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- (81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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- (54) **Title:** TURBINE BLADE WITH AIRFOIL TIP HAVING CUTTING TIPS

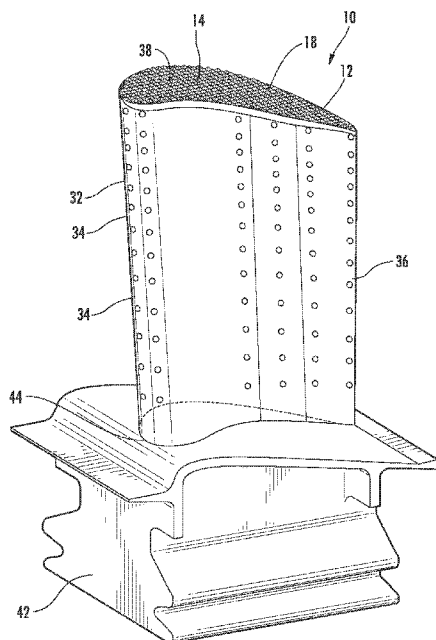


FIG. 1

(57) **Abstract:** A turbine blade (10) having a squealer tip (12) at a radially outer end of the turbine blade (10) with a plurality of abradable coating cutting tips (18) extending radially therefrom toward a ring segment (20) is disclosed. During operation, the abradable coating cutting tips (18) may cut into an abradable coating (22) on the ring segments (20) of the turbine engine that are positioned radially outward from the turbine blade (10). The plurality of abradable coating cutting tips (18) may include one or more cutting ar- rises (28) extending from the squealer tip (12) to an outermost tip (30) of the at least one of the abradable coating cutting tips (18).

TURBINE BLADE WITH AIRFOIL TIP HAVING CUTTING TIPS

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Development of this invention was supported in part by the United States Department of Energy, Advanced Hydrogen Turbine Development Program, Contract No. DE-FC26-05NT42644. Accordingly, the United States Government may have certain rights in this invention.

FIELD OF THE INVENTION

This invention is directed generally to turbine blades, and more particularly to tip configurations of turbine blades in gas turbine engines.

BACKGROUND

Typically, gas turbine engines include a compressor for compressing air, a combustor for mixing the compressed air with fuel and igniting the mixture, and a turbine blade assembly for producing power. Combustors often operate at high temperatures that may exceed 2,500 degrees Fahrenheit. Typical turbine combustor configurations expose turbine blade assemblies to these high temperatures. As a result, turbine blades must be made of materials capable of withstanding such high temperatures. In addition, turbine blades often contain cooling systems for prolonging the life of the blades and reducing the likelihood of failure as a result of excessive temperatures.

Typically, turbine blades are formed from a root portion at one end and an elongated portion forming a blade that extends outwardly from a platform coupled to the root portion at an opposite end of the turbine blade. The blade is ordinarily composed of a tip opposite the root section, a leading edge, and a trailing edge. The tip of a turbine blade often has a tip seals to reduce the gap between ring segments and blades in the gas path of the turbine. The tip seals are often referred to as squealer tips and are frequently incorporated onto the tips of blades to help reduce pressure losses between turbine stages. These features are designed to minimize

the gap between the blade tip and the ring segment. Nonetheless, during startup, the blade tip often contacts the ring segments and causes wear on the blade tip, which damages the blade. Thus, a need exists for accommodating startup conditions without damaging the turbine blades.

SUMMARY OF THE INVENTION

A turbine blade having a squealer tip at a radially outer end of the turbine blade with a plurality of abradable coating cutting tips extending radially therefrom toward a ring segment is disclosed. During operation, the abradable coating cutting tips may cut into an abradable coating on the ring segments of the turbine engine that are positioned radially outward from the turbine blade. The plurality of abradable coating cutting tips may include one or more cutting arrises extending from the squealer tip to an outermost tip of the abradable coating cutting tips. By cutting into the adjacent abradable coating, the abradable coating cutting tips enable the turbine engine to continue operating without losing efficiency.

The turbine blade may be formed from a generally elongated blade having a leading edge, a trailing edge, a tip at a first end, a root coupled to the blade at a second end generally opposite the first end for supporting the blade and for coupling the blade to a disc. The blade may also include a squealer tip coupled to the tip at the first end. The squealer tip may include a plurality of abradable coating cutting tips that extend radially from the squealer tip toward a ring segment positioned radially outward from the generally elongated blade. The plurality of abradable coating cutting tips may be formed into at least two rows of abradable coating cutting tips extending generally orthogonal to a flow of combustion exhaust gases between the squealer tip and the ring segment. A second row of abradable coating cutting tips may be positioned downstream from a first row of abradable coating cutting tips and may be offset orthogally to the flow of combustion exhaust gases relative to the first row of abradable coating cutting tips.

In at least one embodiment, one or more of the abradable coating cutting tips may have at least one cutting arrises extending from the squealer tip to an outermost tip of the abradable coating cutting tip. In another embodiment, one or more of the abradable coating cutting tips have at least three cutting arrises extending from the

squealer tip to an outermost tip of the at least one of the abratable coating cutting tips. A first cutting arris may be positioned on an upstream side of the abratable coating cutting tip. A second cutting arris may extend from the squealer tip to the outermost tip of the abratable coating cutting tip at a first intersection between the upstream side and a downstream side of the abratable coating cutting tip. A third cutting arris may extend from the squealer tip to the outermost tip of the abratable coating cutting tip at a second intersection between the upstream side and the downstream side of the abratable coating cutting tip. The second intersection may be on an opposite side of the tip from the first side.

In at least one embodiment, one or more of the plurality of abratable coating cutting tips may have a pyramid shape. In another embodiment, each of the plurality of abratable coating cutting tips may have a pyramid shape. At least one of the plurality of abratable coating cutting tips may extend from the squealer tip a distance of at least 125 microns. In another embodiment, at least one of the plurality of abratable coating cutting tips may extend from the squealer tip a distance of at least 250 microns. In a further embodiment, at least one of the plurality of abratable coating cutting tips may extend from the squealer tip a distance of 1000 microns, which is 1 millimeter. In yet another embodiment, the plurality of abratable coating cutting tips may extend from the squealer tip a distance of at least 125 microns and less than 1,025 microns. The plurality of abratable coating cutting tips may be formed from a knurled surface on the radially outer end of the squealer tip.

In another embodiment, at least one of the plurality of abratable coating cutting tips is formed from a plurality of planar surfaces, wherein adjacent planar surfaces intersect to form a cutting arris. At least one of the plurality of abratable coating cutting tips may be formed from at least four planar surfaces. Adjacent abratable coating cutting tips may be separated at an outer surface of the squealer tip by a linear line. The plurality of abratable coating cutting tips may be separated at an outer surface of the squealer tip into rows by a plurality of linear lines positioned in a first orientation and a plurality of linear lines positioned in a second orientation. The second orientation may be orthogonal to the first orientation. The first orientation and the second orientation may also be nonparallel and nonorthogonal relative to a direction of flow of combustion exhaust gases.

An advantage of this invention is that the improved clearance control increases engine efficiency and power by improving the ability of the blade tips to engrave or cut the abradable material on the stationary component.

Another advantage of this invention is that the abradable coating cutting tips cut into the abradable coating on the radially inner surface of the ring segments producing a profile that corresponds with the abradable coating cutting tips extending from the turbine blade.

Yet another advantage of this invention is that the profile of the turbine blade corresponds exactly to the swept profile in the ring segments, thereby improving clearance control.

These and other embodiments are described in more detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and form a part of the specification, illustrate embodiments of the presently disclosed invention and, together with the description, disclose the principles of the invention.

Figure 1 is a perspective view of a turbine blade having features according to the instant invention.

Figure 2 is a detailed cross-sectional view of a turbine blade tip adjacent to a radially outward positioned ring segment, whereby the scale of the abradable coating cutting tips are enlarged so that they can be seen.

Figure 3 is a detailed top view of a portion of the tip of the turbine blade with abradable coating cutting tips.

Figure 4 is a detailed side view of the portion of the tip of the turbine blade with abradable coating cutting tips shown in Figure 3.

Figure 5 is a detailed top view of a portion of another embodiment of the tip of the turbine blade with abradable coating cutting tips.

Figure 6 is a detailed side view of the portion of the tip of the turbine blade with abradable coating cutting tips shown in Figure 5.

Figure 7 is a photograph of the results of a test of a turbine blade contacting a strip of material, whereby the top strip of material was struck by a flat metal turbine blade tip, the middle strip of material was struck by a turbine blade tip having

abradable coating cutting tips with a height of about 125 microns, and the bottom strip of material was struck by a turbine blade tip having abradable coating cutting tips with a height of about 250 microns.

Figure 8 is a perspective view of a portion of the tip of the turbine blade with abradable coating cutting tips.

DETAILED DESCRIPTION OF THE INVENTION

As shown in Figures 1-8, a turbine blade 10 having a squealer tip 12 at a radially outer end 14 of the turbine blade 16 with a plurality of abradable coating cutting tips 18 extending radially therefrom toward a ring segment 20 is disclosed. During operation, the abradable coating cutting tips 18 may cut into an abradable coating 22 on the ring segments 20 of the turbine engine that are positioned radially outward from the turbine blade 10, as shown in Figure 2. The plurality of abradable coating cutting tips 18 may include one or more cutting arrises 28 extending from the squealer tip 12 to an outermost tip 30 of the abradable coating cutting tips 18. By cutting into the adjacent abradable coating 22, the abradable coating cutting tips 18 enable the turbine engine to continue operating with losing efficiency.

The turbine blade 10 may be formed from any appropriate configuration. For instance, in at least one embodiment, the turbine blade 10 may be formed from a generally elongated blade 32 having a leading edge 34, a trailing edge 36, a tip 38 at a first end 14, a root 42 coupled to the blade 32 at a second end 44 generally opposite the first end 14 for supporting the blade 32 and for coupling the blade 32 to a disc. The turbine blade 10 may include a squealer tip 12 coupled to the tip 38 at the first end 40. The squealer tip 12 may include a plurality of abradable coating cutting tips 18 that extend radially from the squealer tip 12 toward one or more ring segments 20 positioned radially outward from the generally elongated blade 32.

In at least one embodiment, the abradable coating cutting tips 18 may be formed into at least two rows 46, 48 of abradable coating cutting tips 18 extending generally orthogonal to a flow of combustion exhaust gases 50 between the squealer tip 12 and the ring segment 20. A second row 48 of abradable coating cutting tips 18 may be positioned downstream from a first row 46 of abradable coating cutting tips

18 and may be offset orthogally to the flow of combustion exhaust gases 50 relative to the first row of abradable coating cutting tips 46.

One or more of the abradable coating cutting tips 18 may have one or more cutting arrises 28 extending from the squealer tip 12 to an outermost tip 30 of the abradable coating cutting tips 18, as shown in Figures 1-6 and 8. In at least one embodiment, as shown in Figures 5 and 8, one or more of the abradable coating cutting tips 18 may have at least three cutting arrises 28 extending from the squealer tip 12 to the outermost tip 30 of the abradable coating cutting tip 18. A first cutting arris 54 may be positioned on an upstream side 56 of the abradable coating cutting tip 18. A second cutting arris 58 may extend from the squealer tip 12 to the outermost tip 30 of the abradable coating cutting tip 18 at a first intersection 60 between the upstream side 56 and a downstream side 62 of the abradable coating cutting tip 18. A third cutting arris 64 may extend from the squealer tip 12 to the outermost tip 30 of the abradable coating cutting tip 18 at a second intersection 66 between the upstream side 56 and the downstream side 62 of the abradable coating cutting tip 18. The second intersection 66 may be on an opposite side of the abradable coating cutting tip 18 from a first side 68 with the first intersection 60.

In at least one embodiment, as shown in Figures 3, 5 and 8, one or more of the abradable coating cutting tips 18 may have a pyramid shape with a wide base 70 coupled to the squealer tip 12 and tip 30 at an opposite radially outermost end. In another embodiment, each of the plurality of abradable coating cutting tips 18 may have a pyramid shape. One or more of the abradable coating cutting tips 18 may be formed from a plurality of planar surfaces 72 wherein adjacent planar surfaces 72 intersect to form a cutting arris 28. In an embodiment, where the abradable coating cutting tips 18 are formed of a pyramid shape, one or more of the abradable coating cutting tips 18 may be formed from at least four planar surfaces 72. In such an embodiment, the four planar surfaces 72 may each be separated by a cutting arris 28 for a total of four cutting arrises 28. In other embodiments, an abradable coating cutting tip 18 may include more than four planar sides or less than four planar sides and similarly, more or less than four cutting arrises 28.

Adjacent abradable coating cutting tips 18 may be separated at an outer surface 74 of the squealer tip 12 by a linear line 76. In at least one embodiment, the

abradable coating cutting tips 18 may be separated at the outer surface 74 of the squealer tip 12 into rows by a plurality of linear lines 76 positioned in a first orientation 78 and a plurality of linear lines 76 positioned in a second orientation 80, wherein the second orientation 80 is orthogonal to the first orientation 78. The first orientation 78 and the second orientation 80 may be nonparallel and nonorthogonal relative to a direction of flow 50 of combustion exhaust gases.

In at least one embodiment, the abradable coating cutting tips 18 extend from the squealer tip 12 a distance of about 5 mils, which is about 125 microns. In another embodiment, the abradable coating cutting tips 18 may extend from the squealer tip 12 a distance of about 10 mils, which is about 250 microns. In a further embodiment, at least one of the plurality of abradable coating cutting tips may extend from the squealer tip a distance of 1000 microns, which is 1 millimeter. In another embodiment, the abradable coating cutting tips 18 may extend from the squealer tip 12 a distance of at least 125 microns and less than 1,025 microns. In at least one embodiment, the abradable coating cutting tips 18 form a knurled surface on the radially outer end of the squealer tip 12.

The abradable coating cutting tips 18 may be formed by machining the abradable coating cutting tips 18 in the tip 38 of the generally elongated blade 32. In particular, the machining the abradable coating cutting tips 18 may be formed by a grinding or milling operation. The grinding or milling operation may produce a pattern of pyramidal abradable coating cutting tips 18,

During use, the turbine blades 10 are coupled to a rotor assembly that rotates, while ring segments 20 form a boundary radially outward from the turbine blades 10. As the combustion exhaust gases flow past the turbine blades 10, the turbine blade and ring segments are heated and thermally expand. During the startup process before reaching a steady state operating condition, the turbine blade 10 may contact the ring segments 20 as the turbine blade 10 is rotated. The abradable coating cutting tips 18 cut into the abradable coating on the radially inner surface of the ring segments 20 producing a profile that corresponds with the abradable coating cutting tips 18 extending from the turbine blade 10. As such, the profile of the turbine blade 10 corresponds exactly to the swept profile in the ring segments 20, thereby improving clearance control. The improved clearance control increases engine

efficiency and power by improving the ability of the blade tips to engrave or cut the abradable material on the stationary component.

The foregoing is provided for purposes of illustrating, explaining, and describing embodiments of this invention. Modifications and adaptations to these embodiments will be apparent to those skilled in the art and may be made without departing from the scope or spirit of this invention.

CLAIMS

I claim:

1. A turbine blade (10), characterized in that:
a generally elongated blade (32) having a leading edge (34), a trailing edge (36), a tip (38) at a first end (14), a root (42) coupled to the blade (32) at a second end (44) generally opposite the first end (14) for supporting the blade (32) and for coupling the blade (32) to a disc; and
a squealer tip (12) coupled to the tip (38) at the first end, wherein the squealer tip (12) includes a plurality of abradable coating cutting tips (18) that extend radially from the squealer tip (12) toward a ring segment (20) positioned radially outward from the generally elongated blade (32).
2. The turbine blade (10) of claim 1, characterized in that the plurality of abradable coating cutting tips (18) is formed into at least two rows (46, 48) of abradable coating cutting tips (18) extending generally orthogonal to a flow of combustion exhaust gases (50) between the squealer tip (12) and the ring segment (20), and wherein a second row (48) of abradable coating cutting tips (18) is positioned downstream from a first row (46) of abradable coating cutting tips (18) and is offset orthogally to the flow of combustion exhaust gases (50) relative to the first row (46) of abradable coating cutting tips (18).
3. The turbine blade (10) of claim 1, characterized in that at least one of the abradable coating cutting tips (18) has at least one cutting arris (54) extending from the squealer tip (12) to an outermost tip (30) of the at least one of the abradable coating cutting tips (18).
4. The turbine blade (10) of claim 3, characterized in that at least one of the abradable coating cutting tips (18) has at least three cutting arrises (54) extending from the squealer tip (12) to an outermost tip (30) of the at least one of the abradable coating cutting tips (18), wherein a first cutting arris (58) is positioned on

an upstream side (56) of the at least one of the abradable coating cutting tips (18), a second cutting arris (58) extending from the squealer tip (12) to the outermost tip (30) of the at least one of the abradable coating cutting tips (18) at a first intersection (60) between the upstream side (56) and a downstream side (62) of the at least one of the abradable coating cutting tips (18), and a third cutting arris (64) extending from the squealer tip (12) to the outermost tip (30) of the at least one of the abradable coating cutting tips (18) at a second intersection (66) between the upstream side (56) and the downstream side (62) of the at least one of the abradable coating cutting tips (18), wherein the second intersection (66) is on an opposite side of the tip (18) from a first side (68).

5. The turbine blade (10) of claim 1, characterized in that at least one of the plurality of abradable coating cutting tips (18) has a pyramid shape.

6. The turbine blade (10) of claim 1, characterized in that at least one of the plurality of abradable coating cutting tips (18) extends from the squealer tip (12) a distance of at least 125 microns.

7. The turbine blade (10) of claim 1, characterized in that at least one of the plurality of abradable coating cutting tips (18) extends from the squealer tip (12) a distance of at least 250 microns.

8. The turbine blade (10) of claim 1, characterized in that at least one of the plurality of abradable coating cutting tips (18) extends from the squealer tip (12) a distance of up to 1000 microns.

9. The turbine blade (10) of claim 1, characterized in that of the plurality of abradable coating cutting tips (18) forms a knurled surface on the radially outer end of the squealer tip (12).

10. The turbine blade (10) of claim 1, characterized in that at least one of the plurality of abradable coating cutting tips (18) is formed from a plurality of planar

surfaces (72), wherein adjacent planar surfaces (72) intersect to form a cutting arris (28).

11. The turbine blade (10) of claim 10, characterized in that the at least one of the plurality of abradable coating cutting tips (18) is formed from at least four planar surfaces (72).

12. The turbine blade (10) of claim 10, characterized in that adjacent abradable coating cutting tips (18) are separated at an outer surface (74) of the squealer tip (12) by a linear line (76).

13. The turbine blade (10) of claim 10, characterized in that the plurality of abradable coating cutting tips (18) are separated at an outer surface (74) of the squealer tip (12) into rows by a plurality of linear lines (76) positioned in a first orientation (78) and a plurality of linear lines (76) positioned in a second orientation (80), wherein the second orientation (80) is orthogonal to the first orientation (78).

14. The turbine blade (10) of claim 13, characterized in that the first orientation (78) and the second orientation (80) are nonparallel and nonorthogonal relative to a direction of flow of combustion exhaust gases (50).

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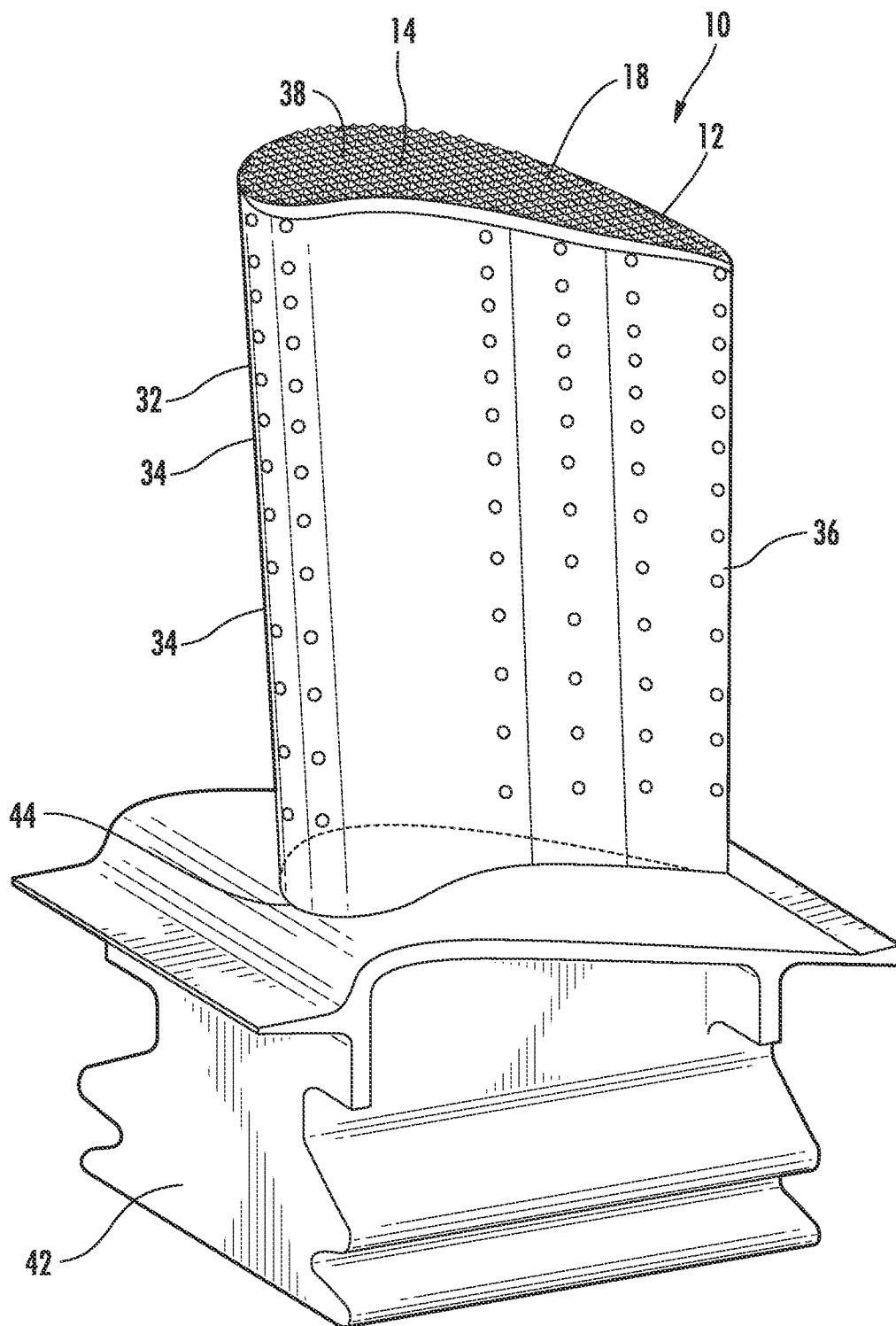


FIG. 1

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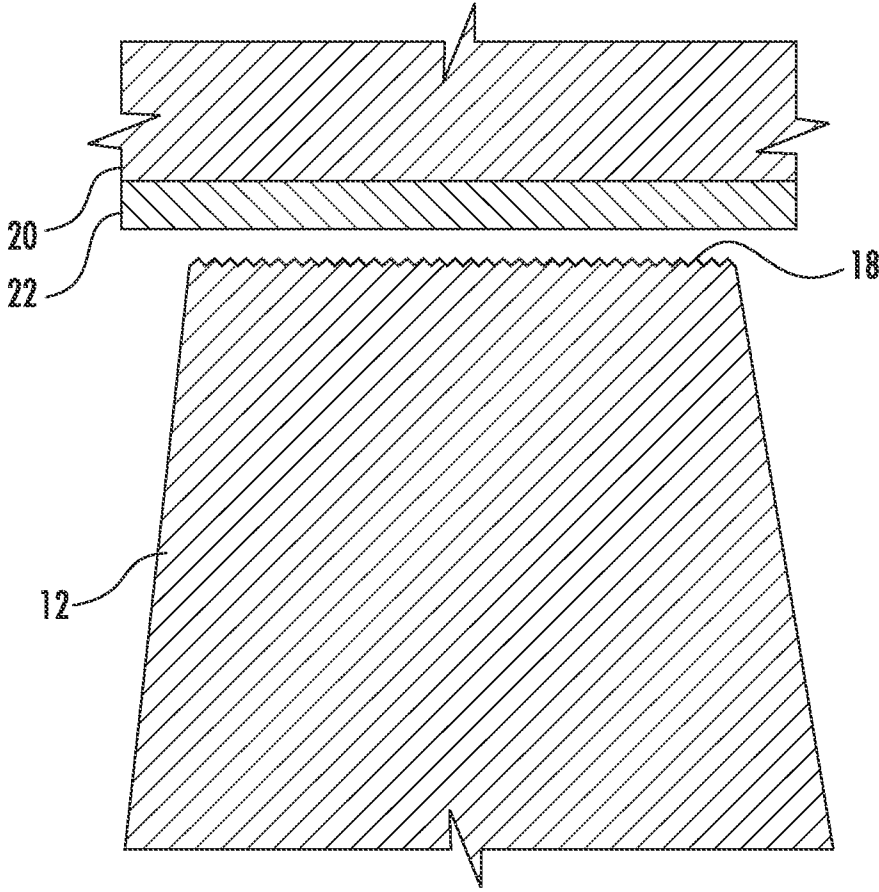


FIG. 2

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FIG. 3

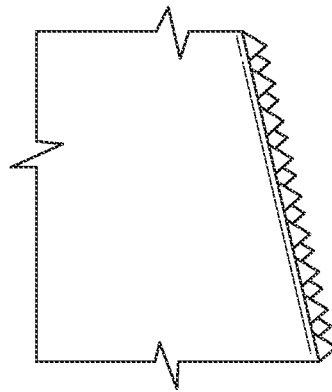


FIG. 4

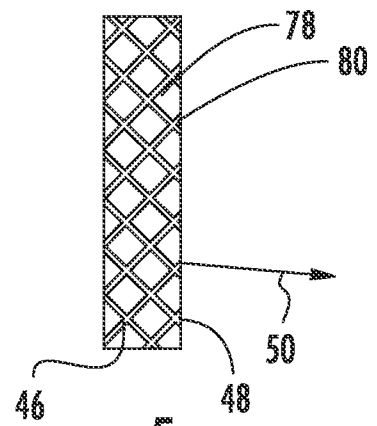


FIG. 5

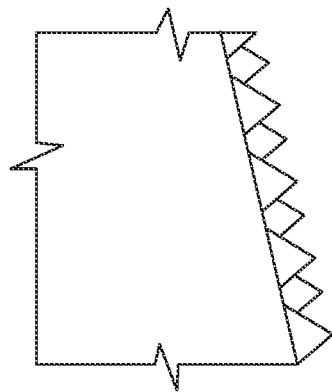
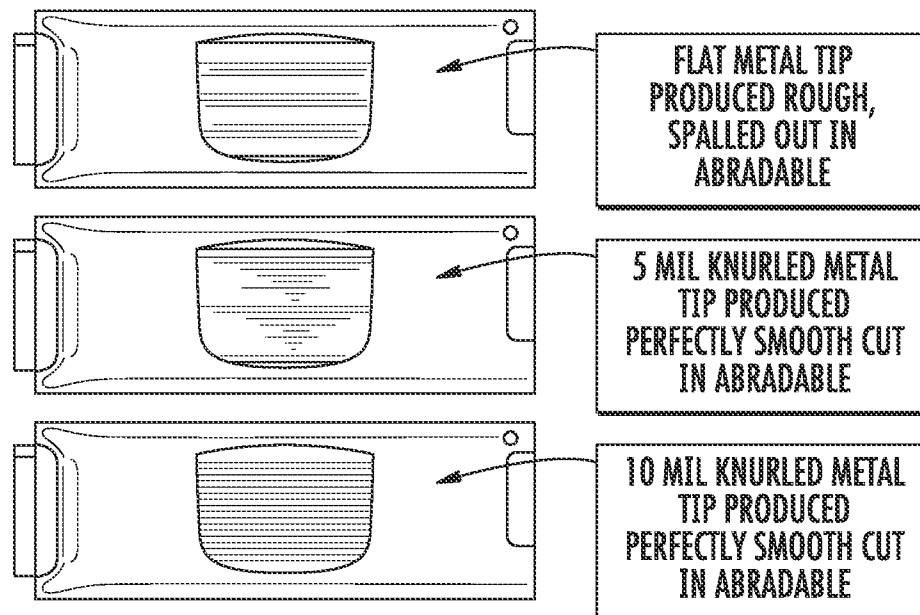


FIG. 6

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**FIG. 7**

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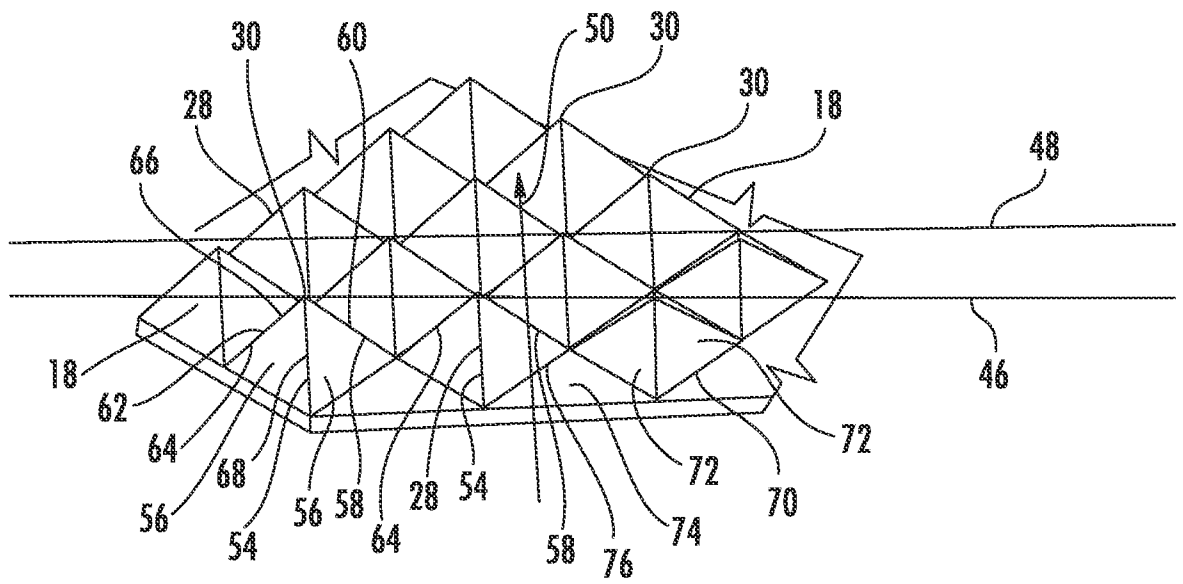


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/051777

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D11/12
ADD. F01D5/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

21 October 2014

Date of mailing of the international search report

29/10/2014

Name and mailing address of the ISA/

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Raspo, Fabrice

INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

International application No

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