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AL BA HR MK RS(30) Priority: **14.11.2006 US 600416**(71) Applicant: **United Technologies Corporation
Hartford, Connecticut 06101 (US)**

(72) Inventors:

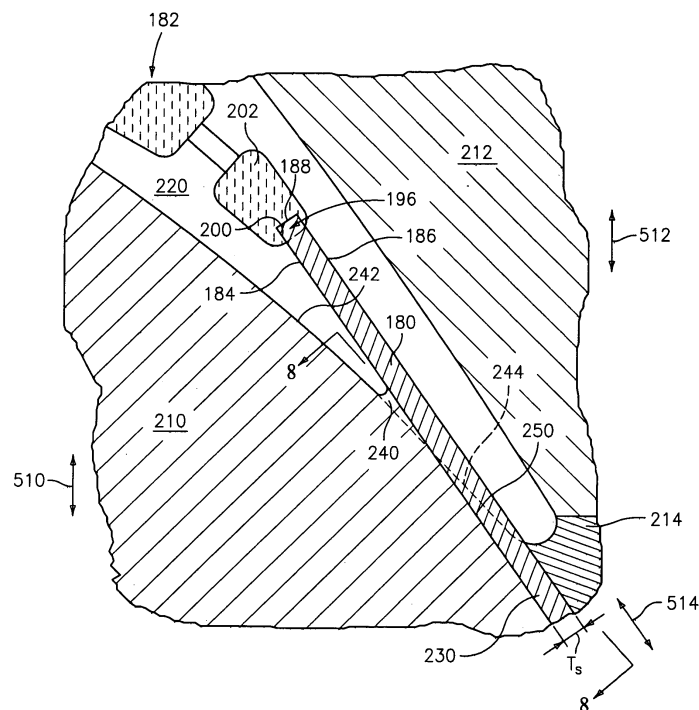
- **Reilly, P. Brennan
Boston, MA 02116 (US)**
- **Kennard, Lea D.
Manchester
Connecticut 06042 (US)**

(74) Representative: **Leckey, David Herbert
Frank B. Dehn & Co.
St Bride's House
10 Salisbury Square
London EC4Y 8JD (GB)**

(54) **Airfoil casting methods**

(57) In the castings of a turbine element, a sheet casting core (180) is assembled to a feedcore (182). The sheet casting core (180) and feedcore (182) are placed in a die (210,212,214). A sacrificial pattern material is molded over the sheet casting core (180) and feedcore (182) to form a pattern including an airfoil. The sheet

casting core (180) extends from at or adjacent a trailing edge of the airfoil. The sheet casting core (180) has a first array of open areas and a second array of portions interspersed with the open areas. A first portion of the die (210) has a third array of projections contacting the second array.

**FIG. 7**

Description

BACKGROUND OF THE INVENTION

[0001] This invention relates to gas turbine engines, and more particularly to cooled turbine elements (e.g., blades and vanes).

[0002] In the exemplary cooling of turbine elements, air from the engine's compressor bypasses the combustor and cools the elements, allowing them to be exposed to temperatures well in excess of the melting point of the element's alloy substrate. Trailing edge cooling of the element's airfoil is particularly significant.

[0003] In one common method of turbine element manufacture, the main passageways of a cooling network within the element airfoil are formed utilizing a sacrificial core (e.g., a molded ceramic core) during the element casting process. The airfoil surface may be provided with holes communicating with the network. Some or all of these holes may be drilled. These holes may include film holes on pressure and suction side surfaces and holes along or near the trailing edge. US patent 4601638 discloses the casting of trailing edge cooling passageways by a portion of the ceramic core. US patent 7014424 discloses the casting of trailing edge cooling passageways by a refractory metal core assembled to a ceramic feed-core.

SUMMARY OF THE INVENTION

[0004] Accordingly, one aspect of the invention involves a method for casting a turbine element. A sheet casting core is assembled to a feedcore. The sheet casting core and feedcore are placed in a die. A sacrificial pattern material is molded over the casting core and feedcore to form a pattern including an airfoil. The sheet casting core extends from at or adjacent a trailing edge of the airfoil. The sheet casting core has a first array of open areas and a second array of portions interspersed with the open areas. A first portion of the die has a third array of projections contacting the second array.

[0005] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006]

FIG. 1 is a view of a turbine blade.

FIG. 2 is a streamwise sectional view of an airfoil of the blade of FIG. 1, taken along line 2-2.

FIG. 3 is an enlarged view of a trailing portion of the airfoil of FIG. 2.

FIG. 4 is a spanwise sectional view of the airfoil of FIG. 3.

FIG. 5 is a partial view of pressure side cooling outlets of the airfoil of FIG. 3.

FIG. 6 is a partial view of a core assembly.

FIG. 7 is a streamwise sectional view of a pattern die before wax injection.

FIG. 8 is a partial view of a pressure side die part of the pattern die.

[0007] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0008] FIG. 1 shows a turbine blade 20 having an airfoil 22 extending along a length from a proximal inboard end/root 24 at an inboard platform 26 to a distal end 28 defining a blade tip. A convoluted "fir tree" attachment root 29 depends from the underside of the platform 26 for mounting the blade to a complementary slot in a disk (not shown). A number of such blades may be assembled to the disk side by side with their respective platforms forming an inboard ring bounding an inboard portion of a flow path. In an exemplary embodiment, the blade is unitarily formed of a metal alloy.

[0009] The airfoil extends from a leading edge 30 to a trailing edge 32. The leading and trailing edges separate pressure and suction sides or surfaces 34 and 36 (FIG. 2). For cooling the airfoil, the airfoil is provided with a cooling passageway network 40 (FIG. 1) coupled to ports 42 in the root 29. The exemplary passageway network includes a series of cavities extending generally lengthwise along the airfoil. An aftmost cavity is identified as a trailing edge cavity 44 extending generally parallel to the trailing edge 32. A penultimate cavity 46 is located ahead of the trailing edge cavity 32. In the illustrated embodiment, the cavities 44 and 46 are impingement cavities. The penultimate cavity 46 receives air from a supply cavity 48 through an array of apertures 50 in the wall 52 separating the two. The exemplary supply cavity 48 receives air from one or more of the ports 42. Likewise, the trailing edge cavity 44 receives air from the penultimate cavity 46 via apertures 56 in the wall 58 between the two.

[0010] FIG. 3 shows a trailing edge portion of the airfoil including a trailing edge cooling slot 70 extending from an inlet 72 at the cavity 44 to an outlet 74 at the trailing end of the airfoil pressure side 34. The slot 70 has pressure and suction side wall surfaces 76 and 78 along pressure and suction side walls 80 and 82 of the airfoil. An exemplary slot height H between the surfaces 76 and 78 is an essentially constant 2.5mm, more broadly 2-3mm or 1.2-7.6mm. An exemplary slot streamwise length L_s is 12.7mm, more broadly 10-15mm. An exemplary outlet

length L_o (streamwise and parallel to the slot) is 2.54mm, more broadly 2-3mm.

[0011] FIG. 4 shows further details of the slot 70. The exemplary slot 70 includes a number of posts spanning between the surfaces 76 and 78. The exemplary slot includes a first/upstream/leading array of posts 90, a second array of posts 92, a third array of posts 94, a fourth array of posts 96, a fifth array of posts 98, and a sixth/downstream/trailing array of posts 100. Each of the exemplary arrays 90-100 extends essentially spanwise along the airfoil. The size and cross-sectional shape of the posts, the pitch or spacing within an array, the pitch or spacing between arrays, and the relative phases of the arrays may be selected to achieve desired airflow and heat transfer properties. The exemplary trailing posts 100 are streamwise elongate of near teardrop planform. The posts 100 have width W_p and length L_p .

[0012] Between each of the trailing posts 100 the pressure side wall 80 has a small recess 120 (FIG. 5) forming an upstream portion of the outlet 74. Along the recess 120, the pressure side wall 80 has a trailing portion 122. The exemplary trailing portion 122 is arcuate and downstream concave to merge with the adjacent posts 100.

[0013] In an investment casting manufacturing process, the main passageways of the airfoil may be cast against a sacrificial ceramic feedcore. The slot 70 may be cast against a refractory metal core (RMC) assembled to the feedcore. The core assembly may be molded within sacrificial material (e.g., wax) of an investment casting pattern. A ceramic shell may be formed over the pattern (e.g., in a multi-stage stuccoing process). The sacrificial material may be removed (e.g., in an autoclave), leaving the core assembly within the ceramic shell. In such a process, the pattern may have surface features corresponding with or essentially identical to corresponding external surface features of the turbine element to be cast. These features form inverse surface features of the associated shell and are, themselves, molded against inverse features of an associated die.

[0014] FIG. 6 shows a refractory metal core 180 assembled to a ceramic feedcore 182. FIG. 7 shows the core assembly mounted in a pattern molding die. The exemplary RMC 180 is formed as a sheet of essentially constant thickness T_s between first and second surfaces (faces) 184 and 186 generally along pressure and suction sides. The faces 184 and 186 extend between a leading/upstream end 188 and a trailing/downstream end 190 (FIG. 6). The faces also extend between first (e.g., in-board) and second (e.g., outboard) spanwise ends 192 and 194. A leading portion 196 (FIG. 7) of the RMC is captured within a trailing slot 200 in a trailing leg 202 of the feedcore.

[0015] FIG. 6 further shows the RMC as including arrays of through-holes 204, 206, 208, 210, 212, and 214 complementary to and for casting the posts 90, 92, 94, 96, 98, and 100, respectively. To facilitate flexing of the RMC out of a planar configuration, the exemplary RMC has a series of relief notches 216 each extending to a

single one of several of the holes 214.

[0016] FIG. 7 shows the exemplary die as including a series of die elements 210, 212, and 214. The elements combine to define a cavity 220 for receiving wax to be molded over the core assembly. The die elements 210, 212, and 214 may be assembled over the core assembly by relative translations in associated pull directions 510, 512, and 514. After molding, separation of the die elements may be by a reverse translation. In the exemplary die, the first element 210 falls generally along the pressure side of the airfoil portion of the cavity and pattern. The second element 212 falls generally along the suction side. The third element 214 has a relatively small extent along a cavity 220 just at the trailing edge thereof. In the exemplary die, a portion 230 of the RMC 200 extending beyond the trailing edge is captured between the first and third die elements 210 and 214.

[0017] The pattern preferably includes recesses corresponding to the recesses 120 in the wall 80. To provide these recesses, in the exemplary die the first element 210 includes a spanwise array of projections 240 (see also FIG. 8). FIG. 8 also shows a surface portion 242 of the die element 210 for molding the pressure side surface of the pattern. This surface portion 242 includes a trailing array of portions 244 alternately extending between the projections 240 for molding the exposed pressure side surfaces of the trailing array of pattern posts (corresponding to the airfoil posts 100). FIG. 8 further shows a surface portion 250 for contacting the pressure side surface 184 of the RMC downstream of the surface portion 242 and projections 240.

[0018] The present teachings may be implemented to manufacture a reengineered turbine element as a replacement for an existing element (or element configuration). An exemplary existing element may be manufactured using a molded ceramic core to provide both the feed passageways and the outlet passageways. The present teachings may permit finer features to be formed in the outlet passageway (e.g., a passageway with a smaller height, more and differently shaped posts, and the like). In such an implementation, the projections 240 may provide similar ultimate features in the wax pattern to features molded by projections from the trailing portion of the baseline ceramic core. However, in the present implementation, the recesses formed by these projections would be filled during the shelling process rather than being formed over and remaining filled by the core projections.

[0019] One or more embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the scope of the invention. For example, when implemented as a reengineering of an existing turbine element or using existing equipment, details of the existing element or equipment may influence details of any particular implementation. Accordingly, other embodiments are within the scope of the following claims.

Claims

1. A method comprising:
- assembling a sheet casting core (180) to a feed-core (182);
 placing the sheet casting core (180) and feed-core (182) in a die (210,212,214); and
 molding a sacrificial pattern material over the sheet casting core (180) and feedcore (182) to form an airfoil pattern, the sheet casting core extending from at or adjacent a trailing edge of the airfoil, wherein:
- the sheet casting core (180) has a first array of open areas and a second array of portions interspersed with the open areas; and a portion of the die (210) has a third array of projections (240) contacting the second array.
2. The method of claim 1, wherein:
- the placing comprises positioning relative to a first die element (210) and then assembling a second die element (212) to the first die element.
3. The method of claim 1 or 2 wherein:
- the molding comprises introducing a wax as said sacrificial pattern material.
4. The method of claim 1, 2 or 3, wherein:
- the assembling is entirely before the placing.
5. The method of any preceding claim, wherein:
- the third array falls along a pressure side of the airfoil; and
 the third array includes 5-50 such projections (240).
6. The method of any preceding claim, wherein:
- the feedcore (182) comprises a molded ceramic; and
 the sheet casting core (180) consists essentially of a refractory metal-based member.
7. The method of claim 6, wherein:
- the sheet casting core consists essentially of a coated refractory metal-based member.
8. The method of any preceding claim, wherein:
- the sheet casting core (180) has a thickness of 1.2-7.6mm along a majority of its surface area.
9. The method of any preceding claim, wherein:
- the sheet casting core (180) has an essentially uniform thickness of 2-3mm along a majority of its surface area.
10. A casting core and die assembly for molding an airfoil pattern having pressure and suction sides, the assembly comprising:
- a feedcore (182);
 a sheet casting core (180) assembled to the feedcore (182);
 a die (210,212,214) at least partially containing the feedcore (182) and sheet casting core (180) and including first (210) and second (212) surface sections shaped to respectively form the airfoil pattern pressure and suction sides; and
 means on the die (210) and sheet casting core (180) for forming an array of trailing edge slots (70) open along one side of a pressure side (34) and a suction side (30) of an airfoil to be cast via the airfoil pattern.
11. The assembly of claim 10, wherein:
- each of the slots (70) has an opening along said one side having a length and a width; and
 for at least some of the slots, the length is at least 50% of the width.
12. The assembly of claim 10 or 11, wherein:
- each of the slots (70) has an opening along said one side; and
 for at least some of the slots, said opening has an arcuate leading extremity.
13. The assembly of claim 10, 11 or 12, wherein:
- the one side is the pressure side (34) of the airfoil.
14. The assembly of any of claims 10 to 13, wherein:
- the feedcore (182) consists essentially of a ceramic; and
 the sheet casting core (180) comprises a refractory metal-based sheet.
15. The assembly of any of claims 10 to 14, wherein:
- the sheet casting core (180) has a thickness of 1.2-7.6mm along a majority of its surface area.
16. The assembly of any of claims 10 to 15, wherein:

the sheet casting core (180) has an essentially uniform thickness of 2-3mm along a majority of its surface area.

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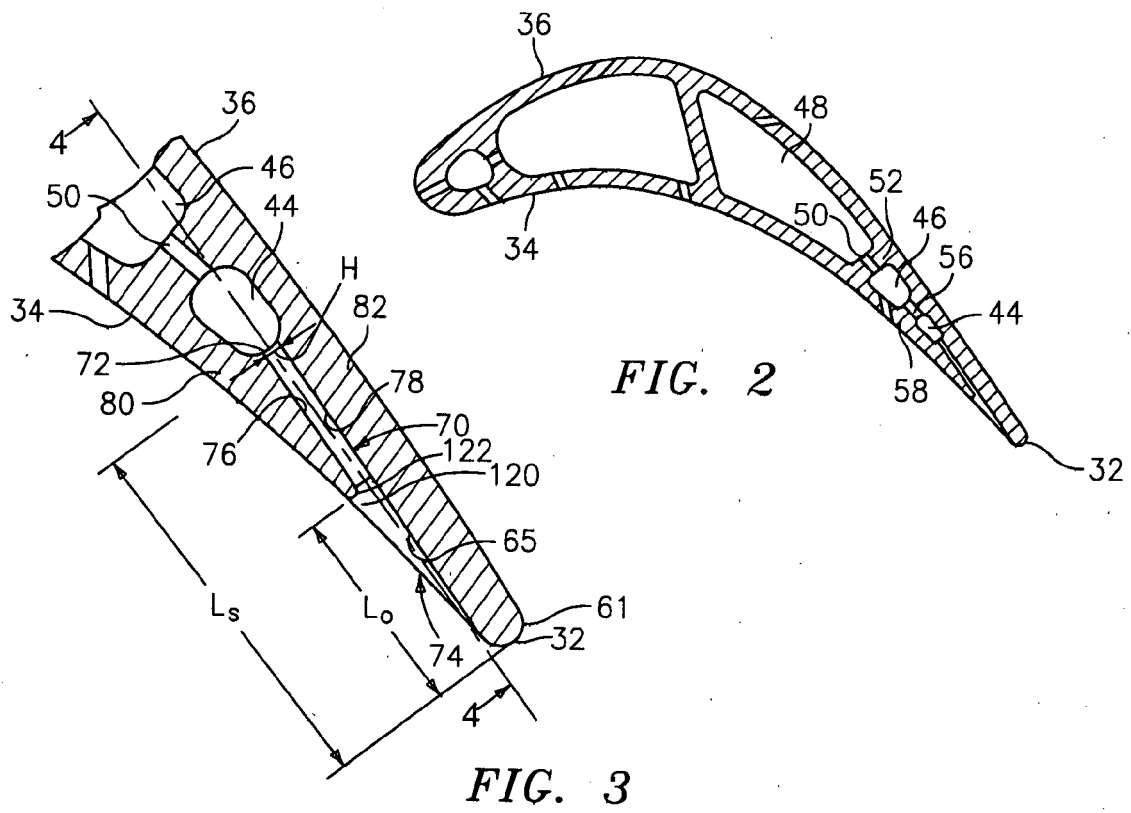
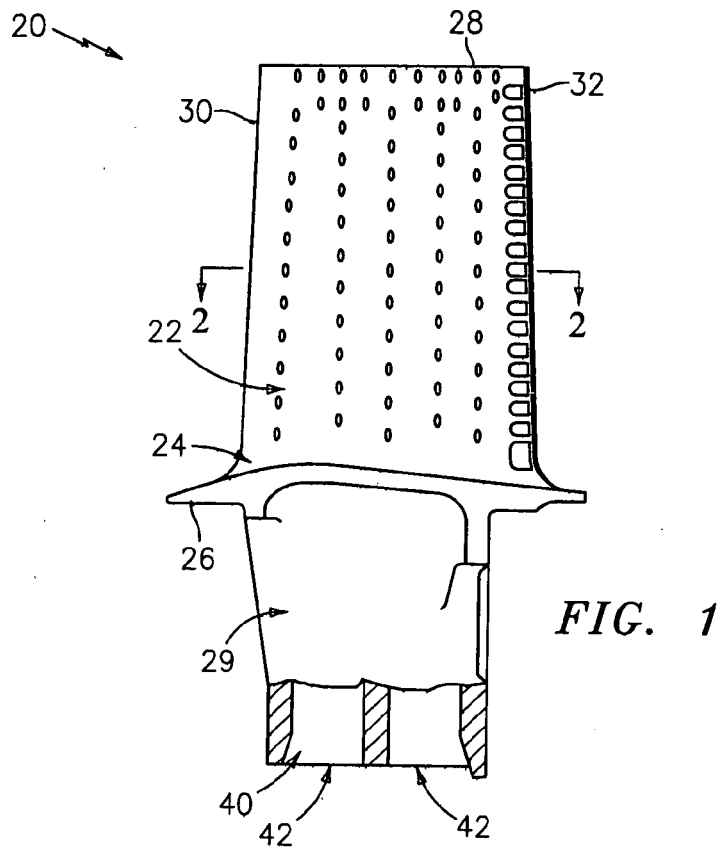
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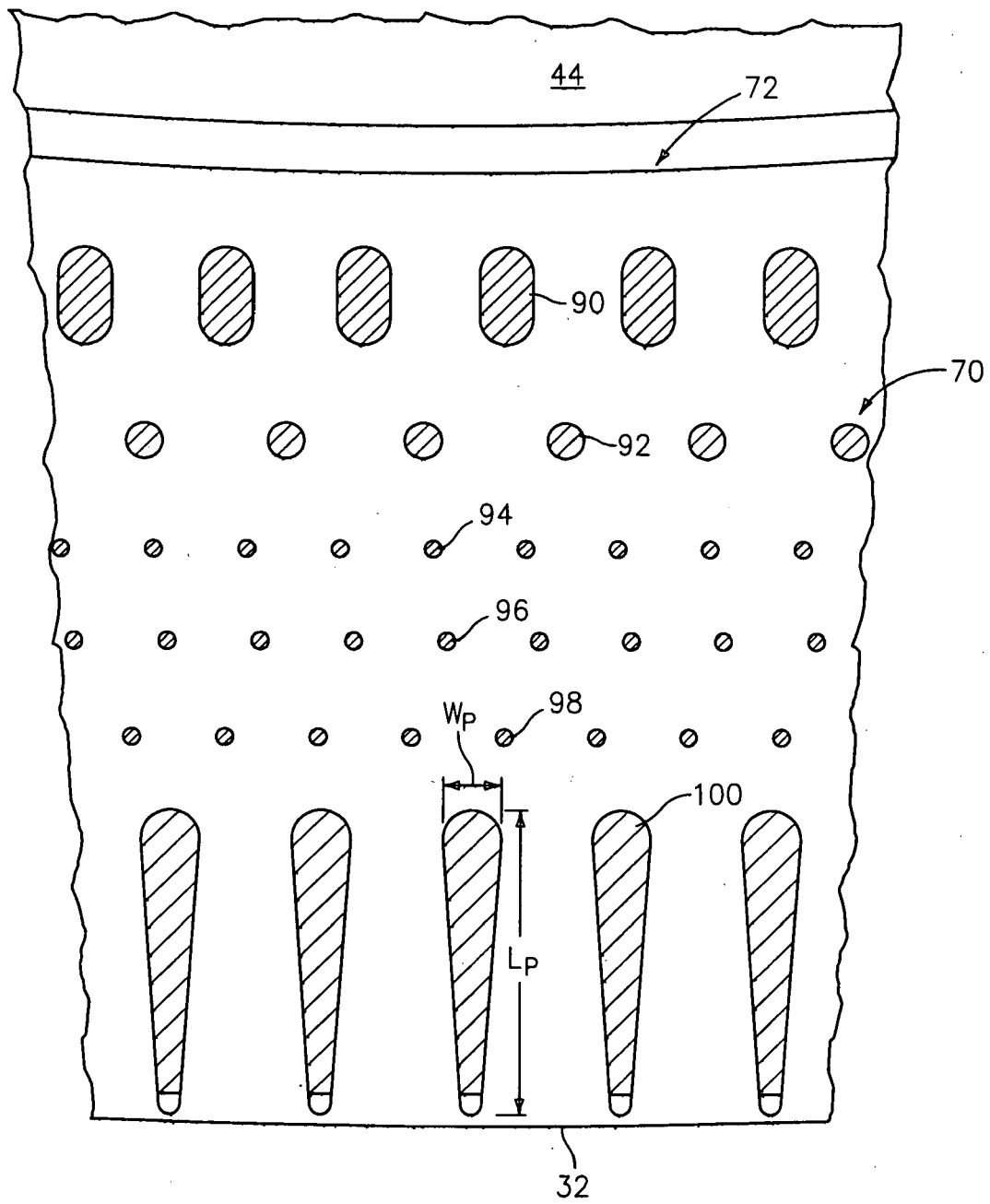


FIG. 4

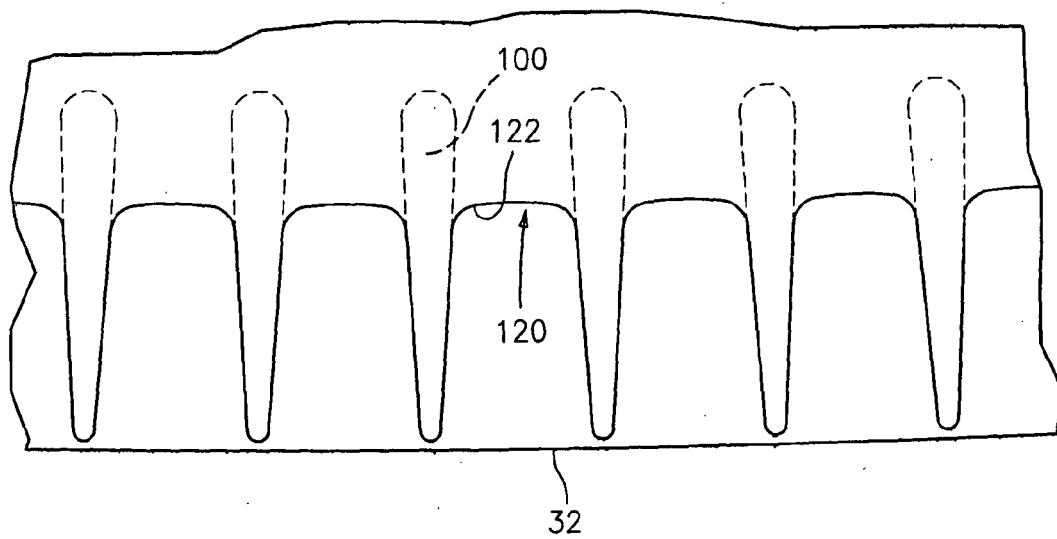


FIG. 5

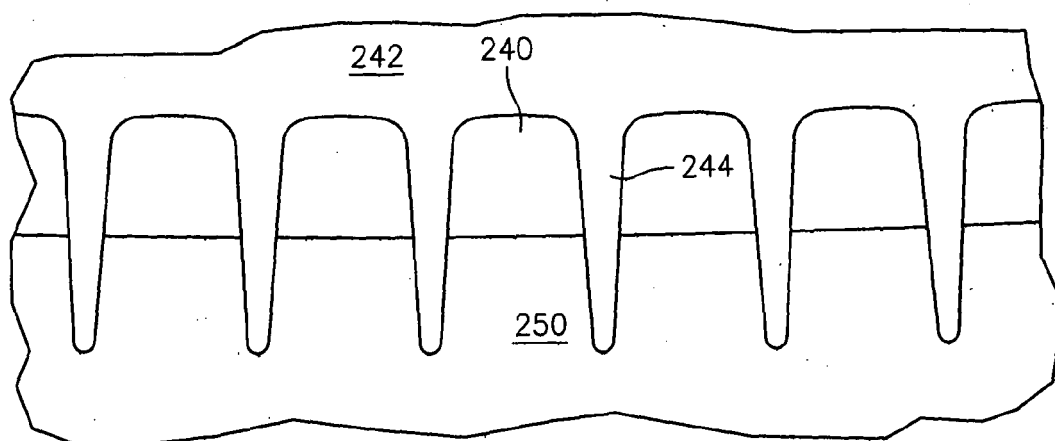


FIG. 8

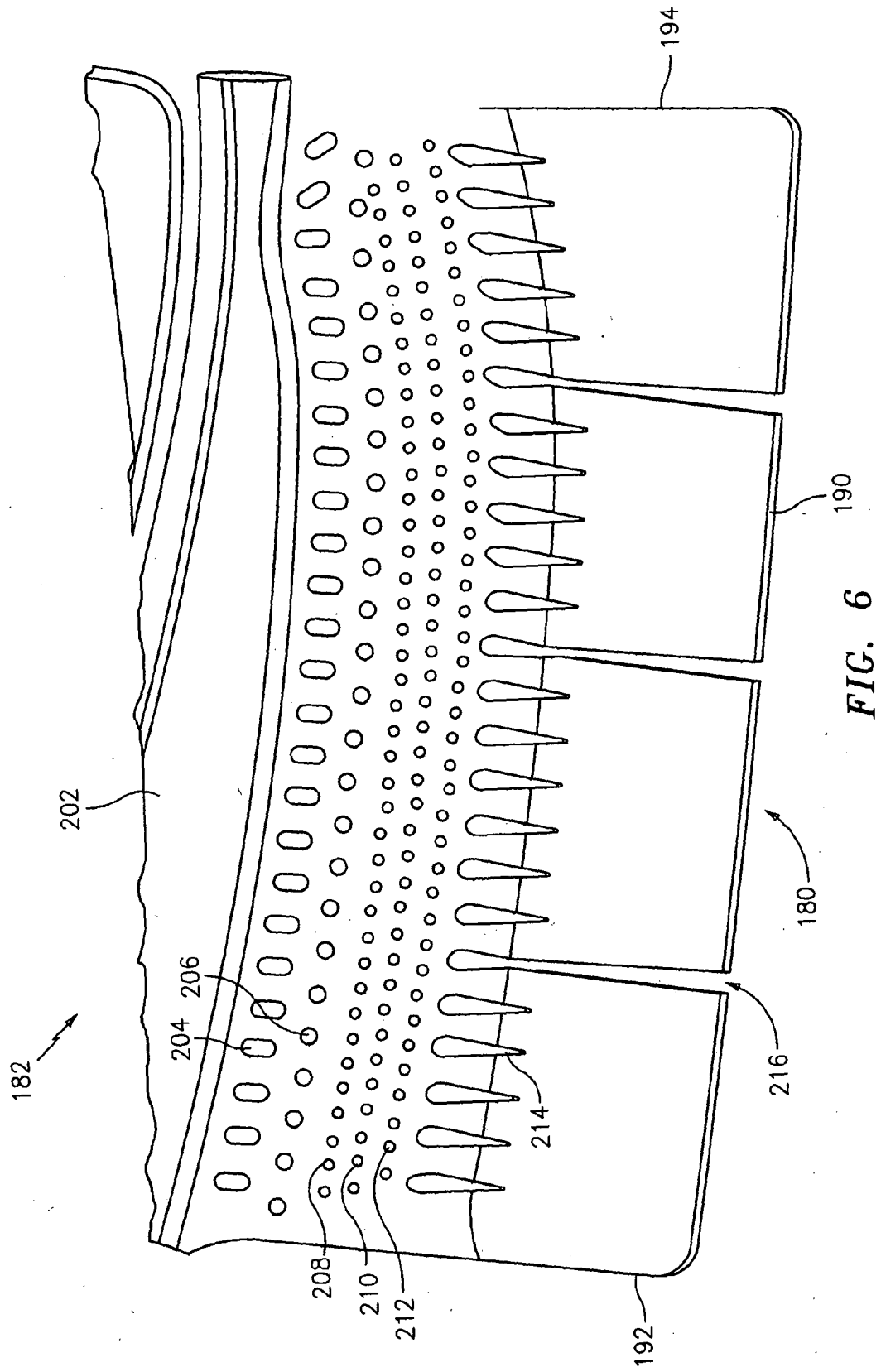


FIG. 6

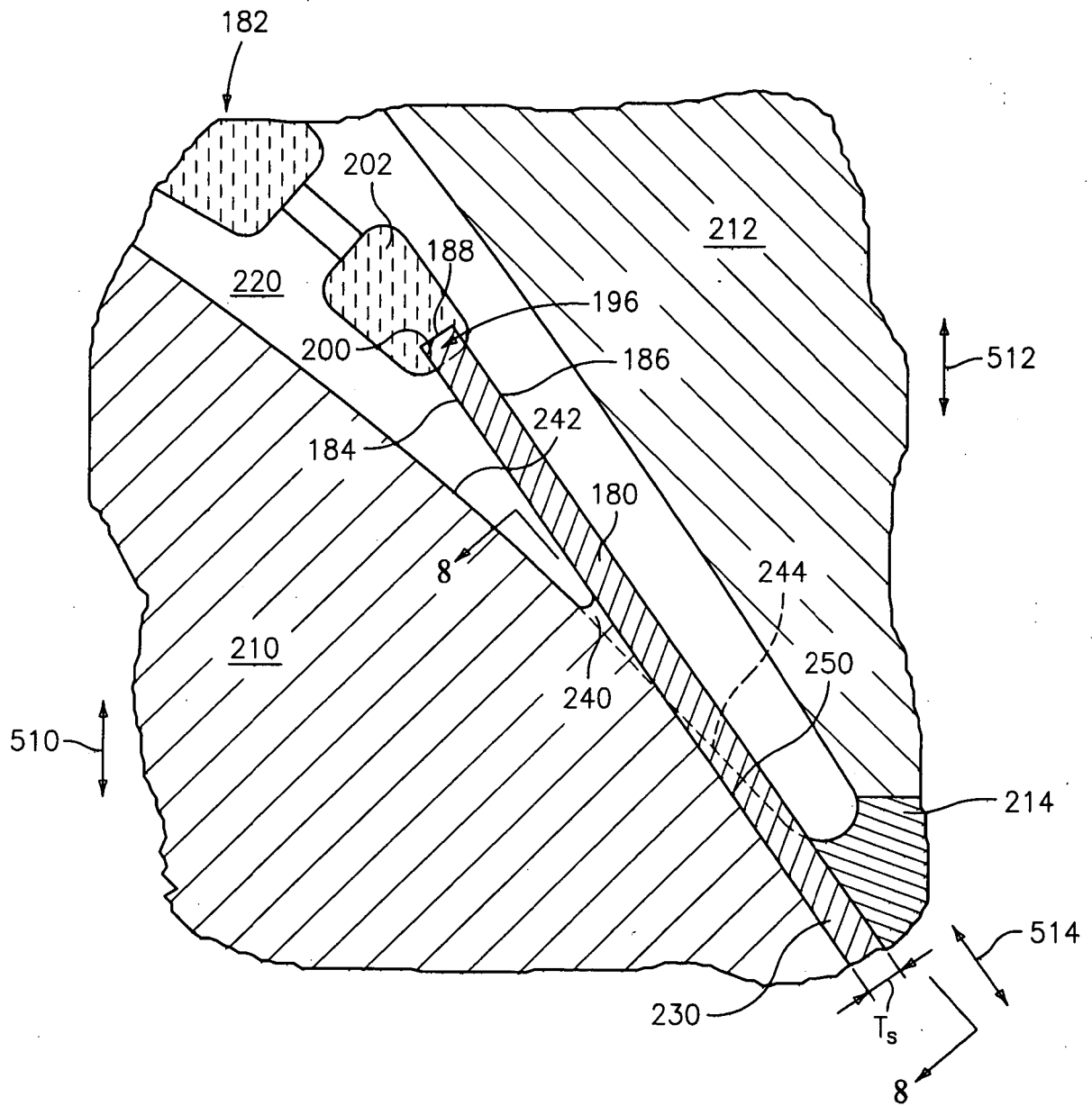


FIG. 7



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Application Number
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