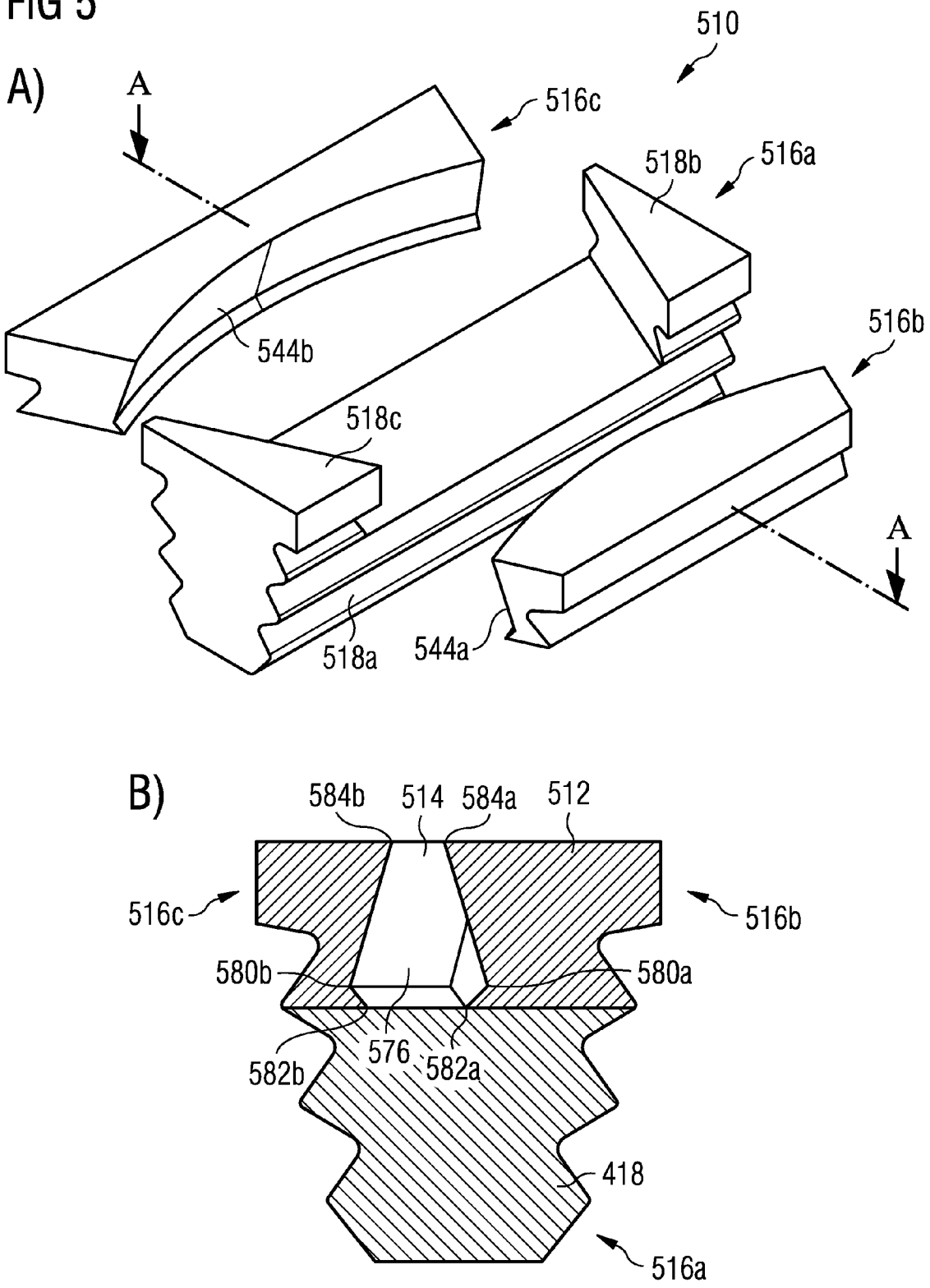

442a
418b
416c
428a
442b
444b
418c
448
416a
418a
428b

FIG 5


A)
A
510
516c
518b
516a
544b
516b
518c
A
518a
544a
B)
584b
514
584a
512
516c
516b
580b
580a
582b
576
582a
418
516a

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EUROPEAN SEARCH REPORT

Application Number
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Place of search	Date of completion of the search	Examiner
The Hague	7 April 2011	Steinhauser, Udo

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