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(71) Applicant: **General Electric Company**
Schenectady, NY 12345 (US)

(72) Inventors:
- **Vitron, Christen Andrew**
  Clifton Park, NY 12065 (US)
- **Farineau, Thomas J.**
  Schoharie, NY 12157 (US)

(74) Representative: **Gray, Thomas**
GE International Inc.
Global Patent Operation - Europe
15 John Adam Street
London WC2N 6LU (GB)

(54) **Gas turbine bucket dovetail**

(57) Tangential entry dovetail cantilever load sharing is described herein. In one embodiment, a turbine bucket dovetail (210) is provided that facilitates substantially even distribution of centrifugal loads on a plurality of hooks (250) that define the bucket dovetail (210).

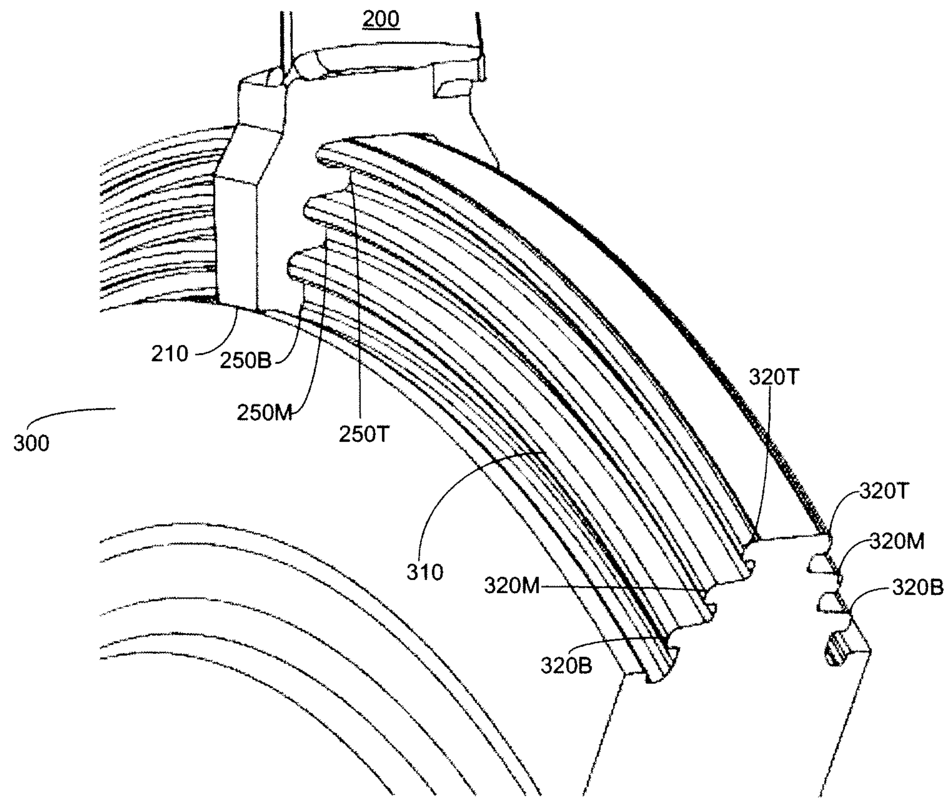

FIG. 3

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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to a steam turbine and more particularly to a dovetail design for attaching a steam turbine bucket to a steam turbine rotor wheel.

[0002] Generally steam turbine buckets and steam turbine rotor wheels in the latter stages of a low pressure turbine are usually highly stressed during operation due to large centrifugal loads applied by the rotation of longer and heavier latter stage buckets. In particular, large centrifugal loads are placed on the buckets due to the high rotational speed of the rotor wheels which in turn stress the blades. These loads induce higher average and local stresses in the connective dovetails that attach the buckets to the rotor wheels. These stresses along with moisture from the steam flow path of the steam turbine drive stress corrosion cracking. Both the higher average and local stress concentrations can lead to lower fatigue life and stress corrosion of turbine rotor wheels and dovetails. Reducing stress concentrations and stress corrosion cracking in the dovetails under large centrifugal loads is a design challenge for steam turbine manufacturers, especially as the demand for longer blades increases.

BRIEF DESCRIPTION OF THE INVENTION

[0003] In one aspect of the present invention, a bucket dovetail for securing a bucket to a rotor wheel is provided. The dovetail comprises a plurality of hooks that connect the bucket with the rotor wheel. The plurality of hooks are shaped to distribute centrifugal loads placed on the bucket in a substantially even distribution among each of the plurality of hooks.

[0004] In another aspect of the present invention, there is a turbine rotor that includes a plurality of turbine buckets coupled with a rotor wheel. Each turbine bucket comprises a bucket dovetail having a plurality of bucket dovetail hooks. The rotor wheel comprises a wheel post dovetail shaped with wheel post dovetail hooks to engage with the bucket dovetail hooks of each bucket dovetail. The connection of the plurality of bucket dovetail hooks from each bucket dovetail with the wheel post dovetail hooks forms at least one pocket therebetween to facilitate substantial sharing of centrifugal loads placed on the turbine bucket by the plurality of bucket dovetail hooks.

[0005] In a third aspect of the present invention, there is a bucket dovetail for securing a bucket to a rotor wheel. In this embodiment, the dovetail comprises a plurality hooks that connect the bucket with the rotor wheel. The plurality of hooks are shaped to distribute centrifugal loads placed on the bucket in a desired distribution among each of the plurality of hooks, wherein the desired distribution subjects each of the plurality of hooks to a predetermined amount of centrifugal load and stress.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] There follows a detailed description of embodiments of the invention by way of example only with reference to the accompanying drawings, in which:

FIG. 1 is a schematic diagram of an exemplary opposed-flow steam turbine engine;

FIG. 2 is a schematic perspective illustration of a bucket with dovetail that may be used with the steam turbine shown in FIG. 1 according to one embodiment of the present invention;

FIG. 3 is a schematic perspective illustration showing a turbine rotor wheel engaging with the bucket dovetail shown in FIG. 2 according to one embodiment of the present invention;

FIG. 4 is a schematic front view showing the attachment of a bucket dovetail to a turbine rotor wheel according to the prior art; and

FIG. 5 is a schematic front view showing the attachment of the bucket dovetail shown in FIG. 2 to the turbine rotor wheel shown in FIG. 3 according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0007] Referring to the drawings, FIG. 1 shows a schematic diagram of an exemplary opposed-flow steam turbine 100. Turbine 100 includes a first low pressure (LP) section 105 and a second LP section 110. As is known in the art, each LP section 105 and 110 includes a plurality of stages of diaphragms (not shown in FIG. 1). In one embodiment of the present invention, each LP section 105 and 110 comprises five stages. The five stages are referred to as L0, L1, L2, L3 and L4. The L4 stage is the first stage and is the smallest (in a radial direction) of the five stages. The L3 stage is the second stage and is the next stage in an axial direction. The L2 stage is the third stage and is in the middle of the five stages. The L1 stage is the fourth and next-to-last stage. The L0 stage is the last stage and is the largest (in a radial direction). It is to be understood that five stages are shown as one example only, and LP sections 105 and 110 can have more or less than five stages.

[0008] A rotor shaft 115 extends through LP sections 105 and 110. Each LP section 105 and 110 includes a nozzle 120 and 125, respectively. A single outer shell or casing 130 is divided along a horizontal plane and axially into upper and lower half sections 135 and 140, respectively, and spans both LP sections 105 and 110. A central section 145 of shell 130 includes a low pressure steam inlet 150. Within outer shell or casing 130, LP sections 105 and 110 are arranged in a single bearing span supported by journal bearings 155 and 160. A flow splitter 165 extends between LP sections 105 and 110.

[0009] During operation, low pressure steam inlet 150 receives low pressure/intermediate temperature steam 170 from a source, such as, but not limited to, a high pressure (HP) turbine or an intermediate (IP) turbine through a cross-over pipe (not shown). Steam 170 is channeled through inlet 150 wherein flow splitter 165 splits the steam flow into two opposite flow paths 175 and 180. More specifically, in the exemplary embodiment, steam 170 is routed through LP sections 105 and 110 wherein work is extracted from the steam to rotate rotor shaft 115. The steam exits LP sections 105 and 110 where it is routed for further processing (e.g., to a condenser).

[0010] It should be noted that although FIG. 1 illustrates an opposed-flow, LP turbine, as will be appreciated by one of ordinary skill in the art, the present invention is not limited to being used only with LP turbines and can be used with any opposed-flow turbine including, but not limited to, IP turbines and/or HP turbines. In addition, the present invention is not limited to only being used with opposed-flow turbines, but rather may also be used with other turbines (e.g., single flow steam turbines).

[0011] FIG. 2 is a schematic perspective illustration of a bucket 200 with dovetail 210 that may be used with the steam turbine shown in FIG. 1 according to one embodiment of the present invention. As shown in FIG. 2, dovetail 210 is a tangential entry dovetail with a three hook design having six contact surfaces configured to engage with a turbine rotor wheel 300 (shown in FIG. 3). Although the description that follows is for a tangential entry dovetail with a three hook design, the principles of the present invention are not limited to such a configuration and are suitable for use with a tangential entry dovetail that has less than or more than three hooks. Referring back to FIG. 2, dovetail 210 comprises six bucket dovetail hooks 250 (collectively 250T, 250M and 250B) with two hooks 250T located at a top section of dovetail 210, two hooks 250M at a middle section of dovetail 210, and two hooks 250B at a bottom section of dovetail 210. Hooks 250T, 250M and 250B are located in the radial direction such that dovetail 210 is inserted in rotor wheel 300 (FIG. 3) radially and then slid tangentially into place.

[0012] In one embodiment, hooks 250T and 250M are shaped to form a cantilever to distribute centrifugal pull loads that are placed on bucket 200 as a result of high rotational speeds obtained by rotor wheel 300. These centrifugal loads induce stresses in bucket 200 which minimize its life expectancy of use. A top portion of hooks 250T and 250M is defined by a radius 260 and a flat depth 270. The distribution of the centrifugal loads by hooks 250T and 250M is a function of the radius and/or flat depth. In particular, an increase in radius 260 and/or an increase in the flat depth section 270 will be proportional to a decrease in the centrifugal load that is placed on hooks 250T and 250M. Likewise, the stress that the centrifugal loads will have on the cantilever is a function of the radius 260 and/or flat depth 270. In particular, an increase in radius 260 and/or an increase in flat depth 270 will be proportional to a decrease in the stress that is experienced by hooks 250T and 250M. In one embodiment, radius 260 ranges from about 2 millimeters (0.079 inches) to about 8 millimeters (0.31 inches), while flat depth 270 ranges from about 2 millimeters (0.079 inches) to about 9 millimeters (0.35 inches). Those skilled in the art will recognize that the values selected for radius 260 and flat depth 270 will depend on how much centrifugal load and stress is desired for a particular hook, and thus values may vary from one dovetail design to the next.

[0013] FIG. 3 is a schematic perspective illustration of a portion of a turbine rotor wheel 300 engaging with dovetail 210 shown in FIG. 2 according to one embodiment of the present invention. As shown in FIG. 3, rotor wheel 300 comprises a wheel post dovetail 310 having a wheel post gate opening (not shown) in which bucket 200 and other buckets of a turbine rotor are slid into position therewith. Wheel post dovetail comprises six wheel post dovetail hooks 320 (collectively 320T, 320M and 320B), with two hooks 320T located in a top section of wheel post dovetail 310, two hooks 320M in a middle section of wheel post dovetail 310, and two hooks 320B in a bottom section of wheel post dovetail 310. In this configuration, once bucket 200 and other buckets of a turbine rotor have been inserted in the wheel post gate opening (not shown), the buckets are slid tangentially into place such that hooks 250T, 250M and 250B of bucket dovetail 210 mate or engage with hooks 320T, 320M and 320B of wheel post dovetail 310, respectively.

[0014] When operational, bucket 200 and the other buckets that form the turbine rotor are subject to large centrifugal pull loads due to the high rotational speed of rotor wheel 300 which in turn stresses the buckets. In a conventional bucket assembly, it has been determined herein that most of the load is concentrated on the top bucket dovetail hooks of the dovetail as compared to the hooks of the other sections of the dovetail. As a result, the bucket will be subject to higher stresses at the top section of bucket dovetail hooks which limit how much load the bucket dovetail can actually carry. Sometimes, the actual load may be less than what the bucket dovetail was designed to carry. Further, such higher stresses will diminish the overall life of the turbine bucket.

[0015] Embodiments of the present invention overcome these load problems by ensuring that the centrifugal loads are shared by all of the bucket dovetail hooks in the dovetail and not concentrated on only one section of bucket dovetail hooks. In particular, by having hooks 250T and 250M form a cantilever, the centrifugal loads are distributed substantially even among all of the hooks (i.e., 250T, 250M, 250B). As used herein, centrifugal loads that are distributed substantially even mean that the load on any hook is within about 15% of the load placed on any of the other bucket dovetail hooks. By using radius and flat depth values in the ranges identified above, hooks 250T and 250M become longer, which makes them less stiff and more flexible. Furthermore, as will be shown below, such values will result in the formation of pockets at locations where bucket dovetail hooks 250T and 250M of dovetail 210 engage with wheel post dovetail hooks 320T and 320M, respectively. These pockets form because the values of the radius and flat depth of bucket dovetail hooks 250T and 250M change with respect to the values of the radius and flat depth of wheel post dovetail hooks 320T and 320M. A conventional assembly of bucket dovetails to the wheel post dovetail will not have pockets as herein because the dimensions of the bucket dovetail hooks and wheel post dovetail hooks are substantially similar. As a result of the configuration described herein, embodiments of the present invention are able to distribute the loads substantially even among all of the bucket dovetail hooks (e.g., 250T, 250M, 250B) as compared to the conventional assembly which has the loads concentrated on the top hooks of the bucket dovetail.

[0016] A comparison of the difference between the assembly of the bucket dovetail hooks to the wheel post dovetail hooks is illustrated in FIGS. 4-5. In particular, FIG. 4 is a schematic front view 400 showing the attachment of a bucket dovetail 410 to turbine rotor wheel 300 according to the prior art, and FIG. 5 is a schematic front view 500 showing the attachment of the bucket dovetail 210 shown in FIG. 2 to turbine rotor wheel 300 shown in FIG. 3 according to one embodiment of the present invention. As shown in FIG. 4, bucket dovetail 410 comprises bucket dovetail hooks 420 which include top hooks 420T, middle hooks 420M and bottom hooks 420B. The values for the radius and flat depth for bucket dovetail hooks 420T and 420M and wheel post dovetail hooks 320T and 320M are similar and therefore engage continuously (i.e., closely mated). As a result of this configuration, bucket dovetail hooks 420T and 420M are shorter and stiffer. In comparison, the assembly of bucket dovetail 210 to wheel post dovetail 310 as shown in FIG. 5 has the formation of pockets 510 in the regions about the bucket dovetail hooks 250T and 250M and wheel post dovetail hooks 320T and 320M, respectively, because of the cantilever shaped hooks 250T and 250M. In particular, because the radius and flat depth of bucket dovetail hooks 250T and 250M have increased with respect to the wheel post dovetail hooks, pockets 510 are formed thereabout. Note that the dimension for hooks 250B are essentially the same as the dimension for hooks 420B (FIG. 4). Because of this type of modification made to hooks 250T and 250M, bucket dovetail 210 is able to substantially distribute or share the loads more evenly about all of the hooks. As a result, there is less stress on the hooks of both the bucket dovetail 210 and wheel post dovetail 310.

[0017] The below table shows an example of results comparing the load sharing and stresses associated with the bucket dovetail 410 shown in FIG. 4 and the bucket dovetail 210 shown in FIGS. 2 and 5.

	Load Sharing (lbf)		**Local Bucket Von Mises Stress (psi)**		**Local Wheel Von Mises Stress (psi)**	
	Prior Art Dovetail	Present Invention Dovetail	Prior Art Dovetail	Present Invention Dovetail	Prior Art Dovetail	Present Invention Dovetail
Top hooks	47,700	36,500	198,700	144,900	173,100	134,400
Middle hooks	37,000	38,300	160,800	127,700	130,600	140,600
Bottom hooks	34,000	42,200	122,900	155,100	129,300	159,100

[0018] As shown in the table, the load on the hooks of the prior art bucket dovetail shown in FIG. 4 is not distributed such that the hooks substantially shared the load. In this instance, most of the load is on the top bucket dovetail hooks (47,700 lbf), while the load on the middle bucket dovetail hooks (37,000 lbf) and bottom bucket dovetail hooks (34,000 lbf) is substantially less. The stress on the turbine bucket (local bucket Von Mises) and the stress on the rotor wheel (local wheel Von Mises) at each of their respective hooks are relative to the amount of load that is carried. For instance, the table indicates that the stress at the top hooks of the bucket dovetail of the prior art is 198,700 psi, while the stress at the middle hooks and bottom hooks of the bucket dovetail is 160,800 psi and 122,900 psi, respectively. The stress at the wheel post dovetail hooks of the rotor wheel is 173,100 psi for the top hooks, 130,600 psi for the middle hooks and 129,300 psi for the bottom hooks. When the hooks of the bucket dovetail 210 are modified in the configuration described herein, the result is a load sharing distribution that is substantially even among the bucket dovetail hooks and stresses that are substantially less at both the bucket dovetail and the wheel post dovetail. For example, the table shows that the load on the top hooks of the bucket dovetail 210 decreases from 47,700 lbf to 36,500 lbf, while the load on the middle hooks increases from 37,000 lbf to 38,300 lbf and the load on the bottom hooks increases from 34,000 lbf to 42,200 lbf. As a result, it is clear that the majority of the load is not on the top hooks and instead, the load is distributed such that the bucket dovetail hooks substantially share evenly in carrying the load. Therefore, it is possible to facilitate carrying higher centrifugal loads.

[0019] The benefits of this load sharing are felt in the stresses that are incurred by the hooks. For example, the table indicates that the stress at the top hooks of the bucket dovetail is 144,900 psi, while the stress at the middle hooks and bottom hooks of the bucket dovetail is 127,700 psi and 155,100 psi, respectively. The stress at the wheel post dovetail hooks of the rotor wheel is 134,400 psi for the top hooks, 140,600 psi for the middle hooks and 159,100 psi for the bottom hooks. As one can see, the maximum stress on the hooks of the bucket dovetail for the designs of the embodiments of the present invention is 155,100 psi, which is significantly less than 198,700 psi for the prior art design. And this maximum stress is on the bottom bucket dovetail hooks and not the top bucket dovetail hooks. Similarly, the maximum stress on the hooks of the wheel post dovetail for the designs of the embodiments of the present invention is 159,100 psi, which is less than 173,100 psi for the prior art design. Reducing stresses on the hooks for both the turbine bucket dovetail and the wheel post dovetail will lead to an increased life for both.

[0020] Note that although the results shown in the table were obtained by making modifications to bucket dovetail hooks 250T and 250M in the ranges described above, those skilled in the art will recognize that this is only an example and that one may obtain a desirable load distribution by modifying only the bucket dovetail hooks in the top hook section or the hooks in the middle hook section. Moreover, those skilled in the art will recognize that modifications to bucket dovetails that comprise more or less than three hooks will result in different possibilities for making modifications to the bucket dovetail hooks. Selection of such modifications will ultimately depend on the desired load distribution and the number of hooks in the bucket dovetail.

[0021] For completeness, various aspects of the invention are now set out in the following numbered clauses:

1. A bucket dovetail for securing a bucket to a rotor wheel, comprising:

   a plurality of hooks that connect the bucket with the rotor wheel, the plurality of hooks shaped to distribute centrifugal loads placed on the bucket in a substantially even distribution among each of the plurality of hooks.

2. The dovetail according to clause 1, wherein some of the plurality of hooks form a cantilever to distribute the centrifugal loads.

3. The dovetail according to clause 2, wherein a top portion of the cantilever is defined by a radius and a flat depth.

4. The dovetail according to clause 3, wherein distribution of centrifugal loads by the cantilever is a function of the radius and the flat depth.

5. The dovetail according to clause 4, wherein an increase in the radius and/or an increase in the flat depth is proportional to a decrease in the centrifugal load on the cantilever.

6. The dovetail according to clause 3, wherein stress caused by the centrifugal loads on the cantilever is a function of the radius and the flat depth.

7. The dovetail according to clause 6, wherein an increase in the radius and/or an increase in the flat depth is proportional to a decrease in the stress on the cantilever.

8. The dovetail according to clause 3, wherein the radius ranges from about 2 millimeters (0.079 inches) to about 8 millimeters (0.31 inches).

9. The dovetail according to clause 3, wherein the flat depth ranges from about 2 millimeters (0.079 inches) to about 9 millimeters (0.35 inches).

10. A turbine rotor including a plurality of turbine buckets coupled with a rotor wheel, each turbine bucket comprising a bucket dovetail having a plurality of bucket dovetail hooks, and the rotor wheel comprising a wheel post dovetail shaped with wheel post dovetail hooks to engage with the bucket dovetail hooks of each bucket dovetail, the connection of the plurality of bucket dovetail hooks from each bucket dovetail with the wheel post dovetail hooks

forms at least one pocket therebetween to facilitate substantial sharing of centrifugal loads placed on the turbine bucket by the plurality of bucket dovetail hooks.

11. The turbine rotor according to clause 10, wherein a top portion of each of the plurality of bucket dovetail hooks comprises a radius and a flat depth.

12. The turbine rotor according to clause 11, wherein the sharing of the centrifugal loads by each of the plurality of bucket dovetail hooks is a function of the radius and the flat depth.

13. The turbine rotor according to clause 11, wherein the amount of stress caused by the centrifugal loads on each of the plurality of bucket dovetail hooks is a function of the radius and the flat depth.

14. The turbine rotor according to clause 11, wherein the size of the at least one pocket is a function of the radius and the flat depth.

15. The turbine rotor according to clause 11, wherein the radius ranges from about 2 millimeters (0.079 inches) to about 8 millimeters (0.31 inches).

16. The turbine rotor according to clause 11, wherein the flat depth ranges from about 2 millimeters (0.079 inches) to about 9 millimeters (0.35 inches).

17. A bucket dovetail for securing a bucket to a rotor wheel, comprising:

a plurality hooks that connect the bucket with the rotor wheel, the plurality of hooks shaped to distribute centrifugal loads placed on the bucket in a desired distribution among each of the plurality of hooks, wherein the desired distribution subjects each of the plurality of hooks to a predetermined amount of centrifugal load and stress.

18. The dovetail according to clause 17, wherein some of the plurality of hooks form a cantilever to distribute the centrifugal loads.

19. The dovetail according to clause 18, wherein a top portion of the cantilever is defined by a radius and a flat depth.

20. The dovetail according to clause 19, wherein distribution of centrifugal loads by the cantilever is a function of the radius and the flat depth.

Claims

1. A bucket dovetail (210) for securing a bucket (200) to a rotor wheel (300), comprising:

a plurality of hooks (250) that connect the bucket (200) with the rotor wheel (300), the plurality of hooks (250) shaped to distribute centrifugal loads placed on the bucket (200) in a substantially even distribution among each of the plurality of hooks (250).

2. The dovetail (210) according to claim 1, wherein some of the plurality of hooks (250) form a cantilever to distribute the centrifugal loads.

3. The dovetail (210) according to claim 2, wherein a top portion of the cantilever is defined by a radius (260) and a flat depth (270).

4. The dovetail (210) according to claim 3, wherein distribution of centrifugal loads by the cantilever is a function of the radius (260) and the flat depth (270).

5. The dovetail according to claim 4, wherein an increase in the radius and/or an increase in the flat depth is proportional to a decrease in the centrifugal load on the cantilever.

6. The dovetail (210) according to claim 3, wherein stress caused by the centrifugal loads on the cantilever is a function of the radius (260) and the flat depth (270).

7. The dovetail according to claim 6, wherein an increase in the radius and/or an increase in the flat depth is proportional to a decrease in the stress on the cantilever.

8. The dovetail (210) according to claim 3, wherein the radius (260) ranges from about 2 millimeters (0.079 inches) to about 8 millimeters (0.31 inches).

9. The dovetail (210) according to claim 3, wherein the flat depth (270) ranges from about 2 millimeters (0.079 inches) to about 9 millimeters (0.35 inches).

10. A turbine rotor including a plurality of turbine buckets (200) coupled with a rotor wheel (300), each turbine bucket (200) comprising a bucket dovetail (210) having a plurality of bucket dovetail hooks (250), and the rotor wheel (300) comprising a wheel post dovetail (310) shaped with wheel post dovetail hooks (320) to engage with the bucket dovetail hooks (250) of each bucket dovetail (210), the connection of the plurality of bucket dovetail hooks (250) from each bucket dovetail (210) with the wheel post dovetail hooks (310) forms at least one pocket (510) therebetween to facilitate substantial sharing of centrifugal loads placed on the turbine bucket (200) by the plurality of bucket dovetail hooks (250).

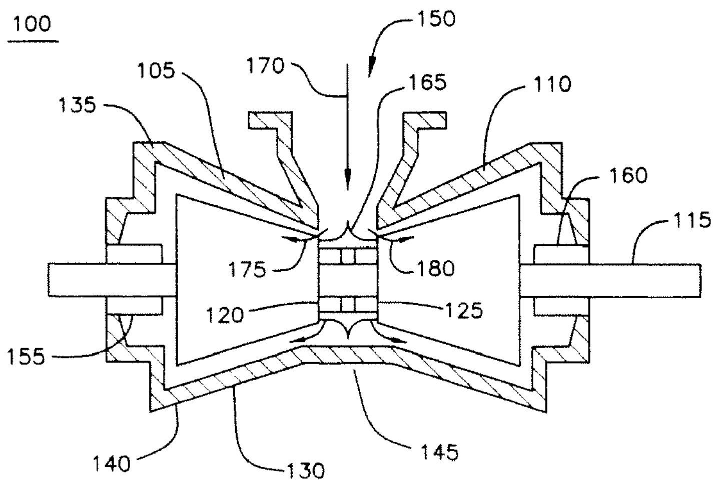
11. The turbine rotor according to claim 10, wherein a top portion of each of the plurality of bucket dovetail hooks (250) comprises a radius (260) and a flat depth (270), wherein the size of the at least one pocket (510) is a function of the radius (260) and the flat depth (270).

12. The turbine rotor according to claim 11, wherein the sharing of the centrifugal loads by each of the plurality of bucket dovetail hooks is a function of the radius and the flat depth.

13. The turbine rotor according to claim 11, wherein the amount of stress caused by the centrifugal loads on each of the plurality of bucket dovetail hooks is a function of the radius and the flat depth.

14. The turbine rotor according to claim 11, wherein the radius ranges from about 2 millimeters (0.079 inches) to about 8 millimeters (0.31 inches).

15. The turbine rotor according to claim 11, wherein the flat depth ranges from about 2 millimeters (0.079 inches) to about 9 millimeters (0.35 inches).


100
150
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125
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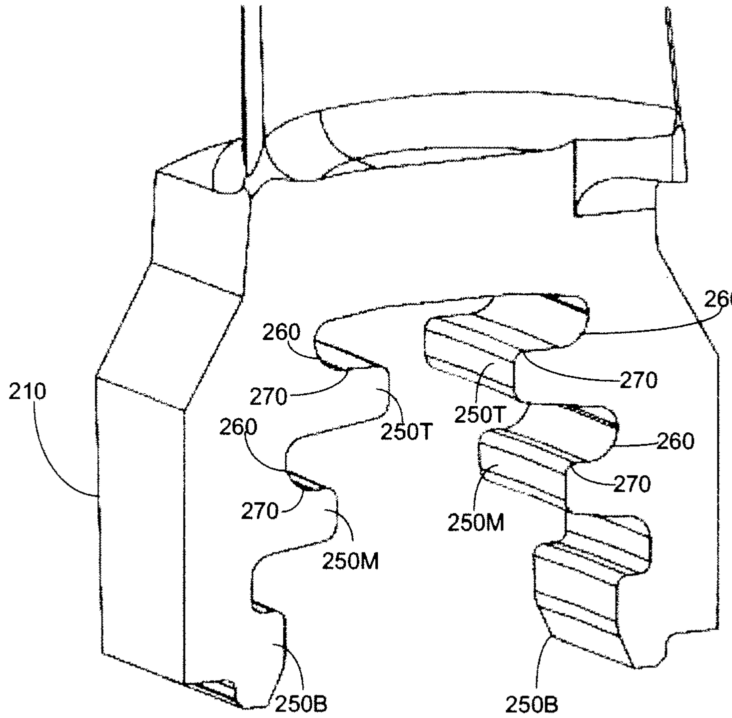
145

FIG. 1

200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260
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FIG. 2

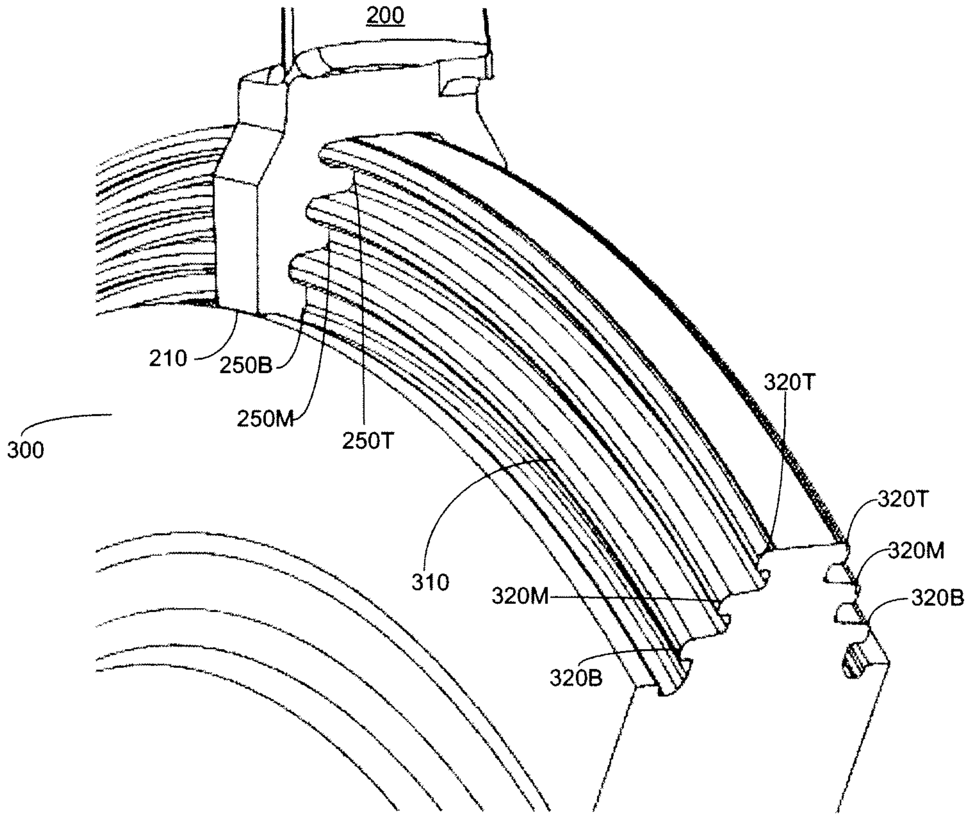
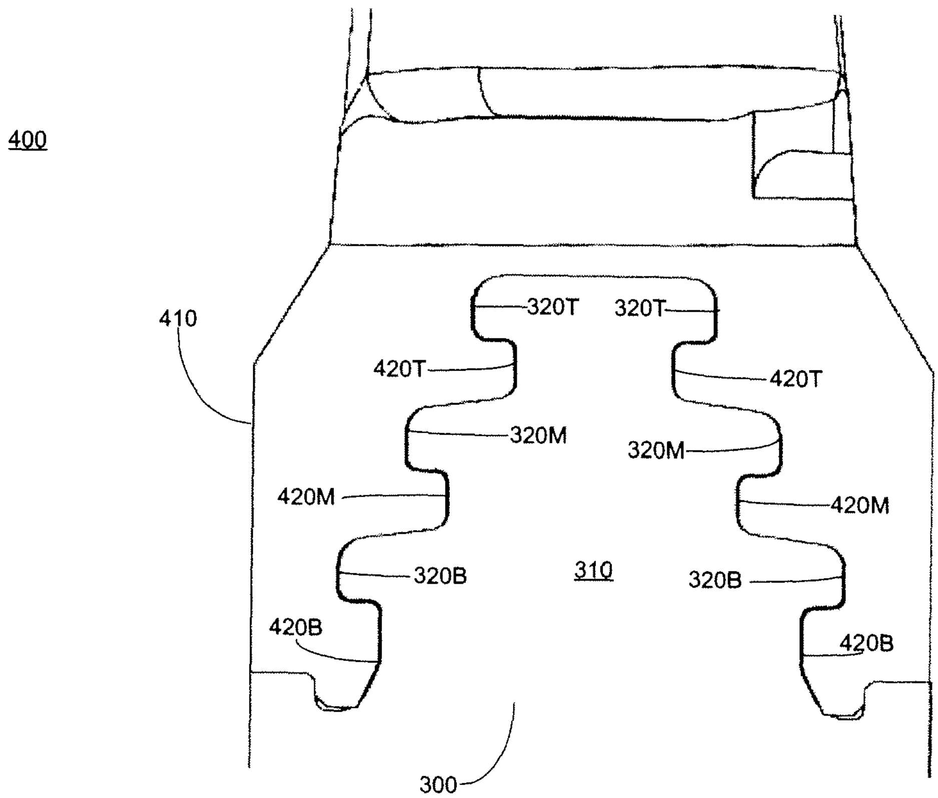
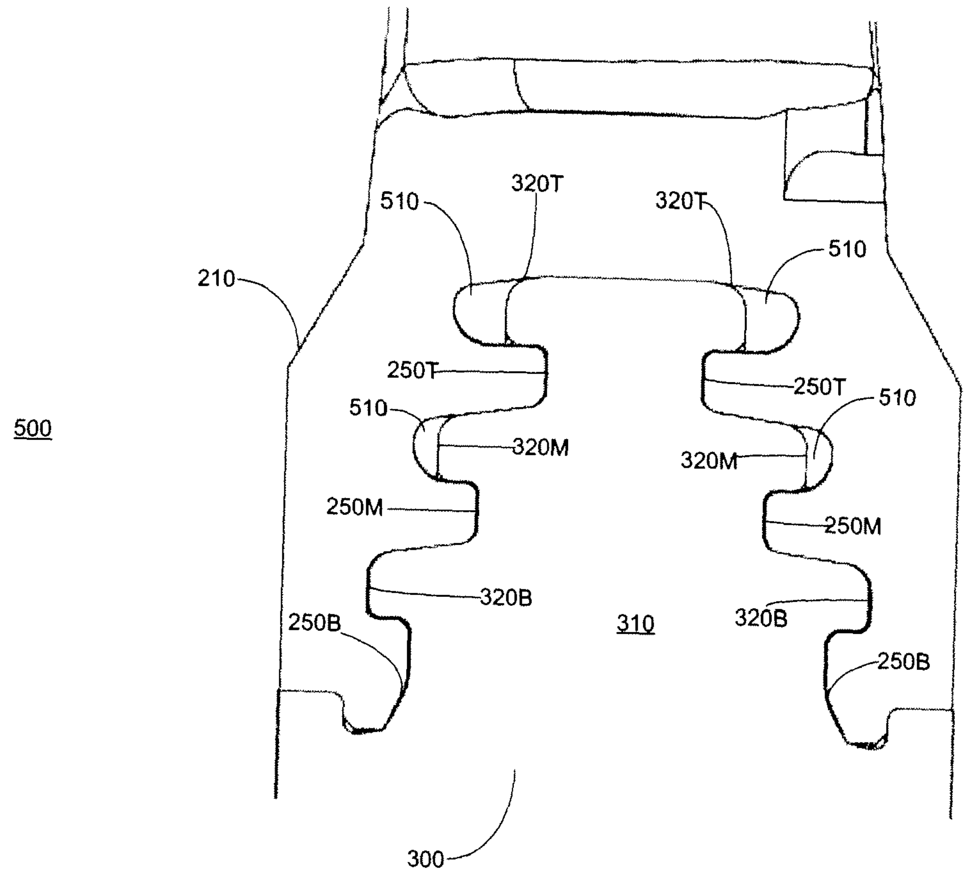


FIG. 3



PRIOR ART

FIG. 4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250M
250M
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250B
250B
300

FIG. 5