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Danowski et al.

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(54) **APPARATUS AND METHODS FOR COOLING SLOT STEP ELIMINATION**

(58) **Field of Classification Search** None
See application file for complete search history.

(75) Inventors: **Michael J. Danowski**, Cincinnati, OH (US); **Gulcharan S. Brainch**, West Chester, OH (US); **Jonathan Phillip Clarke**, West Chester, OH (US)

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(73) Assignee: **General Electric Company**, Cincinnati, OH (US)

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Primary Examiner—Ninh H. Nguyen

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(74) *Attorney, Agent, or Firm*—William Scott Andes; Armstrong Teasdale LLP

Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **6,062,817**
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Appl. No.: **09/186,676**
Filed: **Nov. 6, 1998**

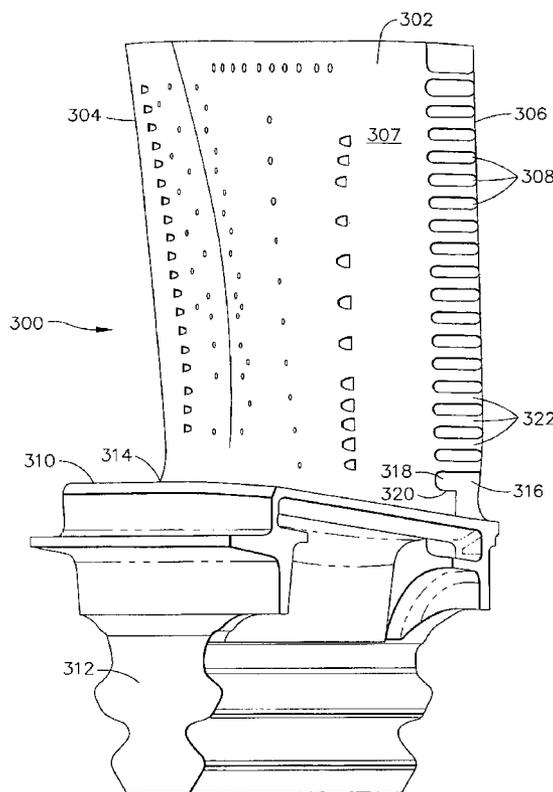
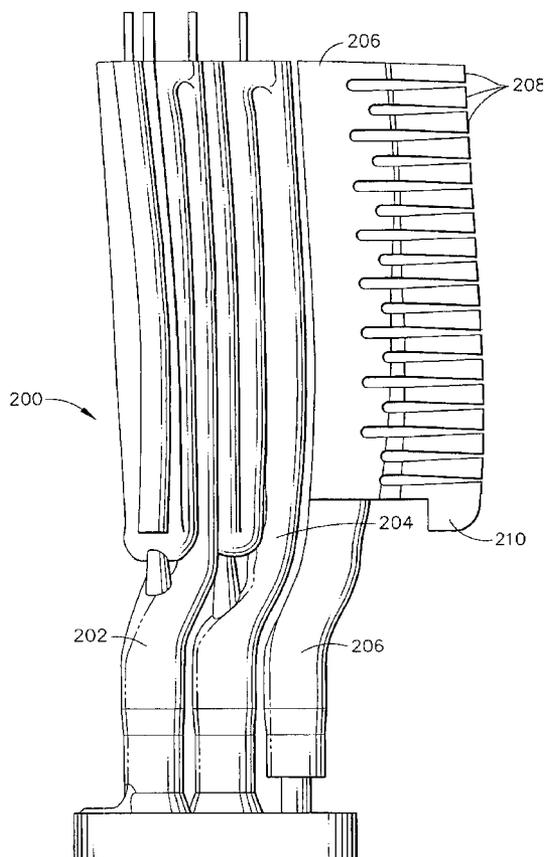
(57) **ABSTRACT**

An airfoil core die includes a tab for forming a continuous and smooth contour and extension of a first trailing edge slot recessed all to a bottom of the airfoil. The contour is formed on each airfoil core at injection and is maintained through to finish casting of the airfoil.

(51) **Int. Cl.**
F01D 5/18 (2006.01)

(52) **U.S. Cl.** **416/97 R; 416/229 A; 416/241 R**

13 Claims, 5 Drawing Sheets



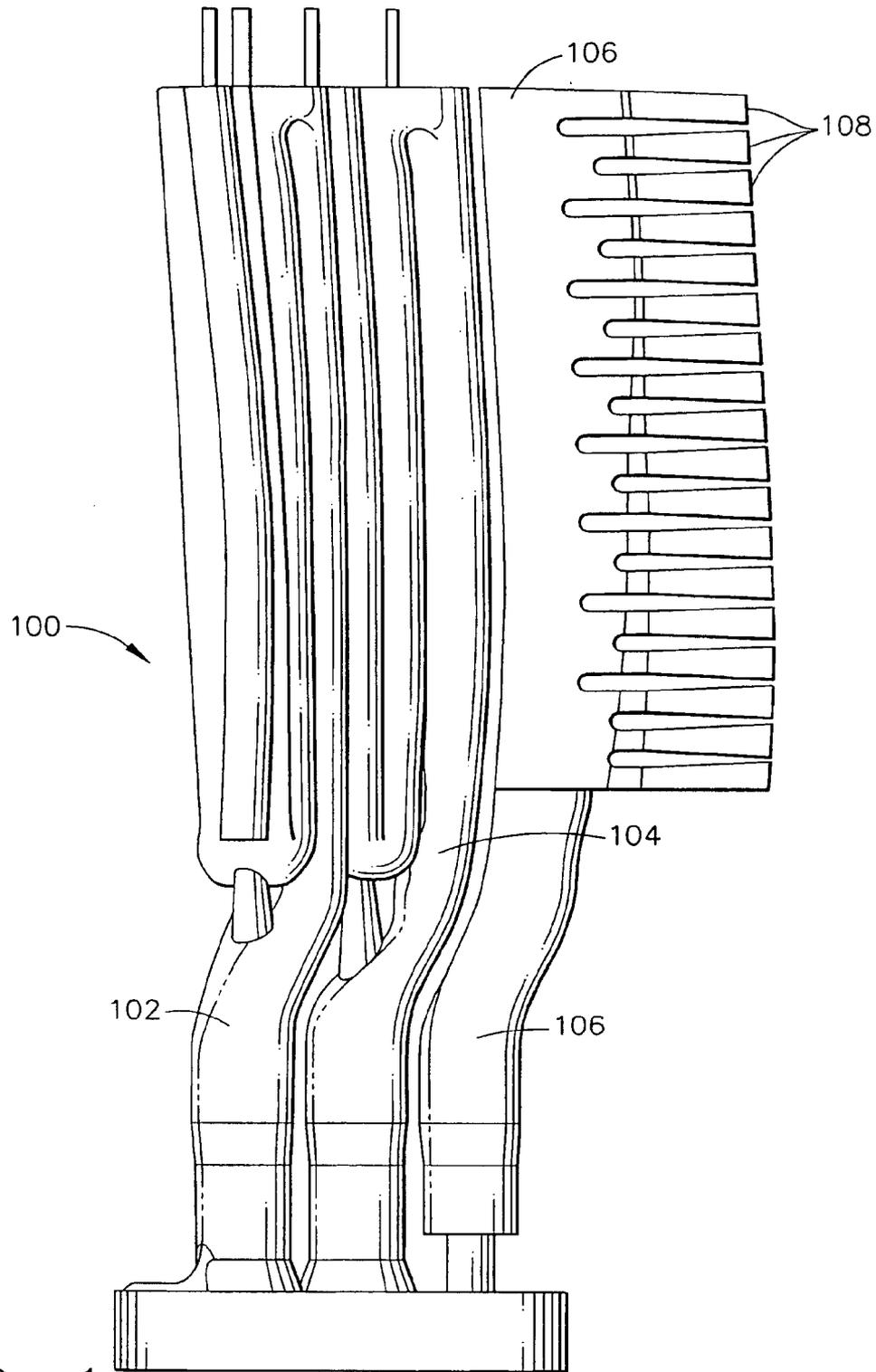


FIG. 1
(PRIOR ART)

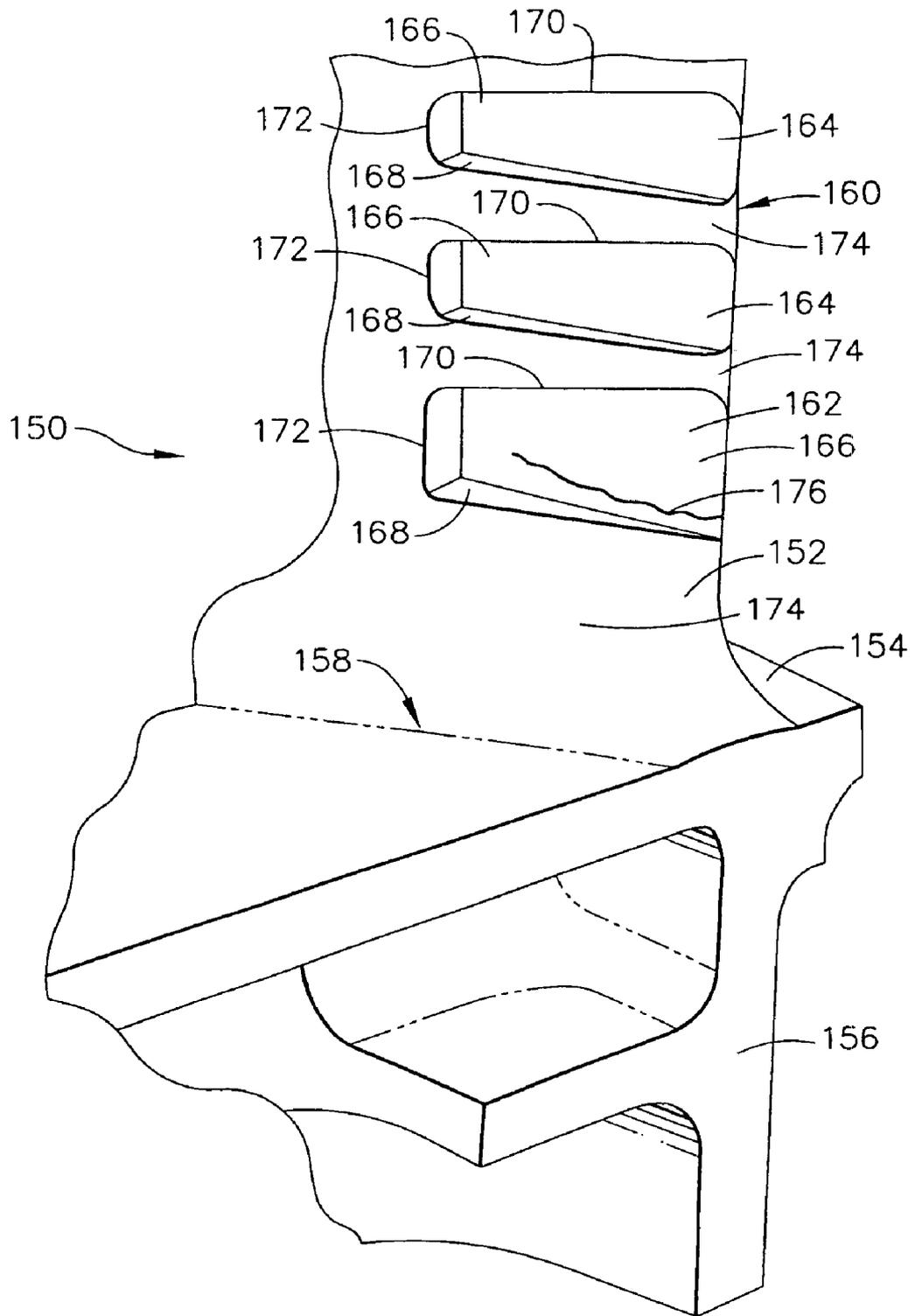


FIG. 2
(PRIOR ART)

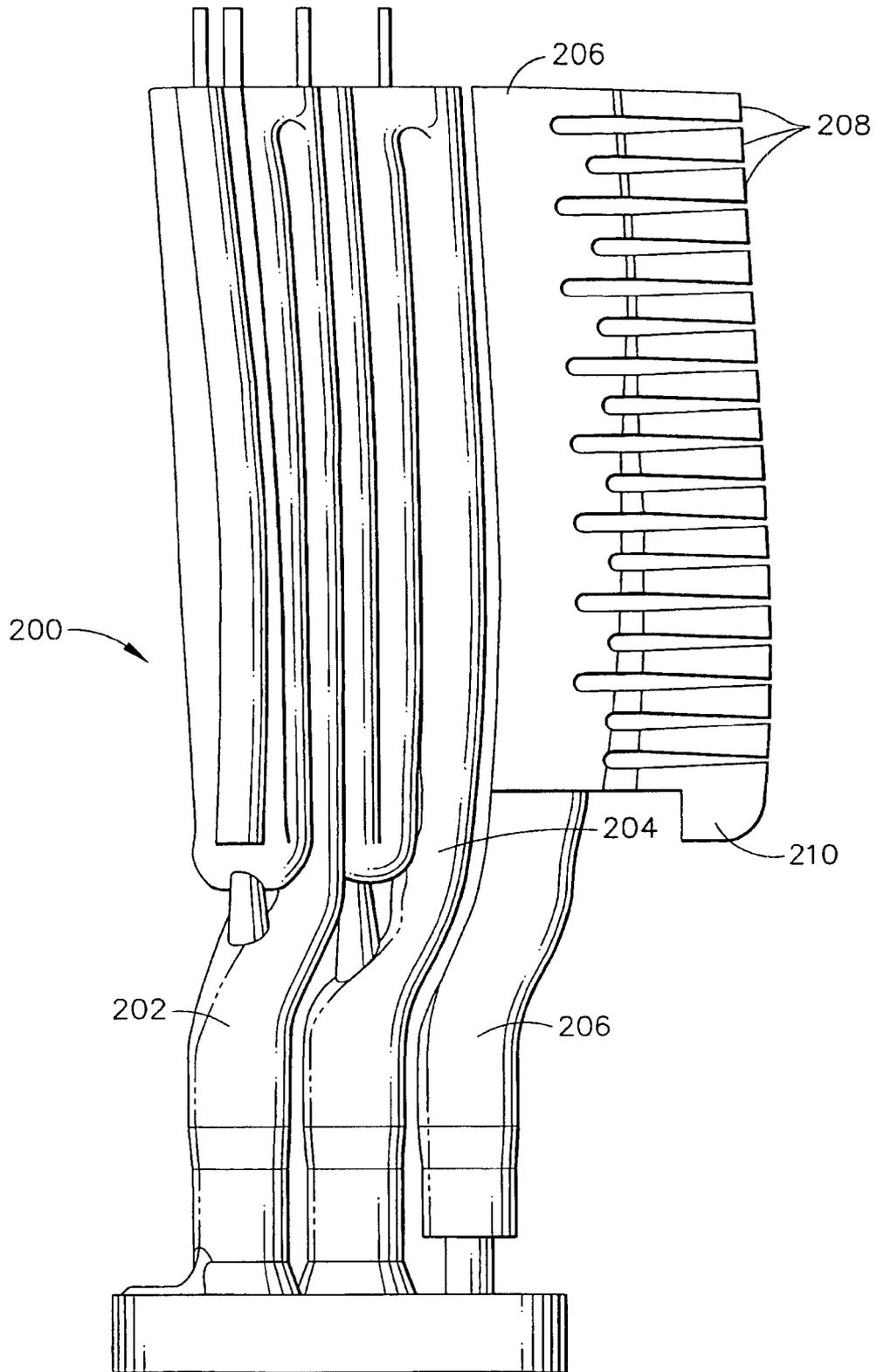


FIG. 3

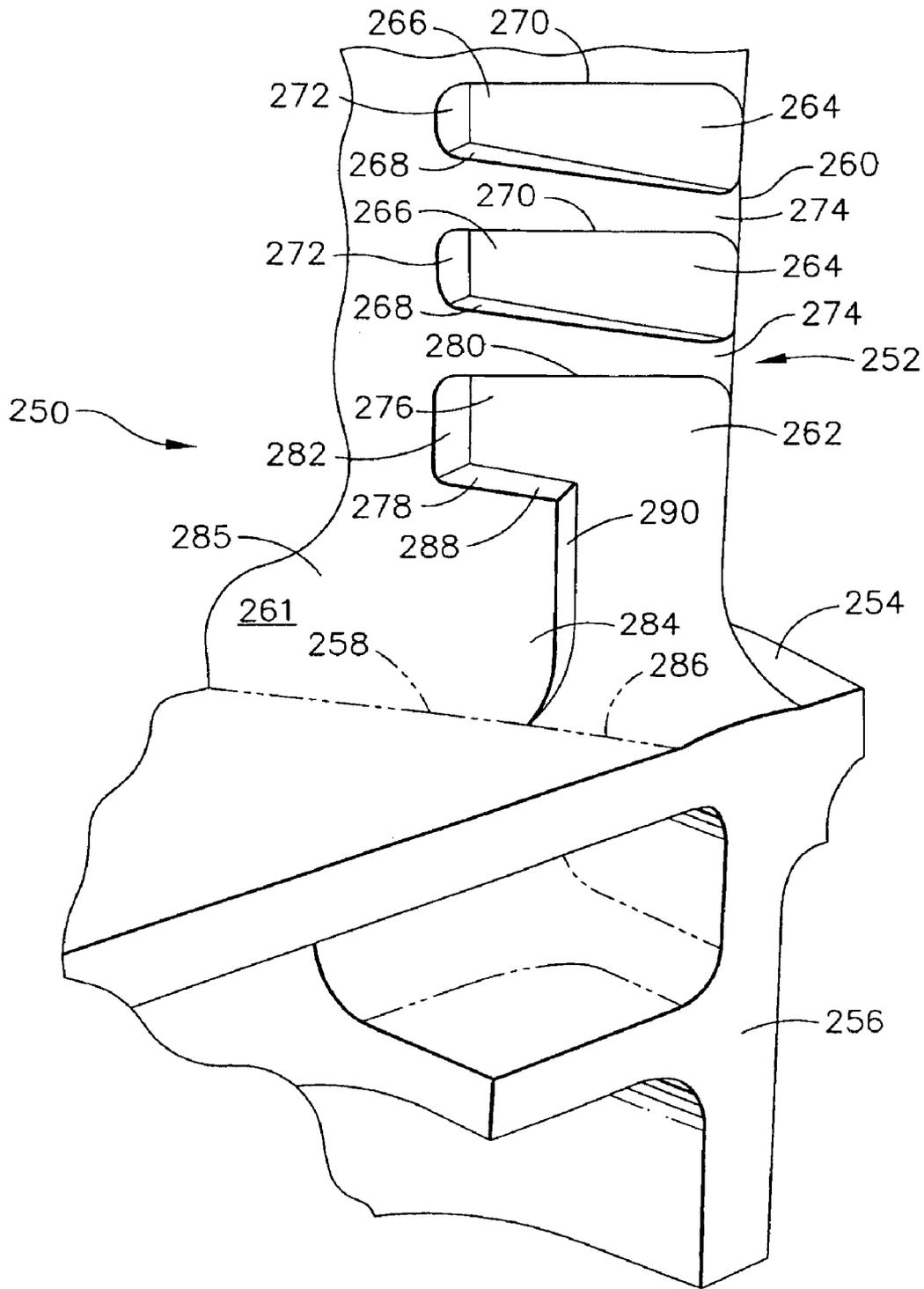


FIG. 4

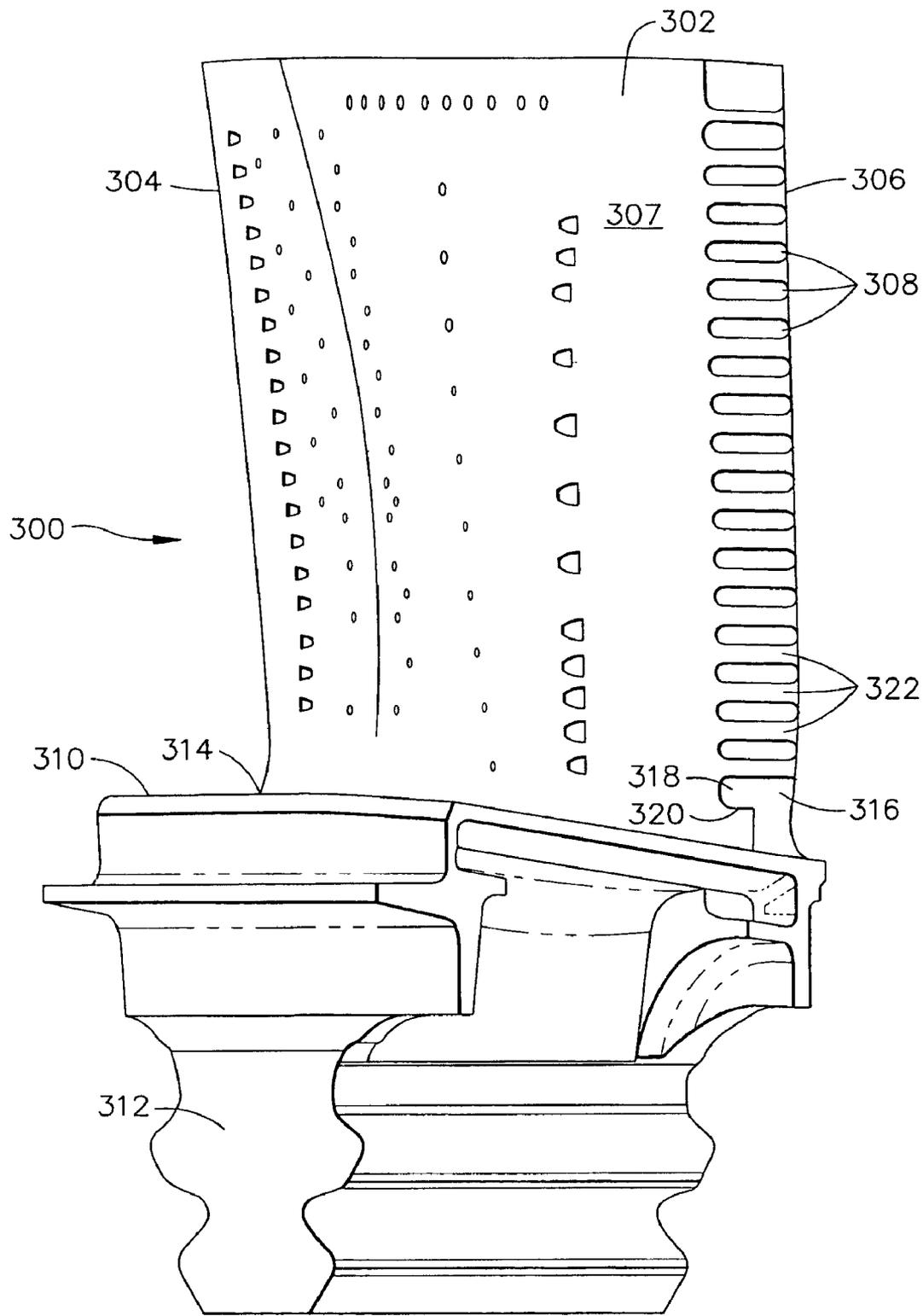


FIG. 5

APPARATUS AND METHODS FOR COOLING SLOT STEP ELIMINATION

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

BACKGROUND OF THE INVENTION

This invention relates generally to turbine engines and, more particularly, to apparatus and methods for reducing stress on turbine blades.

Turbine blades include an airfoil, a platform, and a shank. The airfoil has a leading edge and a trailing edge, with the trailing edge being relatively thin in comparison to the leading edge. Typically turbine blades are subjected to high temperature gases by a combustor located upstream from the turbine blades. The airfoil trailing edge region is exposed to such high temperature gases and is prone to failure due to difficulties associated with providing adequate cooling to the region.

To facilitate preventing airfoil failure, a plurality of slots are located in the airfoil trailing edge and cool air is discharged from the slots to cool the trailing edge. These slots sometimes are referred to herein as trailing edge slots.

Turbine engine airfoils are cast with land areas, or ribs, located between the trailing edge slots. The slots are formed by a recessed wall and two steps extend between the recessed wall and an outer surface of the airfoil. The step in the slot located closest to the platform may cause a large stress concentration with high terminal stresses present. The high thermal stresses may result in trailing edge axial cracks which can propagate through the airfoil. Premature failure of the turbine blade may result from the axial cracks. However, the trailing edge slot located closest to the airfoil platform cannot be eliminated because removal would result in trailing edge overheating.

Accordingly, it would be desirable to reduce stress on turbine engine blades in the area where the airfoil trailing edge joins the platform. Additionally, it would be desirable to improve the longevity of turbine blades.

BRIEF SUMMARY OF THE INVENTION

These and other objects may be attained by a turbine blade wherein at least a portion of a step between an airfoil trailing edge slot and a platform is eliminated. The airfoil is connected to the platform at a base of the airfoil by a fillet. An airfoil core die is utilized to cast the turbine blade airfoil which includes a top, a bottom, a leading edge, and a trailing edge.

The airfoil further includes a plurality of trailing edge slots for cooling the trailing edge. The trailing edge slots include a first step and a second step separated by a recessed wall. A first trailing edge slot is the trailing edge slot closest to the juncture of the airfoil and the platform.

More specifically, the die includes a tab positioned such that a continuous and smooth contour is formed from the first trailing edge slot recessed wall to a juncture of the airfoil and the platform at the fillet. Once the tab is cast onto the airfoil core die, the first step, which is typically located near the juncture of the airfoil and an airfoil platform, is partially eliminated. The elimination of at least a portion of the step reduces stress concentration, potential early fatigue and blade failure. The step is sometimes referred to herein as a ledge.

Utilizing the above described tab with the airfoil core die improves the longevity and performance of the turbine blade by reducing the fatigue of the airfoil at the first trailing edge slot. The tab provides a consistently smooth and continuous contour from the airfoil first trailing edge slot to the juncture of the airfoil and the airfoil platform.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of a known airfoil core die;

FIG. 2 is a schematic view of a partial airfoil cast from the die shown in FIG. 1;

FIG. 3 is a schematic view of an airfoil core die according to one embodiment of the present invention;

FIG. 4 is a schematic view of a partial airfoil cast from the die shown in FIG. 3; and

FIG. 5 is a schematic view of a turbine blade incorporating an airfoil cast from the die shown in FIG. 3.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 illustrates a known airfoil core die **100** utilized for fabricating turbine blades (not shown). Airfoil core **100** includes a first serpentine cooling channel **102**, a second serpentine cooling channel **104**, an aft wedge channel **106**, and a plurality of fingers **108** extending from aft wedge channel **106**.

Airfoil core **100** is fabricated by injecting a liquid ceramic and graphite slurry into core die (not shown). The slurry is heated to form a solid ceramic airfoil core **100**. The airfoil core is suspended in an airfoil die (not shown) and hot wax is injected into the airfoil die to surround the ceramic airfoil core. The hot wax solidifies and forms an airfoil (not shown in FIG. 1) with the ceramic core suspended in the airfoil.

The wax airfoil with the ceramic core is then coated with multiple layers of ceramic and heated to remove the wax, thus forming a cavity shell having the shape of the airfoil. The shell is cured in a heated furnace. Molten metal is then poured into the shell and thus forming a metal airfoil with the ceramic core remaining in place. The airfoil is then cooled, and the ceramic core removed.

First serpentine cooling channel **102** and second serpentine cooling channel **104** form a first serpentine cooling passage (not shown), and a second serpentine cooling passage (not shown), respectively, in the resulting airfoil. Aft wedge channel **106** forms an aft cavity and passage (not shown), and fingers **108** extending from aft wedge channel **106**, form a plurality of trailing edge slots (not shown in FIG. 1) in the resulting airfoil.

FIG. 2 illustrates a portion of a known turbine blade **150** formed using airfoil core **100** shown in FIG. 1. Turbine blade **150** includes an airfoil **152** attached to a platform **154**. Platform **154** forms a top portion of a shank **156** and airfoil **152** is secured to platform **154** by a fillet **158**. Airfoil **152** has a leading edge (not shown in FIG. 2) and a trailing edge **160**. Trailing edge **160** is relatively thin in comparison to the leading edge and is more susceptible to damage from stresses and strains than other areas of airfoil **152** due to the thinness of trailing edge **160**.

Due, at least in part, to the thickness of trailing edge **160**, a first trailing edge slot **162** and a plurality of other trailing edge slots **164** are formed in airfoil **152** to emit cooling air over trailing edge **160**. The cooling air reduces the temperatures, thermal stresses and strains experienced by trailing edge **160**. First trailing edge slot **162** is positioned closest to platform **154** in comparison to other slots **164**.

Slots **162** and **164** include a recessed wall **166**, a first step **168**, a second step **170**, and a side wall **172** having an opening (not shown) extending therethrough. A plurality of land areas, or ribs **174**, separate slots **162** and extend substantially a length of slots **162**. First step **168** and second step **170** extend between recessed wall **166** and land areas **174**.

First step **168** of slot **162** extends between recessed wall **166** and land area **174** that is between first trailing edge slot **162** and platform **154**. Slot **162** may develop one or more trailing edge axial cracks **176** (only one is shown in FIG. 2) due to a large concentration of stresses at slot **162** caused by step **168**. Cracks **176** can propagate in airfoil **152** and may lead to a shortened life of turbine blade **150**.

FIG. 3 illustrates an airfoil core **200** according to one embodiment of the present invention for a turbine blade (not shown). Airfoil core **200** includes a first serpentine cooling channel **202**, a second serpentine cooling channel **204**, an aft wedge channel **206**, a plurality of fingers **208** which extend from the aft wedge **206**, and a tab **210**. In one embodiment, tab **210** is located at a bottommost finger **208** and extends below fingers **208** and substantially perpendicular to fingers **208**.

Airfoil core **200** is fabricated by injecting a liquid ceramic and graphite slurry into core die (not shown). The slurry is heated to form a solid ceramic airfoil core. First serpentine cooling channel **202** and second serpentine cooling channel **204** form a first serpentine cooling passage (not shown) and a second serpentine cooling passage (not shown), respectively, in a resulting airfoil (not shown in FIG. 3).

Aft wedge channel **206** forms an aft cavity and passage (not shown), and fingers **208**, which extend from [the] aft wedge channel **206**, form trailing edge slots (not shown in FIG. 3) in the resulting airfoil. Tab **210** eliminates at least a portion of a first trailing edge slot step (not shown in FIG. 3) and forms a tapered contour in the resulting airfoil from the first trailing edge slot to a platform (not shown) of the turbine blade.

Tab **210** is formed during core injection and is maintained through to finish casting of the resulting airfoil. In one embodiment, the portion of the first trailing edge slot step that is eliminated is that portion typically extending to the trailing edge.

FIG. 4 illustrates a turbine blade **250** formed using airfoil core **200** shown in FIG. 3. Turbine blade **250** includes an airfoil **252** attached to a platform **254**. Platform **254** forms a top portion of a shank **256**, and airfoil **252** is secured to platform **254** by a fillet **258**. Airfoil **252** has a leading edge (not shown in FIG. 4), a trailing edge **260**, a first side wall **261** connecting the leading edge and trailing edge **260** and a second side wall (not shown). Trailing edge **260** is positioned between first side wall **261** and the second side wall.

Airfoil **252** also includes a first trailing edge slot **262** and a plurality of other trailing edge slots **264** that emit cooling air and reduce damage caused by thermal stresses and strains on trailing edge **260**. First trailing edge slot **262** is the closest trailing edge slot to the juncture of airfoil **252** and platform **254**.

Slots **264** include a recessed wall **266**, a first step **268**, a second step **270**, and a side wall **272** having an opening (not shown) extending therethrough. A plurality of land areas, or ribs, **274** separate slots **264** and extend substantially a length of slots **264**. First step **268** and second step **270** extend between recessed wall **266** and land areas **274**.

First slot **262** includes a recessed wall **276**, a first step, or ledge, **278**, a second step, or ledge, **280**, and a side wall **282**

having an opening (not shown) extending therethrough. First step **278** of slot **262** extends between recessed wall **276** and a first land area **284** positioned between first trailing edge slot **262** and platforms **254**. Land area **284** is on an outer surface **285** of first side wall **261**.

In one embodiment, recessed wall **276** extends from second step **280** to fillet **258** at a bottom **286** of airfoil **252**. Recessed wall **276** extends from side wall **282** and the opening extending therethrough to trailing edge **260**. Second step **280** extends from side wall **282** and the opening therethrough to trailing edge **260**.

First step **278** includes a first portion **288** and a second portion **290**. First portion **288** extends from the opening towards trailing edge **260** and is separated from trailing edge **260** by recessed wall **276**. Since recessed wall **276** separates first step **278** from trailing edge **260**, first step **278** is separated from trailing edge **260** by a distance greater than or equal to a length of at least a portion of recessed wall **276**. Second portion **290** extends from first portion **288** to bottom **286** and fillet **258**.

By extending recessed wall **276** of first trailing edge slot **262** to fillet **258**, a consistent and smooth blend is provided from first trailing edge slot **262** to platform **254**. The smooth blend maintains trailing edge slot cooling characteristics of airfoil **252**. In addition, the contour of first trailing edge slot **262** reduces stress concentration and early fatigue of airfoil **252**.

FIG. 5 illustrates a turbine blade **300** including an airfoil **302** having a leading edge **304**, a trailing edge **306**, and a first wall **307** connecting the leading edge **304** and the trailing edge **306**. Trailing edge **306** includes a plurality of trailing edge slots **308** that emit cooling air to reduce thermal stresses and strains experienced by turbine blade **300**.

Turbine blade **300** further includes a platform **310** which forms a top portion of a shank **312** that connects turbine blade **300** to a turbine engine rotor (not shown). Airfoil **302** is connected to platform **310** by a fillet **314**. A first trailing edge slot **316** includes a recessed wall **318** which extends from a first step **320** to fillet **314**. A plurality of land areas **322** separate trailing edge slots **308** from each other.

Thermal stresses and strains which traditionally damage the first trailing edge slot are reduced due to the extension of the recessed wall to the fillet. Cooling air emitted from the first trailing edge slot forms a cooling film that extends from the first step to the fillet along the trailing edge.

From the preceding description of various embodiments of the present invention, it is evident that the objects of the invention are attained. Although the invention has been described and illustrated in detail, it is to be clearly understood that the same is intended by way of illustration and example only and is not to be taken by way of limitation. Accordingly, the spirit and scope of the invention are to be limited only by the terms of the appended claims.

We claim:

1. A turbine blade for a turbine engine, said turbine blade comprising:

an airfoil comprising a first side wall comprising an outer surface, a second side wall, a leading edge, and a trailing edge, said first side wall outer surface extending between said leading edge and said trailing edge, and trailing edge positioned between said first side wall and said second wall, said first side wall further comprising at least one slot defined by a recessed wall and a slot side wall, said slot side wall comprising an opening extending therethrough, said recessed wall extending between said opening and said trailing edge;

5

a platform connected to said airfoil; and
 a fillet connected to said airfoil and said platform, at least
 a portion of said recessed wall extending to said fillet,
 said recessed wall **[tapered]** *is formed integrally with*
said airfoil during a casting process such that said
recessed wall tapers from said opening to said fillet.
 2. An airfoil in accordance with claim 1 further compris-
 ing a first ledge extending between said outer surface and
 said recessed wall, said first ledge separated from said
 trailing edge by a distance.
 3. An airfoil in accordance with claim 2 wherein at least
 a portion of said recessed wall is positioned between said
 first ledge and said trailing edge.
 4. An airfoil in accordance with claim 2 further compris-
 ing a second ledge extending between said outer surface and
 said recessed wall.
 5. An airfoil in accordance with claim 4 wherein said
 second ledge extends between said opening and said trailing
 edge.
 6. A method for fabricating an airfoil of a turbine blade,
 said method comprising the steps of:
 inserting a mold within a die; and
 injecting a slurry into the die to form an airfoil that
 includes a first side including an outer surface, a second
 side, a leading edge, and a trailing edge, the first side
 outer surface extending between the leading edge and the
 trailing edge, the trailing edge positioned between
 the first side and the second side, the first side further
 including at least one slot defined by a recessed wall
 and a slot side wall, the slot side wall including an
 opening extending therethrough, the recessed wall
 extending between the opening and the trailing edge
 and tapered from the opening to the first side outer
 surface.

6

7. A method in accordance with claim 6 further compris-
 ing the step of attaching the airfoil to a platform.
 8. A method in accordance with claim 7 wherein said step
 of attaching the airfoil to a platform further comprises the
 step of extending a fillet from the leading edge to the trailing
 edge to secure the airfoil to the platform.
 9. A method in accordance with claim 8 wherein the
 airfoil is formed such that the first side slot is further defined
 by a second side wall, the second side wall extending from
 the opening to the trailing edge.
 10. A method in accordance with claim 9 wherein the
 airfoil is formed such that the recessed wall is tapered from
 the opening to the fillet.
 11. An airfoil core for a turbine blade, said core compris-
 ing:
 at least one serpentine channel;
 a wedge channel connected to said serpentine channel;
 a plurality of fingers extending from said wedge channel;
 and
 a tab extending from one of said fingers.
 12. An airfoil core in accordance with claim **[1]** //
 wherein said plurality of fingers includes a first finger, said
 tab located at said first finger and extending substantially
 perpendicular to said first finger.
 13. An airfoil core in accordance with claim **[1]** //
 wherein said at least one serpentine channel includes a first
 serpentine channel and a second serpentine channel.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : RE 39,398 E
APPLICATION NO. : 10/858553
DATED : November 14, 2006
INVENTOR(S) : Danowski et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

- In Claim 1, column 4, line 61, delete “and trailing” and insert therefor -- said trailing --.
- In Claim 1, column 4, line 62, between “second” and “wall” insert -- side --.
- In Claim 6, column 5, line 30, delete “slot tide wall” and insert therefor -- slot side wall --.
- In Claim 6, column 5, line 33, delete “tapered form the” and insert therefor -- tapered from the --.
- In Claim 8, column 6, line 5, delete “fillet form the” and insert therefor -- fillet from the --.
- In Claim 11, column 6, line 18, delete “extending form said” and insert therefor -- extending from said --.

Signed and Sealed this

Twenty-sixth Day of February, 2008



JON W. DUDAS
Director of the United States Patent and Trademark Office