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TURBINE BLADE HAVING NON-AXISYMMETRIC ENDWALL CONTOUR AND GAS TURBINE INCLUDING SAME

Abstract

Proposed is a turbine blade which includes an airfoil including a pressure surface, a suction surface, a leading edge, and a trailing edge, an endwall formed integrally on a lower portion of the airfoil, and a root part formed integrally on a lower portion of the endwall, wherein an outer peripheral surface of the endwall is formed with a curved surface from a rim seal positioned at a first side of the endwall to a second end of the endwall.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to Korean Patent Application No. 10-2024-0021554, filed on Feb. 15, 2024, the entire contents of which are incorporated herein for all purposes by this reference.

BACKGROUND

1. Technical Field

[0002] The present disclosure relates to a turbine blade having a non-axisymmetric endwall contour and a gas turbine including the same.

2. Description of the Related Art

[0003] A turbine is a mechanical device that obtains rotational force through impulse or reaction force by utilizing the flow of compressible fluid such as steam or gas. Examples of the turbine include a steam turbine that uses steam and a gas turbine that uses high-temperature combustion gas.

[0004] Among these, the gas turbine is largely composed of a compressor, a combustor, and a turbine. The compressor is provided with an air inlet for introducing air, and a plurality of compressor vanes and a plurality of compressor blades are arranged alternately within a housing of the compressor.

[0005] The combustor supplies fuel to air compressed by the compressor and ignites the mixture of the fuel and air with a burner, thereby generating high-temperature, high-pressure combustion gas.

[0006] A turbine consists of a plurality of turbine vanes and a plurality of turbine blades arranged alternately within a turbine housing. In addition, a rotor is arranged to penetrate the center of the compressor, the combustor, the turbine, and an exhaust chamber.

[0007] The rotor is rotatably supported at opposite end portions by bearings. In addition, a plurality of disks is fixed to the rotor to connect each of the blades, and a drive shaft of a generator is connected to the end portion of the exhaust chamber.

[0008] Such a gas turbine does not have a reciprocating mechanism such as a piston in a four-stroke engine, and thus has no frictional part such as that of a piston and a cylinder, so the gas turbine is extremely low in the consumption of lubricating oil, has greatly reduced amplitude, which is a characteristic of a reciprocating mechanism,, and is capable of high-speed operation.

[0009] To briefly explain the operation of the gas turbine, air compressed by the compressor is mixed with fuel and combusted to produce high-temperature combustion gas, and the combustion gas produced in this way is injected toward the turbine. As the injected combustion gas passes through the turbine vanes and the turbine blades, rotational force is generated, causing the rotor to rotate.

[0010] In order to construct such a turbine, a configuration is widely used in which a plurality of turbine rotor disks is configured in multiple stages, with each of the turbine rotor disks having a plurality of turbine blades arranged on an outer circumferential surface thereof, so that the high-temperature, high-pressure combustion gas passes through the turbine blades.

[0011] Meanwhile, when the turbine blades are assembled on site, workers are required to assemble the multiple turbine blades from a first stage turbine to a last stage turbine, which results in assembly tolerances after a lot of time and work. In addition, as for the turbine blades, irregular steps or gaps are maintained between adjacently assembled turbine blades, and thus when combustion gas flows, issues caused by a secondary vortex are generated.

[0012] In a case in which the secondary vortex is generated when the combustion gas passes through the turbine blades, aerodynamic loss occurs on a suction surface or a pressure surface.

[0013] In this case, since the gas turbine has low efficiency, countermeasures are needed to ensure the stable movement of combustion gas.

[0014] The foregoing is intended merely to aid in the understanding of the background of the present disclosure, and is not intended to mean that the present disclosure falls within the purview of the related art that is already known to those skilled in the art.

SUMMARY

[0015] Accordingly, the present disclosure has been made keeping in mind the above problems occurring in the related art, and an objective of the present disclosure is to provide a turbine blade, and a gas turbine including the same, which can improve aerodynamic performance by reducing a secondary vortex by forming a non-axisymmetric endwall contour having a plurality of convex portions and a plurality of concave portions from a rim seal at a leading edge side.

[0016] In order to achieve the above objective, a turbine blade of the present disclosure includes: an airfoil including a pressure surface, a suction surface, a leading edge, and a trailing edge; an endwall formed integrally on a lower portion of the airfoil; and a root part formed integrally on a lower portion of the endwall, wherein an outer peripheral surface of the endwall is formed as a curved surface from a rim seal positioned at a first side of the endwall to a second end of the endwall.

[0017] The endwall may include: a first rim seal extending upstream from a position of the leading edge; and a second rim seal extending downstream from a position of the trailing edge.

[0018] The outer peripheral surface of the endwall may be formed as a streamlined curved surface connected between the first rim seal and an end portion of the outer peripheral surface on a side of the trailing edge.

[0019] The second rim seal may be arranged to be lower than a radial height of a portion of the outer peripheral surface of the endwall connected to the trailing edge.

[0020] The outer peripheral surface of the endwall may be formed to have a highest radial height at a portion of the outer peripheral surface connected to the leading edge.

[0021] A radial height of the outer peripheral surface of the endwall may increase from the first rim seal to the portion of the outer peripheral surface connected to the leading edge and then decrease toward the trailing edge.

[0022] The outer peripheral surface of the endwall may include two concave parts positioned near an end edge of the pressure surface and positioned between a side portion of the leading edge and a side portion of the trailing edge.

[0023] The outer peripheral surface of the endwall may include two concave parts positioned near an end edge of the suction surface and positioned between a side portion of the leading edge and a side portion of the trailing edge.

[0024] A gas turbine of the present disclosure includes: a compressor configured to take in and compress external air; a combustor configured to mix fuel with the air compressed by the compressor and combust the fuel mixed with the air; and a turbine in which turbine blades and turbine vanes are mounted inside a turbine housing, with each of the turbine blades being rotated by combustion gas discharged from the combustor, wherein the turbine blade includes: an airfoil comprising a pressure surface, a suction surface, a leading edge, and a trailing edge; an endwall formed integrally on a lower portion of the airfoil; and a root part formed integrally on a lower portion of the endwall, wherein an outer peripheral surface of the endwall is formed as a curved surface from a rim seal positioned at a first side of the endwall to a second end of the endwall.

[0025] The endwall may include: a first rim seal extending upstream from a position of the leading edge; and a second rim seal extending downstream from a position of the trailing edge.

[0026] The outer peripheral surface of the endwall may be formed as a streamlined curved surface connected between the first rim seal and an end portion of the outer peripheral surface on a side of the trailing edge.

[0027] The second rim seal may be arranged to be lower than a radial height of a portion of the outer peripheral surface of the endwall connected to the trailing edge.

[0028] The outer peripheral surface of the endwall may be formed to have a highest radial height at a portion of the outer peripheral surface connected to the leading edge.

[0029] A radial height of the outer peripheral surface of the endwall may increase from the first rim

seal to the portion of the outer peripheral surface connected to the leading edge and then decrease toward the trailing edge.
[0030] The outer peripheral surface of the endwall may include two concave parts positioned near an end edge of the pressure surface and positioned between a side portion of the leading edge and a side portion of the trailing edge.
[0031] The outer peripheral surface of the endwall may include two concave parts positioned near an end edge of the suction surface and positioned between a side portion of the leading edge and a side portion of the trailing edge.
[0032] As described above, according to the turbine blade and the gas turbine including the same of the present disclosure, a non-axisymmetric endwall contour having a plurality of convex portions and a plurality of concave portions is formed from a rim seal at a leading edge side so as to reduce a secondary vortex, thereby improving aerodynamic performance.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0033] FIG. **1** is a cutaway perspective view of a portion of a gas turbine according to an embodiment of the present disclosure;
[0034] FIG. **2** is a cross-sectional view schematically showing the structure of the gas turbine according to an embodiment of the present disclosure;
[0035] FIG. **3** is a partial cross-sectional view showing the internal structure of the gas turbine according to an embodiment of the present disclosure;
[0036] FIG. **4**A is a partial perspective view showing a turbine blade according to a prior art, and FIG. **4**B is a partial perspective view showing a turbine blade according to an embodiment of the present disclosure;
[0037] FIG. **5** is a perspective view showing the turbine blade according to an embodiment of the present disclosure;
[0038] FIG. **6** is a perspective view of the turbine blade of FIG. **5** viewed from a pressure surface side;
[0039] FIG. **7** is a perspective view of the turbine blade of FIG. **5** viewed from a leading edge side;
[0040] FIG. **8** is a perspective view of the turbine blade of FIG. **5** viewed from a suction surface side;
[0041] FIG. **9** is a top view showing the height of the outer peripheral surface of an endwall in the turbine blade with contour lines according to an embodiment of the present disclosure;
[0042] FIG. **10**A is a photograph showing a secondary vortex generated in the turbine blade according to the prior art, and FIG. **10**B is a photograph showing a secondary vortex generated in the turbine blade according to an embodiment of the present disclosure; and
[0043] FIG. **11** is a graph showing pressure loss according to a position of a span in the turbine blade according to the prior art and in the turbine blade according to an embodiment of the present disclosure.
DETAILED DESCRIPTION
[0044] Since the present disclosure can be modified in various ways and can have various embodiments, specific embodiments will be exemplified and explained in detail in the detailed description. However, it should be noted that the present disclosure is not limited thereto, and may include all of modifications, equivalents, and substitutions within the spirit and scope of the present disclosure.
[0045] Terms used herein are used to merely describe specific embodiments, and are not intended to limit the present disclosure. As used herein, an element expressed as a singular form includes a plurality of elements, unless the context clearly indicates otherwise. Further, it will be understood

that the term “comprising” or “including” specifies the presence of stated features, numbers, steps, operations, elements, parts, or combinations thereof, but does not preclude the presence or addition of one or more other features, numbers, steps, operations, elements, parts, or combinations thereof.

[0046] Hereinafter, preferred embodiments of the present disclosure will be described in detail with reference to the accompanying drawings. It should be noted that like elements are denoted in the drawings by like reference symbols as whenever possible. Further, the detailed description of known functions and configurations that may obscure the gist of the present disclosure will be omitted. For the same reason, some of the elements in the drawings are exaggerated, omitted, or schematically illustrated.

[0047] FIG. **1** is a cutaway perspective view of a portion of a gas turbine according to an embodiment of the present disclosure; FIG. **2** is a cross-sectional view schematically showing the structure of the gas turbine according to an embodiment of the present disclosure; and FIG. **3** is a partial cross-sectional view showing the internal structure of the gas turbine according to an embodiment of the present disclosure.

[0048] As illustrated in FIG. **1**, a gas turbine **1000** according to an embodiment of the present disclosure includes a compressor **1100**, a combustor **1200**, and a turbine **1300**. The compressor **1100** includes multiple blades **1110** installed radially. The compressor **1100** rotates the blades **1110**, and air moves while being compressed by the rotation of the blades **1110**. The size and installation angle of each of the blades **1110** may vary depending on an installation location. In an embodiment, the compressor **1100** may be directly or indirectly connected to the turbine **1300** to receive some of power generated by the turbine **1300** and may rotate the blades **1110**.

[0049] The air compressed from the compressor **1100** moves to the combustor **1200**. The combustor **1200** includes a plurality of combustion chambers **1210** and fuel nozzle modules **1220** arranged in an annular configuration.

[0050] As illustrated in FIG. **2**, the gas turbine **1000** according to an embodiment of the present disclosure has a housing **1010**, wherein the housing **1010** has a diffuser **1400** provided at a rear side thereof so that combustion gas passing through the turbine is injected through the diffuser **1400**. In addition, the combustor **1200**, which receives and combusts compressed air, is arranged in front of the diffuser **1400**.

[0051] In terms of the direction of air flow, the compressor **1100** is located at the upstream side of the housing **1010**, and the turbine **1300** is located at the downstream side of the housing **1010**. In addition, a torque tube unit **1500** as a torque transmission member that transmits rotational torque generated in the turbine **1300** to the compressor **1100** is arranged between the compressor **1100** and the turbine **1300**.

[0052] The compressor **1100** is provided with a plurality of compressor rotor disks **1120** (e.g. 14 disks), and each of the compressor rotor disks **1120** is connected to each other by a tie rod **1600** so as not to be spaced apart from each other in an axial direction.

[0053] Specifically, each of the compressor rotor disks **1120** are aligned axially with each other while the tie rod **1600**, which constitutes a rotational shaft of the compressor rotor disks **1120**, passes roughly through the center thereof. Here, the neighboring compressor rotor disks **1120** have opposing surfaces pressed by the tie rod **1600** to prevent relative rotations thereof.

[0054] The compressor rotor disk **1120** has a plurality of blades **1110** coupled radially on an outer circumferential surface thereof. Each of the blades **1110** has a dovetail portion **1112** to be connected to the compressor rotor disk **1120**.

[0055] A vane (not shown) is positioned between each of the compressor rotor disks **1120** by being fixed to the housing. The vane, unlike the rotor disk, is fixed so as not to rotate, and serves to align the flow of compressed air passing through the blades of the compressor rotor disk and to guide the air to the blades of the rotor disk located on the downstream side.

[0056] The fastening method of the dovetail portion **1112** includes a tangential-type method and an axial-type method. This may be selected according to the required structure of a commercially available gas turbine, and the dovetail portion **1112** may have a commonly known dovetail or fir-tree shape. In some cases, the blades may be fastened to the rotor disk by using fasteners other than those mentioned above, such as keys or bolts.

[0057] The tie rod **1600** is arranged to penetrate the centers of the plurality of compressor rotor disks **1120** and turbine rotor disks **1320**. The tie rod **1600** may include one or a plurality of tie rods. A first end portion of the tie rod **1600** is fastened within the compressor rotor disk located on the most upstream side, and a second end portion of the tie rod **1600** is fastened by a fixing nut **1450**.

[0058] The shape of the tie rod **1600** may have various structures depending on a gas turbine, and is not necessarily limited to the shape presented in FIG. **2**. That is, as illustrated, one tie rod may have the form of penetrating the center of the rotor disk, or a plurality of tie rods may have a form arranged circumferentially, and a combination thereof is also possible.

[0059] Although not shown, the compressor of the gas turbine may have a vane that acts as a guide vane installed at a position next to the diffuser to adjust a flow angle of fluid entering the inlet of the combustor to a design flow angle after increasing the pressure of the fluid. This vane is called a deswirler.

[0060] In the combustor **1200**, compressed air introduced thereto is mixed with fuel and combusted to produce high-temperature, high-pressure combustion gas with high energy, and the temperature of the combustion gas is increased to a heat resistance limit to which the combustor and turbine components can withstand through an isobaric combustion process.

[0061] The combustor, which constitutes the combustion system of the gas turbine, may include multiple combustors arranged within the housing formed in a cell shape, and may include a burner including a fuel injection nozzle, a combustor liner constituting a combustion chamber, and a transition piece that serves as a connection portion between the combustor and the turbine.

[0062] Specifically, the liner provides a combustion space in which fuel injected by a fuel nozzle is mixed with the compressed air of the compressor and combusted. Such a liner may include a flame tube providing a combustion space in which fuel mixed with air is combusted, and a flow sleeve forming an annular space while surrounding the flame tube. Additionally, the fuel nozzle is coupled to the front end of the liner, and a spark plug is coupled to a side wall of the liner.

[0063] Meanwhile, the transition piece is connected to the rear end of the liner so as to send combustion gas combusted by the spark plug to the turbine. The outer wall of the transition piece is cooled by compressed air supplied from the compressor to prevent damage caused by the high temperature of the combustion gas.

[0064] To this end, the transition piece is provided with holes for cooling so that air can be injected into the interior thereof, and the compressed air cools a body of the transition piece inside through the holes and then flows to the liner.

[0065] Cooling air that has cooled the aforementioned transition piece flows in the annular space of the liner, and compressed air from the outside of the flow sleeve is supplied as cooling air through cooling holes formed in the flow sleeve and impinges on the outer wall of the liner.

[0066] Meanwhile, high temperature and high pressure combustion gas from the combustor is supplied to the turbine **1300** described above. As the supplied high-temperature and high-pressure combustion gas expands, the gas collides with the rotating blades of the turbine, providing a reaction force to generate rotational torque. The rotational torque thus obtained is transmitted to the compressor through the torque tube described above, and any power exceeding power required to drive the compressor is used to drive a generator.

[0067] The turbine **1300** is basically similar in structure to the compressor. That is, the turbine **1300** is also provided with the plurality of turbine rotor disks **1320** similar to the compressor rotor disks of the compressor. Accordingly, the turbine rotor disks **1320** also include a plurality of turbine blades **1340** that are radially arranged. The turbine blades **1340** may also be coupled to the turbine rotor disks **1320** in a dovetail manner. In addition, a turbine vane **1330** fixed to the housing is provided between the turbine blades **1340** of the turbine rotor disks **1320** to guide the flow

direction of combustion gas passing through the blades.
[0068] As illustrated in FIG. **3**, the turbine vane **1330** is fixedly mounted within the housing by a vane carrier **1335**. The vane carrier **1335** forms an endwall coupled to each of the inner and outer end portions of the turbine vane **1330**. Meanwhile, a ring segment **1345** is mounted at a position facing the outer end portion of the turbine blade **1340** that rotates inside the housing such that a predetermined gap is formed between the ring segment **1345** and the outer end portion of the turbine blade **1340**. That is, the gap between the ring segment **1345** and the outer end portion of the turbine blade **1340** forms a tip clearance.
[0069] FIG. **4**A is a partial perspective view showing a turbine blade according to a prior art, and FIG. **4**B is a partial perspective view showing a turbine blade according to an embodiment of the present disclosure.
[0070] A turbine blade **10** according to the prior art, as illustrated in FIG. **4**A, includes an airfoil **11** and an endwall **12** integrally formed on the lower portion of the airfoil **11**. The airfoil **11** includes a pressure surface, a suction surface, a leading edge, and a trailing edge. The outer peripheral surface of the endwall **12** appears to be in a nearly flat shape. However, technically speaking, the outer peripheral surface of the endwall **12** is formed as a curved surface with a constant radius of curvature about the rotation axis of the turbine **1300**. Accordingly, the endwall **12** shown in FIG. **4**A is axisymmetric relative to the rotation axis of the turbine **1300**.
[0071] As illustrated in FIG. **4**B, a turbine blade **100** according to an embodiment of the present disclosure includes an airfoil **110** and an endwall **120** integrally formed at the lower portion of the airfoil **110**. The endwall **120** may have a rim seal formed on each of axial upstream and downstream sides. According to an embodiment, the outer circumferential surface of the endwall **120** may be formed as a smooth curved surface by being connected to the upper surface (i.e., outer circumferential surface) of the upstream rim seal.
[0072] FIG. **5** is a perspective view showing the turbine blade according to an embodiment of the present disclosure, FIG. **6** is a perspective view of the turbine blade of FIG. **5** viewed from a pressure surface side, FIG. **7** is a perspective view of the turbine blade of FIG. **5** viewed from a leading edge side, and FIG. **8** is a perspective view of the turbine blade of FIG. **5** viewed from a suction surface side.
[0073] The turbine blade **100** according to an embodiment of the present disclosure includes the airfoil **110**, the endwall **120** integrally formed on a lower portion of the airfoil, and a root part **130** integrally formed on a lower portion of the endwall **120**. A surface part or a position of the endwall **120** at which the endwall **120** meets the airfoil **110** may be referred to a connecting part **123**.
[0074] The airfoil **110** includes the pressure surface **111** formed concavely on a first side surface thereof, the suction surface **112** formed convexly on a second side surface thereof, the leading edge **113** formed on an upstream edge, and the trailing edge **114** formed on a downstream end portion.
[0075] A direction in which the root part **130** is extended under the endwall **120** may be referred to as an axial direction, defining upstream and downstream along the axial direction. A circumferential direction from the suction surface **112** toward the pressure surface **111** may be referred to as a pressure side circumferential direction or a circumferentially pressure side, and an opposite direction to the pressure side circumferential direction may be referred to as a suction side circumferential direction or a circumferentially suction side.
[0076] The endwall **120** may be integrally connected to the lower portion of the airfoil **110**, that is, a radially inner end portion thereof. An outer surface of the endwall **120** may be formed as a curved surface from a rim seal at a first end (i.e., an upstream end) of the endwall **120** to a second end (i.e., a downstream end) of the endwall **120**.
[0077] The endwall **120** may include a first rim seal **121** extending upstream from an upstream side of the endwall **120** before a position of the leading edge **113** and a second rim seal **122** extending downstream from a downstream side of the endwall **120** after a position of the trailing edge **114**.
[0078] A plurality of turbine blades **100** are mounted on the circumference of each of the turbine

rotor disks **1320**. The first rim seal **121** of the endwall **120** of a turbine blade **100** may be formed to seal a gap between an upstream turbine vane **1330**, which is a stationary element, and the said turbine blade **100**. The second rim seal **122** of the endwall **120** of the turbine blade **100** may be formed to seal a gap between a downstream turbine vane **1330**, which is a stationary element, and the said turbine blade **100**.

[0079] The outer peripheral surface of the endwall **120** may be formed in general as a streamlined curved surface connected between the first rim seal **121** and an end portion of the endwall **120** on a side of the trailing edge **114**.

[0080] As illustrated in FIG. **5**, the upper surface of the endwall **120** may be formed as a smooth and streamlined curved surface continuing from the upper surface of the first rim seal **121**.

[0081] The second rim seal **122** may be positioned at a radial height lower than that of a portion of the outer peripheral surface of the endwall **120** connected to the trailing edge **114**.

[0082] The second rim seal **122** may be formed to extend radially inwardly and downstream from the downstream end edge of the outer peripheral surface of the endwall **120**. The second rim seal **122** may be formed to extend from a lower surface of the endwall **120** from a position slightly upstream than a tip of the downstream end edge of the endwall **120**.

[0083] As illustrated in FIG. **6**, the first rim seal **121** may be positioned slightly higher in the radial direction than the second rim seal **122**, while the radial height of the first rim seal **121** may be slightly lower than the downstream end edge of the outer peripheral surface of the endwall **120**.

[0084] As illustrated in FIGS. **5** and **6**, the outer peripheral surface of the endwall **120** may be formed to have a highest radial height at a portion of the connecting part **123** (i.e., a portion A) that is connected to the leading edge **113** of the airfoil **110**.

[0085] The portion A of the connecting part **123** at which the outer peripheral surface of the endwall **120** is connected to the radially inner end portion of the leading edge **113** of the airfoil **110** may be formed to have the highest radial height. According to an embodiment, the portion A of the connecting part **123** may be formed with a convex curved surface when viewed from a pressure surface side of the blade **100**. According to an embodiment, the portion A of the connecting part **123** may include a partially flat portion, which has the highest radial height.

[0086] Meanwhile, a portion B of the connecting part **123** immediately before (i.e., at a position immediately upstream than) the trailing edge **114** may be formed to have the lowest radial height. In other words, according to an embodiment, a portion of the connecting part **123** connected to the radially inner end portion of the trailing edge **114** may have a higher radial height than the one of the portion B of the connecting part **123**. According to an embodiment, the portion B of the connecting part **123** may be formed with a concaved curved surface.

[0087] The radial height of the outer peripheral surface of the endwall **120** may increase from the first rim seal **121** to a portion of the outer peripheral surface connected to the leading edge **113** and then decrease toward the trailing edge **114**.

[0088] According to an embodiment, a position where the second rim seal **122** starts to extend radially inwardly and downstream from a lower surface of the endwall **120** may be positioned between, in the axial direction, the portion B and the portion of the connecting part **123** connected to the radially inner end portion of the trailing edge **114** (i.e., positioned downstream than the portion B and upstream than the portion of the connecting part **123** connected to the radially inner end portion of the trailing edge **114**).

[0089] As illustrated in FIGS. **5** and **6**, according to an embodiment, the outer peripheral surface of the endwall **120** may include two concave parts **127** near the end edge of the pressure surface **111** between, in the axial direction, a side portion of the leading edge **113** and a side portion of the trailing edge **114**. The two concave parts **127** may be positioned at a circumferentially pressure side end edge of the outer peripheral surface of the endwall **120**.

[0090] The outer peripheral surface of the endwall **120** may have a first convex part **125-1** and a second convex part **125-2** at the circumferentially pressure side end edge of the outer peripheral surface of the endwall **120**.

[0091] The first convex part **125-1** may be formed near, or substantially same axial location with, a portion of the outer peripheral surface connected to the leading edge **113** at the side of the pressure surface **111** of the airfoil **110**. In addition, the second convex part **125-2** may be formed at an axial location slightly downstream of a middle portion of the side of the pressure surface **111**. On the outer peripheral surface of the endwall **120**, the second convex part **125-2** may be formed to be radially higher at an axial end edge portion thereof than the connecting part **123** which is the radially lower end of the pressure surface **111**.

[0092] On the outer peripheral surface of the endwall **120**, a first concave part **127-1** may be positioned slightly downstream, in the axial direction, than a portion of the outer peripheral surface connected to the leading edge **113**. The first concave part **127-1** may be formed to be lower at an axial end edge portion thereof than the connecting part **123** which is the lower end of the pressure surface **111**.

[0093] On the outer peripheral surface of the endwall **120**, a second concave part **127-2** may be positioned slightly upstream, in the axial direction, than a portion of the outer peripheral surface connected to the trailing edge **114**. The second concave part **127-2** may be formed to be lower at an axial end edge portion thereof than the connecting part **123** which is the lower end of the pressure surface **111**. According to an embodiment, the second concave part **127-2** may correspond to portion B of the connecting part **123**.

[0094] The radial height of the outer peripheral surface of the endwall **120** may increase from the first rim seal **121** through the portion of the connecting part **123** connected to the leading edge **113** to the first convex part **125-1**, then generally decrease to the second concave part **127-2**, and increase again toward a rear end of the connecting part **123** at which the outer peripheral surface is connected to the trailing edge **114**, along the axial direction.

[0095] The outer peripheral surface of the endwall **120** may have a third convex part **125-3**, a fourth convex part **125-4**, a third concave part **127-3**, and a fourth concave part **127-4** at the circumferentially suction side end edge of the outer peripheral surface of the end wall **120**. The third convex part **125-3**, the fourth convex part **125-4**, the third concave part **127-3**, and the fourth concave part **127-4** may be positioned substantially along the same axial locations as the first convex part **125-1**, the second convex part **125-2**, the third concave part **127-3**, and the fourth concave **127-4**. This arrangement ensures that, when turbine blades **100** are assembled, the concave parts and the convex parts of one turbine blade may align with the corresponding concave parts and the convex parts of an adjacent turbine blade, thereby mitigate the secondary vortex.

[0096] As illustrated in FIG. **8**, according to an embodiment, the outer peripheral surface of the endwall **120** may include two concave parts **127** near the end edge of the suction surface **112** between, in the axial direction, a side portion of the leading edge **113** and a side portion of the trailing edge **114**. The two concave parts **127** may be positioned at a circumferentially suction side end edge of the outer peripheral surface of the endwall **120**.

[0097] On the basis of the axial end edge portion of the suction surface **112** on the outer peripheral surface of the endwall **120**, the third convex part **125-3**, the third concave part **127-3**, the fourth convex part **125-4**, and the fourth concave part **127-4** may be formed in sequence in a downstream direction from an upstream side.

[0098] The third convex part **125-3** may be positioned at the same axial location as the leading edge **113**, or slightly upstream of the leading edge **113**, with respect to the flow direction of combustion gas.

[0099] On the outer peripheral surface of the endwall **120**, the third concave part **127-3** may be formed to be the lowest at an axial end edge thereof at a connection portion thereof with the suction surface **112** at a side downstream from the leading edge **113**. According to an embodiment, on the outer peripheral surface of the endwall **120**, the third concave part **127-3** may be positioned slightly downstream, in the axial direction, than a portion of the outer peripheral surface connected to the

leading edge **113**. The third concave part **127-3** may be formed to be lower at an axial end edge portion thereof than the connecting part **123** which is the lower end of the suction surface **112**.
[0100] The fourth convex part **125-4** may be formed at an axial location slightly downstream of the middle portion of the suction surface **112**. On the outer peripheral surface of the endwall **120**, the fourth convex part **125-4** may be formed to be radially higher at an axial end edge portion thereof than the portion of the outer peripheral surface connected to the lower end of the suction surface **112**.
[0101] The fourth concave part **127-4** is formed to be the lowest at an axial end edge thereof at a connection portion thereof with the trailing edge **114**, and may be arranged between the fourth convex part **125-4** and the connection portion with the trailing edge **114**.
[0102] FIG. **9** is a top view showing the radial height of the outer peripheral surface of an endwall in the turbine blade with contour lines according to an embodiment of the present disclosure. Each of the contour lines indicate the same radial height.
[0103] In the turbine blade, the outer peripheral surface of the endwall **120** may be formed to have a high radial height at the leading edge of the airfoil **110** and the region upstream of the pressure surface. The outer peripheral surface of the endwall **120** may be formed to have a lower radial height in a region in which the outer peripheral surface meets the trailing edge of the airfoil **110**.
[0104] When the axial chord length of the airfoil **110** of the turbine blade is Cx, the radial height of the outer peripheral surface of the endwall **120** may be within a range of ±0.2 Cx. For example, when Cx is approximately 100 mm, the outer peripheral surface of the endwall **120** may be formed within a range of −20 mm to +20 mm with respect to a reference surface, and particularly may be formed within a range of −10 mm to +15 mm. In FIG. **9**, contour lines may be displayed at radial height differences of 2 mm.
[0105] FIG. **10**A is a photograph showing a secondary vortex generated in the turbine blade according to the prior art, and FIG. **10**B is a photograph showing a secondary vortex generated in the turbine blade according to an embodiment of the present disclosure.
[0106] As illustrated in FIG. **10**A, in the turbine blade **10** according to the prior art of FIG. **4**A, it can be seen that a large secondary vortex is generated at a portion downstream of the leading edge **113** near the connection portion between the outer peripheral surface of the endwall **120** and the pressure surface **111**.
[0107] On the other hand, as illustrated in FIG. **10**B, in the turbine blade **100** according to the present disclosure of FIG. **5**, it can be seen that a secondary vortex that occurs at a portion immediately following the leading edge **113** near the connection portion between the pressure surface **111** and the outer peripheral surface of the endwall **120** is significantly reduced.
[0108] FIG. **11** is a graph showing pressure loss according to a position of a span in the turbine blade according to the prior art and in the turbine blade according to an embodiment of the present disclosure.
[0109] FIG. **11** shows total pressure loss coefficient at the turbine blade exit plane of the first stage of the turbine. For the turbine blade of the present disclosure, it can be seen that the total pressure loss coefficient is reduced compared to the prior art, especially in the span range of 0.1 to 0.3.
[0110] According to the turbine blade of the present disclosure, it was seen that the stage efficiency of the first stage was improved compared to the prior art, and overall turbine efficiency was also improved.
[0111] In addition, when the endwall shape of the present disclosure was applied, it was confirmed that compared to the prior art, the efficiency of the gas turbine was improved, the efficiency of the combined cycle of the gas turbine and steam turbine was improved by about 0.05%, the output of the gas turbine was improved, and the output of the combined cycle was improved.
[0112] According to the turbine blade and the gas turbine including the same of the present disclosure, a non-axisymmetric endwall contour having a plurality of convex portions and a plurality of concave portions is formed from a rim seal at a leading edge side so as to reduce a

secondary vortex, thereby improving aerodynamic performance and efficiency.
[0113] While the embodiments of the present disclosure have been described, it will be apparent to those skilled in the art that various modifications and variations can be made in the present disclosure through addition, change, omission, or substitution of components without departing from the spirit of the disclosure as set forth in the appended claims, and such modifications and changes may also be included within the scope of the present disclosure.

Claims

1. A turbine blade comprising: an airfoil comprising a pressure surface, a suction surface, a leading edge, and a trailing edge; an endwall formed integrally on a lower portion of the airfoil; and a root part formed integrally on a lower portion of the endwall, wherein an outer peripheral surface of the endwall is formed as a curved surface from a rim seal positioned at a first side of the endwall to a second end of the endwall.
2. The turbine blade of claim 1, wherein the endwall comprises: a first rim seal extending upstream from a position of the leading edge; and a second rim seal extending downstream from a position of the trailing edge.
3. The turbine blade of claim 2, wherein the outer peripheral surface of the endwall is formed as a streamlined curved surface connected between the first rim seal and an end portion of the outer peripheral surface on a side of the trailing edge.
4. The turbine blade of claim 3, wherein the second rim seal is arranged to be lower than a radial height of a portion of the outer peripheral surface of the endwall connected to the trailing edge.
5. The turbine blade of claim 3, wherein the outer peripheral surface of the endwall is formed to have a highest radial height at a portion of the outer peripheral surface connected to the leading edge.
6. The turbine blade of claim 5, wherein a radial height of the outer peripheral surface of the endwall increases from the first rim seal to the portion of the outer peripheral surface connected to the leading edge and then decreases toward the trailing edge.
7. The turbine blade of claim 6, wherein the outer peripheral surface of the endwall comprises two concave parts positioned near an end edge of the pressure surface and positioned between a side portion of the leading edge and a side portion of the trailing edge.
8. The turbine blade of claim 6, wherein the outer peripheral surface of the endwall comprises two concave parts positioned near an end edge of the suction surface and positioned between a side portion of the leading edge and a side portion of the trailing edge.
9. A gas turbine comprising: a compressor configured to take in and compress external air; a combustor configured to mix fuel with the air compressed by the compressor and combust the fuel mixed with the air; and a turbine in which turbine blades and turbine vanes are mounted inside a turbine housing, with each of the turbine blades being rotated by combustion gas discharged from the combustor, wherein the turbine blade comprises: an airfoil comprising a pressure surface, a suction surface, a leading edge, and a trailing edge; an endwall formed integrally on a lower portion of the airfoil; and a root part formed integrally on a lower portion of the endwall, wherein an outer peripheral surface of the endwall is formed as a curved surface from a rim seal positioned at a first side of the endwall to a second end of the endwall.
10. The gas turbine of claim 9, wherein the endwall comprises: a first rim seal extending upstream from a position of the leading edge; and a second rim seal extending downstream from a position of the trailing edge.
11. The gas turbine of claim 10, wherein the outer peripheral surface of the endwall is formed as a streamlined curved surface connected between the first rim seal and an end portion of the outer peripheral surface on a side of the trailing edge.
12. The gas turbine of claim 11, wherein the second rim seal is arranged to be lower than a radial

height of a portion of the outer peripheral surface of the endwall connected to the trailing edge.

13. The gas turbine of claim 11, wherein the outer peripheral surface of the endwall is formed to have a highest radial height at a portion of the outer peripheral surface connected to the leading edge.

14. The gas turbine of claim 13, wherein a radial height of the outer peripheral surface of the endwall increases from the first rim seal to the portion of the outer peripheral surface connected to the leading edge and then decreases toward the trailing edge.

15. The gas turbine of claim 14, wherein the outer peripheral surface of the endwall comprises two concave parts positioned near an end edge of the pressure surface and positioned between a side portion of the leading edge and a side portion of the trailing edge.

16. The gas turbine of claim 14, wherein the outer peripheral surface of the endwall comprises two concave parts positioned near an end edge of the suction surface and positioned between a side portion of the leading edge and a side portion of the trailing edge.
