

(19)



(11)

EP 2 385 217 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
09.11.2011 Bulletin 2011/45

(51) Int Cl.:
F01D 5/22 (2006.01)

(21) Application number: **11165003.2**

(22) Date of filing: **05.05.2011**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

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(30) Priority: **06.05.2010 RU 2010117972**

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(54) **Blade having asymmetrical mid-span structure portions and related bladed wheel structure for vibration damping**

(57) A blade includes a body including an airfoil section, a root at an end of the body for coupling the blade to a hub, a first mid-span structure portion extending from the body, and a second mid-span structure portion extending from the body. The first and second mid-span structure portions extend from the body in an asymmetrical manner. A structure includes a bladed wheel including a plurality of circumferentially spaced blades extending from a hub, and a set of mid-span structures coupling adjacent blades of the plurality of circumferentially spaced blades. The set of mid-span structures are positioned in a non-uniform radial position arrangement.

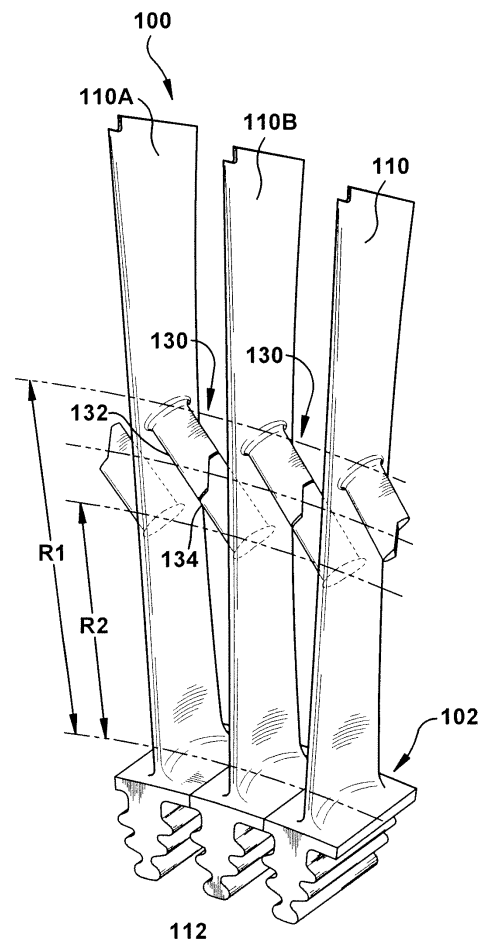


FIG. 2

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Description**BACKGROUND OF THE INVENTION**

[0001] The disclosure relates generally to bladed wheels, and more particularly, to a blade for a bladed wheel having asymmetrical mid-span structure portions and a related bladed wheel structure.

[0002] In the design of bladed wheels for industrial purposes, it is necessary to ensure that the structure can withstand a range of operating frequencies. Such bladed wheels may be employed in machines such as fans, compressors, turbines, etc. In designs including long blades on a bladed wheel, as shown in FIG. 1, adjacent blades 10 are commonly connected by one or more sets of circumferentially extending mid-span structures 12. Each set and each individual mid-span structure 12 extends at a uniform radial position R throughout the bladed wheel relative to a hub 14 thereof. The number, size and radial position of mid-span structures 12 are some of the main factors that impact bladed wheel frequencies and must be detuned to handle critical resonant crossings for all operational modes of interest. Consequently, adjustments in the radial position, number and size of mid-span structures are oftentimes a focus of frequency detuning during design. Unfortunately, increasing the number or size of mid-span structures increases the total mass and makes the design more complex. In addition, varying the uniform radial position R of the mid-span structures does not necessarily detune critical resonant crossings for all operational modes of interest.

BRIEF DESCRIPTION OF THE INVENTION

[0003] A first aspect of the disclosure provides a bladed wheel structure comprising: a bladed wheel including a plurality of circumferentially spaced blades extending from a hub; and a set of mid-span structures coupling adjacent blades of the plurality of circumferentially spaced blades, wherein the set of mid-span structures are positioned in a non-uniform radial position arrangement.

[0004] A second aspect of the disclosure provides a blade comprising: a body including an airfoil section; a root at an end of the body for coupling the blade to a hub; a first mid-span structure portion extending from the body; and a second mid-span structure portion extending from the body, wherein the first and second mid-span structure portions extend from the body in an asymmetrical manner.

[0005] The illustrative aspects of the present disclosure are designed to solve the problems herein described and/or other problems not discussed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] These and other features of this disclosure will be more readily understood from the following detailed

description of the various aspects of the disclosure taken in conjunction with the accompanying drawings that depict various embodiments of the disclosure, in which:

FIG. 1 shows a schematic view of a conventional bladed wheel configuration.

FIG. 2 shows a perspective view of a bladed wheel structure according to embodiments of the invention.

FIG. 3 shows a perspective view of a blade of FIG. 2 including mid-span structure portions according to embodiments of the invention.

FIG. 4 shows a schematic view of a bladed wheel structure according to other embodiments of the invention.

FIGS. 5 and 6 show perspective views of mating blades of FIG. 4 including the mid-span structure portions according to embodiments of the invention.

FIGS. 7 and 8 show perspective views of mating mid-span structure portions of FIG. 3 and FIGS. 5-6, respectively, according to embodiments of the invention.

FIG. 9 shows a perspective view of a combination of the FIGS. 2 and 4 embodiments.

FIGS. 10 and 11 show side views of alternative wire mid-span structures according to embodiments of the invention.

[0007] It is noted that the drawings of the disclosure are not to scale. The drawings are intended to depict only typical aspects of the disclosure, and therefore should not be considered as limiting the scope of the disclosure. In the drawings, like numbering represents like elements between the drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0008] Referring to FIGS. 2-6, perspective views of a bladed wheel structure 100, 200 according to various embodiments are illustrated. As shown in FIGS. 2 and 4, each structure 100, 200 includes a bladed wheel 102 including a plurality of circumferentially spaced blades 110, 210 extending from a hub 112. Each blade 110, 210, as shown best in FIGS. 3, 5 and 6, includes a body 120 including an airfoil section 122, e.g., along the length of body 120, and a root 124 at an end of body 120 for coupling blade 110 to hub 112. As understood, airfoil section 122 and root 124 may take a variety of forms depending on the application for blades 110, 210. As also understood, hub 112 is coupled to a rotating shaft (not shown) to either create rotation therein by a fluid passing over blades 110, 210, or creating a fluid flow by rotation of

blades 110, 210 by forced rotation of the rotating shaft. Each blade 110, 210, as shown in FIG. 3 and FIGS. 5-6, may include a cover or integral cover 140, although this may not be necessary for all applications.

[0009] As indicated above, modifications of mid-span structures are oftentimes the focus of detuning resonant frequencies of a bladed wheel. Conventionally, the modifications include increasing the number or size of mid-span structures and/or varying the uniform radial position of the mid-span structures. Increasing the number and size increases the total mass and makes the design more complex, and varying the uniform radial position of the mid-span structures does not necessarily detune critical resonant crossings for all operational modes of interest.

[0010] In order to address the above-described challenges, among others, embodiments of the invention provide a set of mid-span structures 130 (FIGS. 2 and 3) and 230, 232 (FIGS. 4-6), each extending between adjacent circumferentially spaced blades 110, 210, respectively. In contrast to conventional mid-span structures, however, embodiments of the invention provide set of mid-span structures 130 and 230, 232 positioned in a non-uniform radial position arrangement. That is, in contrast to mid-span structures 12, shown in FIG. 1, mid-span structures 130 and 230, 232 are not all positioned at a uniform radial position relative to hub 112. As described further herein, the non-uniform radial position arrangement may be configured to detune resonant frequency vibrations.

[0011] In one embodiment, shown in FIGS. 2 and 3, the non-uniform radial position arrangement of structure 100 includes each mid-span structure 130 extending radially obliquely relative to each adjacent blade 110. This radially oblique angling is in contrast to, or in addition to, an oblique angle of attack that each mid-span structure 130 may have relative to a fluid passing thereby, i.e., into and out of the page of FIGS. 2 and 3. In other words, as shown in FIG. 2, each mid-span structure 130 includes a first end 132 having a first radial position R1 relative to hub 112 on a first blade (e.g., 110A) and a second end 134 having a second radial position R2 relative to hub 112 different than first radial position R1 on a second blade (e.g., 110B) that is adjacent to first blade (e.g., 110A). Consequently, the radial position of each mid-span structure 130 relative to hub 112 varies between adjacent blades 110. This arrangement repeats between each pair of adjacent blades about hub 112. An advantage that may be realized in the practice of some embodiments of the described structure 100 is that radial positions R1 and R2 may be modified to detune the resonant frequencies of bladed wheel 102. Consequently, the radially oblique angling of mid-span structures 130 provide another feature that can be modified for detuning purposes. Mid-span structures 130 may be positioned practically anywhere along blades 110, and have any of a variety of oblique angles relative to blades 110.

[0012] In another embodiment, shown in FIG. 4, the non-uniform radial position arrangement of structure 200

includes a first mid-span structure 230 positioned at a first radial position R3 relative to hub 112 between a first blade 210A and a second blade 210B adjacent to first blade 210A. In addition, a second mid-span structure 232 may be positioned at a second radial position R4 relative to hub 112 different than first radial position R1 between first blade 210A and a third blade 210C adjacent to first blade 210A. In this embodiment, each mid-span structure 230, 232 has a substantially uniform radial position between respective adjacent blades 210. An advantage that may be realized in the practice of some embodiments of the described structure 200 is that radial positions R3 and R4 may be modified to detune the resonant frequencies of bladed wheel 102. Consequently, having mid-span structures 230, 232 of adjacent pairs of blades at different radial positions provides another feature that can be modified for detuning purposes. Mid-span structures 230, 232 may be positioned practically anywhere along blades 210.

[0013] Each blade 110, 210 may be manufactured using any now known or later developed technique, e.g., casting with conventional finishing, and may be made of any conventional material such as steel, titanium, etc. Referring to FIGS. 3 and 5-8, in one embodiment, each mid-span structure 130 (FIG. 2) and 230, 232 (FIG. 4) may be formed using mating portions, which may be helpful for, e.g., assembly and/or replacement purposes. More specifically, as shown in FIG. 3 for the FIG. 2 embodiment, for example, each mid-span structure 130 (FIG. 2) may include a first mid-span structure portion 140 on one blade 110 capable of mating with a complementary mid-span structure portion 142 of an adjacent blade. Similarly, as shown in FIGS. 5-6 for the FIG. 4 embodiment, each mid-span structure 230 or 232 (FIG. 4) may include a first mid-span structure portion 240 on one blade 110 capable of mating with a complimentary mid-span structure portion 242 of an adjacent blade. That is, each blade 110, 210 includes first mid-span structure portion 140, 240 extending from body 120, and second mid-span structure portion 142, 242 extending from body 120. In one embodiment, each blade 110 includes only first mid-span structure portion 140, 240 and second mid-span structure portion 142, 242 extending from a mid-span section (i.e., anywhere along body 120) of blade 110, 210. Illustrative configurations of how portions 140, 142 and 240, 242 mate are illustrated in FIGS. 7 and 8, respectively. In these examples, a mating zig-zag surface configuration 146 (FIG. 7) and 246 (FIG. 8) is employed. It is understood that there exists a myriad of different manners of mating mid-span structure portions known in the art, and all are included within the scope of the invention.

[0014] Due to the nature of the non-uniform radial position arrangement described herein, first and second mid-span structure portions 140, 240 and 142, 242 extend from body 120 in an asymmetrical manner. Conventional blades may include differently shaped mid-span structure portions that accommodate mating, similarly to

the mating surface configurations 146, 246 shown in FIGS. 7 and 8, respectively, but the mid-span structure portions extend symmetrically from each blade, i.e., from substantially the same radial position on opposite sides of the blade. For example, as shown in FIG. 1, they extend at a uniform radial position relative to hub 14 (or the root of the blade) and perhaps with some minor radial inward tilt to accommodate mating. However, blades 110, 210 according to embodiments of the invention, in contrast to conventional blades, have mid-span structure portions 140, 240 and 142, 242 extending asymmetrically from body 120, i.e., from different radial positions on each side of the blade.

[0015] In the FIG. 3 embodiment, first mid-span structure portion 140 includes a longitudinal axis L1 that extends at an oblique angle from a first side 150 of body 120, and second mid-span structure portion 142 includes a longitudinal axis L2 that extends at an oblique angle from a second side 152 of body 120 such that the first and second mid-span structure portions 140, 142 of adjacent blades mate, as shown in FIG. 2. In this case, first mid-span structure portion 140 may include a first end having a first radial position R11 relative to hub 112 (FIG. 2 only) (or root 124 thereof) and a second end having a second radial position R12 relative to hub 112 (or root 124 thereof) that is different than first radial position R11. Similarly, second mid-span structure portion 142 may include a first end having a third radial position R13 relative to hub 112 (or root 124 thereof) and a second end having a fourth radial position R14 relative to hub 112 (or root 124 thereof) that is different than third radial position R13. In one embodiment, first radial position R11 of the first end of first mid-span structure portion 140 is greater than fourth radial position R14 of the second end of second mid-span structure portion 142, and second radial position R12 and third radial position R13 are substantially equal, so as to accommodate mating. Again, the oblique angles and radial positions in which first and second mid-span structure portions 140, 142 extend from body 120 may be configured to detune resonant frequency vibrations.

[0016] In the FIGS. 5 and 6 embodiment, each mating blade 210A (FIG. 5) and 210B (FIG. 6) includes a first mid-span structure portion 240 extending from a first side 250 of body 120 at a first radial position R21, and second mid-span structure portion 242 extending from a second side 252 of body 120 at a second radial position R22 different than first radial position R21. In this fashion, each mid-span structure portion 240, 242 is configured for mating with one of a mating portion 242, 240, respectively, of the respective mid-span structure on an adjacent blade. First and second radial positions R21, R22 can be configured to detune resonant frequency vibrations.

[0017] In an alternative embodiment, each mid-span structure portion 240, 242 may simply mate with body 120 of an adjacent blade. It is understood that this embodiment does not appear any differently than FIGS. 4-6,

except the mating surface configurations of FIG. 7 and 8 would not be necessary as the end of each portion would simply mate with body 120.

[0018] It is understood that the teachings of the above-described embodiments may be employed alone or in combination. FIG. 9 shows an example of a combination of the embodiments described. In addition, in an alternate embodiment, shown in FIGS. 10 and 11, a set of mid-span structures 130 (FIGS. 2 and 3) and 230, 232 (FIGS. 4-6) may be constructed in the form of a wire 330 or 430, 432, respectively. In this case, each mid-span structure includes a wire 360, 460 that extends through openings 362, 462 in respective adjacent blades 110, 210. Wire 360, as shown in FIG. 10, may include bends 361 to accommodate the radially oblique angling between adjacent blades 110. Each wire may include an anchor 364, 464 to hold the respective ends in place. As illustrated, each anchor 364, 464 includes an enlarged end on each wire that is positioned in a seat 366, 466; however, any other mechanism of anchoring a wire may be employed, e.g., threaded bolts, welding, etc.

[0019] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the disclosure. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0020] The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present disclosure has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the disclosure in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the disclosure. The embodiment was chosen and described in order to best explain the principles of the disclosure and the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

Claims

1. A bladed wheel structure (100) comprising:

a bladed wheel (102) including a plurality of circumferentially spaced blades (110, 210) extend-

- ing from a hub (112);
 a set of mid-span structures (130, 230, 232) coupling adjacent blades (110A, 110B, 210A, 210B, 210C) of the plurality of circumferentially spaced blades (110, 210),
 wherein the set of mid-span structures (130, 230, 232) are positioned in a non-uniform radial position arrangement.
2. The bladed wheel structure (100) of claim 1, wherein the non-uniform radial position arrangement includes each mid-span structure (130, 230, 232) extending obliquely relative to each adjacent blade (110A, 110B, 210A, 210B, 210C).
 3. The bladed wheel structure (100) of claim 1 or 2, wherein the non-uniform radial position arrangement includes each mid-span structure (130, 230, 232) having a first end (132) having a first radial position relative to the hub (112) on a first blade (110A) and a second end (134) having a second radial position relative to the hub (112) different than the first radial position on a second blade (110B) that is adjacent to the first blade (110A).
 4. The bladed wheel structure (100) of any of the preceding claims, wherein the non-uniform radial position arrangement includes a first mid-span structure (130) positioned at a first radial position relative to the hub (112) between a first blade (110A) and a second blade (110B) adjacent to the first blade (110A), and a second mid-span structure (230) positioned at a second radial position relative to the hub (112) different than the first radial position between the first blade (210A) and a third blade (210C) adjacent to the first blade (210A).
 5. The bladed wheel structure (100) of any of the preceding claims, wherein the non-uniform radial position arrangement is configured to detune resonant frequency vibrations.
 6. The bladed wheel (102) of any of the preceding claims, wherein each mid-span structure (130, 230, 232) includes a wire (330, 430, 432, 360, 460) extending between the adjacent blades.
 7. A blade (110) comprising:
 - a body (120) including an airfoil section (122);
 - a root (124) at an end of the body (120) for coupling the blade to a hub (112);
 - a first mid-span structure portion (140) extending from the body (120); and
 - a second mid-span structure portion (142) extending from the body (120),
 wherein the first and second mid-span structure portions (140, 142) extend from the body (120)
 - in an asymmetrical manner.
 8. The blade (110) of claim 7, wherein the asymmetrical manner in which the first and second mid-span structure portions (140, 142) extend from the body (120) is configured to detune resonant frequency vibrations.
 9. The blade (110) of claim 7 or 8, wherein the first mid-span structure portion (140) includes a longitudinal axis that extends at an oblique angle from a first side (150) of the body (120), and the second mid-span structure portion (142) includes a longitudinal axis that extends at an oblique angle from a second side (152) of the body (120) such that the first and second mid-span structure portions (140, 142) of adjacent blades (110A, 110B) mate.
 10. The blade (110) of claim 8, wherein the oblique angles in which the first and second mid-span structure portions (140, 142) extend from the body (120) are configured to detune resonant frequency vibrations.
 11. The blade of any of claims 7 to 10, wherein the first mid-span structure portion includes a first end having a first radial position relative to the hub and a second end having a second radial position relative to the hub that is different than the first radial position, and the second mid-span structure portion includes a first end having a third radial position relative to the hub and a second end having a fourth radial position relative to the hub that is different than the third radial position.
 12. The blade of claim 11, wherein the first radial position of the first end of the first mid-span structure portion is greater than the fourth radial position of the second end of the second mid-span structure portion, and the second radial position and the third radial position are substantially equal.
 13. The blade of any of claims 7 to 12, wherein the blade includes only the first mid-span structure portion and the second mid-span structure portion extending from a mid-span section of the blade.
 14. The blade of claim 13, wherein the first mid-span structure portion extends from a first side of the body at a first radial position, and the second mid-span structure portion extends from a second side of the body at a second radial position different than the first radial position, wherein each mid-span structure portion is configured for mating with one of a mating portion of the respective mid-span structure on an adjacent blade and a body of the adjacent blade.
 15. The blade of claim 14, wherein the first and second

radial positions are configured to detune resonant frequency vibrations.

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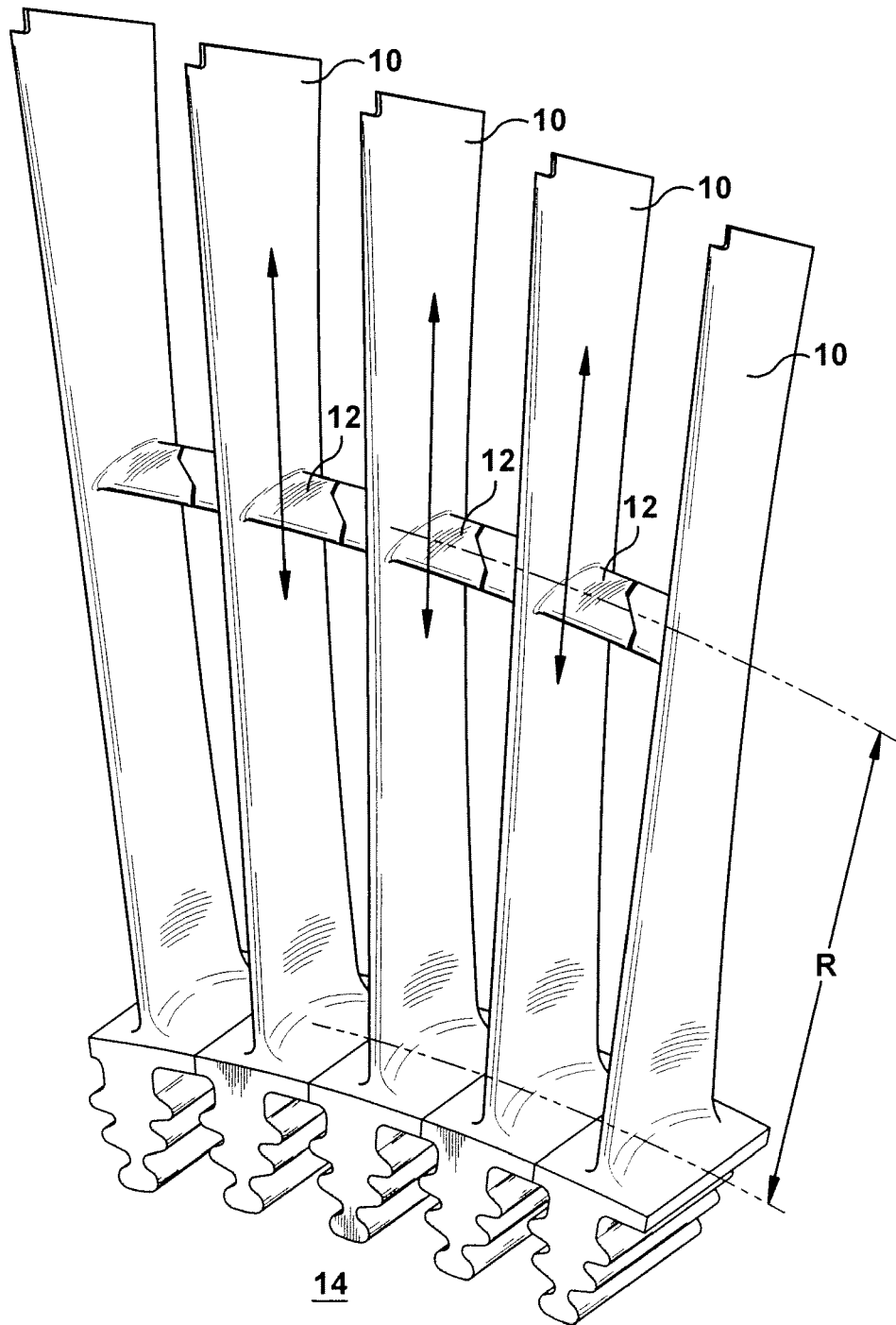


FIG. 1
(Prior Art)

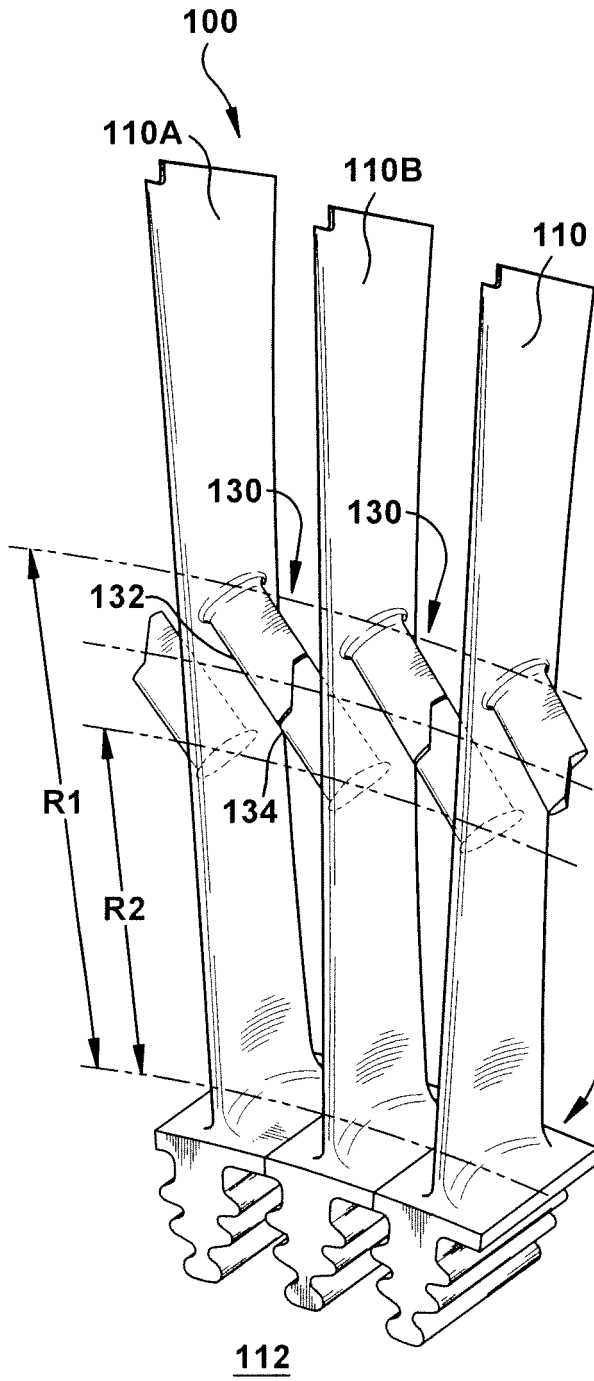


FIG. 2

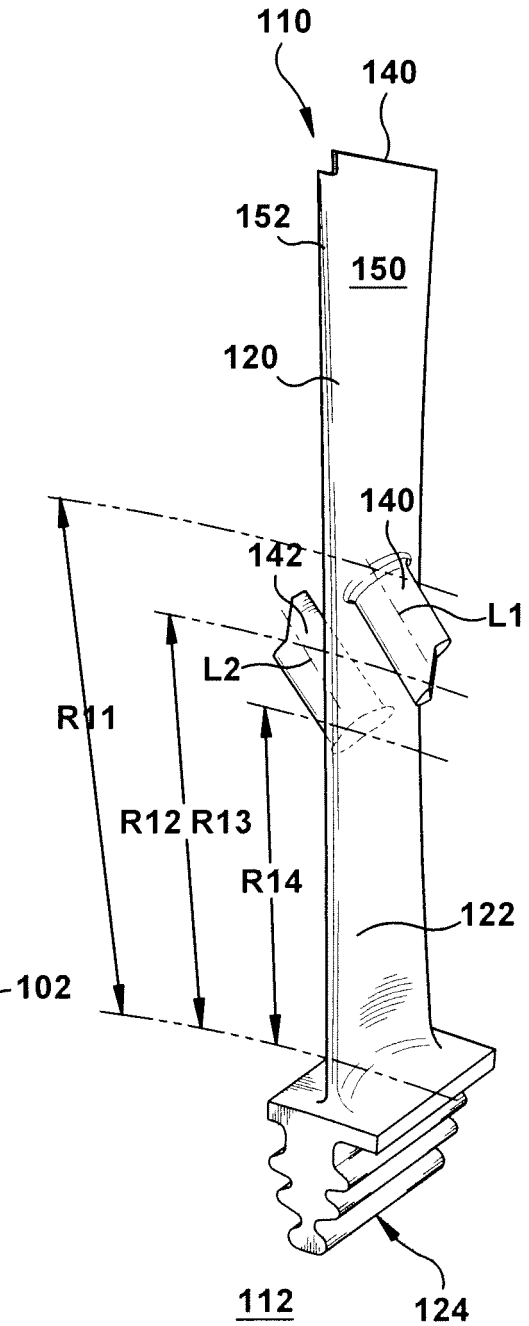


FIG. 3

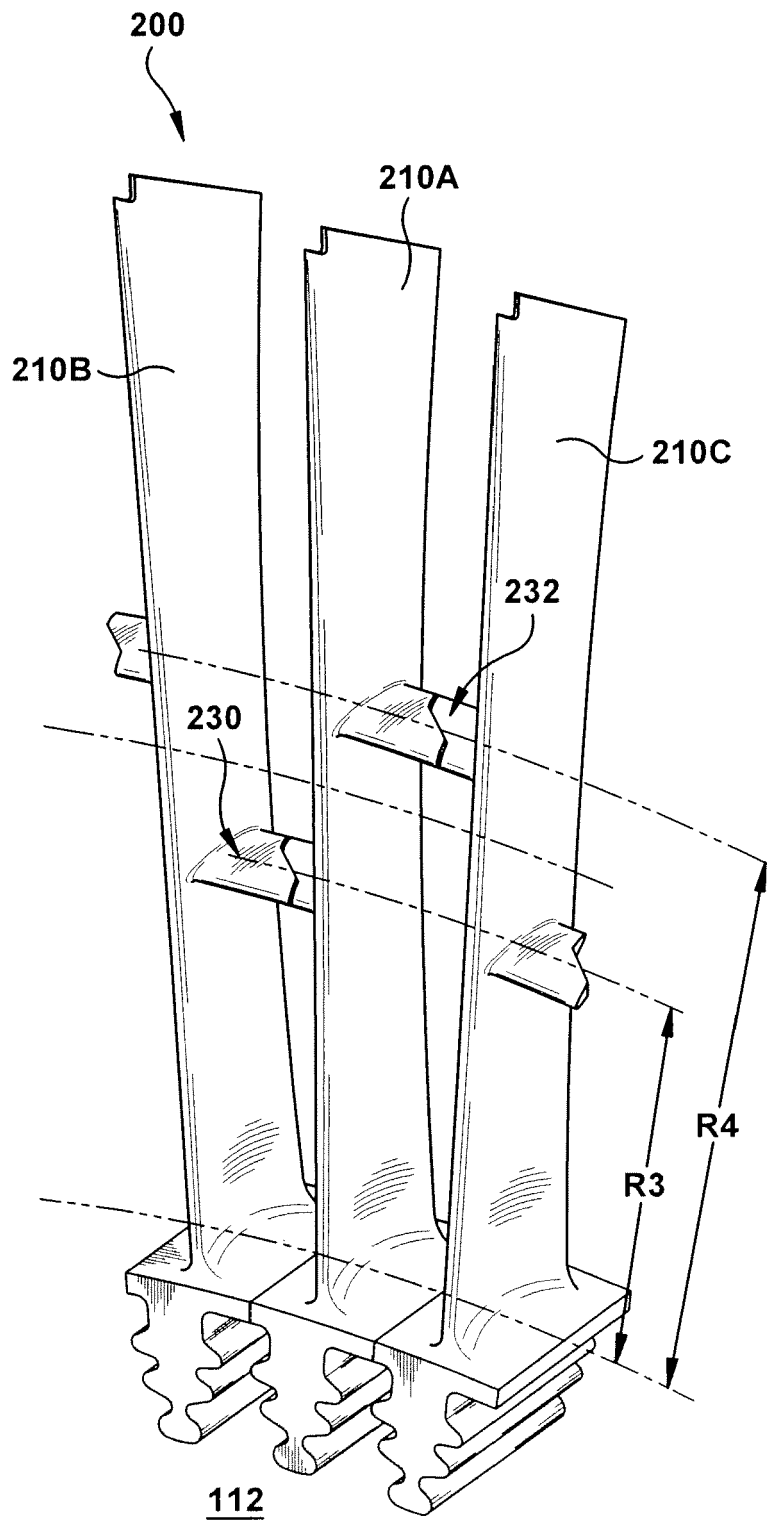


FIG. 4

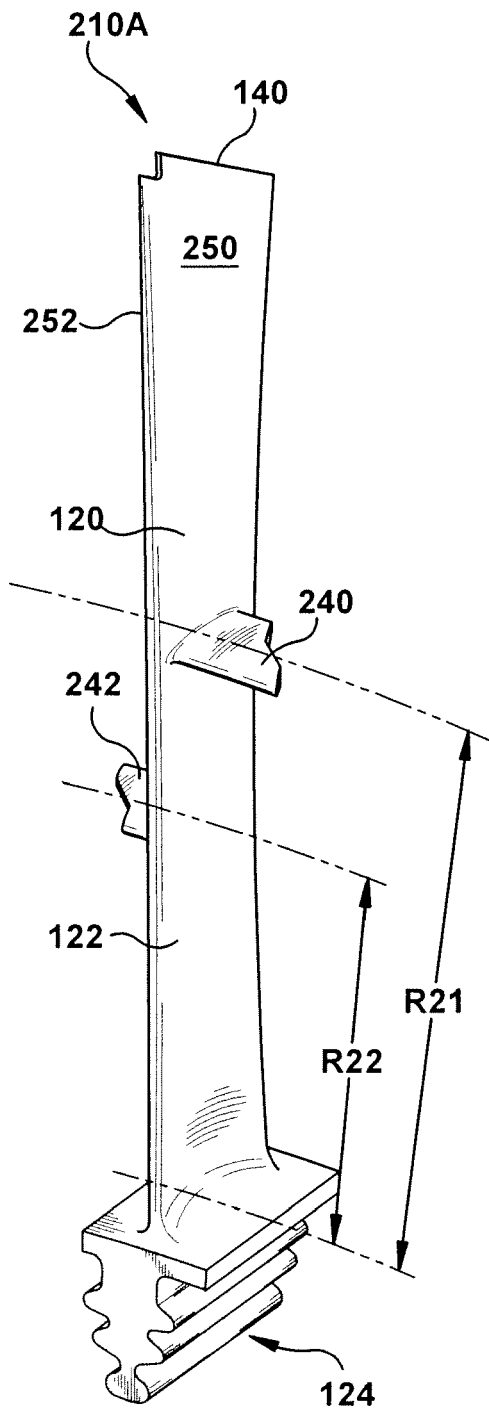


FIG. 5

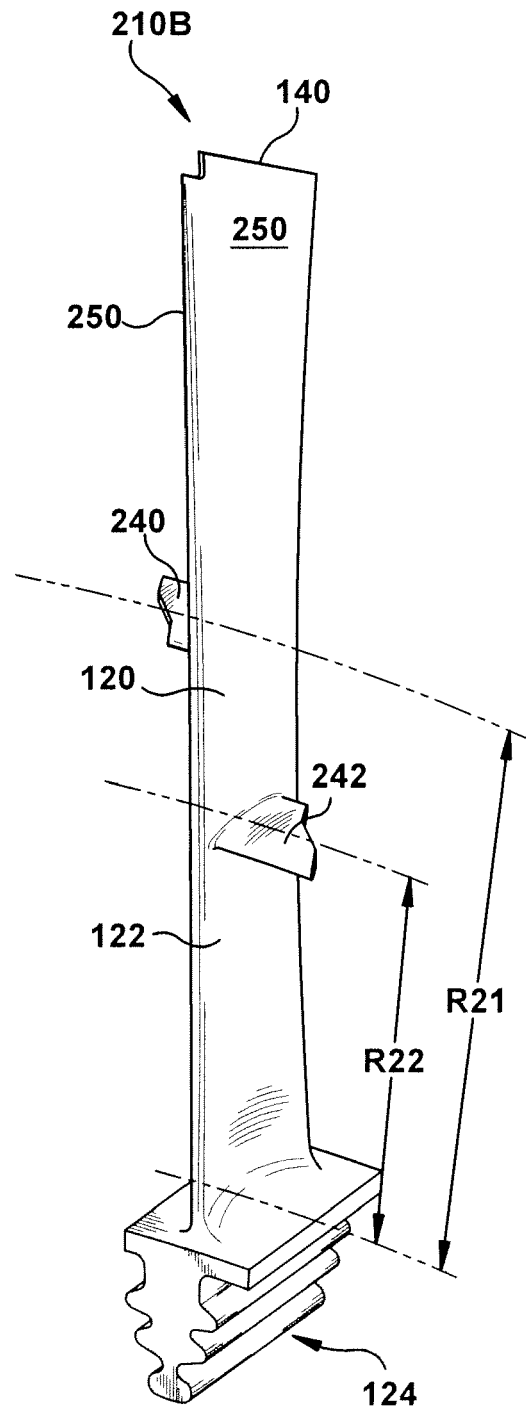
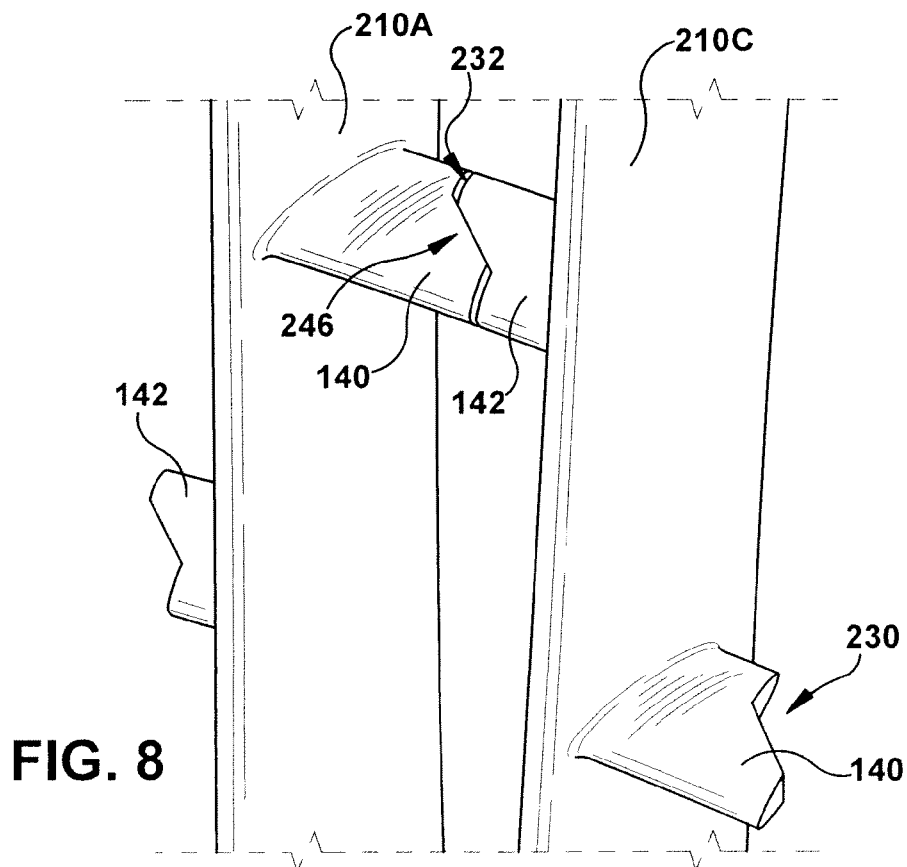
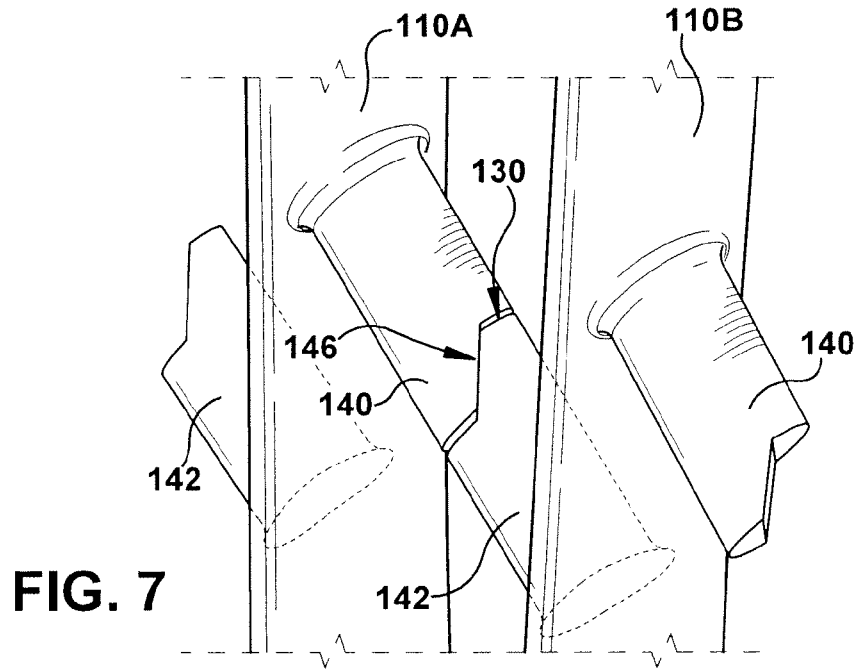


FIG. 6



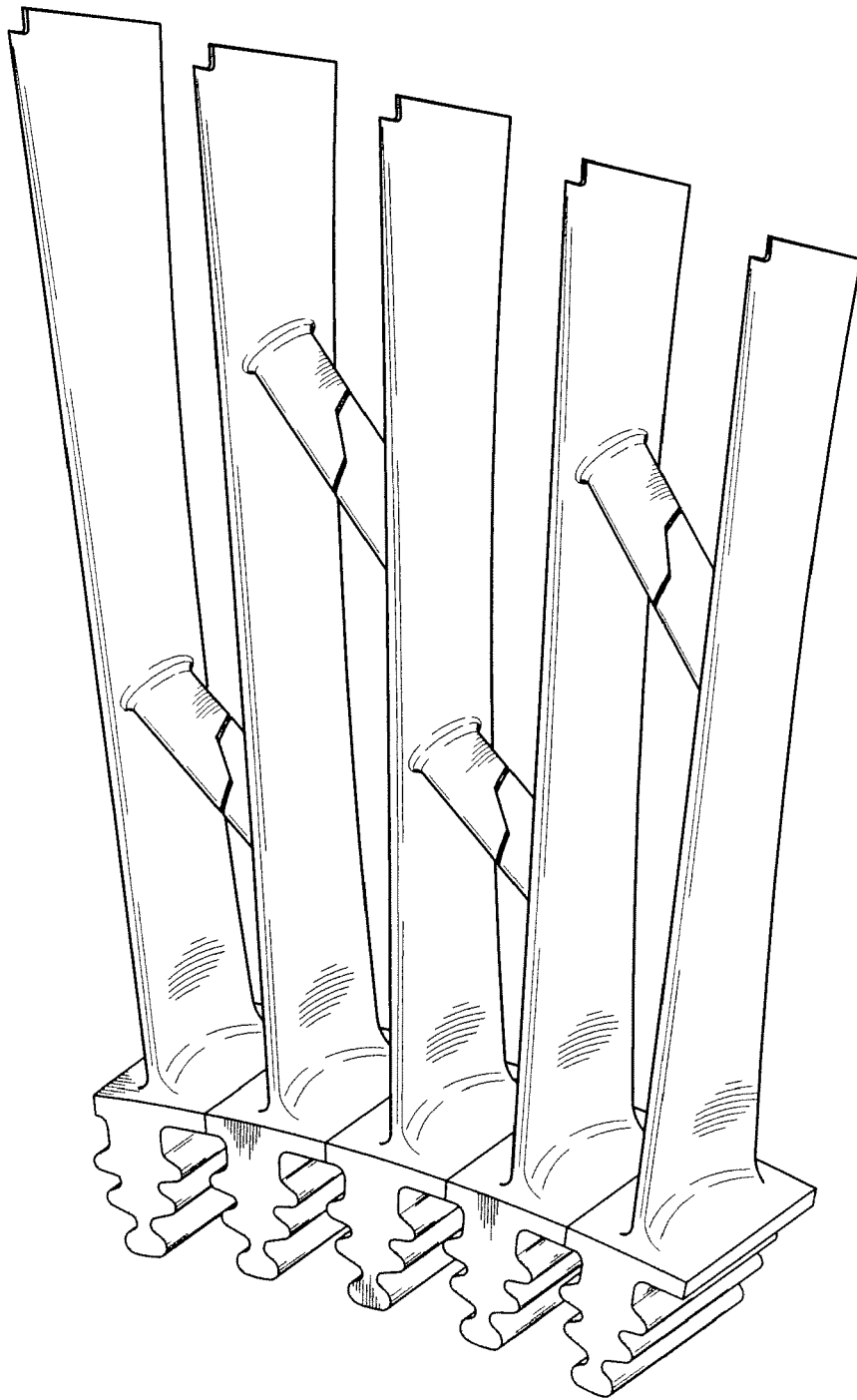


FIG. 9

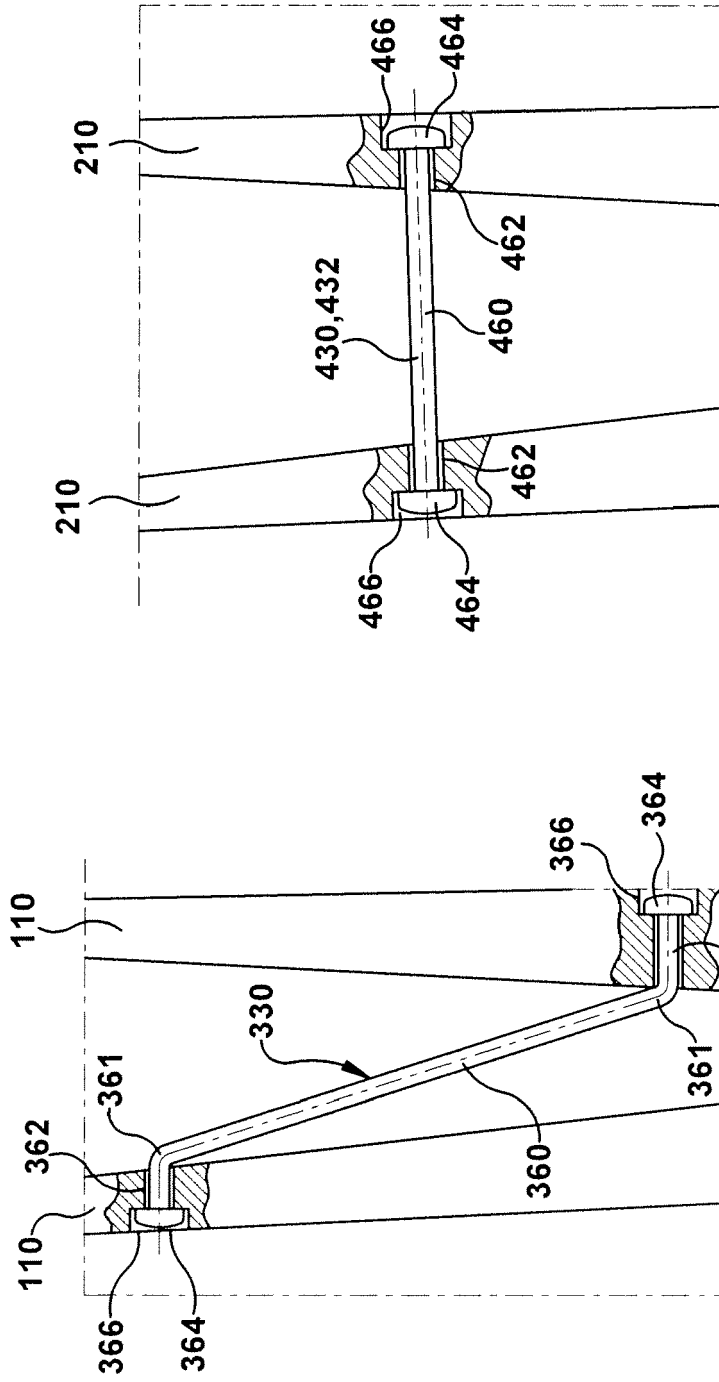


FIG. 11

FIG. 10