AXIAL TURBINE FOR A GAS TURBINE WITH LIMITED PLAY BETWEEN BLADES AND HOUSING

Inventors: Stefan Braun, Neukirchen-Vluyn (DE); Christian Cornelius, Sprockhovel (DE); Annika Emde, Mulheim (DE); Andreas Heilos, Mulheim an der Ruhr (DE); Olaf Hein, Mulheim an der Ruhr (DE); Thomas Hofbauer, Wassenroth (DE); Christian Lerner, Dorsten (DE); Silvio-Ulrich Martin, Oberhausen (DE); Thorsten Mattheis, Mulheim (DE); Ralf Müsgen, Essen (DE); Eckart Schumann, Mulheim an der Ruhr (DE); Rostislav Teteruk, Mulheim an der Ruhr (DE); Adam Zimmermann, Mulheim a.d. Ruhr (DE)

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ABSTRACT
An axial turbine for a gas turbine including a rotor blade cascade is provided. The rotor blade cascade is formed from rotor blades each including, a front edge, a blade tip, and an annular space wall that surrounds the rotor blade cascade and includes an annular space inner side, enabling the annular space wall to be arranged directly adjacent to the blade tip forming a radial gap of the covering of the blade tip and the annular space inner side. When the turbine is in operation, the area of the blade tip with the highest pressure load is disposed in the region of the front edges, and the rotor blades in the region of their front edges include a radial projection and the annular space wall includes on the annular space inner side, a peripheral radial recess that interacts with the radial projections such that a minimum is established in the direction of the main through-flow of the turbine.
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CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is the US National Stage of International Application No. PCT/EP2009/058682, filed Jul. 8, 2009 and claims the benefit thereof. The International Application claims the benefits of European Patent Office application No. 08012960.4 EP filed Jul. 17, 2008. All of the applications are incorporated by reference herein in their entirety.

FIELD OF INVENTION

[0002] The invention refers to an axial turbine for a gas turbine, the axial turbine having low tip clearance losses.

BACKGROUND OF INVENTION

[0003] A gas turbine has a turbine, for example in an axial type of construction. The turbine has a casing and a rotor which is enclosed by the casing. The rotor has a shaft, from which shaft output can be tapped off. Provision is made for a hub, encompassing the shaft, the hub contour of which, together with the inner contour of the casing, forms a flow passage through the turbine. The flow passage has a cross section which diverges in the flow direction on account of a mostly conical inner contour of the casing.

[0004] The rotor has a multiplicity of rotor stages which are formed in each case by a rotor blade cascade. The rotor blade cascades have a multiplicity of rotor blades which by one of their ends are fastened in each case on the rotor on the hub side and by their other end radially outwardly. A blade tip, which faces the inner side of the casing and is arranged directly adjacent thereto, is formed at the other end of the rotor blade. The distance between the blade tips and the inner side of the casing is formed as a radial gap which is dimensioned in such a way that on the one hand the blade tips do not rub against the casing during operation of the gas turbine and on the other hand the leakage flow through the radial gap which ensues during operation of the gas turbine is as low as possible. So that the gas turbine has high efficiency, it is desirable that the leakage flow through the radial gap is as low as possible so that the power gain in the turbine is as high as possible.

[0005] The casing of the turbine is solidly constructed in order to be able to withstand the pressure stresses and temperature stresses during operation of the gas turbine. Furthermore, the casing is rigidly constructed so that the load yield to the casing during operation of the gas turbine results in only minimal deformation of the casing. In contrast to this, the rotor blades are thinner and less solidly constructed in comparison to the casing.

[0006] During operation of the axial turbine, the inner side of the casing and the rotor blades are in contact with hot gas, the rotor blades being completely exposed to airflow by the hot gas. Due to the fact that the rotor blades are of a more filigree design than the casing and are in more extensive contact with the hot gas than the casing, the rotor blades heat up more quickly than the casing. This has the result that for startup and shutdown of the gas turbine the rotor blades and the casing have different rates of thermal expansion so that during startup and shutdown of the gas turbine the height of the radial gap changes, the radial gap becoming smaller during startup and larger during shutdown. So that during startup the blade tips of the rotor blades do not butt against the casing and damage this, the radial gap is provided with a minimum height which is dimensioned in such a way that during startup of the gas turbine the blade tips seldom if ever come into contact with the casing. This has the result that provision is made for a correspondingly dimensioned radial gap at the blade tips which leads to a reduction in the power density and efficiency of the gas turbine.

[0007] Modern rotor blades have a very high aerodynamic efficiency which is achieved as a result of a high pressure load of the rotor blades. Brought about by the high pressure load, the leakage flow through the radial gap is high so that the overall efficiency of the rotor blade is seriously impaired as a result of the character and the intensity of the leakage flow through the radial gap. A reduction to the losses which are brought about by the leakage flow has the effect of a great improvement in the overall efficiency of the rotor blade.

[0008] Attempts are customarily made to reduce the aerodynamic losses in the gap region of the rotor blade by means of measures for reducing the leakage flow. In this case, provision is made for measures for reducing the radial gap or for a special profile of the blade tips, such as crowsns or directed cooling air blowouts. Alternatively to this, a rotor blade with a curved blade tip which, for forming a minimum radial gap, can rub a groove into an oppositely disposed passage wall, is known from DE 10 2004 059 904 A1. The curvature is achieved by means of an abrasive coating, with varying coating thickness, which is applied to the blade tip. On the edges, i.e. on the leading edge and trailing edge, the coating is formed in a manner in which it runs out so that the rubbed-in groove merges into the adjacent passage walls without steps. The more costly production process of the rotor blade is considered to be disadvantageous and requires the application of the rubbing-in process, which results in an increased minimum strength of rotor blades.

[0009] Conventional turbine rotor blades are configured according to the "rear-loaded design", the maximum pressure stress of the rotor blade being located in the region of its trailing edge. Known as being obsolete are also rotor blades configured according to the "front-loaded design", in which the highest pressure load is located in the region of the leading edge. In this respect, a turbine rotor blade with a blade airfoil is known for example from EP 1 057 969 A2, which blade airfoil on the hub side has a "front-loaded design" or "intermediate-loaded design", and on the tip side has a "rear-loaded design", as a result of which the distribution of the rate of change of the tip speed is facilitated.

SUMMARY OF INVENTION

[0010] It is the object of the invention to create an axial turbine for a gas turbine which has high aerodynamic efficiency.

[0011] The axial turbine according to the invention for a gas turbine has a rotor blade cascade, which is formed from rotor blades having in each case a leading edge, a trailing edge and a radially outwardly disposed, free-standing blade tip, an annulus wall which encases the rotor blade cascade, with an annulus inner side by which the annulus wall is arranged directly adjacent to the blade tips, forming the radial gap between the contours of the blade tips and the annulus inner side, wherein the rotor blades at their blade tips have a region with the highest pressure load of the blade tips between the leading edge and the trailing edge, and wherein in the region
of the highest pressure load the rotor blades have in each case a radial projection and the annulus wall on the annulus inner side has an encompassing radial recess which lies opposite the radial projections. The pressure load, in the sense of this document, corresponds to this case to the pressure difference between suction side and pressure side of the rotor blade, which is of variable value along the profile section.

[0012] As a result, by making use of the blade tip, which is optimized directly with regard to minimum losses, and the annulus contour, the unfavorable, loss-affected gap flow is reduced. In this case, the annulus in the region of the blade tip is constructed as a contour which deviates from the conventional annulus. When establishing the shape of the annulus contour, moreover, consideration is given to the fact that the minimum gap width during operation of the axial turbine is arranged in the region of the maximum pressure difference between the pressure side and the suction side of the rotor blade. These measures have almost no influence upon the aerodynamic principle of operation of the rotor blade and bring about a significant reduction in the gap flow from the pressure side to the suction side over the blade tip compared with a conventionally designed axial turbine. Furthermore, it is possible to additionally apply all previously known measures for reducing the negative effects of leakage flow in the axial turbine according to the invention.

[0013] Furthermore, the radial recess and the radial projections are formed in such a way that the progression of the radial gap, as seen in the principal flow direction of the axial turbine, extends essentially with constant width in a wave-like and step-free manner.

[0014] The progression of the radial recess, as seen in the principal flow direction of the axial turbine, on the annulus inner side has a first curvature section, a second curvature section adjoining the first, and a third curvature section adjoining the second, wherein the first curvature section is delimited from the second curvature section by a first inflection point and the second curvature section is delimited from the third curvature section by a second inflection point so that the curvatures of the first curvature section and of the third curvature section have the same sign which is different from the sign of the curvature of the second curvature section. In this case, the size of the radial gap between blade tip and annulus wall—as seen along the axial direction—can also be constant.

[0015] Consequently, the annular gap, as seen in the principal flow direction, has a uniform, non-abruptly changing progression so that the flow in the region of the blade tip is low in loss.

[0016] The volume of leakage flow is advantageously reduced in a directly aimed manner and its unfavorable effects upon the overall efficiency of the rotor blade cascade are reduced. As a result, an improved aerodynamic quality of the rotor blade cascade ensues without having to provide additional constructional measures.

[0017] The profile section at the blade tip can be advantageously constructed, contrary to the conventional construction as a “front-loaded design”. That is to say, the largest pressure load is shifted from the rear part (close to the trailing edge) of the blade into the region of the profile inlet edge (close to the leading edge). This region, as seen over the height of the rotor blade, can amount to about 20%. The remaining region of the rotor blade can then be conventionally constructed in the “rear-loaded design”. The transition from “front-loaded design” to “rear-loaded design” within some 20% of the height of the rotor blade is carried out preferably steplessly.

[0018] It is preferred that with regard to the extent of the radial gap, as seen in the principal flow direction of the axial turbine, the radial recess is arranged in the front third.

[0019] Consequently, the radial recess is located in the region of the highest pressure load of the blade tip so that the gap flow is reduced.

[0020] It is preferred that the progression of the radial projections, as seen in the principal flow direction of the axial turbine, on their sides facing the radial gap is adapted to the progression of the radial recess.

[0021] Moreover, it is preferred that the curvature of the first curvature section is greater than that of the third curvature section. Furthermore, it is preferred that the first inflection point is located in the region of the leading edge.

[0022] It is preferred that the sections of the annular passage which upstream and downstream are adjacent to the radial recess, as seen in the principal flow direction of the axial turbine, are conical.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The invention is explained in the following text, based on a preferred embodiment of an axial turbine according to the invention with reference to the attached schematic drawings. In the drawing:

[0024] FIG. 1 shows a profile section of a rotor blade according to the invention in the region of the blade tip,

[0025] FIG. 2 shows a side view of an axial turbine according to the invention, and

[0026] FIG. 3 shows the side view from FIG. 2 compared with a conventional axial turbine.

DETAILED DESCRIPTION OF INVENTION

[0027] As is apparent from FIGS. 1 to 3, an axial turbine 1 has a rotor blade 2 which has a leading edge 3 and a trailing edge 4.

[0028] The rotor blade 2 has a pressure side 5 and a suction side 6 which extend in each case from the leading edge 3 to the trailing edge 4. The pressure side 5, compared with the suction side 6, is more sharply concave curved. The rotor blade 2, at its radially outer side end, has a blade tip 13 which is freestanding. In the region of the blade tip 13, the rotor blade 2 is constructed in the “front-loaded design” 7. In comparison to this, the “rear-loaded design” 8 is shown, in which the pressure side 5 is less sharply curved in the region of the leading edge 3 than in the case of the “front-loaded design” 7.

[0029] Due to the fact that the rotor blade 2 is constructed in the “front-loaded design” 7 in the region of the blade tip 13, the region 9 with the highest pressure load of the rotor blade 2 is located in the region of the blade tip 13 in the proximity of the leading edge 3.

[0030] Furthermore, the axial turbine 1 on the hub side has a hub contour 10 on which the rotor blade 2 is fastened. The axial turbine 1 has an annulus wall 11, terminating radially on the outside, which has an annulus inner side 12 facing the blade tip 13. The rotor blade 2 is encased by the annulus wall 11 and with the annulus inner side 13, together with the hub contour 10, forms a divergent annulus of the axial turbine 1. The annulus wall 11 in this case is principally—i.e. apart from a radial recess 15—of conical design with a greater inclination than the hub contour 10.
[0031] Between the blade tip 13 and the annulus inner side 12, provision is made for a space so that a radial gap 14 is formed between the blade tip 13 and the annulus inner side 12.

[0032] In FIG. 3, the rotor blade 2 with a conventional blade tip 23 and the annulus wall 11 with a conventional annulus inner side 24 is also shown, wherein the conventional blade tip 23 and the conventional annulus inner side 24 have a straight progression.

[0033] In contrast to this, the annulus wall 11 according to the invention on the annulus inner side 12 has the radial recess 15 which is arranged in the region of the leading edge 3 of the rotor blade 3. In correlation to the radial recess 15, and engaging in this, a radial projection 16 is provided at the blade tip 13. The radial projection 16 extends essentially parallel to the radial recess 15 so that the radial gap 14 has a uniform progression, as seen in the principal flow direction of the axial turbine 1.

[0034] As seen in the principal flow direction of the axial turbine 1, the radial recess has a first curvature section 17, a second curvature section 19 adjoining the first, and a third curvature section 21 adjoining the second. The first curvature section 17 is delimited from the second curvature section 19 by a first inflection point 18, and the second curvature section 19 is delimited from the third curvature section 21 by a second inflection point 20. Consequently, the curvature middle point of the first curvature section 17 and of the third curvature section 21, as seen radially, lies outside the axial turbine 1 and the curvature middle point of the second curvature section 19 lies inside the axial turbine 1.

[0035] The curvature of the first curvature section 17 is greater than the curvature of the third curvature section 21 so that the radial gap 14 in the region of the leading edge 3 has a steeper progression, as seen radially outwardly, than in the region of the third curvature section 21.

[0036] As seen in the principal flow direction of the axial turbine 1, the radial recess 15 and the radial projection 16 are arranged in the front third of the blade tip 13. Due to the fact that in the region of the blade tip 13 the rotor blade 2 is formed in the “front-loaded design”, the region 9 with the highest pressure load is located specifically in this region.

[0037] The radial recess 15 and the radial projection 16 are arranged in relation to each other in such a way that a gap minimum 22 is formed in the region 9 of the highest pressure load. As a result, a leakage flow through the radial gap 14, which develops during operation of the axial turbine 1, is low, specifically in the region 9 with the highest pressure load. Consequently, the rotor blade 2 has high aerodynamic efficiency, especially in the region of the blade tip 13.

1. - 8. (canceled)

9. An axial turbine for a gas turbine including a rotor blade cascade, comprising:
   a plurality of rotor blades each including a leading edge, a trailing edge, and a radially outwardly disposed, free-standing blade tip; and
   a divergent annulus wall, encasing the rotor blade cascade, with an annulus inner side by which the annulus wall is arranged directly adjacent to the blade tips, forming a radial gap between the contours of the blade tips and the annulus inner side,

wherein the plurality of rotor blades at the plurality of blade tips each include a region with a highest pressure load of the plurality of blade tips between the leading edge and the trailing edge, and

wherein the plurality of rotor blades in the region of the highest pressure load include in each case a radial projection,

wherein the annulus wall on the annulus inner side includes an encompassing radial recess which, lying opposite the radial projections, is formed in such a way that a progression of the radial gap, as seen in the principal throughflow direction of the axial turbine, extends essentially with constant width in a wave-like, edge-free and step-free manner.

wherein the progression of the radial recess, as seen in the principal throughflow direction of the axial turbine, on the annulus inner side includes a first curvature section, a second curvature section adjoining the first, and a third curvature section adjoining the second, and

wherein the first curvature section is delimited from the second curvature section by a first inflection point and the second curvature section is delimited from the third curvature section by a second inflection point so that the curvatures of the first curvature section and the third curvature section include the same sign which is different from the sign of the curvature of the second curvature section.

10. The axial turbine as claimed in claim 11, wherein the region of the highest pressure load of the rotor blade is arranged in a region of the leading edge.

11. The axial turbine as claimed in claim 12, wherein the region of the highest pressure load of the rotor blade includes a region of the leading edge, which is arranged at most to 20% of a height of the rotor blade, and wherein a remaining region of a second height of the rotor blade includes a further highest pressure load which is arranged in a region of the trailing edge.

12. The axial turbine as claimed in claim 12, wherein the radial recess is arranged in the front third of the radial gap, as seen in the principal throughflow direction of the axial turbine.

13. The axial turbine as claimed in claim 12, wherein a curvature of the first curvature section is greater than that of the third curvature section.

14. The axial turbine as claimed in claim 12, wherein the progression of the radial projections, as seen in the principal throughflow direction of the axial turbine, on the plurality of sides of the radial projections facing the radial gap, is adapted to the progression of the radial recess.

15. The axial turbine as claimed in claim 11, wherein the first inflection point is located in the region of the leading edge.

16. The axial turbine as claimed in claim 11, wherein a plurality of sections of the radial gap, as seen in the principal throughflow direction of the axial turbine, which are upstream and downstream of and adjacent to the radial recess, are conical.

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