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(54) **BOUNDARY LAYER BLOWING USING STEAM SEAL LEAKAGE FLOW**

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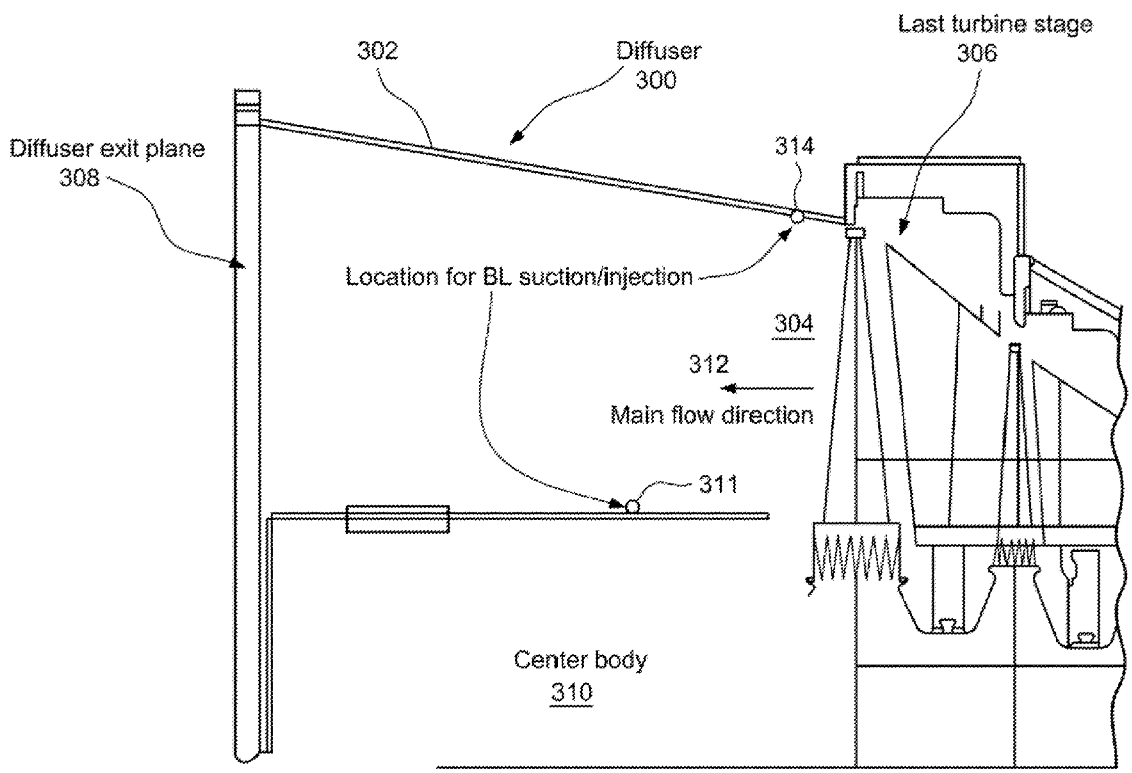
(57) **ABSTRACT**

A steam turbine includes a final turbine stage, a flow diffuser receiving a main flow from the final turbine stage, a diverging wall in the axial or radial flow diffuser that extends from a diffuser inlet to a diffuser exit, and a centerbody in the axial or radial flow diffuser. An opening is provided in the diverging wall and an opening is provided in the centerbody for fluidically actuating the main flow. The openings are located downstream from the diffuser inlet and upstream from a point where boundary layer separation would occur along the walls in a diffuser without the openings. A plurality of openings are provided in the diverging wall, and an end packing seal is positioned adjacent an end portion of the final turbine stage. An annular manifold collects fluid from leakage flow from the end packing seal and distributes the leakage flow to the openings.



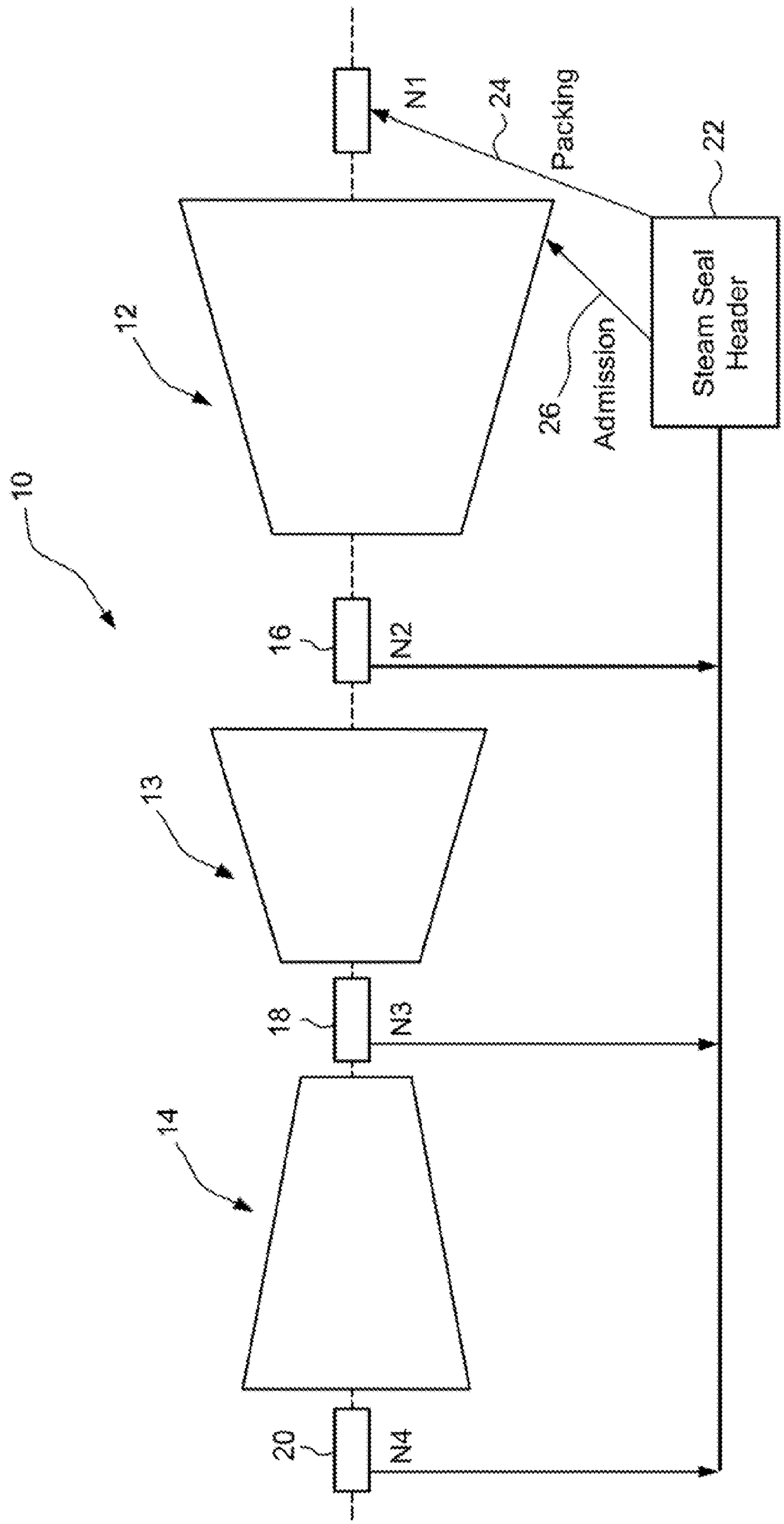

10
12
13
14
16
18
20
22
24
26
N1
N2
N3
N4
Packing
Admission
Steam Seal Header

FIG. 1

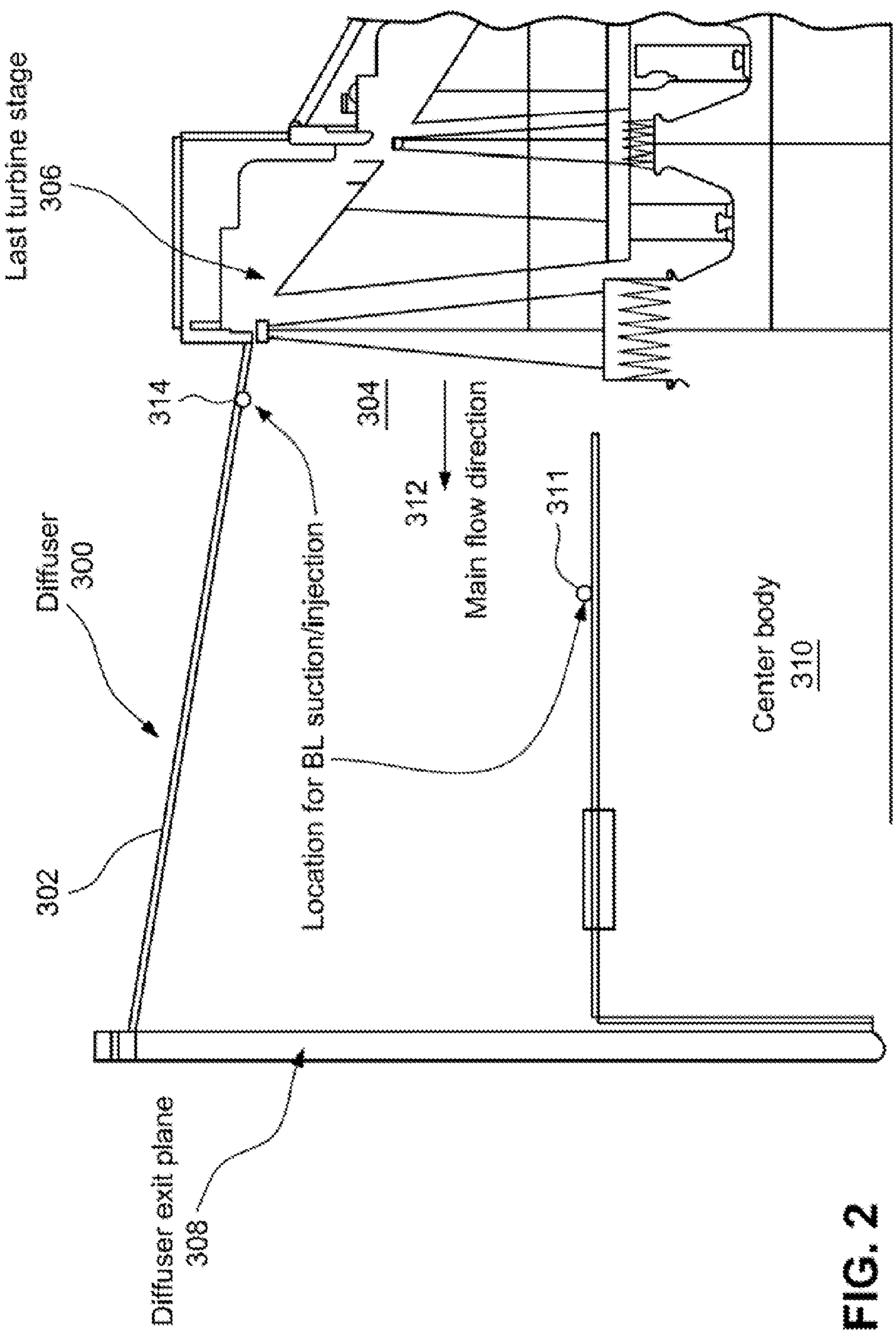

Last turbine stage
306
Diffuser
300
314
304
312
Main flow direction
311
Location for BL suction/injection
302
Center body
310
Diffuser exit plane
308

FIG. 2

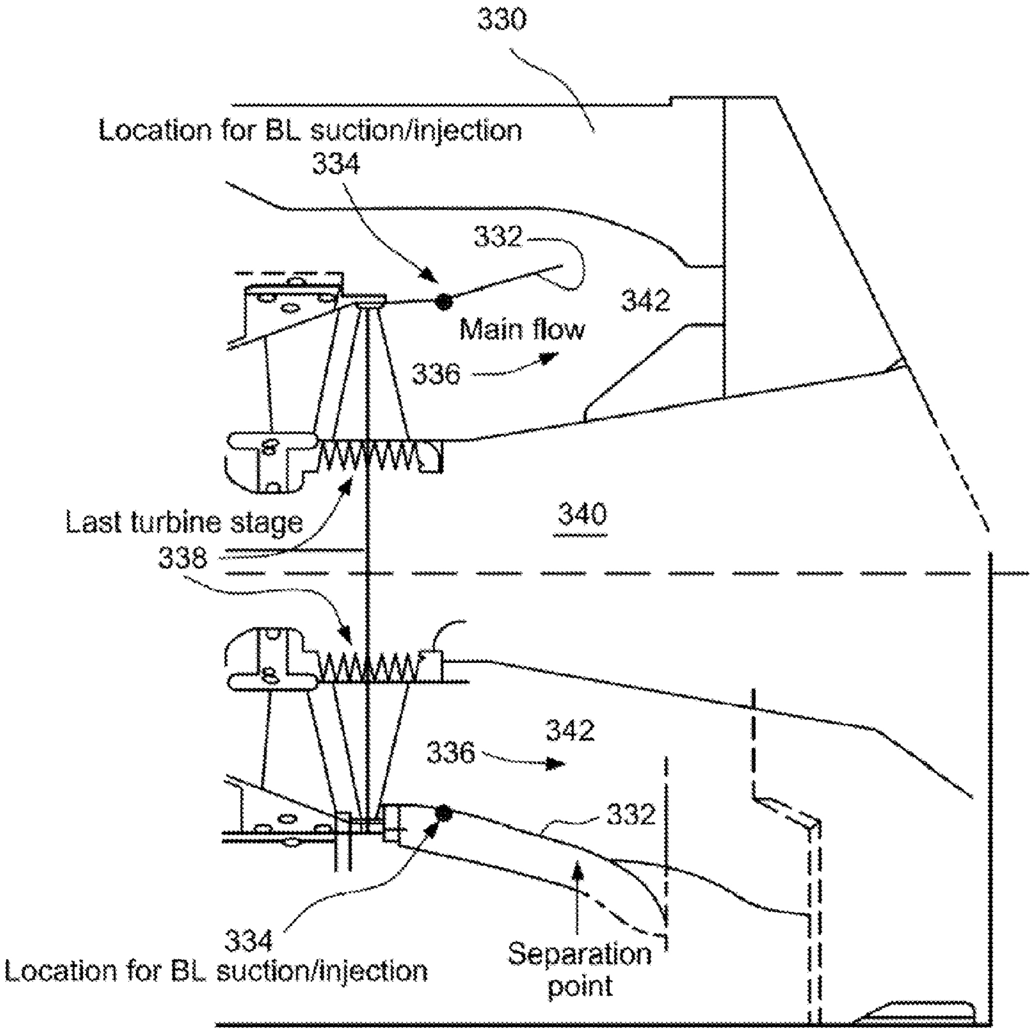

330
Location for BL suction/injection
334
332
342
Main flow
336
Last turbine stage
338
340
342
336
332
334
Location for BL suction/injection
Separation point

FIG. 3

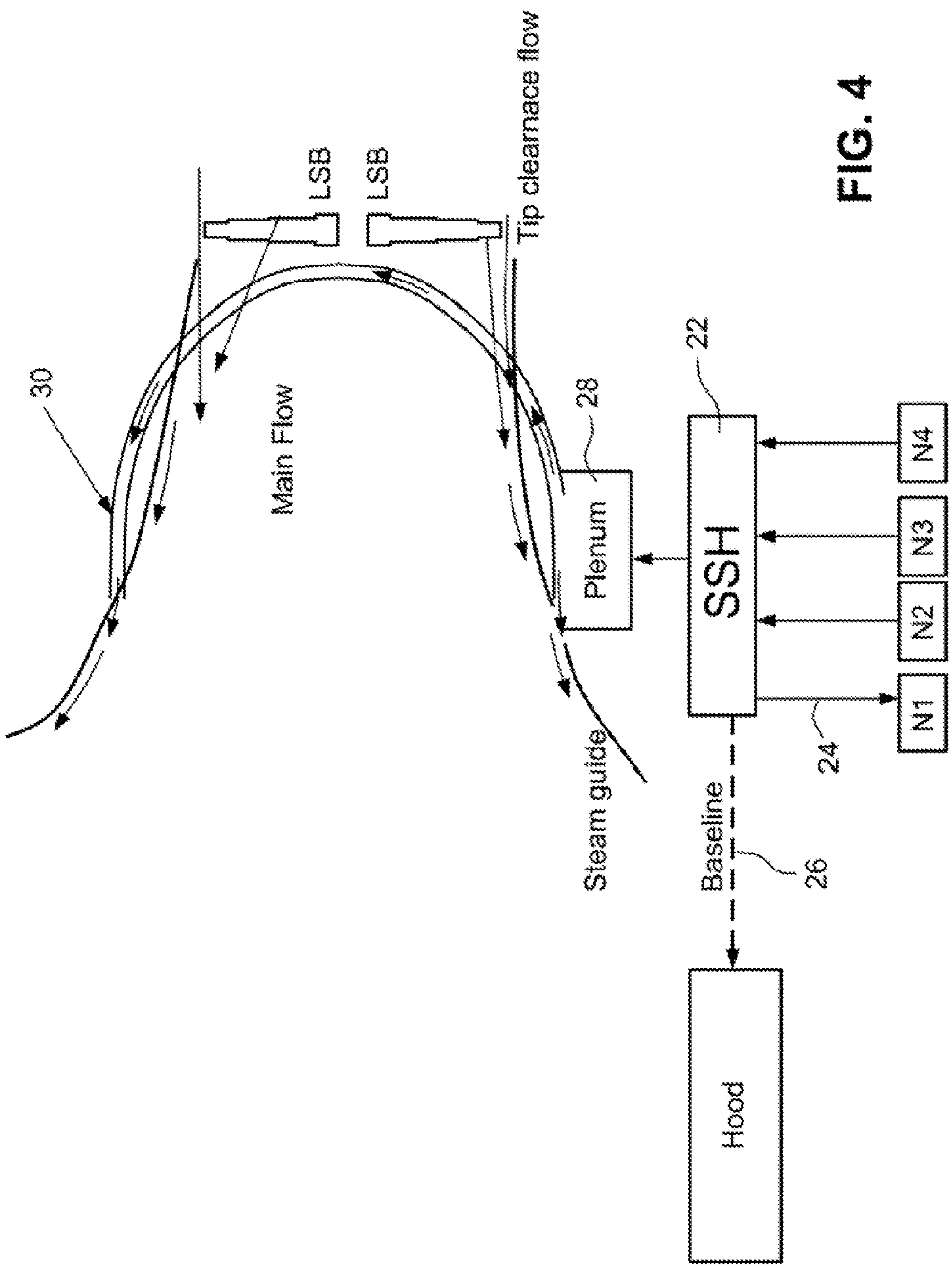

LSB
LSB
Tip clearnace flow
30
Main Flow
28
Plenum
22
SSH
N1
N2
N3
N4
24
Steam guide
Baseline
26
Hood

FIG. 4

BOUNDARY LAYER BLOWING USING STEAM SEAL LEAKAGE FLOW

BACKGROUND OF THE INVENTION

[0001] The invention relates to steam turbine performance and, more particularly, to a source for a fluidic actuating scheme for improved diffuser performance in a steam turbine.

[0002] In condensing steam turbines used in power generation, steam leaving the last row of turbine blades flows, generally, through an annular outwardly flared passage, known as a diffuser, positioned between the turbine enclosure, or casing, and the exhaust hood. The diffuser is defined by an outwardly flared flow guide extending from the turbine casing. The steam passes from the diffuser into the body of a collector or "exhaust hood" and subsequently discharges from the exhaust hood into a condenser.

[0003] The diffuser serves to decelerate, or diffuse, the exhaust steam passing therethrough. This deceleration causes a decrease in the kinetic energy of the steam plus an increase in pressure, the net effect being that the inlet to the diffuser assumes the lowest pressure of the path from the turbine to the condenser so that the steam exhausts from the last turbine blades into a minimum pressure zone thus increasing the velocity of steam flowing through the blades and increasing the energy available to the turbine to do work.

[0004] Each moving blade provides a wake, i.e., in the typical large turbine, as many as a hundred or more wakes are present. In steam turbines, these wakes are especially thick when the turbine operates at condenser pressures higher than the design condenser pressure because under such conditions, the boundary layer flow passing over and from the surfaces of the last turbine blades is either on the verge of separation or is partially separated from the blade surfaces.

[0005] U.S. Pat. No. 6,896,475 (the '475 patent) describes a turbine diffuser augmented with fluidic actuation. The '475 patent recognizes that the performance of a steam turbine exhaust system is limited by geometry constraints and flow separation issues. For example, the down flow hood axial length cannot be increased without changing the bearing span of the machine rotor, and the maximum area ratio allowable through the steam guide flow path, before flow separation occurs, yields a low value of the pressure recovery coefficient of 0.3 for the whole exhaust hood. For one type of an axial flow diffuser used in steam turbines, the maximum included angle that can be tolerated before significant separation (and losses) occurs is of the order of 10-15 degrees. This issue, in addition to constraints on the length of the diffuser, limits the exhaust pressure recovery coefficient to a value of 0.25-0.3.

[0006] Previously, options that have been identified to improve diffuser performance relative to conventional designs include use of splitter vanes, vortex generators and wall riblets. Splitter vanes have the disadvantage of increasing skin friction (and therefore losses) and appear to work relatively well only for uniform inlet flows. Inlet swirl, for instance, can substantially deteriorate the performance. Vortex generators and other passive devices need a high momentum core flow to re-energize the boundary layer and delay separation. In principle, they are expected to fail to yield a substantial increase in diffuser performance if, as it is the case downstream of the last turbine stage at the diffuser inlet, the diffuser inlet flow profile is severely skewed and characterized by large regions of low momentum fluid in the vicinity of the separation point. Evidence of diffuser performance improvement due to the use of ribs/riblets on the diverging diffuser walls is uncertain.

[0007] The '475 patent overcomes the drawbacks and deficiencies of prior constructions with a diffuser augmented with fluidic actuation. The present invention relates to a source of the fluidics.

BRIEF DESCRIPTION OF THE INVENTION

[0008] In an exemplary embodiment, a steam turbine includes a final turbine stage, an axial or radial flow diffuser receiving a main flow from the final turbine stage, a diverging wall in the axial or radial flow diffuser that extends from a diffuser inlet to a diffuser exit, and a centerbody in the axial or radial flow diffuser. An opening is provided in the diverging wall and an opening is provided in the centerbody for fluidically actuating the main flow. The openings are located downstream from the diffuser inlet and upstream from a point where boundary layer separation would occur along the walls in a diffuser without the openings. A plurality of openings are provided in the diverging wall, and an end packing seal is positioned adjacent an end portion of the final turbine stage. An annular manifold collects fluid from leakage flow from the end packing seal and distributes the leakage flow to the openings.

[0009] In another exemplary embodiment, a steam turbine includes a final turbine stage, an axial or radial flow diffuser receiving a main flow from the final turbine stage, a diverging wall in the axial or radial flow diffuser that extends from a diffuser inlet to a diffuser exit, and a centerbody in the axial or radial flow diffuser. An opening is provided in the diverging wall and an opening is provided in the centerbody for fluidically actuating the main flow. A steam seal header collects fluid from leakage flow from at least the final turbine stage. The openings in the diverging wall and the centerbody are located downstream from the diffuser inlet and upstream from a point where boundary layer separation would occur along the walls in a diffuser without the openings. Steam is extracted from the steam seal header and directed into the openings in the diverging wall to energize the boundary layer.

[0010] In yet another exemplary embodiment, a method of improving diffuser performance includes the steps of allowing a main flow to pass through the diffuser; providing an opening in a diffuser wall; utilizing a steam seal header as a fluid source; injecting fluid from the steam seal header into the opening for preventing separation of the main flow from the diffuser wall; and directing the fluid at an angle relative to the main flow and relative to the diffuser wall, where directing the fluid at an angle comprises sending the fluid through a curved passageway having a curvature which is convex relative to the main flow prior to injecting fluid into the opening.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a schematic illustration of a steam turbine;

[0012] FIG. **2** shows a steam turbine axial flow diffuser augmented with fluidic actuation;

[0013] FIG. **3** shows a steam turbine down-flow exhaust hood augmented with fluidic actuation; and

[0014] FIG. **4** is a schematic illustration of a steam turbine utilizing end packing leakage flows as a source of fluidics.

DETAILED DESCRIPTION OF THE INVENTION

[0015] Referring to FIG. **1**, a steam turbine **10** is shown which includes a high pressure (HP) section **12**, an intermediate pressure (IP) section **13**, and a low pressure (LP) section **14**. The steam turbine **10** also includes associated high pressure seals **16**, intermediate pressure seals **18**, and low pressure seals **20** generally in the form of end packings, which are provided at the end of each of the HP, IP and LP sections (referred to as N**1**, N**2**, N**3** and N**4**) to seal the stator rotor gaps.

[0016] High-temperature steam or fluid from an inlet passageway is directed to contact a plurality of blades of a first stage plurality of buckets. As the fluid contacts the plurality of blades of the first stage plurality of buckets, the fluid rotates or continues to rotate the plurality of buckets, a wheel member, and a rotor. The fluid then passes through the first stage plurality of buckets in a downstream direction to a second stage. The fluid passes in the downstream direction through the successive plurality of stages in a substantially similar manner, thereby rotating the rotor an additional amount at each stage. By rotating the rotor, the fluid performs work in the steam turbine. Fluid that does not perform work by flowing through the plurality of buckets and rotating the rotor is considered leakage fluid.

[0017] End packing (N**2**, N**3** and N**4**) leakage flows are collected in a steam seal header (SSH) **22**. A portion of the flow (about 1 lbm/sec) is used to seal the LP end packing leakage via line **24**, and the remaining flow (about 1 lbm/sec) is discharged via a line **26** in the exhaust hood. This can be discharged either in the steam guide (diffuser outer wall) or in the diffuser inner surface (bearing cone), depending on where the flow separation occurs. Described in more detail below, the preferred embodiments utilize the discharge flow in the diffuser inner and outer wall surfaces (at certain radial and tangential flow angles) to energize the boundary layer, thereby avoiding separation even at a higher area ratio or steeper wall angles in the case of a shorter diffuser. A higher area ratio leads to higher ideal CP (static pressure recovery), which leads to higher last stage expansion and higher power output.

[0018] Aggressive steam turbine exhaust systems with high potential pressure recovery (high area-ratio, short axial length) can be designed via the implementation of flow control (blowing) to prevent wall boundary layer separation. FIG. **2** shows an axial flow diffuser, and FIG. **3** shows a down-flow exhaust hood. For both exhaust systems, the implementation of the wall blowing technology has the potential of enabling a design which yields high pressure recoveries (low energy losses) within the geometrical constraints of the exhaust configuration. As a result, increased work extraction from the machine can be achieved.

[0019] An example of an augmented steam turbine axial flow diffuser **300** is shown in FIG. **2**. The admission locations in FIGS. **2** and **3** are shown closer to the last stage bucket; however, this location might change depending on the diffuser, last stage bucket, amount of bucket tip leakage, etc. The invention is not necessarily meant to be limited to the illustrated construction. The annular diffuser **300** includes a centerbody **310** and a diverging diffuser wall **302** extending from a diffuser inlet section **304**, which is adjacent the last turbine stage **306**, to the diffuser exit plane **308**. The main flow **312**, indicated by the flow direction arrow, flows from the last turbine stage **306**, through the diffuser **300**, and past the diffuser exit plane **308**. Spots **314** and **311** indicate approximate locations of the boundary layer injection ports. It should be noted that there are injection ports **311**, **314** along the outer diverging diffuser wall **302** and the straight centerbody **310**. The injection ports should be located just upstream the point where boundary layer separation occurs. Also, injection port **311** provided on centerbody **310** is downstream injection port **314** provided on diffuser wall **302**.

[0020] For the down-flow exhaust hood case shown in FIG. **3**, there is very low pressure recovery for the current geometry: for typical machine operating conditions Cp is about 0.3 which is indicative of substantial energy losses through the duct. However, the geometry constraints and flow separation prevent increase in performance. Flow control (blowing) enables the design and implementation of a more aggressive-higher area ratio-exhaust hood geometry with a potentially higher pressure recovery while preventing boundary layer separation and associated losses. Since most of the diffusion in a down-flow exhaust hood **330** occurs through the diffuser outer surface (steam guide passage) **332** (FIG. **3**, a higher area ratio steam guide passage has the potential to yield a higher pressure recovery as long as flow separation is prevented). Blowing is applied at location **334** around the circumference of the steam guide **332** to energize or remove the weakened boundary layer and prevent flow separation of the main flow **342**. The flow may be injected in the inner wall or bearing cone depending on the diffuser design, bucket design, operating conditions, etc.

[0021] For the axial flow diffuser, such as shown in FIG. **2**, annular slots or discrete holes may be employed for the geometry of the injection ports.

[0022] One or more annular slots extending around a portion of the circumference of the outer wall **302** and centerbody **310** are placed in the vicinity of the diffuser inlet **304**.

[0023] Discrete holes discharging high momentum secondary jets from the outer wall **302** and center-body **310** into the wall boundary layers of the main stream **312** at the diffuser inlet **304**. In order to achieve maximum effectiveness for a specific application, provision is made to control the angle between the axis of the secondary jet and the main flow direction and the angle between the axis of the secondary jet and the local diffuser wall slope. It should be noted that this embodiment includes the case of discrete holes discharging secondary jets tangent to the diverging diffuser walls in the direction of the axis of the diffuser and the case of secondary jets parallel to the main flow direction.

[0024] For the down-flow exhaust hood, such as shown in FIG. **3**, annular slots or discrete holes may be used. Annular slots placed on the steam guide or bearing cone **336** and extending around a portion of the circumference of the steam guide **332** may be employed.

[0025] Discrete holes discharging high momentum secondary jets from the steam guide **332** into the wall boundary layers of the main stream **342** in the vicinity of the hood inlet **336** may also be employed. In order to achieve maximum effectiveness for a specific application, provision is made to control the angle between the axis of the secondary jet and the flow direction and the angle between the axis of the secondary jet and the local steam guide slope. It should be noted that this embodiment includes the case of discrete holes discharging secondary jets tangent to the steam guide walls in the direction of the axis of the hood and the case of secondary jets parallel to the main flow direction.

[0026] For the case of injection tangent to the exhaust diffuser/hood walls, the Coanda effect can be used to keep the secondary jets/films attached to the walls.

[0027] Relative to the slots, the discrete holes have the advantage of easier implementation in a steam turbine exhaust system. From the blowing source, the blowing fluid can be collected into an annular manifold mounted around the circumference of the exhaust outer casing. Small circular tubes connected to the manifold can be used to inject secondary jets into the main stream. The cross section of the manifold should be at least 15-20 times larger than the diameter of the holes to avoid injection with circumferential variation. Alternatively, small tubes can be used to carry the secondary flow directly from the blowing source to the location of injection in the main stream.

[0028] A further advantage of discrete holes relative to circumferential slots is the fact that localized circular jets are expected to promote the development of three-dimensional disturbances in the boundary layer along the diffuser walls. This would enhance mixing and could in principle decrease the required secondary mass-flow rate therefore increasing the effectiveness of the blowing scheme.

[0029] It has been suggested so far that steady secondary flow is injected to prevent separation in a high area ratio exhaust geometry. An alternative embodiment, which could substantially decrease the required amount of secondary flow, is to inject pulsating films/jets. Unsteady injection is expected to be more effective at delaying separation than steady injection due to the artificial generation and development of coherent structures in the wall boundary layers which substantially enhance the mixing of the low momentum boundary layer flow with the high momentum core. Parameters which will play a role in the effectiveness of pulsating films/jets include pulsing frequency, duty cycle and amplitude of the pulsations.

[0030] To transition the fluidic actuation scheme to a steam turbine machine, the selection of a blowing source to provide flow control at the exhaust inlet should be addressed. As discussed in more detail below, it is proposed to utilize end packing leakage flow as the source of fluidics.

[0031] FIG. **4** is a schematic illustration of a steam turbine utilizing end packing leakage flows as a source for boundary layer blowing. Leakage flows in the steam seal header **22** are directed to a plenum **28** that disperses flow to a pipe **30** placed outside the steam guide. Openings in the pipe **30** deliver the leakage flow into the main flow to thereby energize the weak boundary layer developed in the diffuser.

[0032] Blowing the steam seal leakage flow through steam guide slots will serve to energize the weak boundary layer and thereby improve pressure recovery. With this construction, the diffuser pressure recovery coefficient can be improved from 0.1 to 0.5 depending on other design parameters, e.g., last stage bucket, diffuser, and admission design parameters. A CP of 0.1 is equivalent to roughly 0.2-0.3% in LP section efficiency. Alternatively, or additionally, with the structure of the described embodiments, a double flow LP turbine axial span can be shortened by up to 2-3 feet by increasing the diffuser wall angles.

[0033] 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 steam turbine comprising:

a final turbine stage;

an axial or radial flow diffuser receiving a main flow from the final turbine stage;

a diverging wall in the axial or radial flow diffuser, the diverging wall extending from a diffuser inlet to a diffuser exit;

a centerbody in the axial or radial flow diffuser;

an opening in the diverging wall and an opening in the centerbody for fluidically actuating the main flow, wherein the openings are located downstream from the diffuser inlet and upstream from a point where boundary layer separation would occur along the walls in a diffuser without the openings;

a plurality of openings in the diverging wall;

an end packing seal positioned adjacent an end portion of the final turbine stage; and

an annular manifold collecting fluid from leakage flow from the end packing seal and distributing the leakage flow to the openings.

2. A steam turbine according to claim **1**, wherein the annular manifold comprises a steam seal header.

3. A steam turbine according to claim **2**,

comprising multiple turbine stages and a corresponding multiple end packing seals, wherein the steam seal header collects fluid from leakage flow from the multiple end packing seals.

4. A steam turbine according to claim **3**, further comprising a steam guide in fluid communication with the steam seal header, the steam guide delivering the leakage flow from the steam seal header to the axial or radial flow diffuser to energize a boundary layer in the axial or radial flow diffuser.

5. A steam turbine according to claim **1**, further comprising tubes connecting the annular manifold to the openings.

6. A steam turbine according to claim **5**, wherein the tubes are curved convexly relative to the main flow.

7. A steam turbine comprising:

a final turbine stage;

an axial or radial flow diffuser receiving a main flow from the final turbine stage;

a diverging wall in the axial or radial flow diffuser, the diverging wall extending from a diffuser inlet to a diffuser exit;

a centerbody in the axial or radial flow diffuser;

an opening in the diverging wall and an opening in the centerbody for fluidically actuating the main flow; and

a steam seal header collecting fluid from leakage flow from at least the final turbine stage,

wherein the openings in the diverging wall and the centerbody are located downstream from the diffuser inlet and upstream from a point where boundary layer separation would occur along the walls in a diffuser without the openings, wherein steam is extracted from the steam seal header and directed into the openings in the diverging wall to energize the boundary layer.

8. A steam turbine according to claim **7**, further comprising multiple turbine stages and a corresponding multiple end packing seals disposed adjacent end portions of the respective turbine stages, wherein the steam seal header collects fluid from leakage flow from the multiple end packing seals.

9. A steam turbine according to claim **8**, further comprising a steam guide in fluid communication with the steam seal header, the steam guide delivering the leakage flow from the steam seal header to the axial or radial flow diffuser to energize a boundary layer in the axial or radial flow diffuser.

10. A steam turbine according to claim **7**, further comprising tubes connecting the steam seal header to the openings.

11. A steam turbine according to claim **10**, wherein the tubes are curved convexly relative to the main flow.

12. A method of improving diffuser performance comprising:

allowing a main flow to pass through the diffuser;

providing an opening in a diffuser wall;

utilizing a steam seal header as a fluid source;

injecting fluid from the steam seal header into the opening for preventing separation of the main flow from the diffuser wall; and

directing the fluid at an angle relative to the main flow and relative to the diffuser wall, wherein directing the fluid at an angle comprises sending the fluid through a curved passageway having a curvature which is convex relative to the main flow prior to injecting fluid into the opening.

13. A method according to claim **12**, further comprising positioning a centerbody within the diffuser and providing an opening in a wall of the centerbody.

14. A method according to claim **13**, further comprising injecting fluid from the steam seal header through the opening of the centerbody and into the diffuser.

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