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

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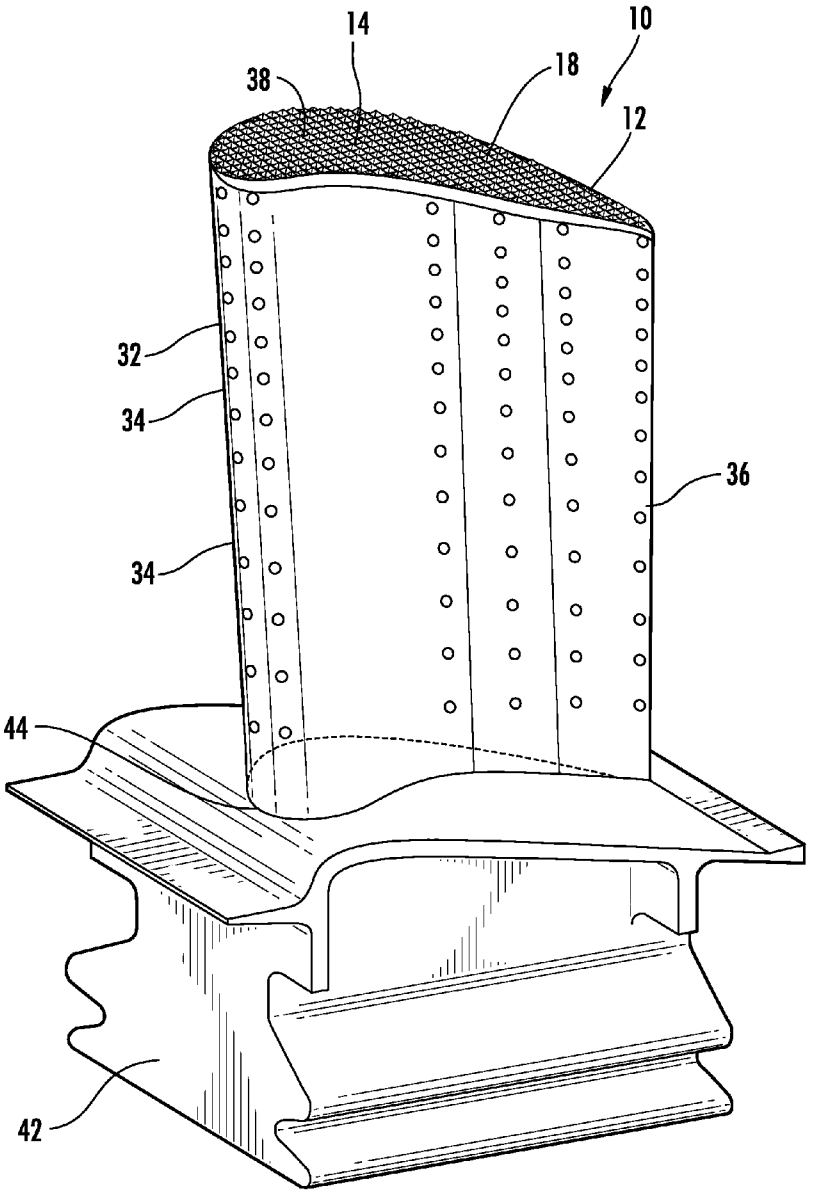
(57) **ABSTRACT**

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 at least one of the abradable coating cutting tips.



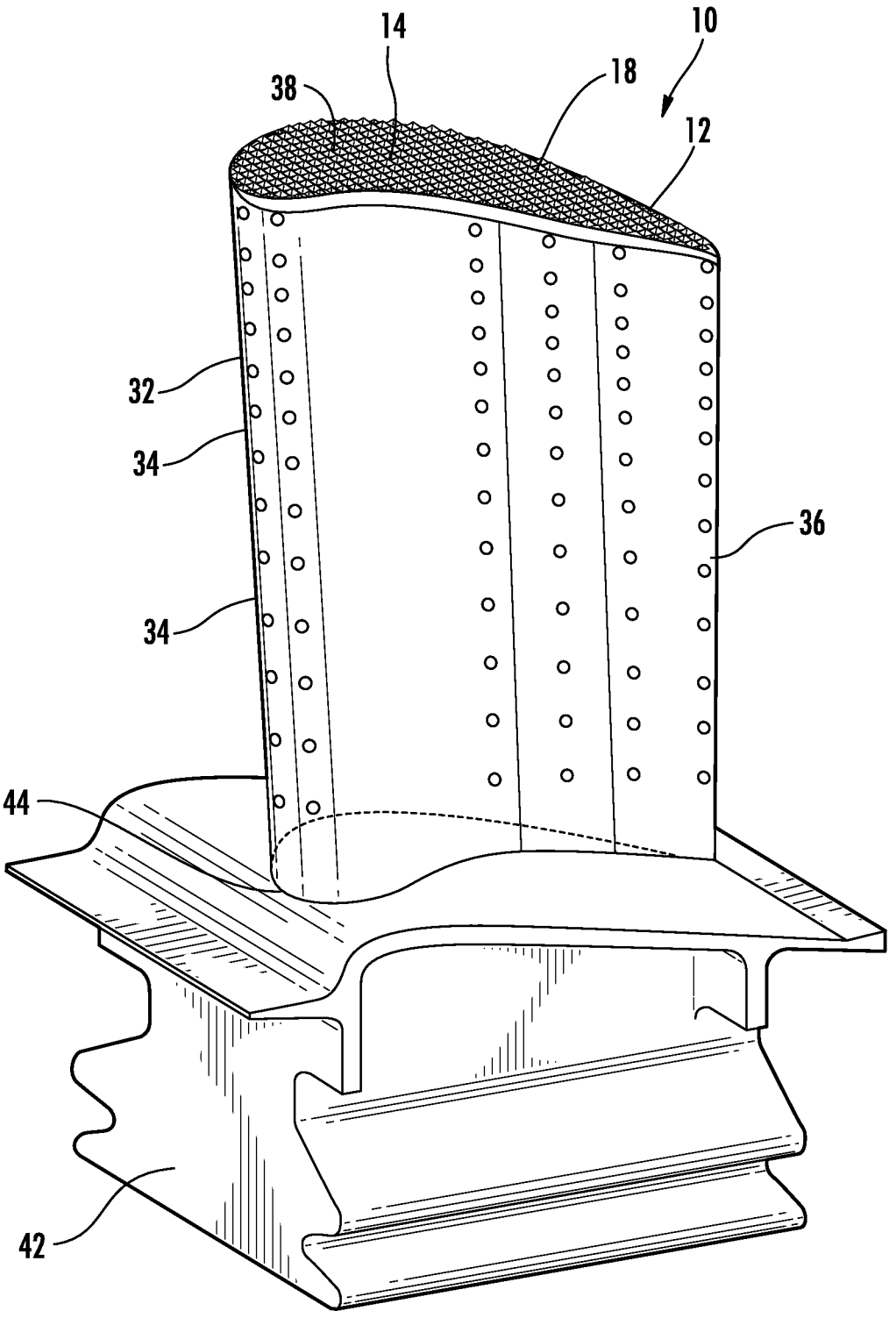


FIG. 1

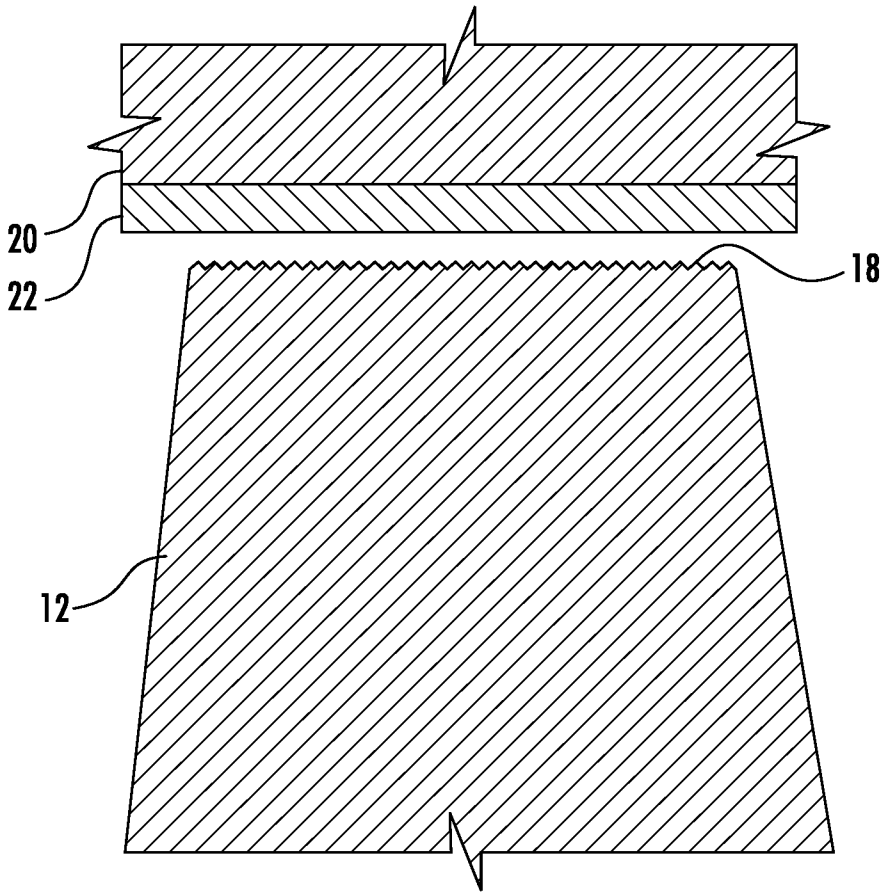


FIG. 2

FIG. 3

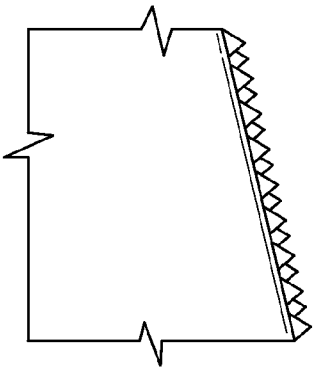


FIG. 4

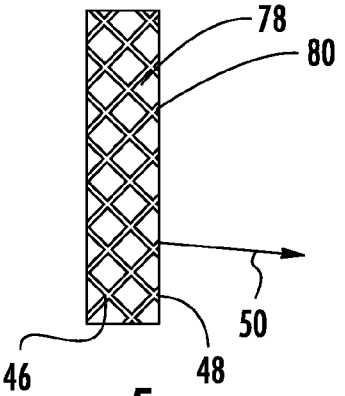


FIG. 5

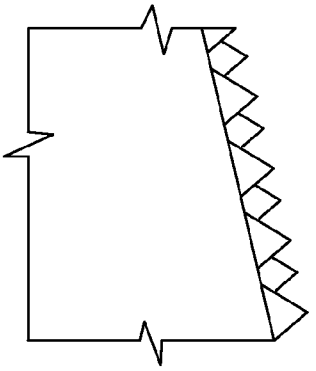


FIG. 6

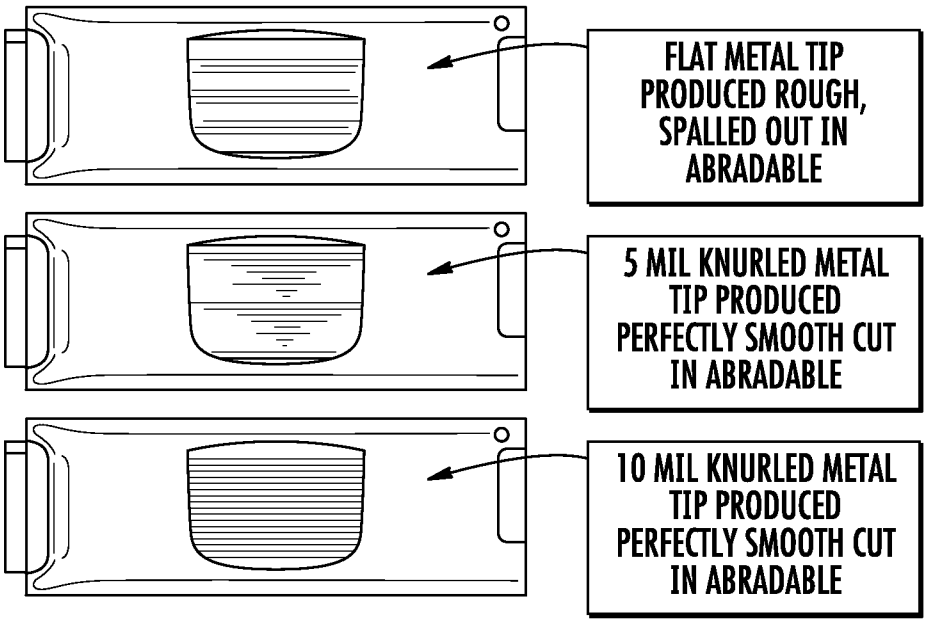

FLAT METAL TIP PRODUCED ROUGH, SPALLED OUT IN ABRADABLE
5 MIL KNURLED METAL TIP PRODUCED PERFECTLY SMOOTH CUT IN ABRADABLE
10 MIL KNURLED METAL TIP PRODUCED PERFECTLY SMOOTH CUT IN ABRADABLE

FIG. 7

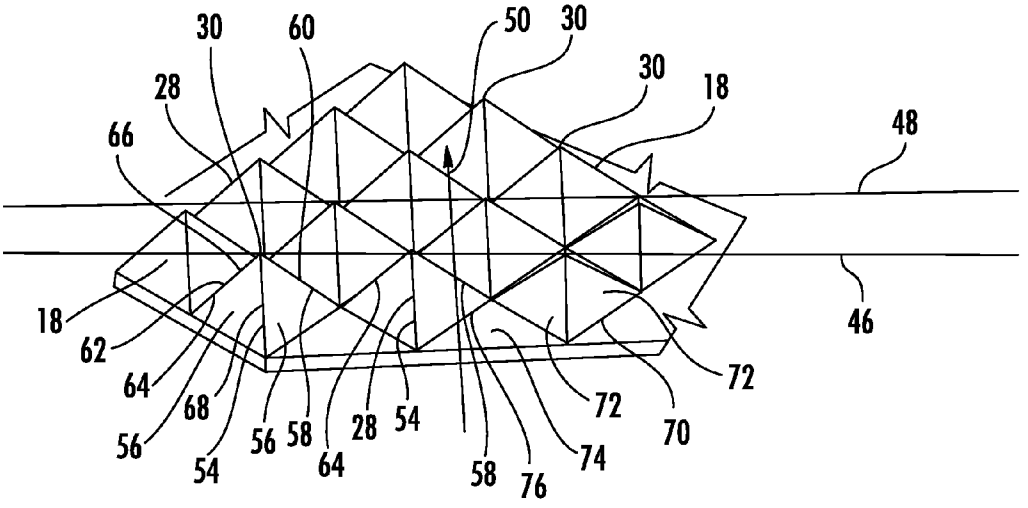

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FIG. 8

TURBINE BLADE WITH AIRFOIL TIP HAVING CUTTING TIPS

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0001] 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

[0002] This invention is directed generally to turbine blades, and more particularly to tip configurations of turbine blades in gas turbine engines.

BACKGROUND

[0003] 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.

[0004] 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

[0005] 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.

[0006] 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.

[0007] 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 abradable coating cutting tips. A first cutting arris may be positioned on an upstream side of the abradable coating cutting tip. A second cutting arris may extend from the squealer tip to the outermost tip of the abradable coating cutting tip at a first intersection between the upstream side and a downstream side of the abradable coating cutting tip. A third cutting arris may extend from the squealer tip to the outermost tip of the abradable coating cutting tip at a second intersection between the upstream side and the downstream side of the abradable coating cutting tip. The second intersection may be on an opposite side of the tip from the first side.

[0008] In at least one embodiment, one or more of the plurality of abradable coating cutting tips may have a pyramid shape. In another embodiment, each of the plurality of abradable coating cutting tips may have a pyramid shape. At least one of the plurality of abradable 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 abradable 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 abradable 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 abradable 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 abradable coating cutting tips may be formed from a knurled surface on the radially outer end of the squealer tip.

[0009] In another embodiment, at least one of the plurality of abradable 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 abradable coating cutting tips may be formed from at least four planar surfaces. Adjacent abradable coating cutting tips may be separated at an outer surface of the squealer tip by a linear line. The plurality of abradable 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.

[0010] 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.

[0011] 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.

[0012] 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.

[0013] These and other embodiments are described in more detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] 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.

[0015] FIG. **1** is a perspective view of a turbine blade having features according to the instant invention.

[0016] FIG. **2** is a detailed cross-sectional view of a tubine blade tip adjacent to a radialy outward positioned ring segment, whereby the scale of the abradable coating cutting tips are enlarged so that they can been seen.

[0017] FIG. **3** is detailed top view of a portion of the tip of the turbine blade with abradable coating cutting tips.

[0018] FIG. **4** is a detailed side view of the portion of the tip of the turbine blade with abradable coating cutting tips shown in FIG. **3**.

[0019] FIG. **5** is detailed top view of a portion of another embodiment of the tip of the turbine blade with abradable coating cutting tips.

[0020] FIG. **6** is a detailed side view of the portion of the tip of the turbine blade with abradable coating cutting tips shown in FIG. **5**.

[0021] FIG. **7** is photograph of the results of 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.

[0022] FIG. **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

[0023] As shown in FIGS. **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 FIG. **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.

[0024] 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**.

[0025] 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**.

[0026] 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 FIGS. **1-6** and **8**. In at least one embodiment, as shown in FIGS. **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**.

[0027] In at least one embodiment, as shown in FIGS. **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**.

[0028] 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.

[0029] 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**.

[0030] 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**,

[0031] 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.

[0032] 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.

I claim:

1. A turbine blade, comprising:

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; and

a squealer tip coupled to the tip at the first end, wherein the squealer tip includes 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.

2. The turbine blade of claim **1**, wherein the plurality of abradable coating cutting tips is 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, and wherein a second row of abradable coating cutting tips is positioned downstream from a first row of abradable coating cutting tips and is offset orthogally to the flow of combustion exhaust gases relative to the first row of abradable coating cutting tips.

3. The turbine blade of claim **1**, wherein at least one of the abradable coating cutting tips has at least one cutting arris extending from the squealer tip to an outermost tip of the at least one of the abradable coating cutting tips.

4. The turbine blade of claim **3**, wherein at least one of the abradable coating cutting tips has at least three cutting arrises extending from the squealer tip to an outermost tip of the at least one of the abradable coating cutting tips, wherein a first cutting arris is positioned on an upstream side of the at least one of the abradable coating cutting tips, a second cutting arris extending from the squealer tip to the outermost tip of the at least one of the abradable coating cutting tips at a first intersection between the upstream side and a downstream side of the at least one of the abradable coating cutting tips, and a third cutting arris extending from the squealer tip to the outermost tip of the at least one of the abradable coating cutting tips at a second intersection between the upstream side and the downstream side of the at least one of the abradable coating cutting tips, wherein the second intersection is on an opposite side of the tip from a first side.

5. The turbine blade of claim **1**, wherein at least one of the plurality of abradable coating cutting tips has a pyramid shape.

6. The turbine blade of claim **1**, wherein at least one of the plurality of abradable coating cutting tips extends from the squealer tip a distance of at least 125 microns.

7. The turbine blade of claim **1**, wherein at least one of the plurality of abradable coating cutting tips extends from the squealer tip a distance of at least 250 microns.

8. The turbine blade of claim **1**, wherein at least one of the plurality of abradable coating cutting tips extends from the squealer tip a distance of up to 1000 microns.

9. The turbine blade of claim **1**, wherein of the plurality of abradable coating cutting tips forms a knurled surface on the radially outer end of the squealer tip.

10. The turbine blade of claim **1**, wherein at least one of the plurality of abradable coating cutting tips is formed from a plurality of planar surfaces, wherein adjacent planar surfaces intersect to form a cutting arris.

11. The turbine blade of claim **10**, wherein the at least one of the plurality of abradable coating cutting tips is formed from at least four planar surfaces.

12. The turbine blade of claim **10**, wherein adjacent abradable coating cutting tips are separated at an outer surface of the squealer tip by a linear line.

13. The turbine blade of claim **10**, wherein the plurality of abradable coating cutting tips are 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, wherein the second orientation is orthogonal to the first orientation.

14. The turbine blade of claim **13**, wherein the first orientation and the second orientation are nonparallel and nonorthogonal relative to a direction of flow of combustion exhaust gases.

15. A turbine blade, comprising:

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;

a squealer tip coupled to the tip at the first end, wherein the squealer tip includes 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;

wherein the plurality of abradable coating cutting tips is 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, and wherein a second row of abradable coating cutting tips is positioned downstream from a first row of abradable coating cutting tips and is offset orthogally to the flow of combustion exhaust gases relative to the first row of abradable coating cutting tips; and

wherein at least one of the abradable coating cutting tips has at least one cutting arris extending from the squealer tip to an outermost tip of the at least one of the abradable coating cutting tips.

16. The turbine blade of claim **15**, wherein at least one of the abradable coating cutting tips has at least three cutting arrises extending from the squealer tip to an outermost tip of the at least one of the abradable coating cutting tips, wherein a first cutting arris is positioned on an upstream side of the at least one of the abradable coating cutting tips, a second cutting arris extending from the squealer tip to the outermost tip of the at least one of the abradable coating cutting tips at a first intersection between the upstream side and a downstream side of the at least one of the abradable coating cutting tips, and a third cutting arris extending from the squealer tip to the outermost tip of the at least one of the abradable coating cutting tips at a second intersection between the upstream side and the downstream side of the at least one of the abradable coating cutting tips, wherein the second intersection is on an opposite side of the tip from the first side.

17. The turbine blade of claim **15**, wherein at least one of the plurality of abradable coating cutting tips has a pyramid shape.

18. The turbine blade of claim **15**, wherein at least one of the plurality of abradable coating cutting tips extends from the squealer tip a distance of at least 125 microns and less than **1,025** microns.

19. The turbine blade of claim **1**, wherein of the plurality of abradable coating cutting tips forms a knurled surface on the radially outer end of the squealer tip, wherein at least one of the plurality of abradable coating cutting tips is formed from a plurality of planar surfaces, wherein adjacent planar surfaces intersect to form a cutting arris.

20. The turbine blade of claim **19**, wherein the plurality of abradable coating cutting tips are 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, wherein the second orientation is orthogonal to the first orientation, and wherein the first orientation and the second orientation are nonparallel and nonorthogonal relative to a direction of flow of combustion exhaust gases.

* * * * *