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(54) **LAST STAGE ROTOR BLADES FOR HALF-SPEED NUCLEAR STEAM TURBINE, CORRESPONDING CIRCUMFERENTIAL ROW OF SUCH BLADES, THEIR USE, AND PROCESS OF MANUFACTURING**

(57) A last stage blade (10) for a half speed nuclear steam turbine operating at 50Hz or 60Hz is provided. The blade (10) includes a single piece steel blade body (12) comprising an airfoil (13) having a height (h) extending between a tip (16) and a base (14) between 1850 mm to 2000 mm, and a base diameter (D) between 2900 mm to 3050 mm. Further, the airfoil (13) having an airfoil mass (M) for the defined airfoil height (H), wherein the airfoil mass (M) to height (H) ratio is in a range of 70 kg/m to 80 kg/m, enabling substantially smaller centrifugal pull on a rotor. The blade (10) further includes a blade root (18), extending from the base, configured to be attachable mounted in a rotor groove of the rotor. Such configuration is capable of withstanding 1.5 times a rotational speed of the turbine for half speed turbine. Corresponding circumferential row of last stage blades, use of such a circumferential row of last stage blades in a half speed nuclear steam turbine, and method of manufacturing a last stage blade are also provided.

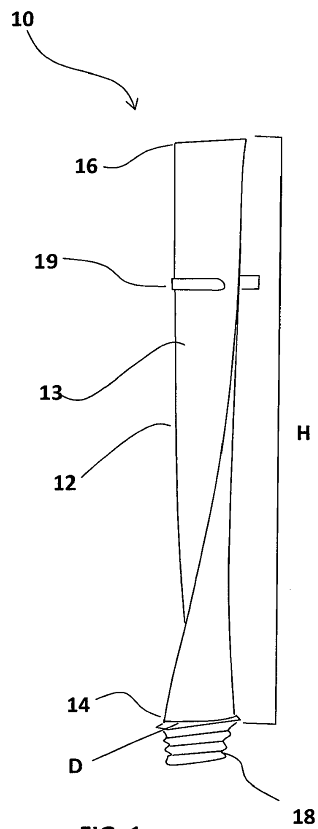

FIG. 1

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Description

BACKGROUND

[0001] Field of Endeavor

[0002] The present disclosure relates generally to a turbine blade, and, more particularly, relates to a last stage rotor blades for half-speed large-capacity nuclear power turbine.

Brief Description of the Related Art

[0003] Demand for Nuclear power plant has been growing globally in recent years due to the fact that the nuclear power is a clean energy, with characteristics of stable production of electricity and is capable of effectively responding to energy depletion, global warming and control of carbon dioxide emissions along with other environmental problems.

[0004] A steam turbine is one of the main equipment items of nuclear power plants, and thus the design thereof affects the efficiency of the nuclear power plants. Nuclear Steam turbines are typically designed as either full-speed (in which the turbine shaft's operates synchronous with the frequency of the electric power system, e.g. 3000 rpm for 50 Hz systems) or half-speed (in which the turbine shaft's operates at the speed of 1500 rpm for 50 Hz systems) turbines.

[0005] The steam turbine includes rotor blades that are mounted on a turbine shaft. The rotor blades, especially, the last stage blade (LSB) are important components for defining annular exhaust area, which has a large influence on the efficiency of the half speed turbine. Annular exhaust area may be determined by the available length of the LSBs and number of exhaust flows. In turn, the maximum LSB length is limited by strength of the LSBs and its ability to withstand centrifugal stresses in the root section.

[0006] There is an ongoing need for blades with longer lengths that are capable of satisfying criteria including stress, frequency behavior, erosion and limited and optimized centrifugal pull of the blades on the rotor.

SUMMARY

[0007] The present disclosure discloses a last stage blade for a half speed nuclear steam turbine, that will be presented in the following simplified summary to provide a basic understanding of one or more aspects of the disclosure that are intended to overcome the discussed drawbacks, but to include all advantages thereof, along with providing some additional advantages. This summary is not an extensive overview of the disclosure. It is intended to neither identify key or critical elements of the disclosure, nor to delineate the scope of the present disclosure. Rather, the sole purpose of this summary is to present some concepts of the disclosure, its aspects and advantages in a simplified form as a prelude to the more detailed description that is presented hereinafter.

[0008] A general object of the present disclosure is to provide a last stage blade for a half speed nuclear steam turbine operating at 50Hz or 60Hz, and that blade length to extent further in such a manner that may be capable of satisfying various other criteria, such as stress, frequency behavior, erosion along with limited and optimized centrifugal pull of the blades.

[0009] In one aspect of the present disclosure, a last stage blade for a half speed nuclear steam turbine operating at 50Hz or 60Hz is provided. The blade includes a single piece steel blade body comprising an airfoil having a tip, a base and an airfoil height extending between the tip and the base. The airfoil height may be in a range of 1850 mm to 2000 mm, and the base may have a base diameter in a range of 2900 mm to 3050 mm. Further, the airfoil has an airfoil mass for the defined airfoil height, wherein the airfoil mass to height ratio is in a range of 70 kg/m to 80 kg/m. Such airfoil height (H) and the airfoil mass (M) combination may enable low centrifugal pull on a rotor. The blade further includes a blade root, extending from the base, configured to be attachable mounted in a rotor groove of the rotor. A configuration of the blade may be capable of withstanding 1.5 times a rotational speed of the turbine for half speed turbine.

[0010] In most preferred embodiment, the airfoil height is 1900 mm. Further, when the airfoil height is 1900 mm, the airfoil mass for the airfoil is about 142 kg.

[0011] In most preferred embodiment, the base diameter is 2940 mm.

[0012] In most preferred embodiment, the blade has an airfoil height to a blade chord ratio, in a range of 3.5 to 4.

[0013] In one embodiment, the blade root includes a fir-tree root curved along a chord at the base of the airfoil, wherein the curvature has a radius in a range of 500 to 400 mm. In most preferred embodiment, the blade root comprises a root axial width in a range of 450 mm to 550 mm.

[0014] In one embodiment, the blade may further includes a snubber configured on the body at a position about 70% to 85% of the airfoil height. In most preferred embodiment, the snubber may be positioned on the body at 81% of the airfoil height.

[0015] In one another aspect of the present disclosure, a circumferential row of the last stage blades, as summarized above, is configured to have an exit area for steam therefrom in a range of 27 m^2 to 31 m^2. In such circumferential row, adjacent blades defines a pitch therebetween, further a pitch to chord ratio at the tip is in a range of 0.9 to 1.1.

[0016] In one further aspect of the present disclosure, use of the circumferential row of last stage blades in a half speed nuclear steam turbine is operated at 50 Hz or 60 Hz.

[0017] In one yet further aspect of the present disclosure, a process for manufacturing a last stage blade for a half speed nuclear steam turbine operating at 50Hz or

60Hz is provided. The method includes configuring a single piece steel blade body to include an airfoil and a blade root, as summarized above. Further, step includes configuring the blade to withstanding 1.5 times the rotational speed of the turbine. In further step, configuring the blade to provide an exit area for steam therefrom in a range of 27 m^2 to 31 m^2, when a plurality of the blades are installed in the half speed nuclear steam turbine to form a circumferential row of last stage blades.

[0018] Certain dimensions are mentioned herein in the 'millimeters (mm),' however, one skilled in the art may convert such dimensions into SI units where appropriate.

[0019] These together with the other aspects of the present disclosure, along with the various features of novelty that characterize the present disclosure, are pointed out with particularity in the present disclosure. For a better understanding of the present disclosure, its operating advantages, and its uses, reference should be made to the accompanying drawings and descriptive matter in which there are illustrated exemplary embodiments of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The advantages and features of the present disclosure will be better understood with reference to the following detailed description and claims taken in conjunction with the accompanying drawings, wherein like elements are identified with like symbols, and in which:

FIG. 1 illustrates a single piece last stage blade for a half speed nuclear steam turbine operating at 50Hz or 60Hz, in accordance with an exemplary embodiment of the present disclosure;

FIGS. 2A and 2B illustrate root of the blade, accordance with an exemplary embodiment of the present disclosure; and

FIGS. 3A and 3B illustrate a circumferential row configured using a plurality of last stage blades, in accordance with various exemplary embodiments of the present disclosure.

[0021] Like reference numerals refer to like parts throughout the description of several views of the drawings.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0022] For a thorough understanding of the present disclosure, reference is to be made to the following detailed description, including the appended claims, in connection with the above-described drawings. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present disclosure. It will be apparent, however, to one skilled in the art that the present disclosure can be practiced without these specific details. In other instances, structures and devices are shown in block diagrams form only, in order to avoid obscuring the disclosure. Reference in this specification to "one embodiment," "an embodiment," "preferred embodiment," "various embodiments," means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present disclosure. The appearance of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments. Moreover, various features are described which may be exhibited by some embodiments and not by others. Similarly, various requirements are described which may be requirements for some embodiments but may not be of other embodiment's requirement.

[0023] Although the following description contains many specifics for the purposes of illustration, anyone skilled in the art will appreciate that many variations and/or alterations to these details are within the scope of the present disclosure. Similarly, although many of the features of the present disclosure are described in terms of each other, or in conjunction with each other, one skilled in the art will appreciate that many of these features can be provided independently of other features. Accordingly, this description of the present disclosure is set forth without any loss of generality to, and without imposing limitations upon, the present disclosure. Further, the relative terms used herein do not denote any order, elevation or importance, but rather are used to distinguish one element from another. Further, the terms "a," "an," and "plurality" herein do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

[0024] Referring to FIG. 1, a last stage blade (LSB) (10) for a half speed nuclear steam turbine capable of operating at 50Hz or 60Hz is illustrated in accordance with an exemplary embodiment of the present disclosure. The half speed nuclear turbine speed is 1500 rpm, half of the speed of the full speed turbine, which is 3000 rpm. In one embodiment, the dimensions illustrated herein are generally for a half speed nuclear steam turbine capable of operating at 50Hz. The turbine for being capable of operating at 60 Hz, the dimensions of the blade may be accordingly scaled.

[0025] The LSB (10) includes a single piece steel blade body (12) having an airfoil (13). The airfoil (13) includes a tip (16), a base (14) and an airfoil height (H) extending between the tip (16) and the base (14). The LSB (10) further includes a blade root (18), extending from the base (14). The blade root (18) is configured to be attachable mounted in a rotor groove of the rotor. In one embodiment, as shown in FIGS. 2A and 2B, the blade root (18) may include a fir-tree root adapted to be inserted in a complementary rotor groove of the rotor thereby connecting the LSB (10) with the rotor. The fir-tree root may be in-line with an axis of the rotor, inclined to the axis, or curved. In a preferred embodiment, the fir-tree root may be curved along a chord (C) at the base of the airfoil (13).

[0026] In an embodiment, the airfoil height (H) may be a range of 1850 mm to 2000 mm, and the base (14) may have a base diameter (D) in a range of 2900 mm to 3050 mm. Further, the airfoil (13) may include an airfoil mass (M) for the defined airfoil height (H), in which the airfoil mass (M) to height (H) ratio may be in a range of 70 kg/m to 80 kg/m.

[0027] In a most preferred embodiment, the airfoil height (H) may be about 1900 mm. In such embodiment, where the airfoil height (H) is about 1900 mm, the mass of the body (12), which includes mass of the airfoil (13) and mass of the blade root (18) may be about 142 kg. In a further preferred embodiment, the base diameter (D) may be about 2940 mm.

[0028] In an embodiment, the LSB (10) may include a snubber (19) configured on the body (12) forming the single piece steel blade body. The snubber (19) is positioned on the body (12) at about 70% to 85% of the blade height. In one specific embodiment, the snubber (19) may be positioned on the body (12) at 81 % of the blade height. For example, if the blade height is 1900 mm, at 81% of the blade height, the snubber (19) is positioned at the height of 1539 mm on the body (12). The snubber (19) may provide stiffness and alleviate vibratory stress in the LSB (10).

[0029] As shown in FIGS. 2A and 2B, in one embodiment, the LSB (10) with height 1900 mm and weight 142 kg, there are various other dimensional parameters that enable such long length LSB (10) in making suitable in its operability. For example, the airfoil height (H) to a blade chord (C) ratio, i.e. aspect ratio, is in a range of 3.5 to 4. Herein, the blade chord (C) is defined as a distance between the leading edge (E1) and the trailing edge (E2) of the LSB (10). Further, the blade root (18) with the curved fir-tree root may include a curvature that has a radius (Rr) in a range of 500 to 400 mm. Furthermore, the blade root (18) has a root axial width (Rw) in a range of 450 mm to 550 mm.

[0030] Referring to FIGS. 3A and 3B, the LSB (10), as described above, may be used to configure a circumferential row (30) using plurality of such LSBs (10) at the last stage of the turbine. In one example, the circumferential row (30) may be configured by using 73 blades. In such circumferential row (30), adjacent blades (10) define a pitch (P) therebetween, where a pitch (P) to chord (C) ratio at the tip (16) may be in a range of 0.9 to 1.1. In operation, the circumferential row (30) is configured to have an exit area for steam therefrom in a range of 27 m^2 to 31 m^2. In one embodiment, the exit area may be calculated at the trailing edge (E2) or on an axis of the blade LSB 10. The exit area of 27m^2 is obtained at the axis of the blade.

[0031] The circumferential row (30) of LSBs (10) in the half speed nuclear steam turbine may be operated at about 50 Hz or 60 Hz. As mentioned above, the half speed nuclear turbine speed is 1500 rpm, half of the speed of the full speed turbine, which is 3000 rpm. In an exemplary embodiment for such a configuration each blade is configured to withstanding at least 1.5 times the rotational speed of the turbine, i.e. for half speed turbine operating at 1500 rpm; the configuration is configured to withstanding a turbine speed of at least 2250 rpm.

[0032] The LSB of the present disclosure is advantageous in various scopes such as described above. The present blade is long, about 1900 mm, and satisfies various criteria, such as, stress, frequency behavior, erosion along with limited and optimized centrifugal pull of the blade. The blade is long thus big exit area giving a performance advantage of allowing reducing the number of low pressure modules. The present blade in spite of its length is light, resulting in low centrifugal pull on the turbine. The centrifugal pull may be below 600 T, which may be calculated along the airfoil height (H) and including a length up to a first hook (11) (seen in FIG. 2A) of the blade (10). The centrifugal pull below 600 T is calculated up to the first hook (11), because in case of blade loss, the root attachment may stay in the rotor groove. Low centrifugal force enables shaftline integrity in case of blade loss. Further, such a blade may be operated with a grid frequency variation of around -6% to +5%, depending upon less (illustrated by negative) or more (illustrated by positive) demand. Moreover, the turbine with this blade configuration may be capable of working with condenser vacuum between 20 to 80 mbars.

[0033] The foregoing descriptions of specific embodiments of the present disclosure have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the present disclosure to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the present disclosure and its practical application, to thereby enable others skilled in the art to best utilize the present disclosure and various embodiments with various modifications as are suited to the particular use contemplated.

REFERENCE NUMERAL LIST

[0034]

10	Last stage blade, LSB
12	Body
11	First hook
13	Airfoil
16	Tip
14	Base
18	Blade root
19	Snubber
30	Circumferential row
H	Airfoil height
C	Chord
D	Base diameter
M	Airfoil mass

E1, E2	Edges
Rr	Root radius of curvature
Rw	Root axial width
P	Pitch

Claims

1. A last stage blade (10) for a half speed nuclear steam turbine operating at 50Hz or 60Hz, the blade (10) having a single piece steel blade body (12) comprising:

    an airfoil (13) having a tip (16), a base (14) and an airfoil height (H) extending between the tip (16) and the base (14), wherein the airfoil height (h) is in a range of 1850 mm to 2000 mm, and the base (14) has a base diameter (D) in a range of 2900 mm to 3050 mm,
    the airfoil (13) having an airfoil mass (M) for the defined airfoil height (H), wherein an airfoil mass (M) to height (H) ratio is in a range of 70 kg/m to 80 kg/m, wherein the airfoil height (H) and the airfoil mass (M) enable low centrifugal pull on a rotor; and
    a blade root (18), extending from the base (14), configured to be attachable mounted in a rotor groove of the rotor.

2. The blade (10) as claimed in claim 1, wherein the airfoil height (H) is 1900 mm.

3. The blade (10) as claimed in claim 2, having a mass of about 142 kg.

4. The blade (10) as claimed in claim 1, wherein the base diameter (D) is 2940 mm.

5. The blade (10) as claimed in claim 1, wherein the blade (10) has an airfoil height (H) to a blade chord (C) ratio, in a range of 3.5 to 4.

6. The blade (10) as claimed in claim 1, wherein the blade root (18) comprises a fir-tree root curved along a chord at the base of the airfoil (13), wherein the curvature has a radius (Rr) in a range of 500 to 400 mm.

7. The blade (10) as claimed in claim 1, wherein the blade root (18) comprises a root axial width (Rw) in a range of 450 mm to 550 mm.

8. The blade (10) as claimed in claim 1 further comprising a snubber (19) configured on the body (12) at a position about 70% to 85% of the airfoil height (H).

9. The blade (10) as claimed in claim 8, wherein the snubber (19) is positioned on the body (12) at 81% of the airfoil height (H).

10. A circumferential row (30) of the last stage blades (10) as claimed in any one of claims 1 to 9 configured to have an exit area for steam therefrom in a range of 27 m^2 to 31 m^2.

11. The circumferential row (30) of last stage blades (10) as claimed in claim 10, wherein adjacent blades (10) defines a pitch (P) therebetween, further a pitch (P) to chord (C) ratio at the tip (16) is in a range of 0.9 to 1.1.

12. The use of the circumferential row (30) of last stage blades (10) as claimed in claim 10 or 11 in a half speed nuclear steam turbine operated at 50 Hz or 60 Hz.

13. A process for manufacturing a last stage blade (10) for a half speed nuclear steam turbine operating at 50Hz or 60Hz, including the steps of:

    configuring a single piece steel blade body (12) to comprise:

        an airfoil (13) having a tip (16), a base (14) and an airfoil height (H) extending between the tip (16) and the base (14), wherein the airfoil height (H) is in a range of 1850 mm to 2000 mm, and the base (14) has a base diameter (D) in a range of 2900 mm to 3050 mm,
        the airfoil (13) having an airfoil mass (M) for the defined airfoil height (H), wherein an airfoil mass (M) to height (H) ratio is in a range of 70 kg/m to 80 kg/m; and
        a blade root (18), extending from the base (14), configured to be attachable mounted in a rotor groove of a rotor; and

    configuring the blade (10) to provide an exit area for steam therefrom in a range of 27 m^2 to 31 m^2.

14. A configuration of the last stage blade (10) as claimed in claims 1-13 capable of withstanding about 1.5 times a rotational speed of the turbine.

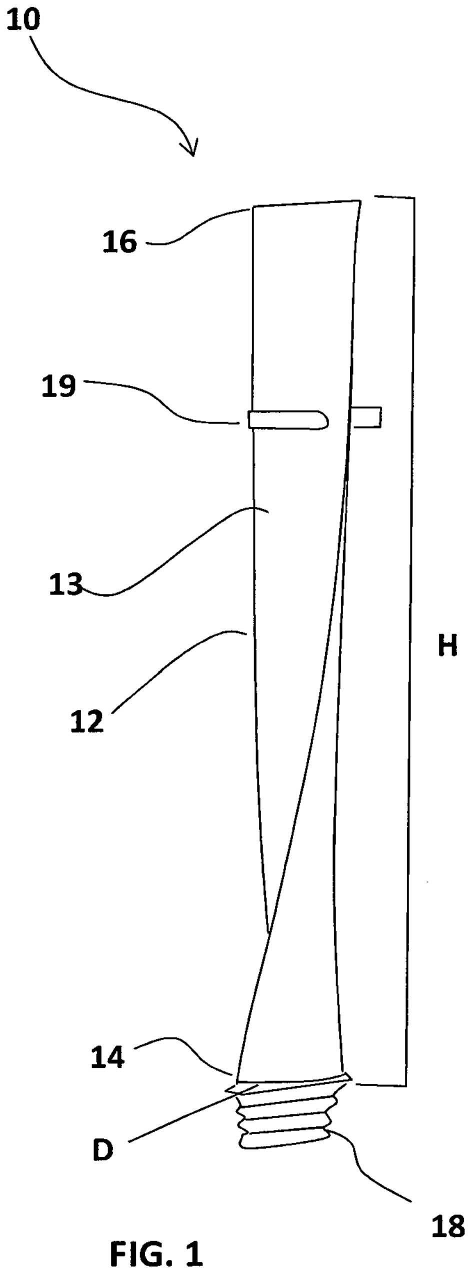

FIG. 1

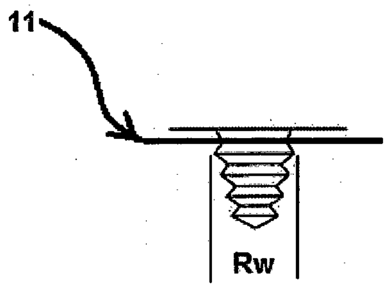

FIG. 2A

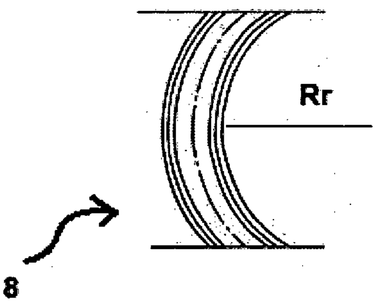

FIG. 2B

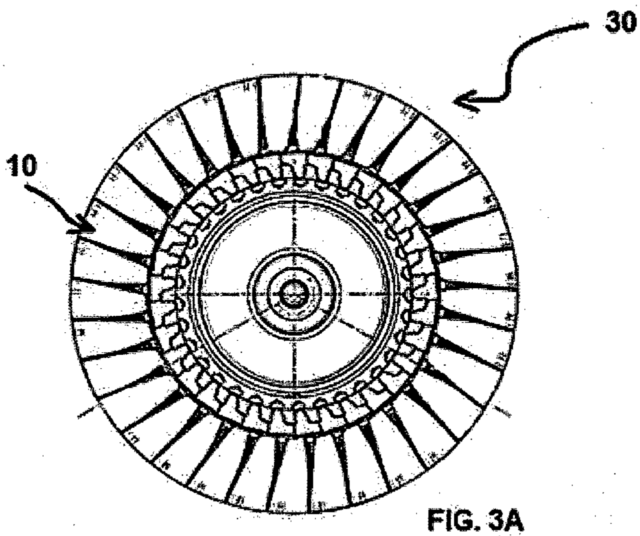

FIG. 3A

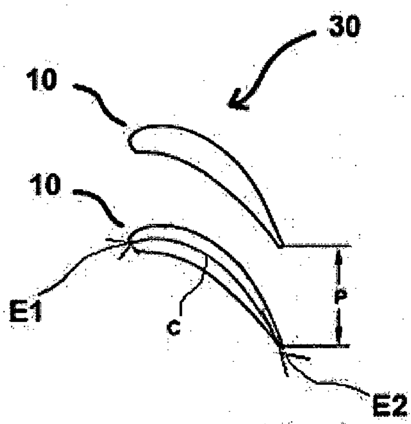

FIG. 3B

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EUROPEAN SEARCH REPORT

Application Number
EP 15 29 0256

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	CN 203 809 057 U (SHANGHAI ELECTRIC POWER GENERATION EQUIPMENT CO LTD) 3 September 2014 (2014-09-03) * claims 1-8; figures 1-4 * * page 1, paragraph [0004] - page 2, paragraph [0014] * * page 3, paragraph [0040] - page 5, paragraph [0062] * -----	1-5,7-14 6	INV. F01D5/14
Y	CN 200 949 477 Y (HARBIN TURBINE CO LTD [CN]) 19 September 2007 (2007-09-19) * figures 1-3 * -----	6	
A	CN 102 108 882 A (DEC DONGFANG TURBINE CO LTD) 29 June 2011 (2011-06-29) * the whole document * -----	1-14	

TECHNICAL FIELDS SEARCHED (IPC)

F01D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	16 March 2016	Lutoschkin, Eugen

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 15 29 0256

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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16-03-2016

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82