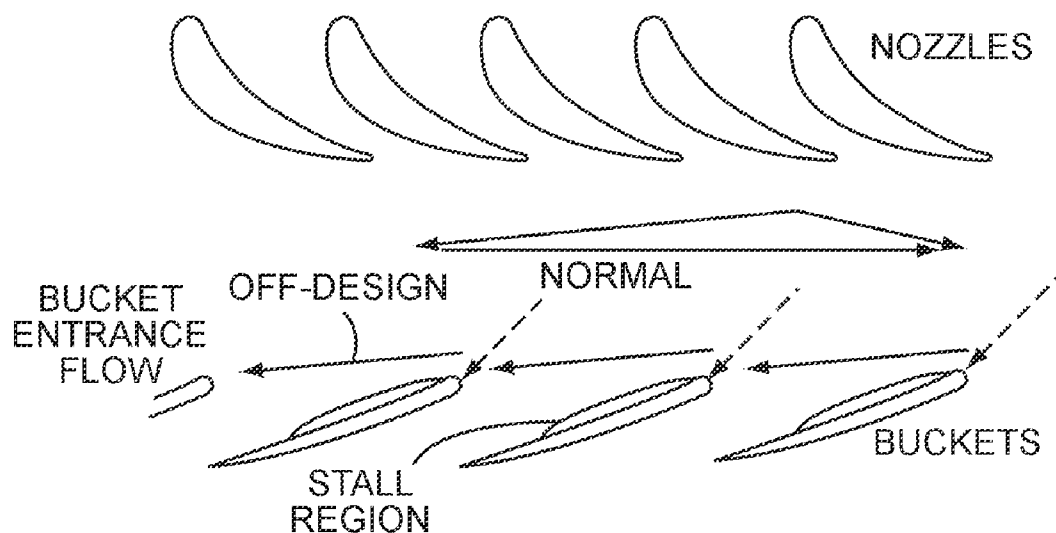




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(19) **United States**(12) **Patent Application Publication**
Maddaus(10) **Pub. No.: US 2013/0170984 A1**(43) **Pub. Date: Jul. 4, 2013**(54) **LAST STAGE BLADE DESIGN TO REDUCE
TURNDOWN VIBRATION**(52) **U.S. Cl.**
USPC 416/1; 416/223 A(76) Inventor: **Alan Donn Maddaus**, Rexford, NY
(US)(57) **ABSTRACT**(21) Appl. No.: **13/343,369**(22) Filed: **Jan. 4, 2012****Publication Classification**(51) **Int. Cl.**
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A turbine bucket includes a bucket airfoil having a cross-section in an airfoil shape. The bucket is twisted from a root end to a tip end. A degree of twist defines an accumulated angular offset of the tip end in a range of 10-15° relative to a tangential direction, thereby reducing excess negative incidence by 15-20° relative to the tangential direction.



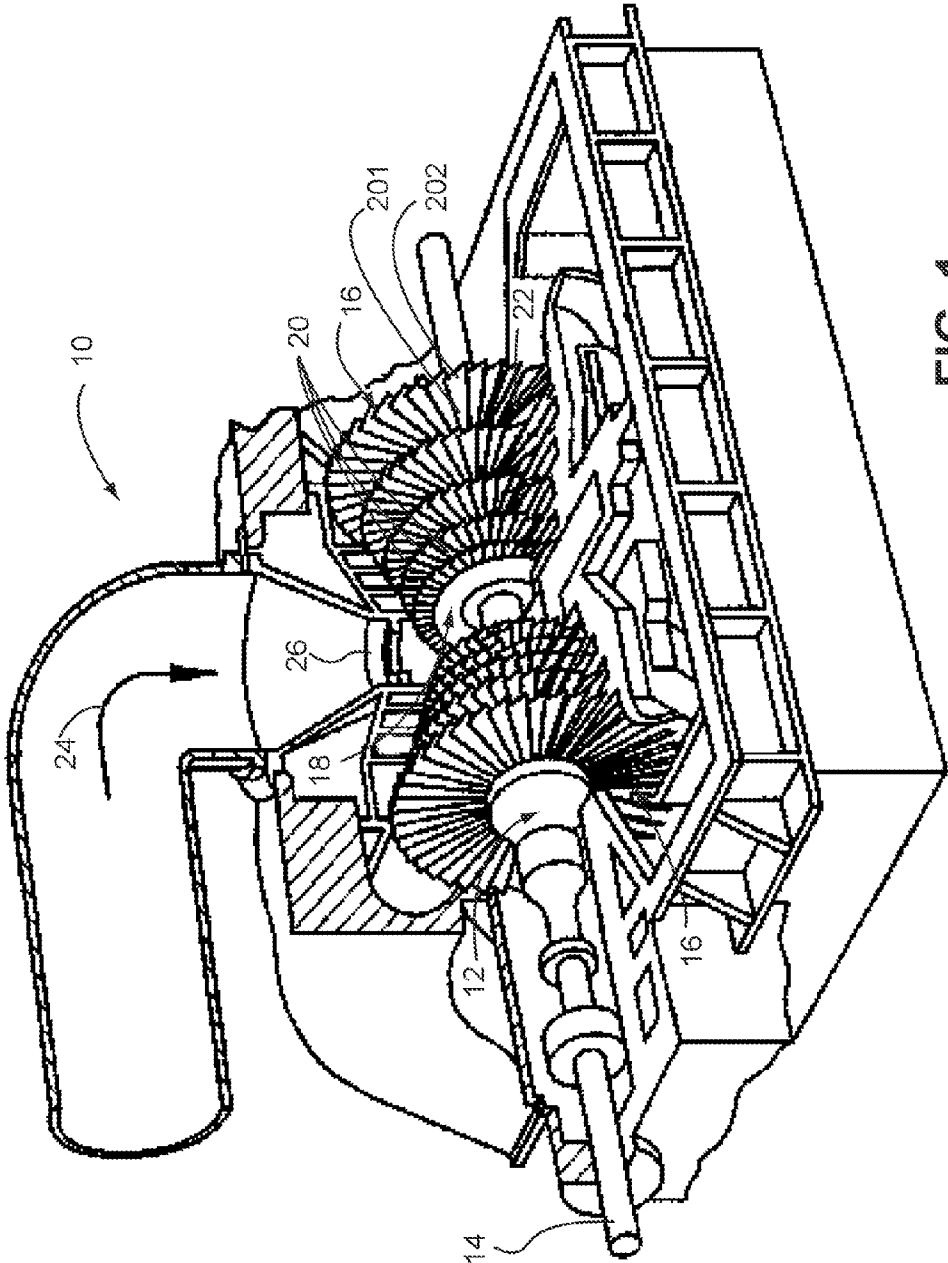


FIG. 1

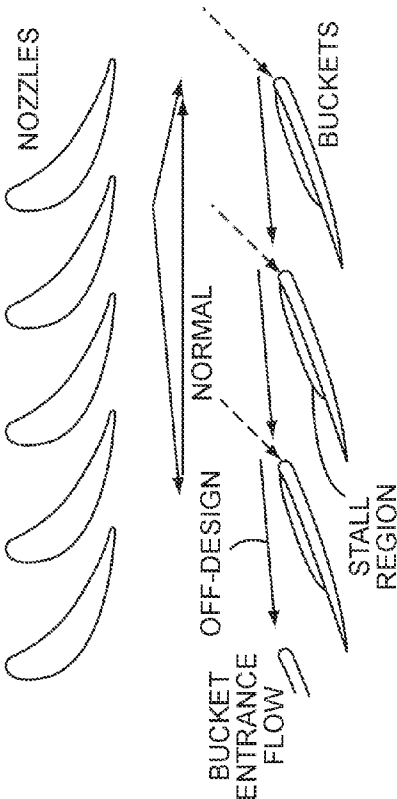


FIG. 2

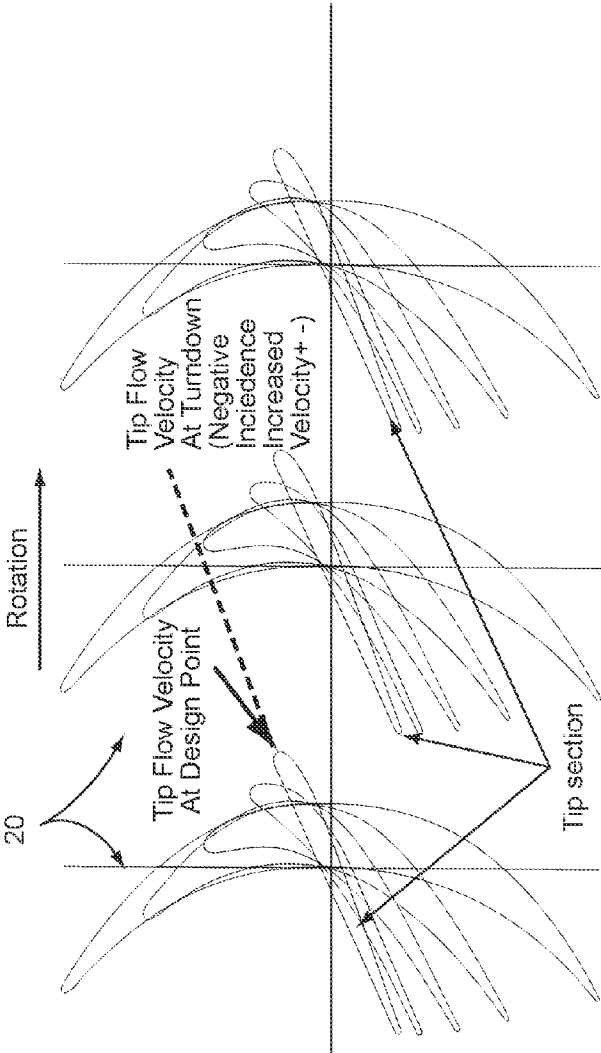


FIG. 3

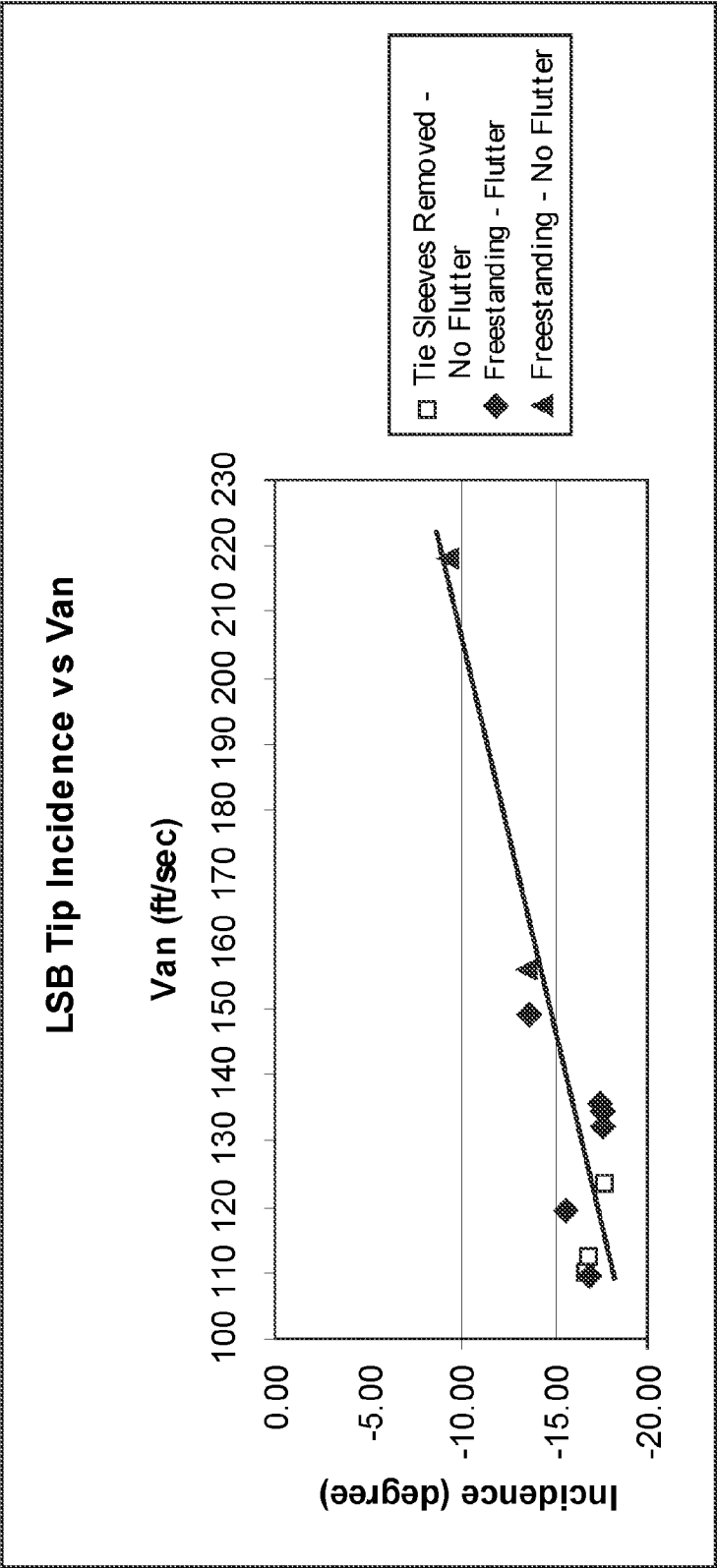


FIG. 4

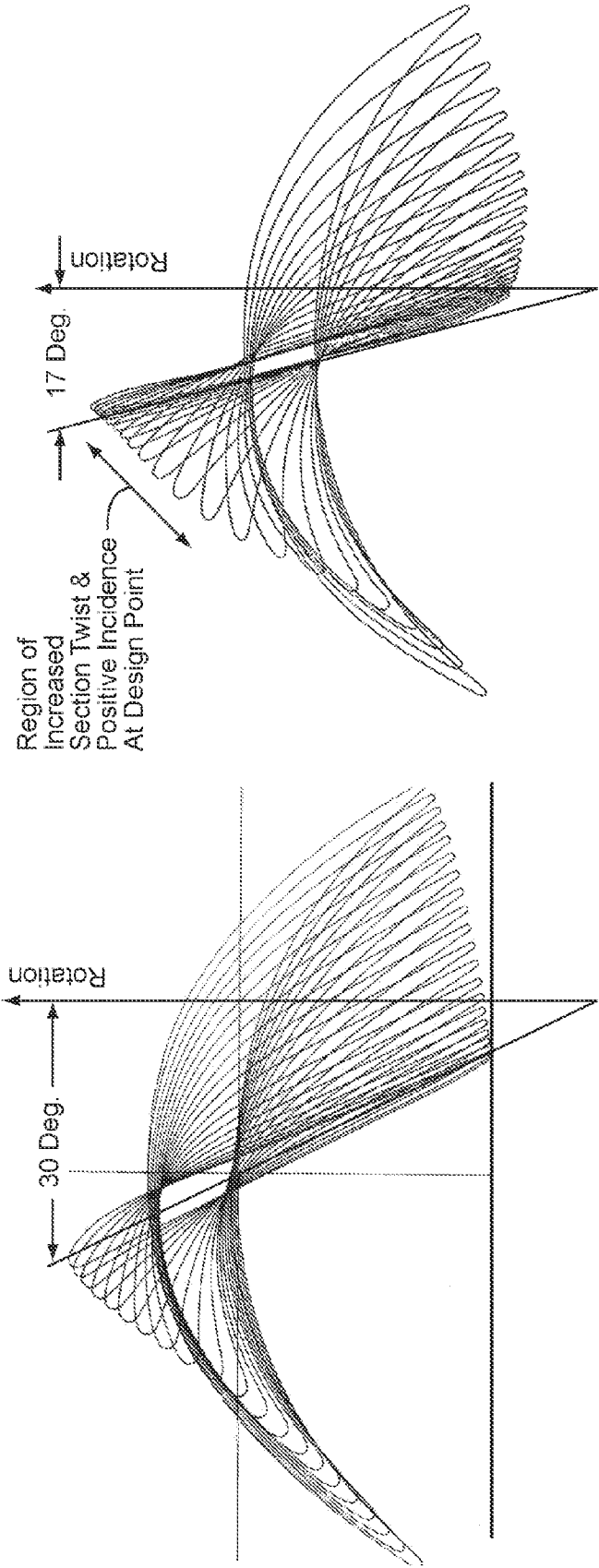


FIG. 6

FIG. 5

LAST STAGE BLADE DESIGN TO REDUCE TURNDOWN VIBRATION

BACKGROUND OF THE INVENTION

[0001] The invention relates generally to turbines and, more particularly, to last stage blades of steam turbines.

[0002] Last stage blades or “buckets” (LSBs) of steam turbines are designed with tip sections resembling flat plates. The orientation of the tip section is more or less closely aligned, depending on rotational speed and radius ratio, with the tangential direction to match the direction of the flow at outer flow filament radial locations. The precise orientation of the tip section is determined by flow analysis, at or near the design point. However, steam turbines are required to operate at very low flows and high exhaust pressures relative to the design point, to accommodate load demand and atmospheric conditions, respectively. This causes significant deviation in the flow direction and velocity at the bucket tip, resulting in flow induced vibration (FIV), which is potentially damaging and limits operational flexibility once a threshold value of negative incidence is exceeded.

[0003] FIG. 2 shows a typical steam turbine last stage geometry at the tip, with flow velocity vectors, and FIG. 3 shows a more detailed view of a last stage blade section viewed radially inward from the tip. At steam turbine turn-down conditions associated with light load and/or high exhaust pressure, the flow at the blade or bucket tip deviates significantly from the design point in both magnitude and direction. The magnitude increases and in the limit of no flow reaches that of the wheelspeed vector W while the direction shifts from design optimum entrance angle toward the tangential direction opposite to blade rotation. If the turn-down is significant, the flow incidence, defined as the difference in optimum entrance angle and the actual flow direction, can exceed 15 degrees and result in elevated FIV, associated with airfoil concave or pressure side flow separation and stall.

[0004] FIG. 4 is a graph of blade or bucket tip flow incidence vs. average flow velocity (V_{av}) in the exit annulus. The graph indicates that at about 15 degrees of incidence, the FIV, flutter, or more specifically stall flutter, is initiated, provided structural damping is low. Stall flutter can result in short term failure of blades. Operating guidelines to avoid the turn-down regime in which it may occur are a standard practice for the industry. A somewhat more benign FIV behavior, buffeting aka “random resonant response” can occur at the same incidence threshold and has been associated with blade failures and/or blade connection failures over longer periods of operation.

[0005] It would be desirable to minimize FIV at turn-down conditions, which can be achieved by modifying the tip design for the applicable range of radius ratios and speeds.

BRIEF DESCRIPTION OF THE INVENTION

[0006] A turbine bucket includes a bucket airfoil having a cross-section in an airfoil shape. The bucket is twisted from a root end to a tip end. A degree of twist defines an accumulated angular offset of the tip end in a range of 10-15° relative to a tangential direction, thereby reducing excess negative incidence by 15-20° relative to the tangential direction.

[0007] In another exemplary embodiment, a turbine includes a rotor, a rotatable shaft that rotates with the rotor, and a turbine coupled with the rotatable shaft and the rotor. The turbine includes a plurality of axially spaced rotor

wheels. A plurality of buckets are coupled with each rotor wheel, where each of the buckets has a cross-section in an airfoil shape. A last stage bucket is twisted from a root end to a tip end, and a degree of twist defines an accumulated angular offset of the tip end in a range of 10-15° relative to a tangential direction, thereby reducing excess negative incidence by 15-20° relative to the tangential direction.

[0008] In yet another exemplary embodiment, a method of reducing flow induced vibration in a last stage turbine bucket includes the step of twisting the turbine bucket to a degree that defines an accumulated angular offset of the tip end in a range of 10-15° relative to a tangential direction, thereby reducing excess negative incidence by 15-20° relative to the tangential direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a perspective partial cut-away illustration of a low pressure section of a condensing steam turbine, i.e. a steam turbine section that has a sub-atmospheric exhaust pressure;

[0010] FIG. 2 shows a typical steam turbine last stage geometry at the tip, indicating design and off-design bucket tip entrance velocities;

[0011] FIG. 3 shows a detailed view of a last stage blade section viewed radially inward from the tip;

[0012] FIG. 4 is a graph of blade tip flow incidence versus average flow velocity in the exit annulus; and

[0013] FIGS. 5 and 6 compare a last stage bucket existing design (FIG. 5) with the last stage bucket design of the described embodiments (FIG. 6).

DETAILED DESCRIPTION OF THE INVENTION

[0014] FIG. 1 is a perspective partial cut away view of a low pressure (LP) steam turbine section 10 including a rotor 12 that includes a shaft 14 and a last stage bucket (LSB) row 16. The LP turbine 10 includes a plurality of axially spaced rotor wheels 18. A plurality of buckets 20 are mechanically coupled to each rotor wheel 18. More specifically, the buckets 20 are arranged in rows that extend circumferentially around each rotor wheel 18. A plurality of stationary nozzles 22 extend circumferentially around the rotor 12 and are axially positioned between adjacent rows of the buckets 20. Nozzles 22 cooperate with the buckets 20 to form a turbine stage and to define a portion of a steam flow path through the turbine 10.

[0015] In operation, steam 24 enters an inlet 26 of the turbine 10 and is channeled through the nozzles 22. The nozzles 22 direct the steam 24 downstream against the buckets 20. The steam 24 passes through the remaining stages imparting a force on the buckets 20 causing the rotor 12 to rotate. At least one end of the turbine 10 may extend axially away from the rotor 12 and may be attached to a load or machinery (not shown), such as, but not limited to, a generator, and/or another turbine. Accordingly, a large steam turbine unit may actually include several low pressure turbines that are all co-axially coupled to the same shaft 14. Such a unit may, for example, include a high-pressure turbine coupled to an intermediate-pressure turbine, which is coupled to a low-pressure turbine.

[0016] The significance of the turn-down FIV region is that at conditions of low flow and high exhaust pressure, the flow through the LSB passage separates at the hub and is confined to a filament between approximately 80 and 100% of the radial height (where radial height is defined as 0% at a root

end **201** of the bucket and 100% at a tip end **202** of the bucket). Thus it is primarily in this region that turndown FIV flow incidence has meaning. The limiting flow angle is the highest value of flow angle that can be achieved. In order for significant FIV to occur, the difference between the LSB tip optimum entrance angle (OEA), frequently taken as the mean of the distribution over the last 20% of radial height, and 180 degrees must exceed 15 degrees, negative. Thus, an LSB design with a tip OEA of 165 or more should not experience turndown FIV. The 40" LSB for 3600 rpm applications closely approaches this criterion, while the 33.5", 30" and 26", at the same rotational speed with progressively more excess negative incidence, have increasing potential for FIV at turndown. Data acquired in the field with strain gages demonstrates conclusively that the 30" LSB vibration amplitudes are significantly greater than those of the 33.5" at similar conditions of turndown operation thus tending to confirm this theory.

[0017] Above approximately 40" radial height, for 3600 rpm designs, it is generally expected that the required 15 degrees of negative incidence cannot be achieved for buckets designed by state of the art aerodynamic design methods, as such LSBs will have tip OEAs greater than 165 degrees. The same statement is true for full and half speed buckets with active lengths scalable from 3600 rpm designs on the basis of speed. For example, at 3000 rpm a bucket with radial height= $(3600/3000) \times 35 = 42$ " should also be low in turndown FIV potential.

[0018] FIGS. 5 and 6 show an existing 30" design (FIG. 5) and a 30" design (FIG. 6) reflecting the concepts of the proposed design. The proposed design increases the twist of the vane in sections between 30% and 60% height range, resulting in an accumulated angular offset of the tip section on the order of 13 degrees. This is consistent with a reduction of excess negative incidence by 17 degrees, greatly reducing FIV potential. An alternative way to achieve the same result of reorienting the tip may be to incorporate the required twist in sections closer to the root and provide relatively little section to section twist near the tip. A performance analysis could accompany any final design to determine the best distribution of optimum entrance angle for design point performance, while ensuring that the goal of minimum excess negative incidence at the tip is achieved. The end result would be an LSB design with a tip orientation as shown in FIG. 6. In addition to optimizing the optimum entrance angle distribution to meet performance and FIV reduction objectives, the leading edge of the blade can be radiused to reduce positive incidence performance sensitivity.

[0019] The design is applicable to LSB designs incorporating pin and finger, dovetails, curved or straight axial entry dovetails or dovetails of the tangential entry type, the latter including a radial notch in the wheel to permit assembly, and a pinned block or notch blade to completely fill the wheel. The design is applicable to LSBs that are of the "freestanding" type (i.e., no connections between adjacent airfoils), as well as LSBs with midspan and/or tip shroud connections. Additionally, the last stage nozzle may remain the same as a design with a LSB of conventional section twist from root to tip, or have adjusted throat openings starting at a location reasonably removed (~25%) from the root to preserve low rotor reaction. The adjustment should be such to ensure that the LSB entrance flow angle is as close as possible to the LSB metal section preferred entrance angle at all radial locations. Alternately an entirely redesigned nozzle may be applied.

The adjustment or redesigned nozzle will ensure the highest possible stage performance. The LSB design approach described herein can be applied to conventional as well as high exhaust pressure designs, the latter having much higher exhaust pressure limits required for steam turbines in power plants with an air cooled condenser operating in high ambient temperature conditions.

[0020] The described embodiments serve to reduce flow induced forces that cause off-design vibration, by airfoil redesign. The airfoil tip section is designed so that stalled flow is greatly mitigated at turndown conditions. Particularly, this is accomplished by specifying a tip section inclination relative to the tangential direction at a specified angle. As a result, a safe operating range is increased, providing customers with more freedom and responding to load demand, particularly in hot weather. Additionally, last stage bucket reliability is increased, particularly in cases where the customer operates the turbine beyond manufacturer recommended limits.

[0021] While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

What is claimed is:

1. A turbine bucket including a bucket airfoil having a cross-section in an airfoil shape, the turbine bucket being twisted from a root end to a tip end, wherein a degree of twist defines an accumulated angular offset of the tip end in a range of 10-15° relative to a tangential direction, thereby reducing excess negative incidence by 15-20° relative to the tangential direction.

2. A turbine bucket according to claim 1, wherein the degree of twist defines an accumulated angular offset of the tip end of 13°, thereby reducing excess negative incidence by 17°.

3. A turbine bucket according to claim 1, comprising a leading edge, the leading edge being radiused to reduce positive incidence performance sensitivity.

4. A turbine bucket according to claim 1, wherein a height dimension is defined as 0% height at the root end and 100% height at the tip end, and wherein the turbine bucket is twisted in a section between 30-60% height to a degree that is higher than other sections of the turbine bucket.

5. A turbine bucket according to claim 1, wherein the turbine bucket is twisted at the root end to a degree that is higher than other sections of the turbine bucket.

6. A turbine bucket according to claim 1, wherein the turbine bucket is a last stage bucket of a turbine.

7. A turbine bucket according to claim 6, wherein at an operating speed of 3,600 RPMs, a maximum height of the turbine bucket is 35 inches.

8. A turbine bucket according to claim 6, wherein at an operating speed of X RPMs, a maximum height of the turbine bucket is $3600/X \times 35$.

9. A turbine comprising:

a rotor;

a rotatable shaft that rotates with the rotor; and

a turbine coupled with the rotatable shaft and the rotor, the turbine including a plurality of axially spaced rotor wheels, wherein a plurality of buckets are coupled with each rotor wheel, each of the buckets having a cross-section in an airfoil shape, wherein a last stage bucket is

twisted from a root end to a tip end, and wherein a degree of twist defines an accumulated angular offset of the tip end in a range of 10-15° relative to a tangential direction, thereby reducing excess negative incidence by 15-20° relative to the tangential direction.

10. A turbine according to claim **9**, wherein the degree of twist defines an accumulated angular offset of the tip end of 13°, thereby reducing excess negative incidence by 17°.

11. A turbine according to claim **9**, wherein the last stage bucket comprises a leading edge, the leading edge being radiused to reduce positive incidence performance sensitivity.

12. A turbine according to claim **9**, wherein a height dimension of the last stage bucket is defined as 0% height at the root end and 100% height at the tip end, and wherein the last stage bucket is twisted in a section between 30-60% height to a degree that is higher than other sections of the bucket.

13. A turbine according to claim **9**, wherein the last stage bucket is twisted at the root end to a degree that is higher than other sections of the bucket.

14. A turbine according to claim **9**, wherein at an operating speed of 3,600 RPMs, a maximum height of the last stage bucket is 35 inches.

15. A turbine according to claim **9**, wherein at an operating speed of X RPMs, a maximum height of the last stage bucket is $3600/X \times 35$.

16. A method of reducing flow induced vibration in a last stage turbine bucket, the turbine bucket being twisted from a root end to a tip end, the method comprising twisting the turbine bucket to a degree that defines an accumulated angular offset of the tip end in a range of 10-15° relative to a tangential direction, thereby reducing excess negative incidence by 15-20° relative to the tangential direction.

17. A method according to claim **16**, wherein the twisting step is practiced such that the degree of twist defines an accumulated angular offset of the tip end of 13°, thereby reducing excess negative incidence by 17°.

18. A method according to claim **16**, comprising radiusing a leading edge of the turbine bucket to reduce positive incidence performance sensitivity.

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