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(54) **SYSTEM AND METHOD TO REDUCE ACOUSTIC SIGNATURE USING PROFILED STAGE DESIGN**

(75) Inventors: **Joseph A. Tecza**, Scio, NY (US); **Stephen S. Rashid**, Wellsville, NY (US)

Correspondence Address:
Edmonds Nolte, PC
16815 ROYAL CREST DRIVE, SUITE 130
HOUSTON, TX 77058 (US)

(73) Assignee: **DRESSER-RAND COMPANY**, Olean, NY (US)

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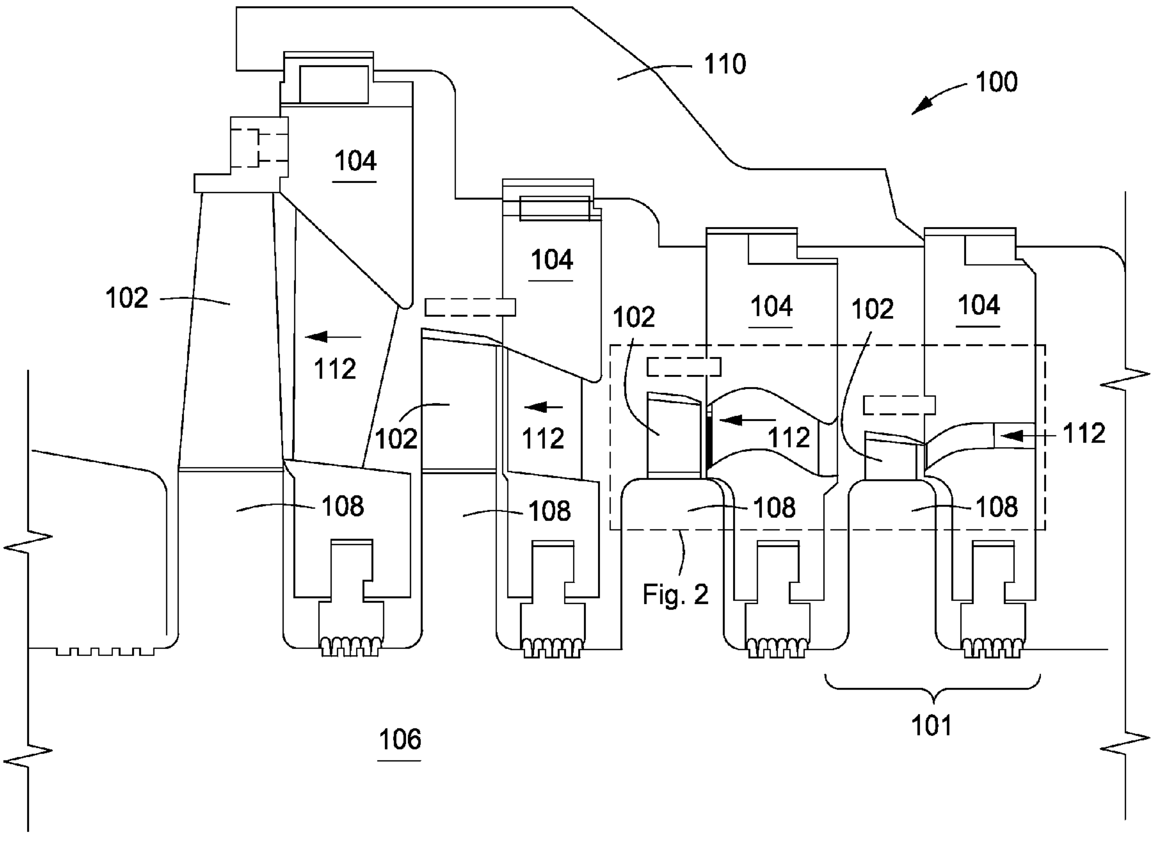
(57) **ABSTRACT**

To reduce noise and thereby increase turbine efficiency, the end walls and airfoils of a turbine are designed to reduce or eliminate radial pressure gradients on rotor blades and their incipient secondary flow vortices which may noisily excite downstream blade and vane rows. Instead of generating inefficient noise, the fluid energy may be properly directed into the shaft as efficient work.



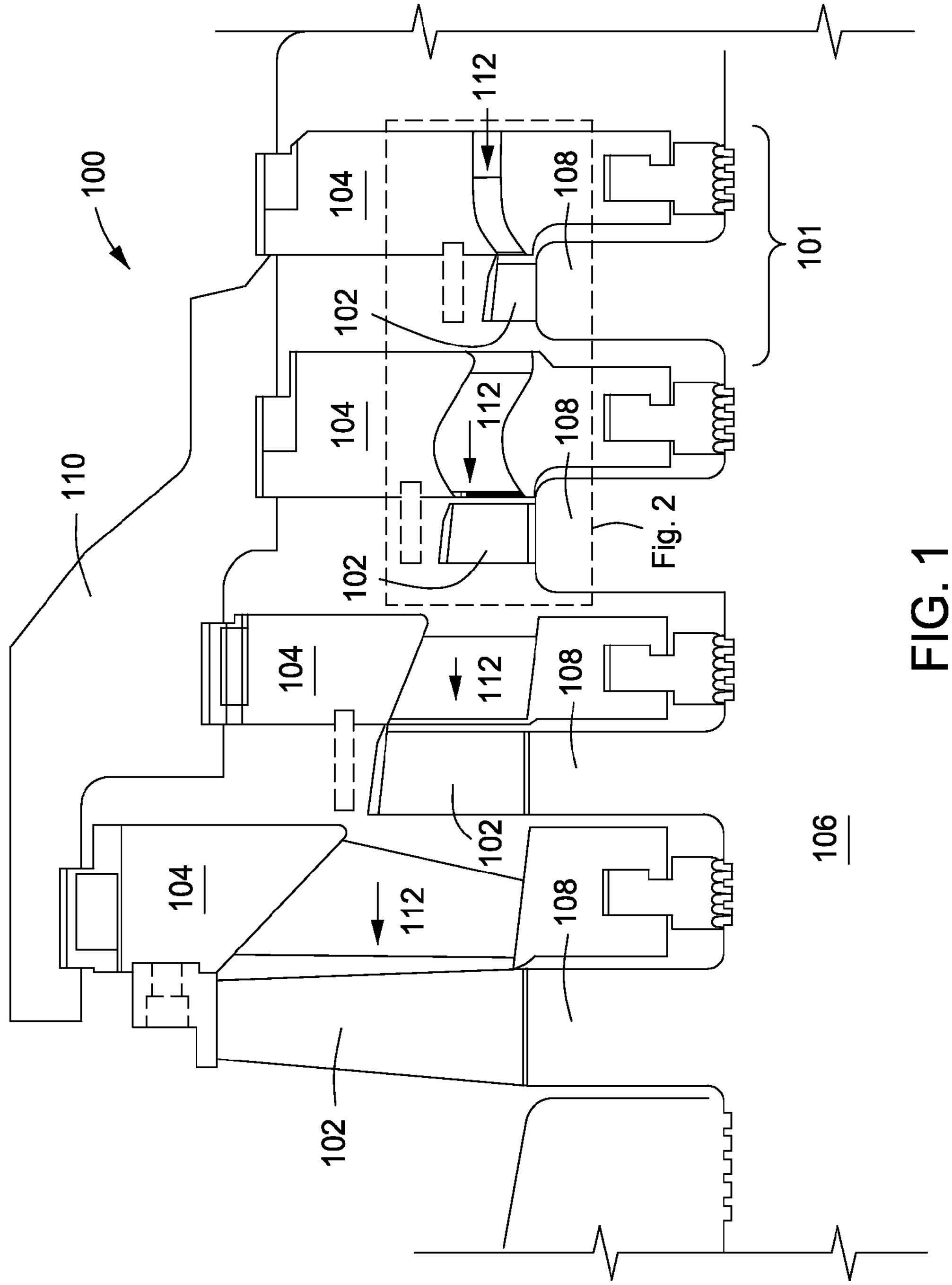
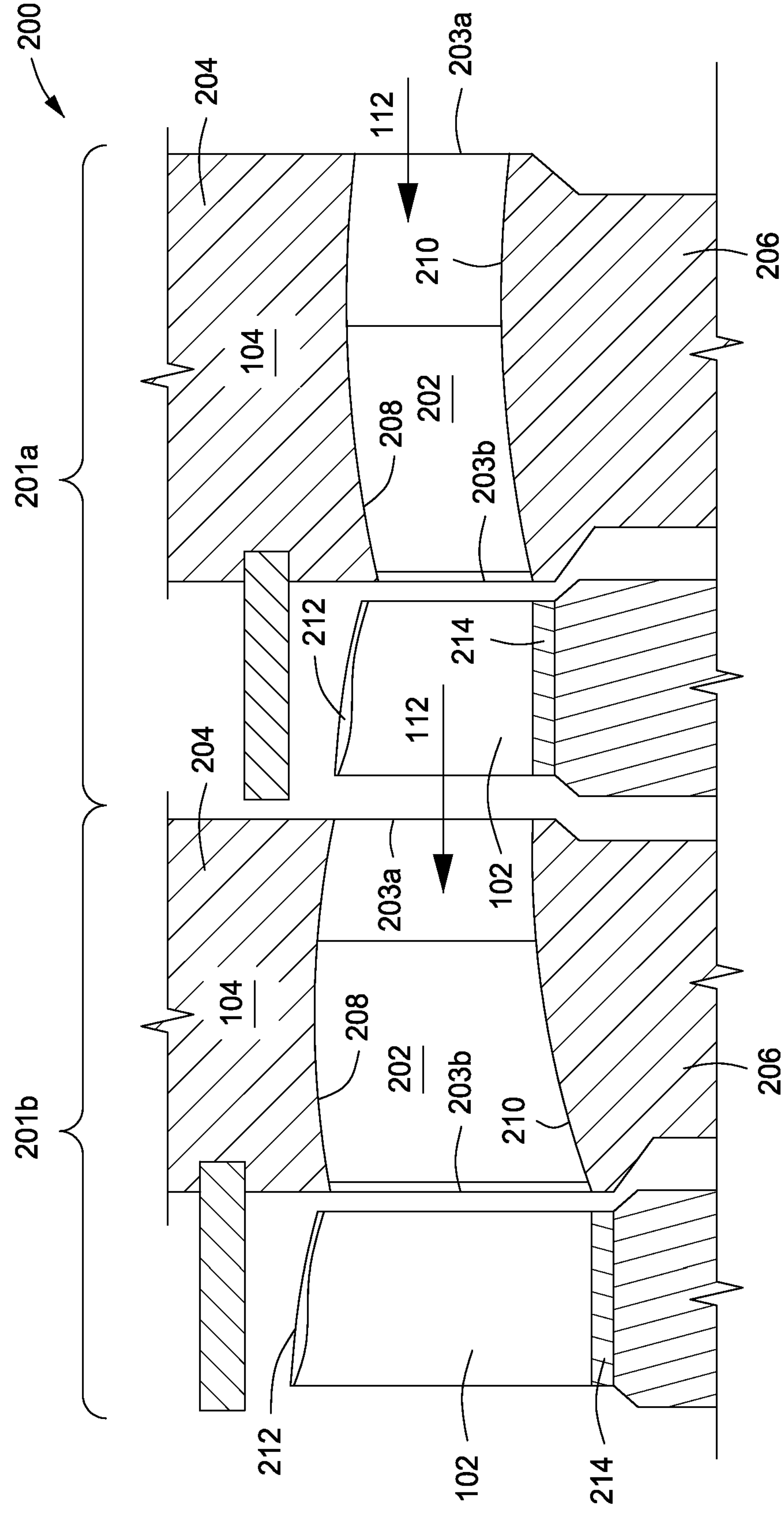

100
112
104
108
101
102
104
112
108
110
102
Fig. 2
104
112
108
102
106
104
112
108
102

FIG. 1


200
201a
201b
204
104
112
203a
210
206
208
202
203b
212
214
102
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112
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203a
104
208
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203b
210
206
212
102
214

FIG. 2

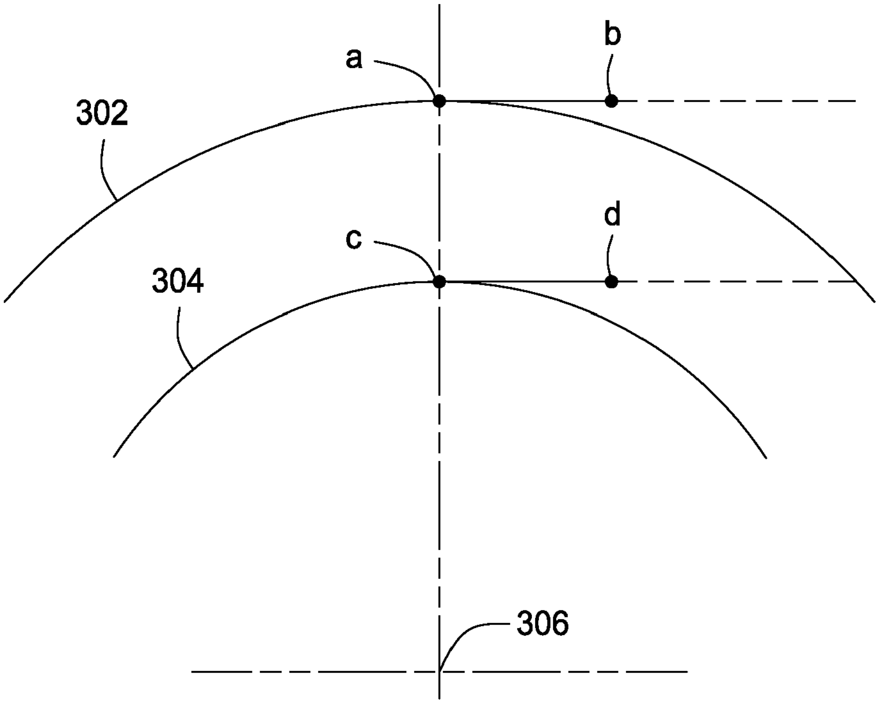

FIG. 3

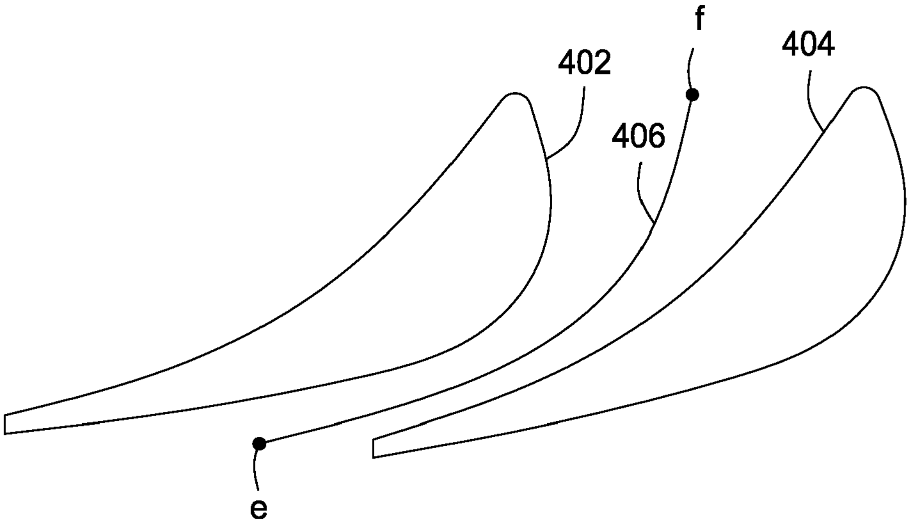

FIG. 4

SYSTEM AND METHOD TO REDUCE ACOUSTIC SIGNATURE USING PROFILED STAGE DESIGN

BACKGROUND

[0001] When the radial pressure gradient in the fluid stream of a turbine is minimized or eliminated, turbine stage efficiency can be significantly improved. Typical turbine inefficiencies may include noise production from several fluid dynamic sources, including wake cutting, high velocity fluid, and turbulent flow fields, including secondary flow vortices. The noise generally results from reflecting and turbulent wave fields incident upon the several stationary and moving blades downstream from a blade set that receives irregular pressure differentials and converts them into secondary flow vortices. As explanation, when a pressure gradient incident on a rotating blade set is intense enough, transient or sustained separation of fluid flow may occur in the vicinity of the trailing edges of the blades. This separation of fluid flow can result in secondary flow vortices directed downstream at stationary and moving blades, thus producing high-intensity noise instead of directing the fluid energy into the output shaft for power generation.

[0002] What is needed, therefore, is a system designed to reduce radial pressure gradients incident upon rotating blades and thereby direct the fluid energy into the output shaft instead of into the creation of noise.

SUMMARY

[0003] Embodiments of the disclosure may provide a turbine having a working fluid. The turbine may include at least one set of rotor blades mounted radially symmetrically about a rotating shaft, wherein each rotor blade has a hub and a tip, and at least one stator axially-spaced from the at least one set of rotor blades and mounted radially symmetrically about the rotating shaft, wherein the at least one stator defines a plurality of radially-spaced vanes having inner and outer end walls that define end wall passages, wherein the end wall passages have a profile shaped to direct a working fluid to a plane substantially tangent to the inner and outer end walls.

[0004] Embodiments of the disclosure may further provide a stator for a turbine. The stator may include an inlet and an outlet, wherein the outlet is adjacent to at least one rotor blade having a hub and a tip, and a plurality of inner and outer end walls extending from the inlet to the outlet and defining a plurality of end wall passages having inner and outer radial limits, wherein the end wall passages have a profile configured to direct a working fluid to a plane substantially tangent to the inner and outer radial limits, wherein the plurality of inner and outer end walls are configured to substantially eliminate the radial pressure gradients incident between the hub and the tip of the at least one rotor blade, thereby attenuating the resultant acoustic signature.

[0005] Embodiments of the disclosure may further provide a method of reducing turbine acoustic signature. The method may include introducing a working fluid into a turbine having at least one stator adjacent to and axially-spaced from at least one rotor blade, wherein the stator comprises a plurality of radially-spaced vanes, each vane having an inlet and an outlet and defining a profile of an end wall passage including an inner and outer end wall, receiving the working fluid through the inlet of the end wall passage, channeling the working fluid through the profile of the end wall passage, and directing the working fluid out the outlet of the vane and substantially tangent to the inner and outer end walls, thereby substantially decreasing the radial pressure gradient incident between a hub and a tip of the at least one rotor blade, and thereby attenuating the resultant acoustic signature.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The present disclosure is best understood from the following detailed description when read with the accompanying Figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0007] FIG. **1** illustrates a partial diagrammatic, longitudinal sectional view of an exemplary turbine according to one or more aspects of the present disclosure.

[0008] FIG. **2** illustrates a fragmentary view of a pair of turbine stages according to one aspect of the present disclosure.

[0009] FIG. **3** illustrates an axial depiction of the defining lines for the profiles of the end wall sections, according to one aspect of the present disclosure.

[0010] FIG. **4** illustrates a radial view of the convex and concave surfaces of an exemplary set of stator vanes.

DETAILED DESCRIPTION

[0011] It is to be understood that the following disclosure describes several exemplary embodiments for implementing different features, structures, or functions of the invention. Exemplary embodiments of components, arrangements, and configurations are described below to simplify the present disclosure, however, these exemplary embodiments are provided merely as examples and are not intended to limit the scope of the invention. Additionally, the present disclosure may repeat reference numerals and/or letters in the various exemplary embodiments and across the Figures provided herein. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various exemplary embodiments and/or configurations discussed in the various Figures. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact. Finally, the exemplary embodiments presented below may be combined in any combination of ways, i.e., any element from one exemplary embodiment may be used in any other exemplary embodiment, without departing from the scope of the disclosure.

[0012] Additionally, certain terms are used throughout the following description and claims to refer to particular components. As one skilled in the art will appreciate, various entities may refer to the same component by different names, and as such, the naming convention for the elements described herein is not intended to limit the scope of the invention, unless otherwise specifically defined herein. Further, the naming convention used herein is not intended to distinguish between components that differ in name but not function. Further, in the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to." All numerical values in this disclosure may be exact or approximate values unless otherwise specifically stated. Accordingly, various embodiments of the disclosure may deviate from the numbers, values, and ranges disclosed herein without departing from the intended scope.

[0013] According to an exemplary embodiment of the present disclosure, to reduce noise and thereby increase turbine efficiency, the end walls and airfoils of a turbine may be designed to reduce or eliminate radial pressure gradients and their potential secondary flow vortices which may excite downstream blade and vane rows into the production of noise. In particular, by channeling reflecting and turbulent flow waves into a continuously-flowing shape through the end walls and airfoils, the fluid flowpath of the working fluid becomes generally linear in the desired direction of flow. Consequently, with a generally linear flowpath, the working fluid may be channeled directly into the succeeding rotor row with a minimal hub to tip velocity differential. Thus, the fluid energy may be directed into the shaft to create work, rather than into the generation of inefficient noise.

[0014] FIG. **1** illustrates an exemplary turbine **100** according to at least one aspect of the present disclosure. In an exemplary embodiment, the turbine **100** may be a multiple-stage steam turbine. The turbine **100** may be composed of a plurality of stages wherein a first stage **101** may include a set of rotor blades **102**, axially-spaced from and interleaved with a set of stator vanes **104**. The first stage **101** may be followed by any number of succeeding stages, The rotor blades **102** may be configured as a circular moving blade set, while the stator vanes **104** may be configured as a circular or semi-circular stationary blade set, each blade set having blades mounted symmetrically radial about a rotating shaft **106**. In an exemplary embodiment, the first stage **101** may be an impulse turbine stage, but may also be a reaction turbine stage. The present disclosure, however, may be less effective in a reaction machine since there is no real danger of the hub pressure at the rotor inlet dropping below the pressure at the rotor exit.

[0015] The rotor blades **102** may each be provided with a root **108** configured to couple the blades **102** to the rotating shaft **106** which rotates around a central axis of the turbine **100**. The stator vanes **104** may be in a fixed arrangement, typically mounted circumferentially to the outer casing **110** of the turbine **100** and extending inwardly therefrom.

[0016] In exemplary operation, a fluid, such as steam, air, products of combustion, or a process fluid such as CO_2 or other fluid may be used as the working fluid. In an embodiment using steam, the fluid may include injected into the turbine **100** and follow a plurality of channels or passageways, depicted by the arrows **112**, thus channeling itself through the various stages of rotor blades **102** and stator vanes **104**. As the steam passes through the various stages of the turbine **100**, the stator vanes **104** may be configured to direct the fluid into contact with the subsequent set of rotor blades **102**, thereby causing the shaft **106** to rotate and produce work.

[0017] However, if the fluid flow directed at the rotor blades **102** is composed of a heightened hub-to-tip pressure gradient, the rotor blades **102** may become agitated and create noise, or they may produce secondary flow vortices, potentially exciting downstream blades **102** or vanes **104** whose vibrations will also create noise. According to one aspect of the present disclosure, to reduce or eliminate the production of noise, the passageways **112** of the vanes **104** may be profiled in a manner that directs the fluid flow in a generally uniform pressure toward the rotor blades **102**.

[0018] Referring now to FIG. **2**, illustrated is an exemplary embodiment of a pair of turbine stages **201***a*, **201***b* according to at least one aspect of the present disclosure. The stages **201***a*, **201***b* may each consist of a plurality of stator vanes **104** followed by a plurality rotating blades **102**, wherein the arrow **112** denotes the direction of fluid flow through the particular stages **201** a, **201** b. Although not fully illustrated, each stage **201** a, **201** b may consist of a body of revolution about the rotational axis of the turbine **100**.

[0019] In particular, FIG. **2** illustrates a pair of stator vanes **104** and a pair of rotating blades **102**, wherein each rotating blade **102** may include a tip **212** and a hub **214**. As illustrated, each stator vane **104** may define an end wall passage **202** extending from an inlet **203**a to an outlet **203**b and configured to direct fluid flow into the subsequent set of rotating blades **102**. The end wall passage **202** may include an outer section **204** and an inner section **206**, wherein each section **204**, **206** may incorporate a given profile **208**, **210**, respectively.

[0020] When fluid flows in the end wall passage **202** the flow is considered "attached" if it flows continuously in one direction in the space defined between the outer section **204** and the inner section **206**. Although the velocity profile of the flow will generally proceed in an equivalent direction, it may change depending on whether the flow is laminar or turbulent. In typical operations, there will be a small boundary layer of slower flow adjacent to each profile **208**, **210**, but the flow in this boundary layer will be in the same direction as the flow in the rest of the space. If the boundary layer gets too thick that the flow within it reverses, a phenomenon called "hub separation" may occur, potentially creating eddy currents.

[0021] In turbines, the flow being accelerated through the end wall passage **202** generally flows in a direction tangent to the circumference at the point in the end wall passage **202** where it turns from the axial direction and is thereby accelerated. The flow continues "straight" in space, but the boundary profiles **208**, **210** both curve inward or downward, tending to bunch up the flow at the outer profile **208** (locally curving toward it) and flow away from the inner profile **210** (locally curving away from it). As can be appreciated, this results in an uneven velocity flow distribution, and is the type of behavior that the present disclosure is designed to prevent or remedy.

[0022] During turbine **100** operation, a pressure gradient incident across the tip **212** and hub **214** of a rotor blade **102** may also generate "hub separation." For example, the centrifugal acceleration of the working fluid in a turbine **100** generally forces, or "stirs," the fluid away from the hub **214** and creates a substantially higher pressure near the tip **212** of the rotating blade **102** than at the hub **214**. However, suppressing the pressure at the hub **214** may potentially cause a negative reaction, typically in the form of a significant potential pressure rise across the hub **214** sections of the blade **102**. Blade **102** reaction may be characterized by the pressure drop across the blade **102** row divided by the pressure drop across the end wall passage **202**. Since this pressure rise at the hub **214** cannot generally be supported, the hub **214** sections of the blade **102** may "separate," resulting in a radial pressure gradient flowing out of the end wall passage **202**.

[0023] The result of this pressure gradient on the rotating blade **102** is that secondary flow vortices may potentially develop and excite or vibrate downstream objects, such as rotor blade **102** and stator vane **104** rows. The excitation or vibration of rotor blade **102** and/or stator vane **104** rows may produce high-intensity noise representing fluid energy that is inefficiently wasted as noise production instead of being directed into the output shaft **106** for generation of power.

[0024] According to one exemplary embodiment of the present disclosure, the profiles **208**, **210** may be configured to provide a constant and equalized pressure gradient across the rotating blades **102**, thereby reducing or eliminating secondary flow vortices. Particularly, the specific profiles **208**, **210** of the end wall passages **202** may be configured to mimic the tangential fluid flow exiting the stator vane **104** and make the exiting pressure substantially uniform as it extends from the hub **214** to the tip **212** of the subsequently located rotating blade **102**. Uniform pressures incident on the rotating blades **102** minimize and/or prevent hub **214** "separation" that would normally result in the production of downstream noise, as described above.

[0025] The curvature, or shape, of the end wall **202** profiles **208**, **210** may be derived via axial and radial projections, upstream from the rotating blades **102**, from a pair of lines of revolution about a centerline of the turbine **100**. Referring to FIG. **3** (in combination with FIG. **2**), illustrated is a depiction of the lines of revolution **302**, **304** for the outer section **204** and the inner section **206**, respectively, of the end wall **202**. As shown, the lines of revolution **302**, **304** may be drawn from the centerline **306** of the turbine **100**. In the axial direction, the outer end wall section **204** may have its profile defined by an extent, tangent to the tip **212** of the rotating blade **102**, obtaining between points "a" and "b". Also, in the axial direction, the inner end wall section **206** has its profile defined by an extent, tangent to the hub **214** of the rotating blade **102**, obtaining between points "c" and "d".

[0026] FIG. **4** shows a radial view of an exemplary stator vane **104** body, where the convex and concave surfaces **402**, **404**, respectively, are illustrated. Inscribed between the surfaces **402**,**404** is a mean line **406** which radially extends between points "e" and "f". In an exemplary embodiment of the disclosure, the mean line **406** may be the axially-defining component for the profiles **208**, **210** and configured to allow the profiles **208**, **210** to mimic tangential fluid flow. In alternative exemplary embodiments, in lieu of the mean between the surfaces **402**, **404**, the axially-defining component for the profiles **208**, **210** can comport to either the convex surface **402** or the concave surface **404**, or any other representative flow line derived through geometric or fluid dynamic calculation.

[0027] According to the present disclosure, with a substantially tangential fluid flow exiting the end wall **202**, the incident pressures on the rotating blades **102** from the hub **214** to the tip **212** may be substantially uniform, and thus reducing or completely eliminating any secondary flow vortices. Particularly, using a profiled end wall **202** may direct a working fluid onto the rotating blades **102** such that the pressure at the hub **214** is equal to the pressure at the tip **212**. By reducing the hub **214** to tip **212** pressure gradient incident on the rotating blades **102**, as explained above, a reduction of downstream turbine **100** acoustic signature may result, thereby increasing turbine **100** efficiency.

[0028] The foregoing has outlined features of several embodiments so that those skilled in the art may better understand the detailed description that follows. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the present disclosure.

We claim:

1. A turbine, comprising:

at least one set of rotor blades mounted radially symmetrically about a rotating shaft, wherein each rotor blade has a hub and a tip; and

at least one stator axially-spaced from the at least one set of rotor blades and mounted radially symmetrically about the rotating shaft, wherein the at least one stator defines a plurality of radially-spaced vanes having inner and outer end walls that define end wall passages, wherein the end wall passages have a profile shaped to direct a working fluid to a plane substantially tangent to the inner and outer end walls.

2. The turbine of claim **1**, wherein the profile of the end wall passages is configured to substantially eliminate the radial pressure gradient incident between the hub and the tip of each rotor blade, whereby the resultant acoustic signature of the turbine is attenuated.

3. The turbine of claim **1**, wherein the turbine is a multiple-stage steam turbine.

4. The turbine of claim **1**, wherein each of the radially-spaced vanes have a convex surface and a concave surface with the convex surface of one vane and the concave surface of an adjacent vane defining the end wall passages.

5. The turbine of claim **4**, wherein the convex and concave surfaces are configured to cause the working fluid passing through the end wall passages to follow a path defined by a mean of the adjacent convex and concave surfaces.

6. The turbine of claim **1**, wherein the inner and outer end walls are configured to make the working fluid pressure at the hub substantially equal to the working fluid pressure at the tip.

7. The turbine of claim **1**, wherein the vanes are configured to direct fluid passing through the end wall passages circumferentially about and radially-spaced from a center line of the turbine.

8. A stator for a turbine, comprising,

an inlet and an outlet, wherein the outlet is adjacent to at least one rotor blade having a hub and a tip; and

a plurality of inner and outer end walls extending from the inlet to the outlet and defining a plurality of end wall passages having inner and outer radial limits, wherein the end wall passages have a profile configured to direct a working fluid to a plane substantially tangent to the inner and outer radial limits, wherein the plurality of inner and outer end walls are configured to substantially eliminate the radial pressure gradients incident between the hub and the tip of the at least one rotor blade, thereby attenuating resultant acoustic signature.

9. The stator of claim **8**, wherein, taken along an axial cross-sectional view, the tip of the at least one rotor blade is substantially tangent to the outer radial limit and the hub of the at least one rotor is substantially tangent to the inner radial limit.

10. The stator of claim **8**, wherein the profile is configured to direct fluid passing through the end wall passages circumferentially about and radially-spaced from a center line of the turbine.

11. A method of reducing turbine acoustic signature, comprising:

introducing a working fluid into a turbine having at least one stator adjacent to and axially-spaced from at least one rotor blade, wherein the stator comprises a plurality of radially-spaced vanes, each vane having an inlet and an outlet and defining a profile of an end wall passage including an inner and outer end wall;

receiving the working fluid through the inlet of the end wall passage;

channeling the working fluid through the profile of the end wall passage; and

directing the working fluid out the outlet of the vane and substantially tangent to the inner and outer end walls, thereby substantially decreasing the radial pressure gradient incident between a hub and a tip of the at least one rotor blade, and thereby attenuating resultant acoustic signature.

12. The method of claim **11**, wherein the turbine is a multiple-stage turbine and the working fluid is steam.

13. The method of claim **11**, wherein each of the radially-spaced vanes have a convex surface and a concave surface with the convex surface of one vane and the concave surface of an adjacent vane defining the end wall passages

14. The method of claim **11**, wherein, taken along an axial cross-sectional view, the tip of the at least one rotor blade is substantially tangent to the outer end wall of the end wall passage and the hub of the at least one rotor blade is substantially tangent to the inner end wall of the end wall passage.

15. The method of claim **11**, wherein each of the radially-spaced vanes have a convex surface and a concave surface with the convex surface of one vane and the concave surface of an adjacent vane defining the end wall passages.

16. The method of claim **15**, wherein the convex and concave surfaces are configured to cause the working fluid passing through the end wall passages to follow a path defined by the mean of the adjacent convex and concave surfaces.

17. The method of claim **11**, wherein the convex and concave surfaces are configured to cause the working fluid passing through the end wall passages to follow a path defined by the concave surface.

18. The method of claim **11**, wherein the convex and concave surfaces are configured to cause the working fluid passing through the end wall passages to follow a path defined by the convex surface.

19. The method of claim **11**, wherein the working fluid one of air, products of combustion, or a process fluid such as carbon dioxide.

* * * * *