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(54) **Cooling system for cooling a turbine blade**

(57) Cooling system for cooling a turbine blade (1) of a gas turbine comprising a rotor with multiple turbine blades and a stator surrounding the rotor and provided with a stator heat shield (2), wherein the stator heat shield (2) comprises a base element (3) covered with at least one abradable thermal barrier coating (4) facing to a tip region of the turbine blade (1) and wherein the cooling system comprises means for generating a cooling air flow, whereby said stator heat shield (2) is provided with a plurality of cooling air holes (5) terminating in the area of said tip region of said turbine blades (1) such that in operation of the turbine a cooling air flow is directed to the tip of respective turbine blades (1).

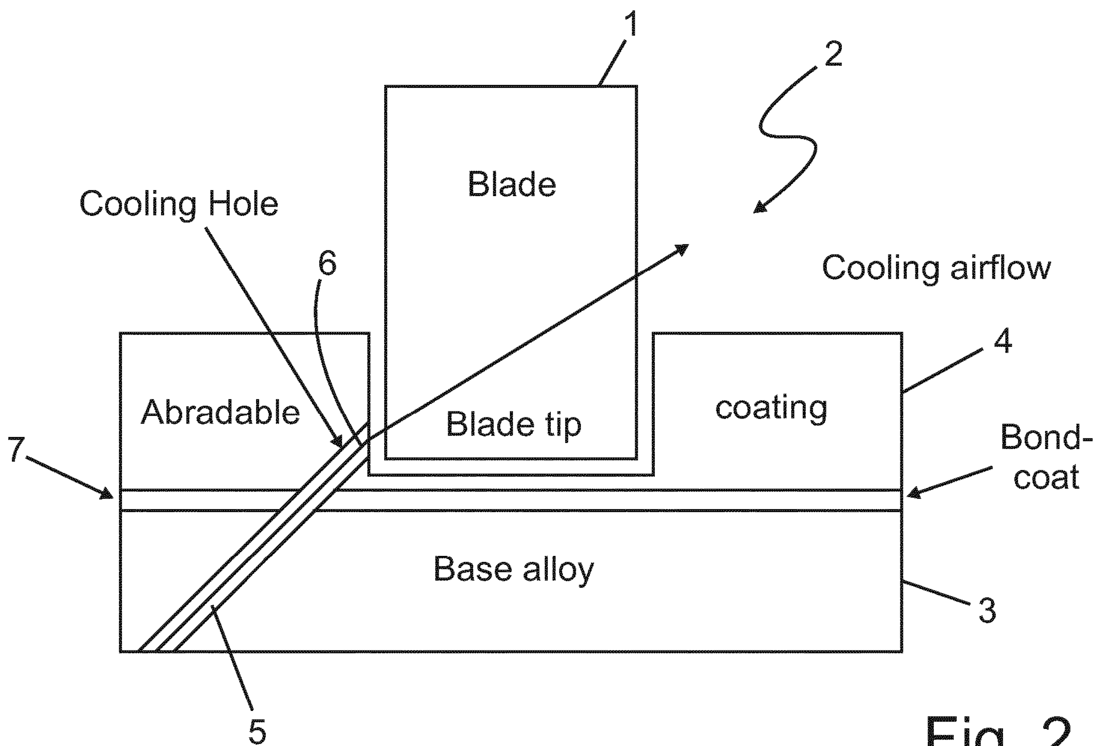

Fig. 2

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Description

Technical Field

[0001] The present invention relates to a cooling system for cooling a turbine blade of a gas turbine comprising a rotor with multiple turbine blades and a stator surrounding the rotor. The invention relates in particular to such a cooling system of high-performance gas turbines, in which due to the increased temperatures a stator heat shield is provided, including at least one abradable thermal barrier coating.

Background Art

[0002] It is desirable to operate for example gas turbines at the highest possible temperature in order to increase the efficiency and performance of the gas turbine engine. In order to enable an operation of such high-performance gas turbines at very high temperatures, it has been proposed in the prior art to provide specific cooling systems for cooling the turbine blades for avoiding too high temperatures. In particular at the tip portion of the turbine blades, the turbines are usually provided with rather complex cooling systems, which run, for example, by means of inner cooling paths in the turbine blades or by means of a combination of cooling air systems and thermal barrier coatings on the metal turbine parts.

[0003] In one of such known cooling systems, some cooling of the turbine blades is achieved through convection by providing passages for a flow of cooling air from the compressor internally within the blades, so that heat may be discharged from the metal structure of the blade by the cooling air. For example, in GB 2 434 842 A a cooling arrangement for a turbine blade shroud is disclosed, in which the turbine blade is provided with several internal cooling passages and cooling air openings such that a cooling air film is directed to the forward face, the rearward face and/or the tip of the turbine blade. Such a cooling arrangement is rather complex with respect to its design and requires a time-consuming and costly manufacturing method for its realization.

[0004] A very critical part in view of the cooling is the tip region of turbine blades, as it is the hottest location of the turbine blade and because it is difficult to provide sufficient cooling at this specific location of the turbine. This problem comes from the rather complex cooling geometries required to cool the tip of the turbine blade and the heat pick-up of any cooling air that is brought through the interior of the turbine blade to the area of the turbine tip. Also due to the geometry and shape of the conventional turbine blade tips and more especially a squealer tip, the possibilities of an internal cooling by means of cooling air passages are rather limited, and it is not simple to create a sufficient film of cooling air on the blade tip in a homogeneous way. Nevertheless, such high-performance gas turbines require a cooling system, which provides a sufficient cooling, in particular of the tip portion of the turbine blades, in order to have an efficient operation performance of the turbine.

Summary of the Invention

[0005] In view of the above-described disadvantages, it is an object of the present invention to provide an efficient cooling system for cooling a turbine blade of a gas turbine with a simple form of construction, which nevertheless allows a reduction of turbine cooling and leakage air and leads to an increased turbine efficiency.

[0006] This problem is solved by means of a cooling system with the features of claim 1. Further developments and preferred embodiments of the invention are subject matter of the dependent claims.

[0007] According to the present invention, a cooling system for cooling a turbine blade of a gas turbine comprising a rotor with multiple turbine blades and a stator surrounding the rotor and provided with a heat shield is provided, wherein the stator heat shield comprises a base element covered with at least one abradable thermal barrier coating facing to a tip region of the turbine blade, and wherein the cooling system comprises means for generating a cooling air flow, characterized in that said stator heat shield is provided with a plurality of cooling air holes terminating in the area of said tip region of said turbine blades such that in operation of the turbine a cooling air flow is directed to the tip of respective turbine blades. By means of this, the cooling system for generating a cooling air flow is integrated within the stator heat shield, and the cooling air flow is directly supplied to the area of the adjacent blade tip of turbine blades. A more efficient cooling in particular of the critical tip region of turbine blades is hereby possible. It is not necessary to provide complex and additional cooling means at the turbine blade itself such that the all-in-all design of the cooling system is comparatively simple. The plurality of cooling air holes in the stator heat shield, which may be realized, for example, by drilling, is arranged such that the cooling air flow efficiently cools the tip region of the turbine blades during the operation of the gas turbine. For this purpose, the plurality of cooling air holes is arranged in a specific pattern and at respective areas of the stator heat shield adjacent to the tip regions of the turbine blades. By using the stator heat shields for the purpose of cooling the turbine blades, an internal cooling of the blades is not required, and independently of the form of turbine blades, an efficient cooling by means of a homogeneous cooling air flow is achieved.

[0008] According to one advantageous aspect of the invention, the cooling air holes in the stator heat shield extend through said base element as well as said at least one thermal barrier coating of said stator heat shield. That means, the cooling air holes pass completely through the elements of the stator heat shield. The cooling air holes of this preferred form of realization are therefore always open, and, when connected to the means for generating a cooling air flow, the cooling air flow surrounding the blade tip of the turbine blade is always generated.

[0009] According to another preferred embodiment of the cooling system according to the invention, the cooling air holes are inclined with respect to a tip front line of the turbine blades in an acute angle of in particular approximately 45°. That means, the cooling air holes are inclined to an outer surface of the heat shield and therefore to the front of the turbine blade. When cooling air flows out of the cooling air holes, the cooling air will therefore pass laterally along the complete width of the tip region of the turbine blade, and a more efficient cooling is achieved.

[0010] According to a further advantageous aspect of the cooling system of the invention, the cooling holes have an exit opening at a lateral position with regard to said turbine blades. A cooling air flow is hereby generated from a side portion of the tip region of the turbine blade. By this, almost the complete cooling air flow coming from the cooling air holes passes around the tip region of the turbine blade. The amount of cooling air needed for the required cooling effect is therefore reduced.

[0011] According to a further advantageous aspect of the cooling system of the invention, the cooling holes are initially closed by at least a part of said thermal barrier coating before an operation of the turbine. The cooling holes in the stator heat shield are, for example, initially closed by means of the abradable thermal barrier coating or a portion of this coating. When the cooling system with the cooling holes integrated in the stator heat shields is installed in the turbine for the first time and the turbine is operated, the thermal barrier coating will be abraded by the tip of the blade in the area of the turbine blades such that the cooling holes will be opened only in the area where the turbine blade is present. The cooling air flow is therefore only given in the respective tip regions of the turbine blades, which minimizes the cooling air need. Only the cooling air holes in the stator heat shield are used for the purpose of cooling the turbine blades, which are in the respective pertinent area of the turbine blades. The initial closure of the cooling air holes can be achieved, for example, by only drilling cooling air holes in the base element of the stator heat shield and by covering the base element with the abradable thermal barrier coating afterwards. During the operation of the turbine, the turbine blade will then abrade this abradable thermal barrier coating only in this area of the turbine blades such that an efficient cooling of the tip region of the turbine blades is provided with a reduced need of cooling air.

[0012] According to a further advantageous aspect of the cooling system of the invention, the cooling air holes have a constant diameter and a straight form through said heat shield. The cooling air holes may therefore be realized by a simple drilling processing. By means of the straight form of the cooling air holes, a maximum pressure of the cooling air flow at the exit opening close to the blade tip is achieved.

[0013] According to a further advantageous aspect of the cooling system of the invention, the cooling air holes have a larger diameter in the base element as compared to the abradable thermal barrier coating. With this design of the cooling air holes, a kind of emergency cooling is achieved in case that the thermal barrier coating of the stator heat shield is completely abraded by the running of the turbine blades. In such a case, the diameter of the cooling air holes is automatically increased, and a larger cooling air flow is generated. On the contrary, when the stator heat shield is still in good shape and the thermal barrier coating is present, the diameter of the cooling air holes is reduced for the normal operation of the turbine, with the cooling system according to the invention integrated in the stator heat shield.

[0014] According to a further advantageous aspect of the cooling system of the invention, the thermal barrier coating is formed of a first inner layer and of a second outer layer. The two separate layers of the thermal barrier coating may be realized with the same material or with a different material. The second outer layer of the thermal barrier coating can specifically be used for the initial closing of the cooling air holes, whereas the cooling air holes are only drilled in the first inner layer of the thermal barrier coating and/or a base element of the stator heat shield. The cooling of the tip region of the turbine blade will therefore only come into effect in the respective pertinent areas, in which the turbine blade is running adjacent to the stator heat shields. With the two-layer form of the abradable thermal barrier coating of the stator heat shield, also different characteristics with respect to the thermal resistance and abrasion resistance can easily be realized.

Brief Description of the Drawings

[0015] In the following, the invention will be described in more detail on the basis of several embodiments of the invention, with reference to the attached drawings, in which:

- Fig. 1 is a schematic cross-section view of a first embodiment of the cooling system of the invention;
- Fig. 2 is a schematic cross-section view of the embodiment of a cooling system of the invention of Fig. 1 with the turbine blade running in the abradable thermal barrier coating;
- Fig. 3 is a schematic cross-section view of a second embodiment of the cooling system according to the invention with initially closed cooling air holes;
- Fig. 4 is a schematic cross-section view of the embodiment of Fig. 3 with the turbine blade running in a part of the abradable thermal barrier coating; and
- Fig. 5 is a schematic cross-section view of a third embodiment of the cooling system according to the present invention including an emergency cooling means.

Ways of Carrying out the Invention

[0016] A first example of realization of the cooling system for turbine blades of the present invention is shown in respective schematic cross-section views in Figs. 1 and 2. The cooling system is integrated within a stator heat shield 2 having in this embodiment a base element 3 and an abradable thermal barrier coating 4, in which a plurality of cooling air holes 5 is formed. The cooling air holes 5 in this embodiment of the invention are always open, with an exit opening 6 on the upper side facing to the critical tip region of a turbine blade (not shown in Fig. 1). The cooling system is furthermore provided with means for generating a cooling air flow, which is arranged outside of the stator heat shield 2 shown in Figs. 1 and 2. The cooling air holes 5 in this first embodiment are inclined at approximately 45° with respect to the upper surface of the stator heat shield 2 and therefore also with respect to the front line of a turbine blade 1 (cf. Fig. 2). An exit opening 6 of the cooling air holes 5 is arranged in a lateral position of the tip region of the turbine blade 1 when the turbine is operated. The cooling air flow according to the arrow in Fig. 2 will therefore pass from one lateral side of the tip region of the turbine blade 1 to the other side and will provide an efficient cooling of in particular the tip region of this turbine blade 1. This cooling effect is also supported by the inclined form of the plurality of cooling air holes 5. In this first embodiment, the cooling air holes 5 go completely through the material of both elements of the stator heat shield 2, namely the base element 3 and the abradable thermal barrier coating 4, which is in this field also denominated as a TBC. The plurality of cooling air holes 5 is, for example, realized by means of a drilling processing and with appropriate diameters for providing a sufficient cooling air flow to the tip region of the turbine blade 1. With this design of a cooling system, which is completely integrated in the stator heat shields 2 adjacent to the tip region of the turbine blade 1, a complex and costly cooling arrangement within the turbine blade 1 itself is avoided. The cooling system of the invention may easily be integrated within existing gas turbines. The base element 3 of the stator heat shield 2 is realized through an appropriate metal or metal alloy, whereas the TBC or thermal barrier coating 4 consists preferably of a ceramic material, such as an Yttria-stabilized zirconia (YSZ), which provides the desired low heat-conductivity and the protection of the outer stator elements of the gas turbine. Between the base element 3 and the thermal barrier coating 4, a bond coat 7 is provided for connecting the two elements to one another. When the gas turbine is run and the turbine blade 1 contacts the abradable thermal barrier coating 4, a portion of the material of the thermal barrier coating 4 will be removed, as it is shown in Fig. 2. The cooling air hole 5 being provided at a lateral position of the tip region of the turbine blade 1 remains open, with its exit opening 6 in such a form that a homogeneous air flow of cooling air is applied to the tip region of the turbine blade 1. With this form of realization, the cooling system may easily be integrated within a given turbine design. Independent of the amount of removal of material in the abradable thermal barrier coating 4, still a sufficient cooling air flow is provided through the exit openings 6 at any circumstance by means of the cooling system of the invention. The multiple cooling air holes 5 in the stator heat shield 2 may preferably be arranged in a specified pattern and with respect to the position of the turbine blades 1 running within the gas turbine in operation. For example, the multiple cooling air holes 5 are arranged in a concentrated form in the areas where the turbine blades 1 will be mounted, facing to the respective stator heat shields 2.

[0017] The further schematic cross-section views of Figs. 3 and 4 of the attached drawings show a second embodiment of the cooling system for cooling a turbine blade of the invention. Contrary to the first example of realization, in this second embodiment the cooling air holes 5 are initially closed by means of an outer layer 42 of the thermal barrier coating 4. The thermal barrier coating 4 is here realized in a two-layer form with a first inner layer 41 and a second outer layer 42, which can be made of the same ceramic material or of different types of ceramic materials. In the initial form of the stator heat shield 2, the multiple cooling air holes 5 are closed by means of the outer layer 42 of the thermal barrier coating 4. According to the invention, the cooling blade will be run as close as possible to the heat shields 2 in order to achieve a sufficient cooling effect. Since it cannot be predicted beforehand, which one of the plurality of stator heat shields 2 will have the closest gap to the tip of the turbine blades 1, the cooling air holes 5 of this form of realization are designed and manufactured such that they are closed by default and will only be opened if the gap between the stator heat shields 2 and the turbine blade 1 is small enough.

[0018] According to the invention, this is achieved by means of the second outer layer 42 of the thermal barrier coating 4, which initially closes the cooling air holes 5 formed in the base element 3, the bond coat 7 and the inner layer 41 of the thermal barrier coating 4, as can be seen when comparing Fig. 3 and Fig. 4 of the attached drawings. When the turbine blade runs in the thermal barrier coating 4, at least to a certain extent, the outer layer 42 will be abraded and consequently the cooling air holes 5 will be opened, so that the efficient cooling by means of the cooling air flow supplied to the tip region of the turbine blade 1 is achieved. This form of realization allows using only the respective cooling air holes 5 of the plurality of cooling air holes 5, which will bring an effective cooling of the blade tip, and the requirement of cooling air pressure and the amount of cooling air are reduced. Also in this second embodiment, the cooling air holes 5 are arranged in a lateral position with regard to the turbine blade 1 and are inclined at approximately 45°with respect to the front line of the tip of the turbine blade. However, this does not limit the scope of protection of the present invention, and the cooling air holes 5 may be not inclined or inclined at another degree and may be arranged at a different position or may be arranged over the whole extension of the respective stator heat shields 2 such that a kind of regular pattern of cooling air holes 5 is provided all around the outer turbine parts. Preferably, the thermal barrier coating 4 is here also realized on the basis of a ceramic material, which can be the same for the outer layer 42 and the inner layer, but which can also be different in any of these two layers. The bond coat 7 provides a secure fitting of the abradable thermal barrier coating 4 to the base element 3, which is preferably made from a metal alloy.

[0019] Figure 5 of the attached drawings shows a third example of realization of a cooling system for cooling a turbine blade integrated within a stator heat shield 2 in a schematic cross-section. This third embodiment is similar to the above-described second embodiment of the invention and comprises a thermal barrier coating 4 made of a first inner layer 41 and a second outer layer 42, which initially closes the plurality of cooling air holes 5. When the gas turbine is operated and the tip of the turbine blades 1 comes in close contact with the stator heat shields 2, the outer layer 42 of the thermal barrier coating 4 will be abraded and the exit opening 6 will afterwards be open, so that a cooling air flow is supplied through the cooling air holes 5, which are in a position adjacent to the tip region of the turbine blade. In this example of realization, the cooling system is furthermore provided with an emergency cooling element in the form of an emergency cooling hole 8 in the base element 3 and the bond coat 7, having a larger diameter as compared to the cooling diameter of the cooling air holes 5 in the thermal barrier coating 4. With this design according to the present invention, an emergency cooling is achieved for the case that the thermal barrier coating falls off. In this event, the larger diameter emergency cooling hole 8 will automatically be opened, and the amount of cooling air flow will thereby be increased. Any deterioration of the turbine blades 1 is hereby avoided also in cases in which the complete thermal barrier coating 4 spalls off and until the stator heat shield 2 is exchanged during the upcoming maintenance of the gas turbine. In this form of realization shown in Fig. 5 of the drawings, the diameter of the emergency cooling hole 8 is approximately twice the diameter of the cooling air hole 5. Also in this example of realization, the cooling air holes 5 extend in an inclined angle at approximately 45° compared to the upper surface of the stator heat shield 2, and therefore to a front line of the turbine blade 1.

[0020] However, the present invention is not limited to this exemplary form of realization, and the cooling air hole 5 may have a different extension and a different position than shown in Fig. 5 of the drawings. It is to be noted that in the drawings only a single cooling air hole 5 is shown, but that the cooling system of the invention has a plurality of cooling air holes 5 in any of the stator heat shields 2.

Claims

1. Cooling system for cooling a turbine blade (1) of a gas turbine comprising a rotor with multiple turbine blades and a stator surrounding the rotor and provided with a stator heat shield (2), wherein the stator heat shield (2) comprises a base element (3) covered with at least one abradable thermal barrier coating (4) facing to a tip region of the turbine blade (1) and wherein the cooling system comprises means for generating a cooling air flow, **characterized in that** said stator heat shield (2) is provided with a plurality of cooling air holes (5) terminating in the area of said tip region of said turbine blades (1) such that in operation of the turbine a cooling air flow is directed to the tip of respective turbine blades (1).

2. Cooling system according to claim 1, **characterized in that** said cooling air holes (5) extend through said base element (3) as well as said at least one thermal barrier coating (4) of said stator heat shield (2).

3. Cooling system according to claim 1 or 2, **characterized in that** said cooling air holes (5) are inclined with respect to a blade tip front line in an acute angle of in particular approximately 45°.

4. Cooling system according to any one of the preceding claims, **characterized in that** said cooling air holes (5) have an exit opening (6) at a lateral position with regard to said turbine blades (1).

5. Cooling system according to any one of the preceding claims, **characterized in that** said cooling air holes (5) are initially closed by at least a part of said thermal barrier coating (4) before operation of said turbine.

6. Cooling system according to any one of the preceding claims, **characterized in that** said cooling air holes (5) have a constant diameter and straight form through said heat shield (2).

7. Cooling system according to any one of the preceding claims 1 to 5, **characterized in that** said cooling air holes (5) have a larger diameter in said base element (3) as compared to in said at least one abradable thermal barrier coating (4).

8. Cooling system according to any one of the preceding claims, **characterized in that** said thermal barrier coating (4) is formed of a first inner layer (41) and a second outer layer (42).

9. Cooling system according to claim 8, **characterized in that** in said second outer layer (42) of said thermal barrier coating (4) the cooling air holes (5) are initially closed before operation of the turbine.

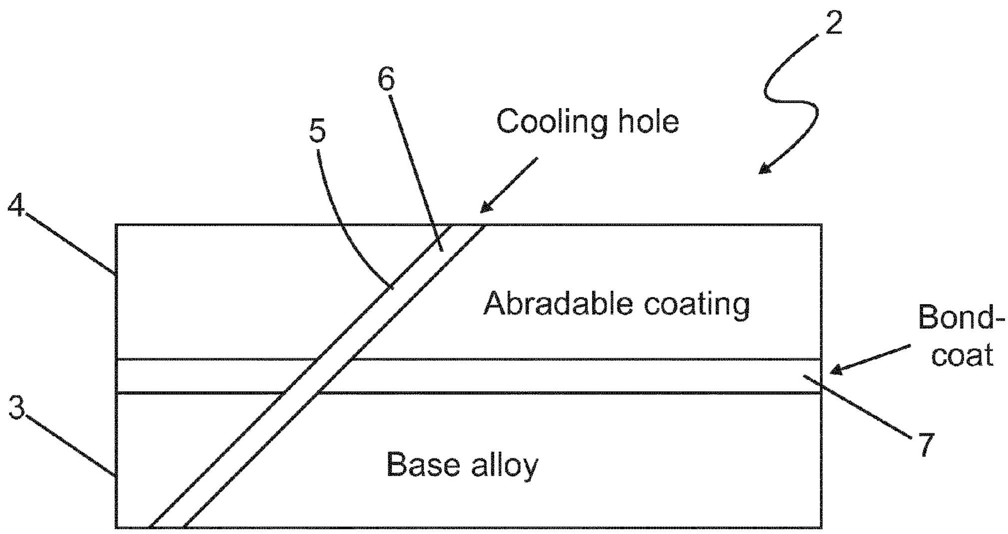
2
6
5
Cooling hole
4
Abradable coating
Bond-
coat
3
7
Base alloy

Fig. 1

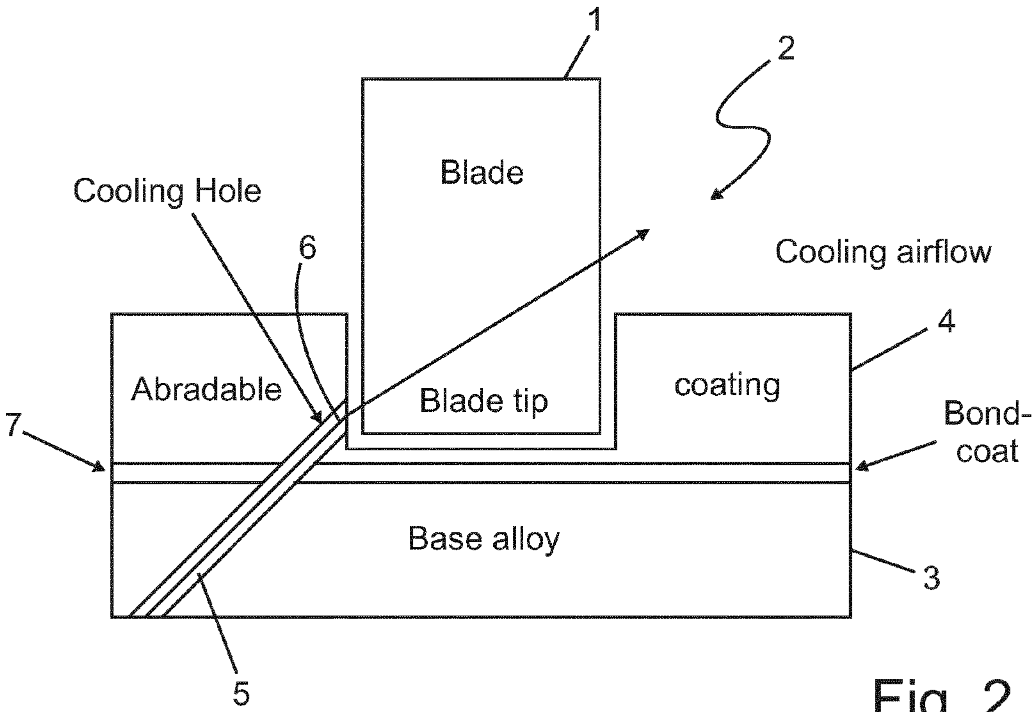
1
2
Blade
Cooling Hole
Cooling airflow
6
4
Abradable
coating
Blade tip
7
Bond-
coat
Base alloy
3
5

Fig. 2

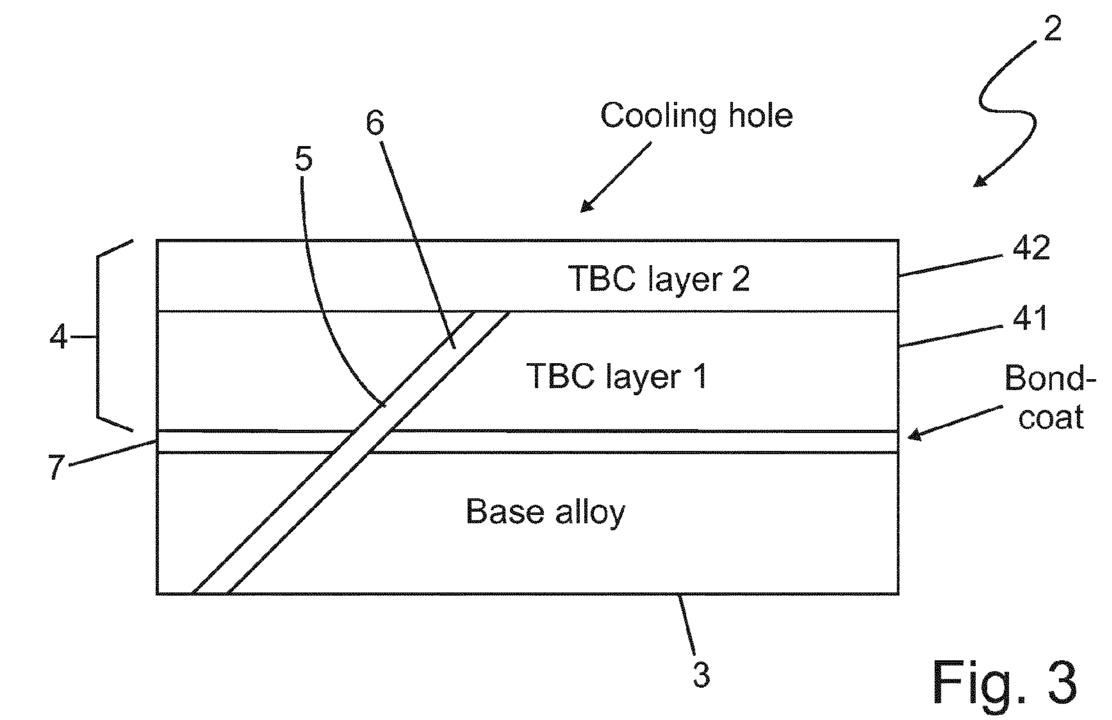
2
Cooling hole
6
5
TBC layer 2
42
41
4
TBC layer 1
Bond-
coat
7
Base alloy
3

Fig. 3

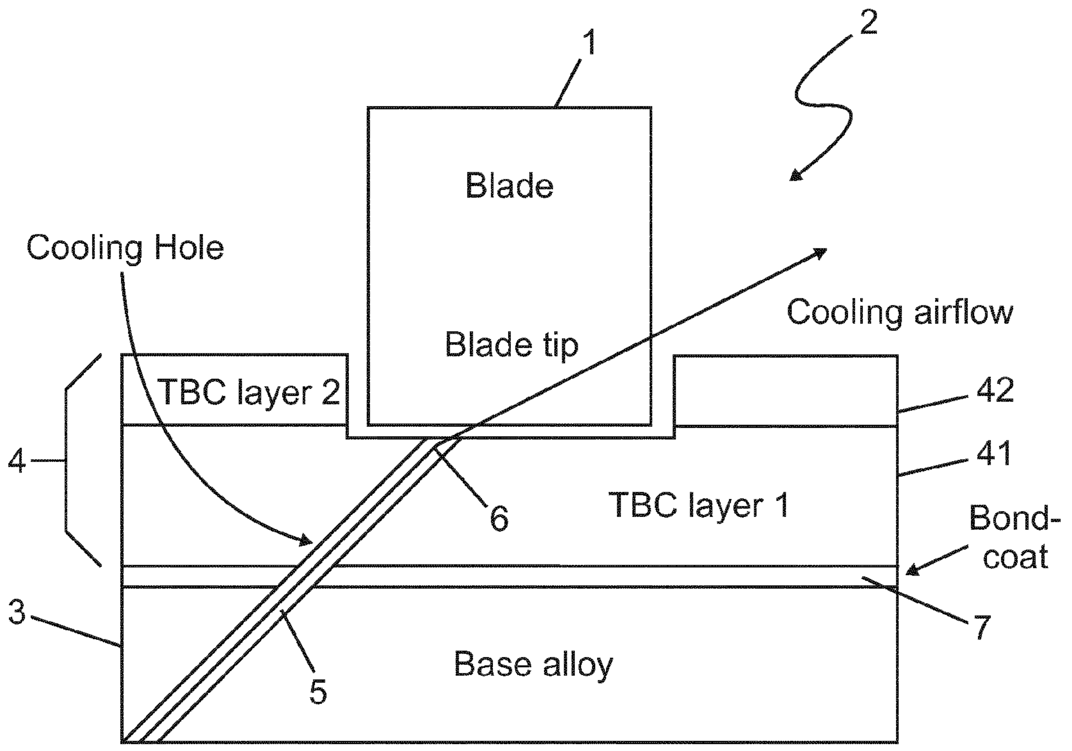
2
1
Blade
Cooling Hole
Cooling airflow
Blade tip
TBC layer 2
42
4
41
6
TBC layer 1
Bond-
coat
3
7
5
Base alloy

Fig. 4

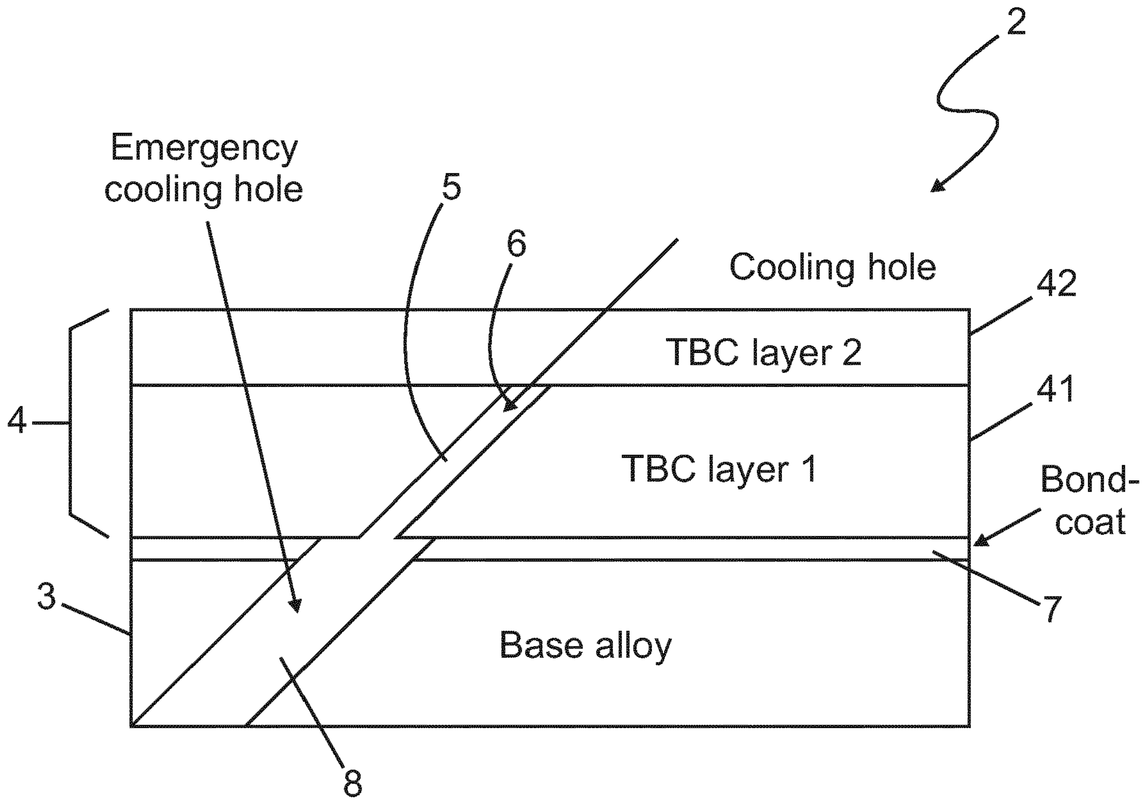
2
Emergency cooling hole
5
6
Cooling hole
42
TBC layer 2
4
41
TBC layer 1
Bond-coat
3
7
Base alloy
8

Fig. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 13 18 7901

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	EP 2 613 015 A1 (UNITED TECHNOLOGIES CORP [US]) 10 July 2013 (2013-07-10) * paragraphs [0020] - [0021]; figure 4 *	1-4,6,8	INV. F01D11/12 F01D25/12 F01D25/24
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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	20 February 2014	Oechsner de Coninck

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20-02-2014

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