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(54) **BLADE HAVING ASYMMETRICAL MID-SPAN STRUCTURE PORTIONS AND RELATED BLADED WHEEL STRUCTURE**

(75) Inventor: **Dmitriy Victorovich Krikunov**, Moscow (RU)

(73) Assignee: **GENERAL ELECTRIC COMPANY**, Schenectady, NY (US)

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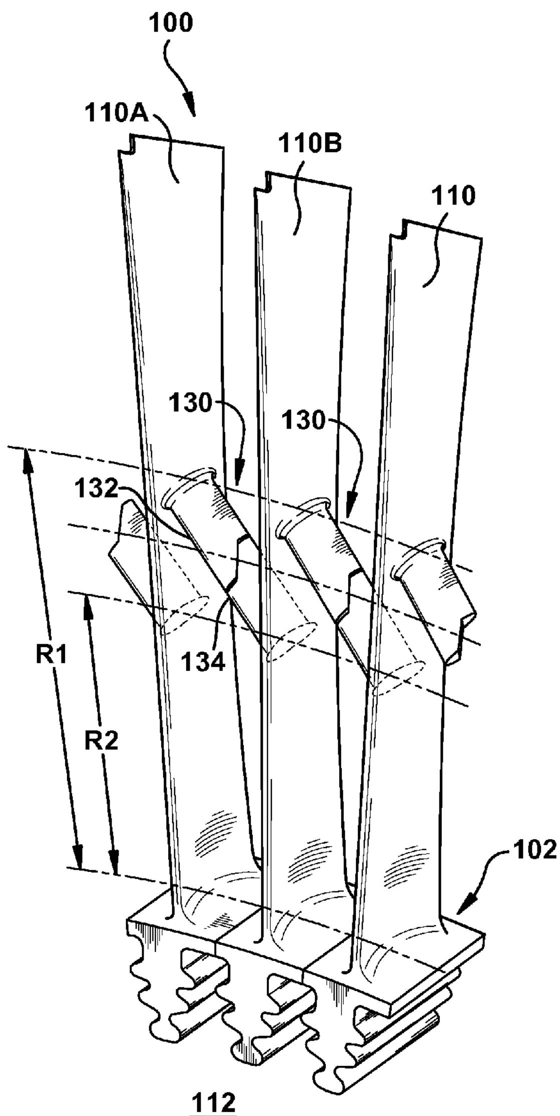
(57) **ABSTRACT**

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.



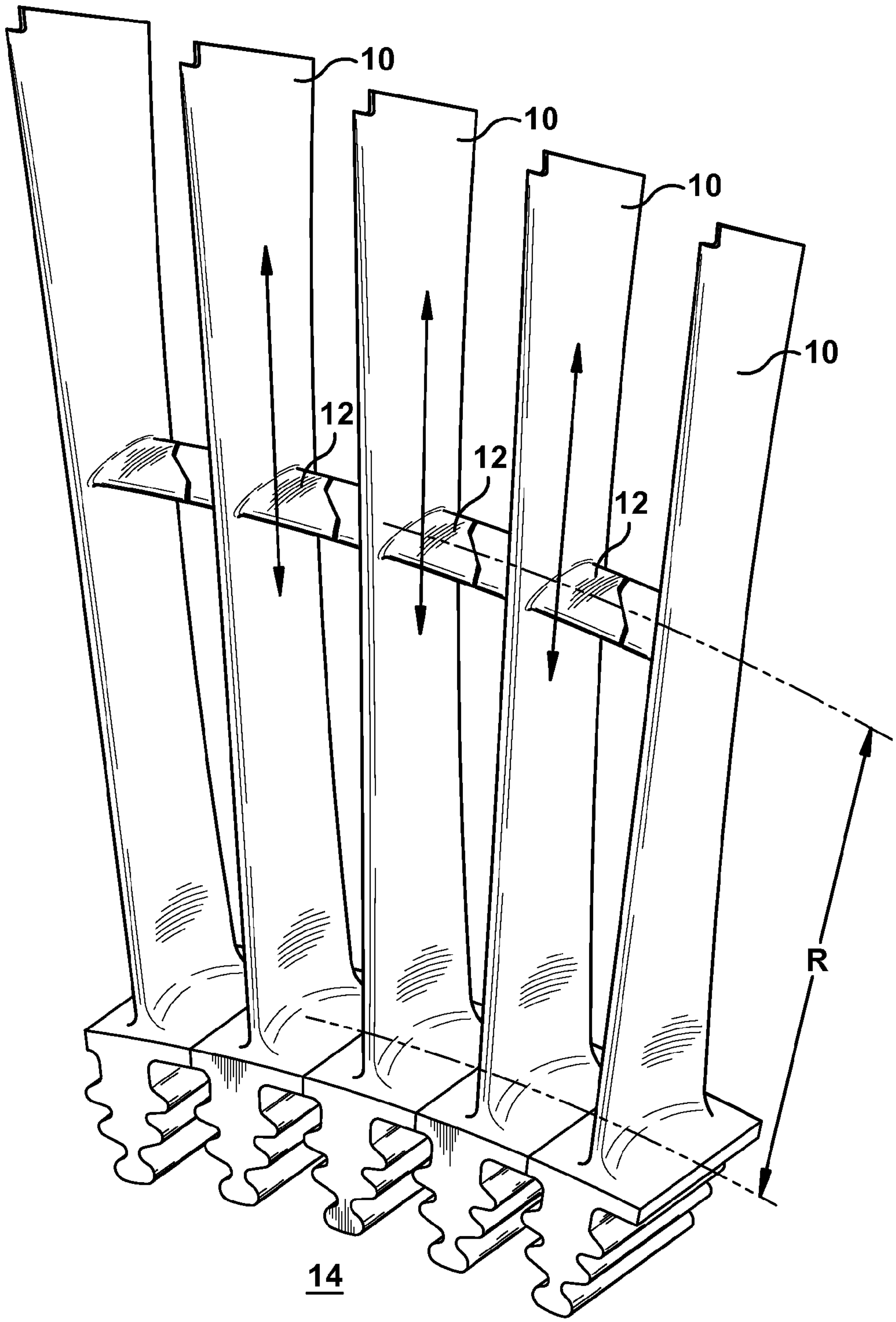


FIG. 1
(Prior Art)

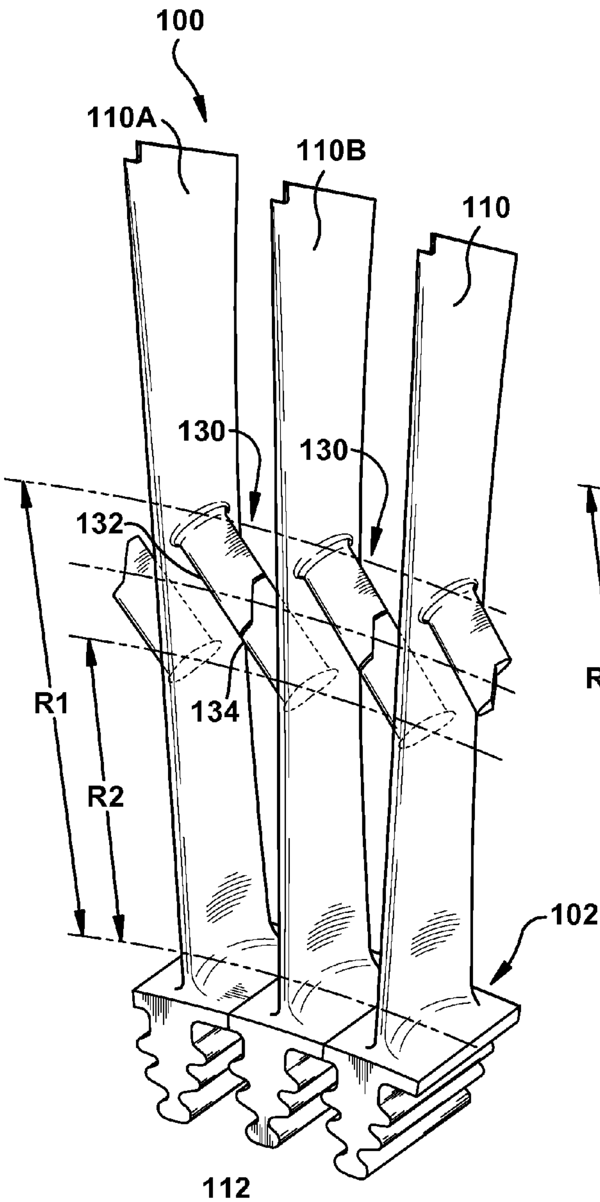

100
110A
110B
110
130
130
132
134
R1
R2
102
112

FIG. 2

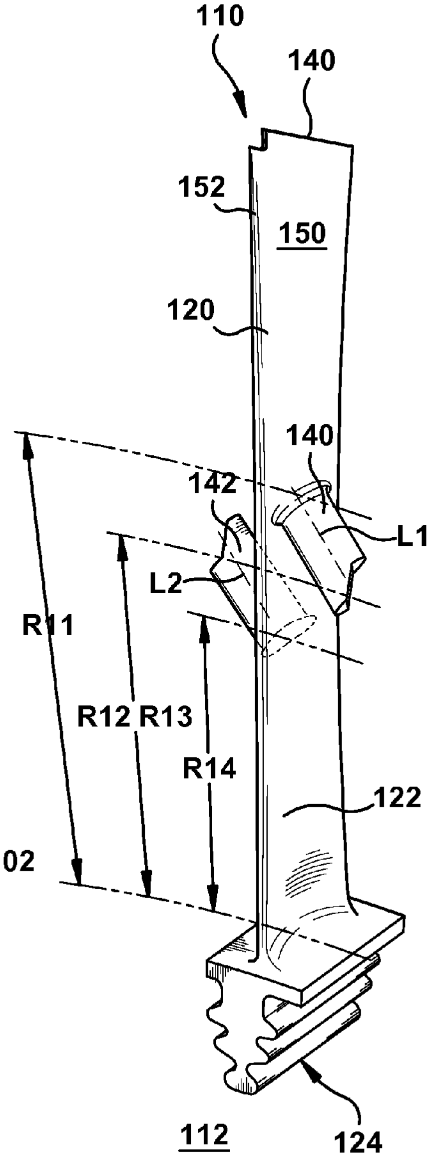

110
140
152
150
120
140
142
L1
L2
R11
R12 R13
R14
122
112
124

FIG. 3

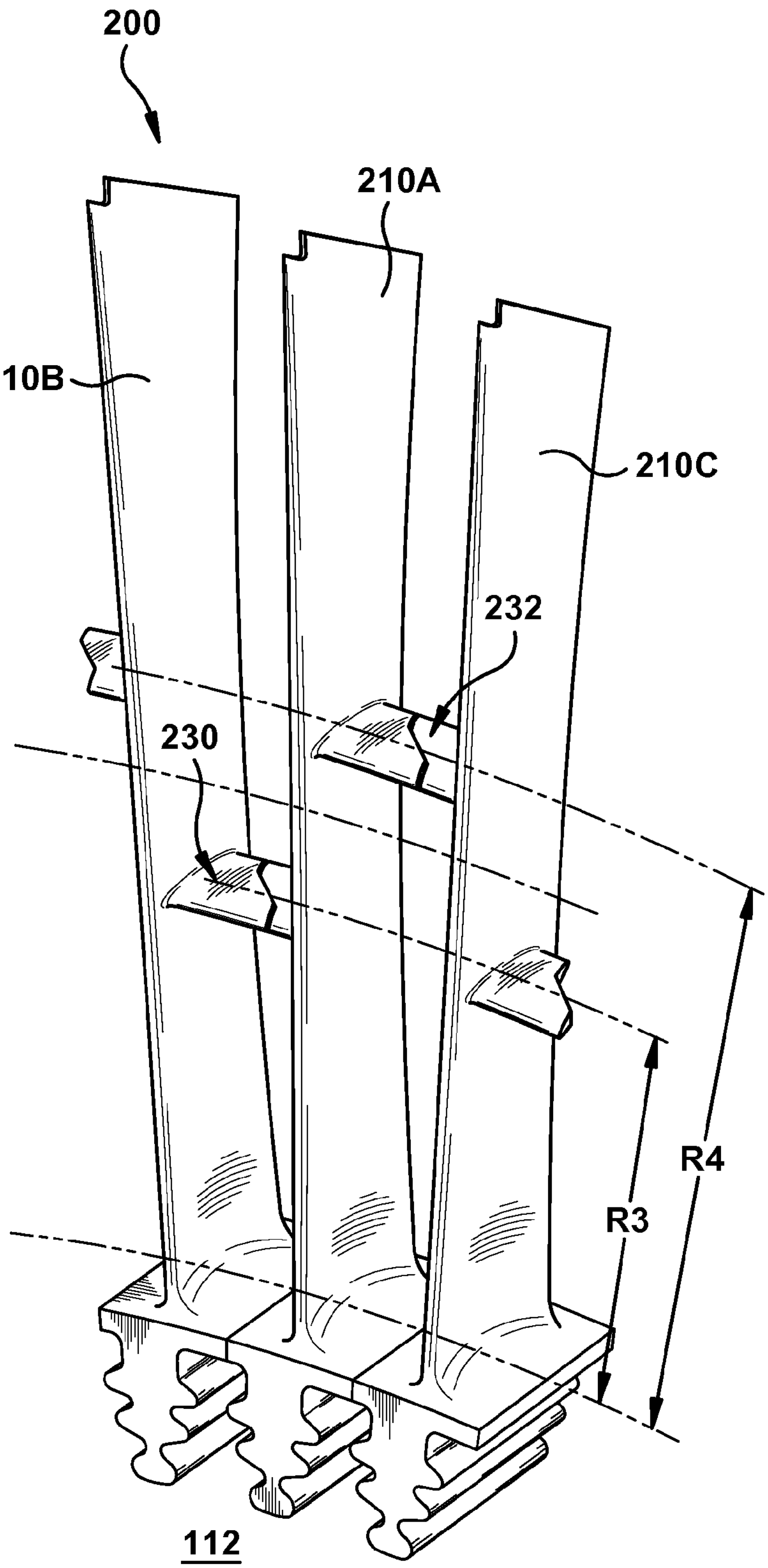


FIG. 4

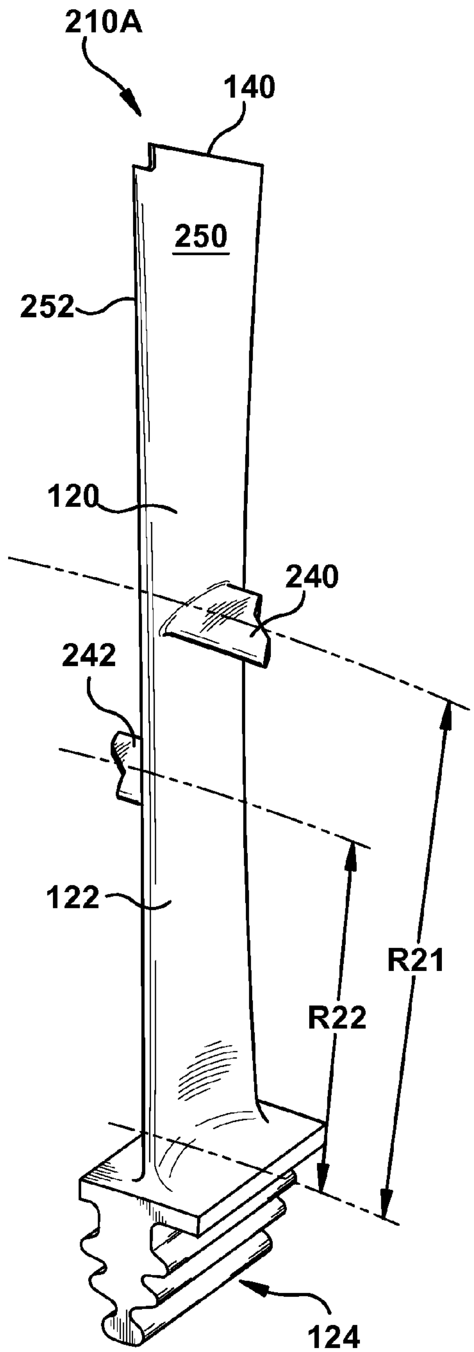

210A
140
250
252
120
240
242
122
R21
R22
124

FIG. 5

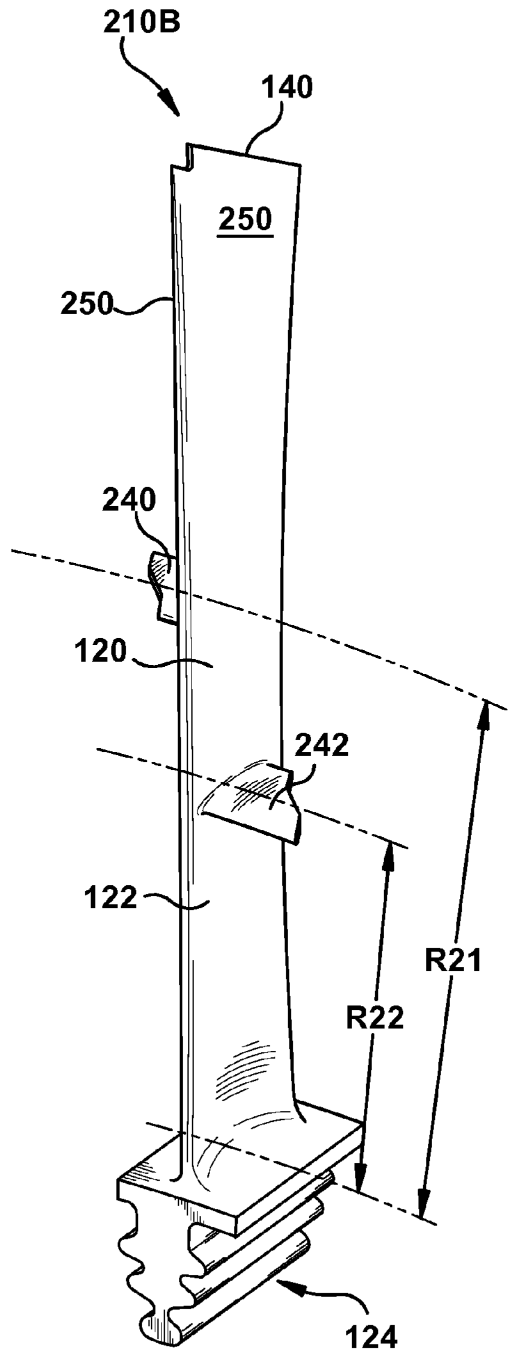

210B
140
250
250
240
120
242
122
R21
R22
124

FIG. 6

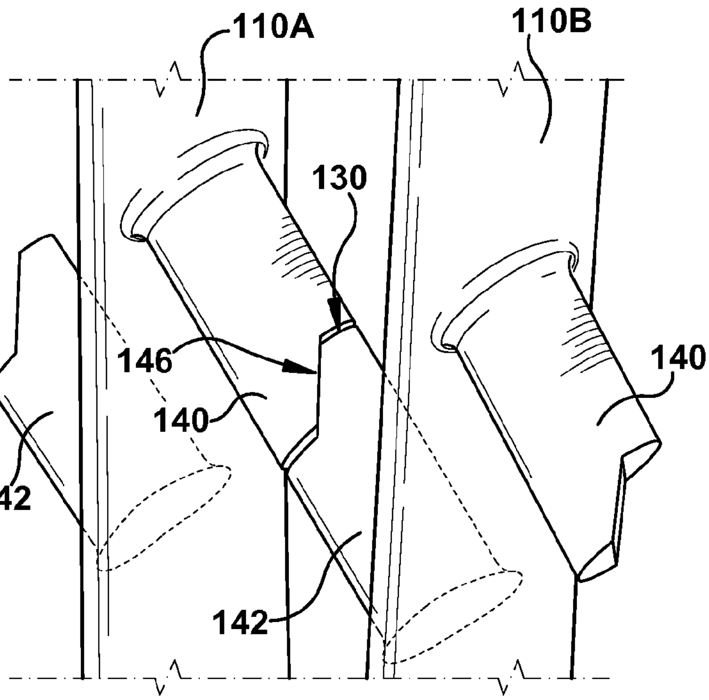

110A
110B
130
146
140
140
142
142

FIG. 7

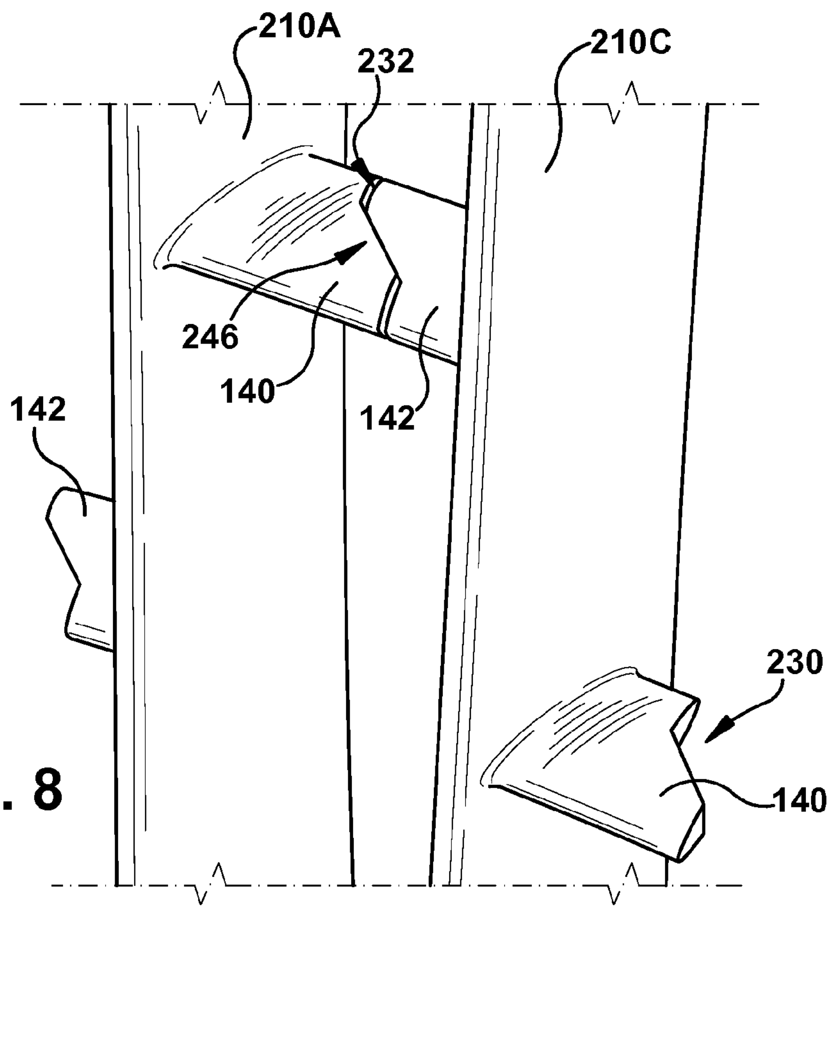

210A
232
210C
246
140
142
142
230
140

FIG. 8

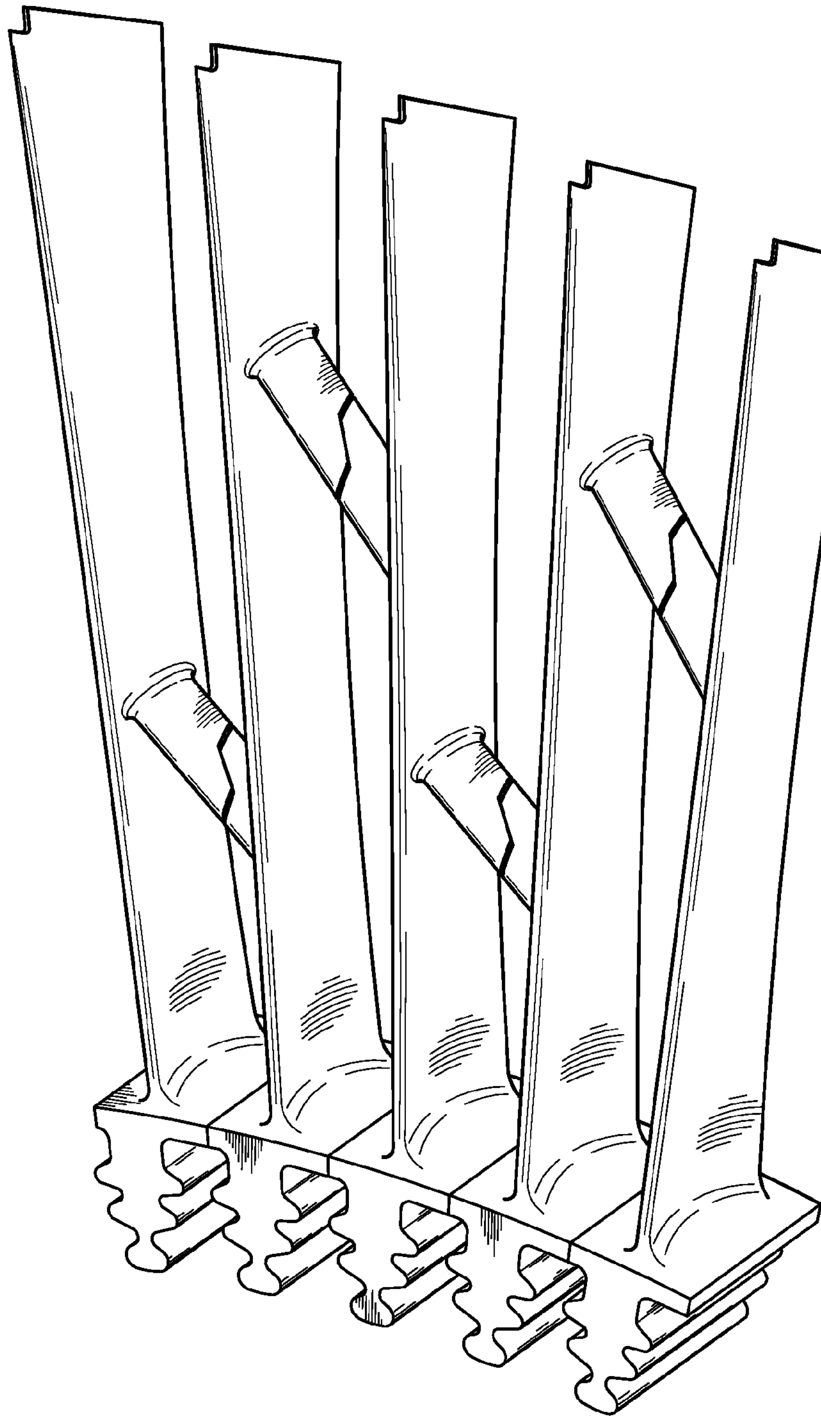


FIG. 9

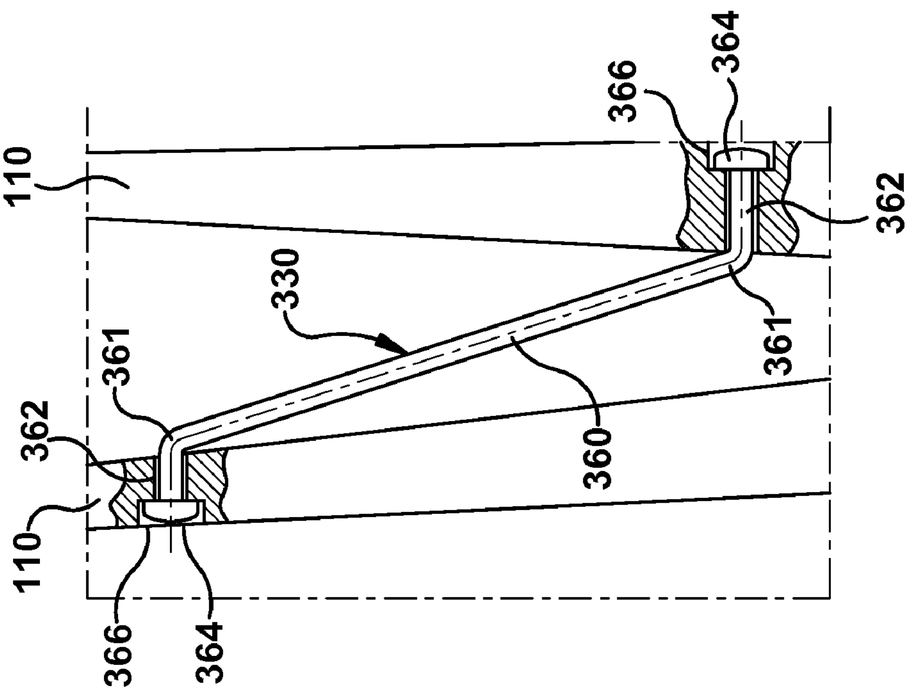

110
110
362
361
330
360
361
362
366
364
366
364

FIG. 10

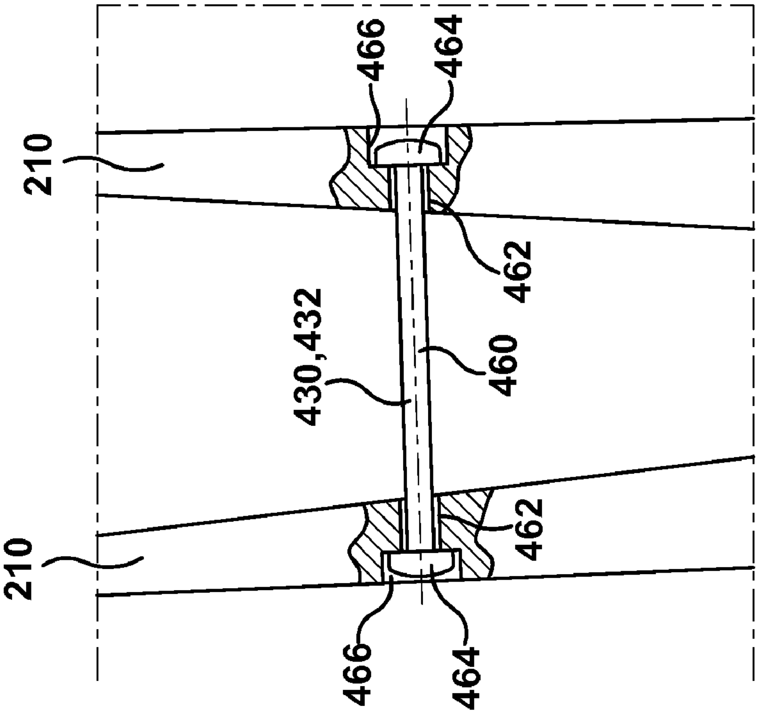

210
210
430,432
460
462
462
466
464
466
464

FIG. 11

BLADE HAVING ASYMMETRICAL MID-SPAN STRUCTURE PORTIONS AND RELATED BLADED WHEEL STRUCTURE

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:

[0007] FIG. **1** shows a schematic view of a conventional bladed wheel configuration.

[0008] FIG. **2** shows a perspective view of a bladed wheel structure according to embodiments of the invention.

[0009] FIG. **3** shows a perspective view of a blade of FIG. **2** including mid-span structure portions according to embodiments of the invention.

[0010] FIG. **4** shows a schematic view of a bladed wheel structure according to other embodiments of the invention.

[0011] 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.

[0012] 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.

[0013] FIG. **9** shows a perspective view of a combination of the FIGS. **2** and **4** embodiments.

[0014] FIGS. **10** and **11** show side views of alternative wire mid-span structures according to embodiments of the invention.

[0015] 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

[0016] 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.

[0017] 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.

[0018] 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.

[0019] 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 R**1** relative to hub **112** on a first blade (e.g., **110**A) and a second end **134** having a second radial position R**2** relative to hub **112** different than first radial position R**1** on a second blade (e.g., **110**B) that is adjacent to first blade (e.g., **110**A). 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 R**1** and R**2** 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**.

[0020] 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 R**3** relative to hub **112** between a first blade **210**A and a second blade **210**B adjacent to first blade **210**A. In addition, a second mid-span structure **232** may be positioned at a second radial position R**4** relative to hub **112** different than first radial position R**1** between first blade **210**A and a third blade **210**C adjacent to first blade **210**A. 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 R**3** and R**4** 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**.

[0021] 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.

[0022] 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.

[0023] 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 R**11** relative to hub **112** (FIG. **2** only) (or root **124** thereof) and a second end having a second radial position R**12** relative to hub **112** (or root **124** thereof) that is different than first radial position R**11**. Similarly, second mid-span structure portion **142** may include a first end having a third radial position R**13** relative to hub **112** (or root **124** thereof) and a second end having a fourth radial position R**14** relative to hub **112** (or root **124** thereof) that is different than third radial position R**13**. In one embodiment, first radial position R**11** of the first end of first mid-span structure portion **140** is greater than fourth radial position R**14** of the second end of second mid-span structure portion **142**, and second radial position R**12** and third radial position R**13** 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.

[0024] In the FIGS. **5** and **6** embodiment, each mating blade **210**A (FIG. **5**) and **210**B (FIG. **6**) includes a first mid-span structure portion **240** extending from a first side **250** of body **120** at a first radial position R**21**, and second mid-span structure portion **242** extending from a second side **252** of body **120** at a second radial position R**22** different than first radial position R**21**. 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 R**21**, R**22** can be configured to detune resonant frequency vibrations.

[0025] 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 FIGS. **7** and **8** would not be necessary as the end of each portion would simply mate with body **120**.

[0026] 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.

[0027] 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.

[0028] 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.

What is claimed is:

1. A bladed wheel structure comprising:

a bladed wheel including a plurality of circumferentially spaced blades extending from a hub;

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.

2. The bladed wheel structure of claim **1**, wherein the non-uniform radial position arrangement includes each mid-span structure extending obliquely relative to each adjacent blade.

3. The bladed wheel structure of claim **1**, wherein the non-uniform radial position arrangement includes each mid-span structure having a first end having a first radial position relative to the hub on a first blade and a second end having a second radial position relative to the hub different than the first radial position on a second blade that is adjacent to the first blade.

4. The bladed wheel structure of claim **1**, wherein the non-uniform radial position arrangement includes a first mid-span structure positioned at a first radial position relative to the hub between a first blade and a second blade adjacent to the first blade, and a second mid-span structure positioned at a second radial position relative to the hub different than the first radial position between the first blade and a third blade adjacent to the first blade.

5. The bladed wheel structure of claim **1**, wherein the non-uniform radial position arrangement is configured to detune resonant frequency vibrations.

6. The bladed wheel of claim **1**, wherein each mid-span structure includes a wire extending between the adjacent blades.

7. 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.

8. The blade of claim **7**, wherein the asymmetrical manner in which the first and second mid-span structure portions extend from the body is configured to detune resonant frequency vibrations.

9. The blade of claim **7**, wherein the first mid-span structure portion includes a longitudinal axis that extends at an oblique angle from a first side of the body, and the second mid-span structure portion includes a longitudinal axis that extends at an oblique angle from a second side of the body such that the first and second mid-span structure portions of adjacent blades mate.

10. The blade of claim **8**, wherein the oblique angles in which the first and second mid-span structure portions extend from the body are configured to detune resonant frequency vibrations.

11. The blade of claim **7**, 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 claim **7**, 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.

* * * * *