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(54) Turbine blade cooling

(57) A blade (10) for a gas turbine engine is disclosed having several improved cooling features. The blade has a plurality of internal cooling passages. The blade has a tip cap aperture (46) and film cooling holes (20), arranged such that the rearmost cooling passage in the blade receives sufficient cooling in all areas to control local heating of the blade. The blade also has angled turbulence promoters to improve internal cooling and a specially shaped platform (14) to avoid heating of the blade platform edges.

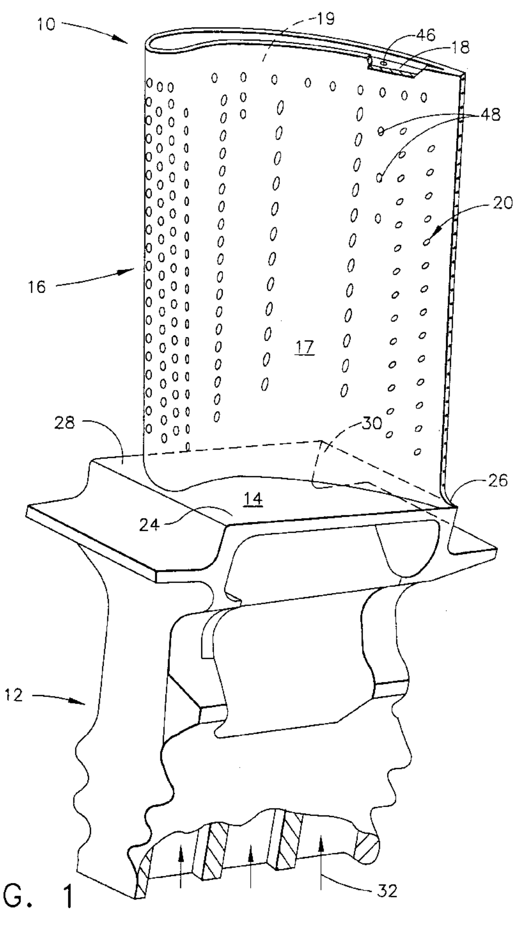

FIG. 1

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Description

[0001] The present invention relates generally to blades in a gas turbine engine, and more particularly to turbine blades having improved cooling features.

[0002] A gas turbine engine includes a compressor for pressurizing air which is channeled to a combustor wherein it is mixed with fuel and ignited for generating hot combustion gas. The combustion gas flows downstream through one or more stages of turbine blades which extract energy from the combustion gas for producing useful work.

[0003] Each turbine blade includes a dovetail which mounts the blade to the perimeter of a rotor disk and an integral hollow airfoil extending radially outwardly from the dovetail. Since the turbine blades are directly exposed to the hot combustion gas, they are typically provided with internal cooling circuits which channel a coolant, such as compressor bleed air, through the airfoil of the blade. The coolant exits the airfoil through a number of film cooling holes distributed over the surface thereof, thereby producing a thin film of cooling air which protects the airfoil from the hot combustion gas.

[0004] The aforementioned cooling circuit is typically arranged in a serpentine fashion in which cooling air enters the airfoil at the base, flows radially outwardly to the blade tip through a first passage, then turns 180° into an adjacent passage parallel to the first and flows back toward the base of the airfoil. The airflow typically passes through several such passages before finally being exhausted out of the airfoil.

[0005] Frequently the cooling passage adjacent to the trailing edge of a turbine blade is a "blind" passage, that is, a passage that does not flow air to another passage in sequence. The airflow is maintained primarily through holes in the trailing edge of the blade that communicate with the rearmost cooling passage In this arrangement, a "dead zone" of reduced airflow can occur in the forward, radially outermost corner of this rearmost cooling passage. This dead zone can lead to localized overheating of the blade which may result in failure of the blade.

[0006] Accordingly, there is a need for a turbine blade which avoids any such dead zones and provides improved cooling.

[0007] In accordance with the present invention, a turbine blade is disclosed having a base section, a platform section, and an airfoil section. The airfoil section has a plurality of internal passages having angled turbulence promoters (or "turbulators"), a plurality of film cooling holes, and a tip cap with a slot near the trailing edge. The combination of features improves cooling of the blade and reduces airflow inefficiencies around the blade.

[0008] The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the concluding part of the specification. The invention, however, may be best understood by reference to the following description taken in conjunction with the accompanying drawing figures in which:

Figure 1 is a pictorial view of the turbine blade of the present invention;
Figure 2 is a sectional side elevation of the blade;
Figure 3 is a schematic view of two adjacent blades;
Figure 4 is a sectional view illustrating the airflow pattern around the forward portion of two adjacent blade platforms;
Figure 5 is a sectional view illustrating the airflow pattern around the aft portion of two adjacent blade platforms; and
Figure 6 is an enlarged sectional side view of the radially outer rear corner of the blade.

[0009] Referring to the drawings wherein identical reference numerals denote the same elements throughout the various views, Figure 1 shows a turbine blade 10 in accordance with the present invention. The blade 10 has a dovetail 12 which mates with matching dovetail features in a turbine rotor, a platform section 14, and a hollow airfoil section 16 with a tip cap 18 that is preferably an integral part of the casting. The airfoil has a pressure side 17 and a suction side 19. The blade 10 also includes internal cooling passages 22 (see Fig. 2) which channel a coolant such as cooling air through the airfoil section 16 for cooling thereof. The pressure side 17 has radial rows of film cooling holes 20 which communicate with the various internal cooling passages of the blade 22 and provide an exit path for cooling air which is introduced through openings 32 in the base of the blade 10.

[0010] The blade 10 is preferably formed as a one-piece casting of the dovetail 12, platform 14, airfoil 16 and tip cap 18 of a suitable high temperature metal such as a nickel-based superalloy which enjoys suitable strength at high temperature operation.

[0011] The platform section 14 of the blade 10 comprises a generally rectangular surface having four corners: a front pressure side corner 24, a rear pressure side corner 26, a front suction side corner 28 and a rear suction side corner 30. As best seen in Figs. 3-5, the platform section 14 of the blade 10 is contoured to improve the flow of hot gas over adjacent blade platforms. Specifically, the front pressure side corner 24 and the rear suction side corner 30 of the platform section 14 are slightly deflected inwardly and the rear pressure side corner 26 and the front suction side corner 28 are slightly deflected outwardly. Thus, in an assembled turbine rotor, the hot gas entering the turbine stage "steps down" as it passes from one blade platform's front suction side corner 28 to the adjacent blade's front pressure side corner 24 (Fig. 4) and "steps down" again as it passes from one blade platform's rear pressure side corner 26 to the adjacent blade's rear suction side corner 30 (Fig. 5). With these "platform steps," the hot gas does not encounter an abrupt transition from one platform section 14 to the next. This feature eliminates hot gas impingement and localized heating on the edge of the blade platform sections 14.

[0012] Fig. 2 illustrates the internal configuration of the blade 10. The casting has multiple internal passages 22 arranged in a serpentine fashion for the flow of cooling air. The cooling air is introduced into the blade through openings 32 in the dovetail 12 of the blade 10. The air then flows around the serpentine passages 22 and out through film cooling holes 20 in the pressure side of the blade 17.

[0013] A rearmost cooling passage 34 is fed through its own opening 32 in the base of the blade 10. Unlike the other passages 22 the rearmost passage 34 is "blind", i.e. the radially outer end of the passage 34 is closed in the sense that the flow passing through it does not enter another cooling passage. As seen in Fig. 6, the rearmost passage 34 can be radially divided into a forward section 36 and a rear section 38. The rearmost passage 34 has a bank of cylindrical pins 40 extending from the inner wall of the pressure side 17 to the inner wall of the suction side 19 which promote turbulence and provide additional surface area for heat transfer inside the blade 10. The airflow through the rearmost passage 34 is vented to the outside of the blade 10 through film cooling holes 20 on the pressure side 17 of the blade 10, through a radial row of holes 42 in the trailing edge 44 of the blade 10, and through an aperture 46 in the tip cap 18.

[0014] Most of the film cooling holes 20 are in radial rows along the pressure side 17 of the blade 10, however, one or more cooling holes 48 (see Fig. 1) are placed on the pressure side 17 of the blade 10 in the radially outer front corner of the rearmost cooling passage 34 This additional hole or holes 48, in cooperation with the aperture 46 in the tip cap 18, which is placed substantially in the forward section 36 of the rearmost cooling passage 34, ensures that airflow will continue through the rearmost cooling passage 34 all the way to the radially outer ends eliminating a "dead zone" of little or no air flow in the radially outer front corner of the rearmost cooling passage 34.

[0015] The tip cap aperture 46 is placed as far forward as practicable, substantially in the forward section 36 of the rearmost passage 34. The aperture 46 is preferably a non-circular shape so that its area can be larger than that of a circular hole given the width constraints at the narrow rear section of the blade 10. The aperture 46 is placed so as to be in communication with the relatively lower pressure airflow outside the blade tip 18. This creates a pressure difference across the aperture 46 which causes the cooling airflow to flow through what would otherwise be a dead zone in the front corner of rearmost cooling passage 34.

[0016] Also seen in Fig. 2 are the turbulence promoters or turbulators 50 which are slender ribs formed as part of the blade casting on the inside walls of the cooling passages 22. The turbulators 50 serve to promote turbulence and increase cooling efficiency of the blade 10. It is beneficial in blade design to maintain as low a pressure drop and as high a heat transfer rate as possible. An improvement, i.e. reduction, in pressure drop can be expected with angled turbulators. Since the pressure drop is proportional to the friction factor, decreasing turbulator angle from 90° to the direction of flow reduces flow resistance or friction thereby reducing pressure drop. However, as turbulators are angled away from 90° to the flow, the rate of heat transfer also decreases. Both heat transfer and friction reach a minimum when the ribs are at 0° (parallel to air flow). In practice, the turbulators 50 are placed at a non-perpendicular angle to the flow to obtain a compromise between optimum heat transfer and minimum flow losses. The non-perpendicular angle is preferably in the range of about 40° to about 90°.

Claims

1. A turbine blade comprising:

   a dovetail for mounting said blade to a rotor disk;
   a platform Joined to said dovetail;
   an airfoil extending outwardly from said platform, said airfoll including a tip cap and laterally opposite pressure and suction sides; and
   a plurality of internal cooling passages disposed in said airfoil, the rearmost of said cooling passages having forward and rear sections, wherein said tip cap has an aperture formed therein, said aperture being positioned substantially in said forward section in fluid communication with said rearmost cooling passage.

2. The turbine blade of claim 1 wherein said aperture is a non-circular slot.

3. The turbine blade of claim 1 or claim 2 wherein said tip cap is an integral part of said airfoil.

4. The turbine blade of any one of claims 1 to 3 further comprising a plurality of film cooling holes formed in said airfoil, at least one of said film cooling holes being positioned on said pressure side in fluid communication with said rearmost cooling passage, said at least one film cooling hole being positioned substantially in said forward section and substantially in the radially outermost corner of said rearmost cooling passage.

5. The turbine blade of any one of claims 1 to 4 wherein said rearmost cooling passage includes a plurality of pins formed therein.

6. The turbine blade of any one of claims 1 to 5 wherein said platform includes a front pressure side cor-

ner, a rear pressure side corner, a front suction side corner and a rear suction side corner. said platform being contoured so that said forward suction side corner is disposed radially outward of the forward pressure side corner and the side corner is disposed radially outward of the rear suction side corner.

7. The turbine blade of any one of claims 1 to 6 further comprising a plurality of turbulence promoters formed in said internal cooling passages, said turbulence promoters being disposed at a non-perpendicular angle with respect to the direction of flow through the respective cooling passage

8. The turbine blade of claim 7 wherein said non-perpendicular angle is between about 40 degrees and about 90 degrees.

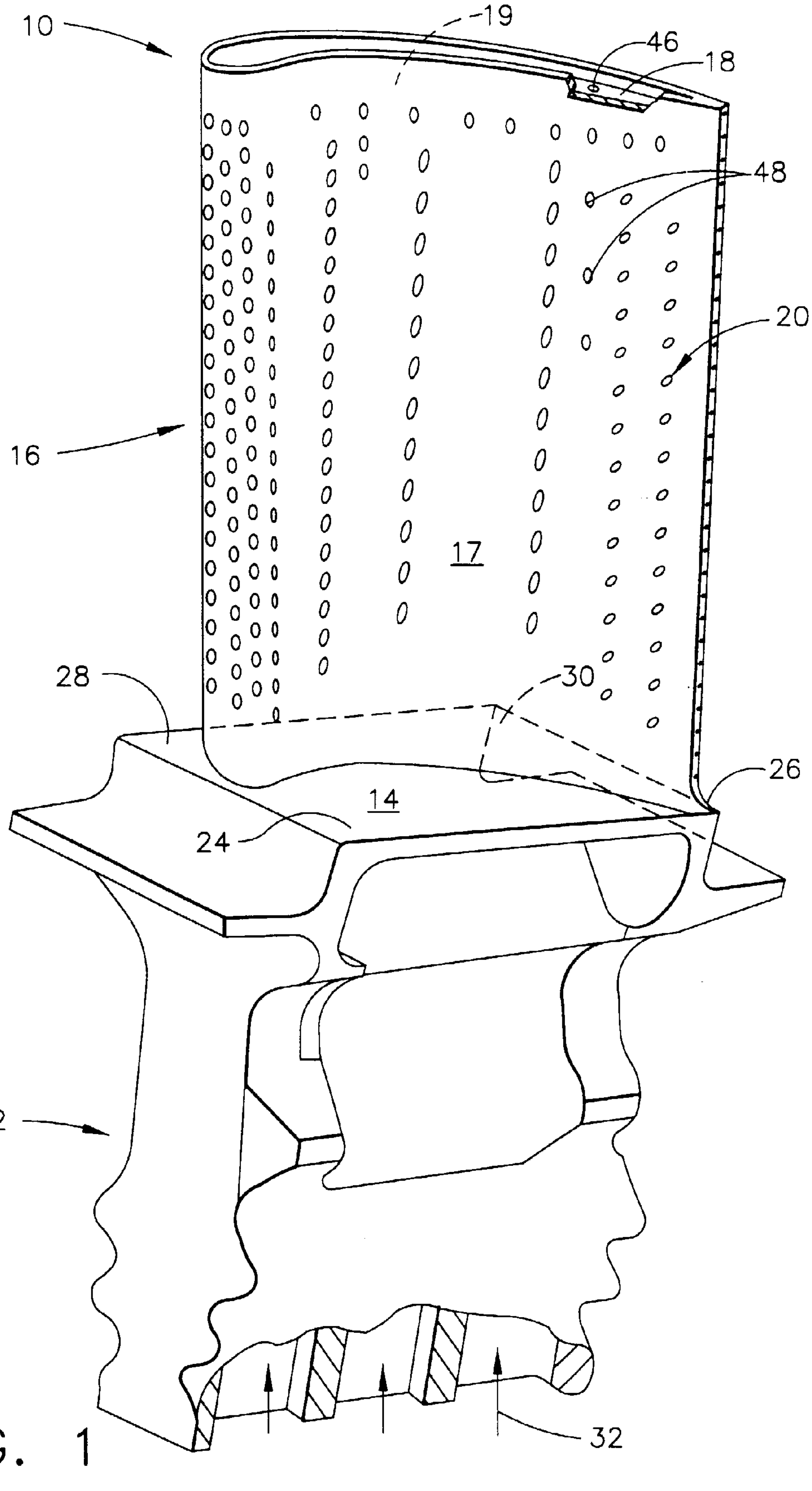

FIG. 1

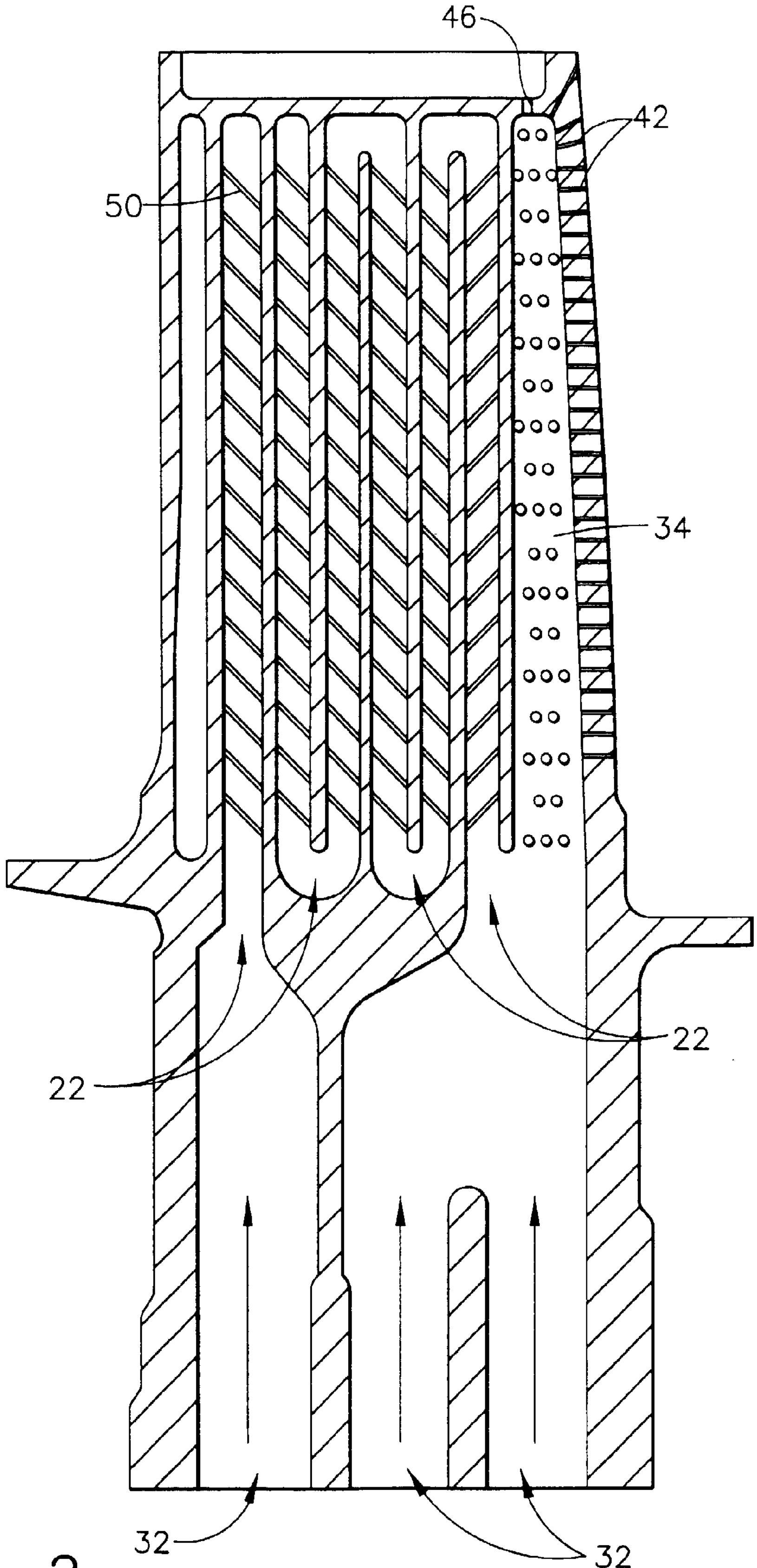

FIG. 2

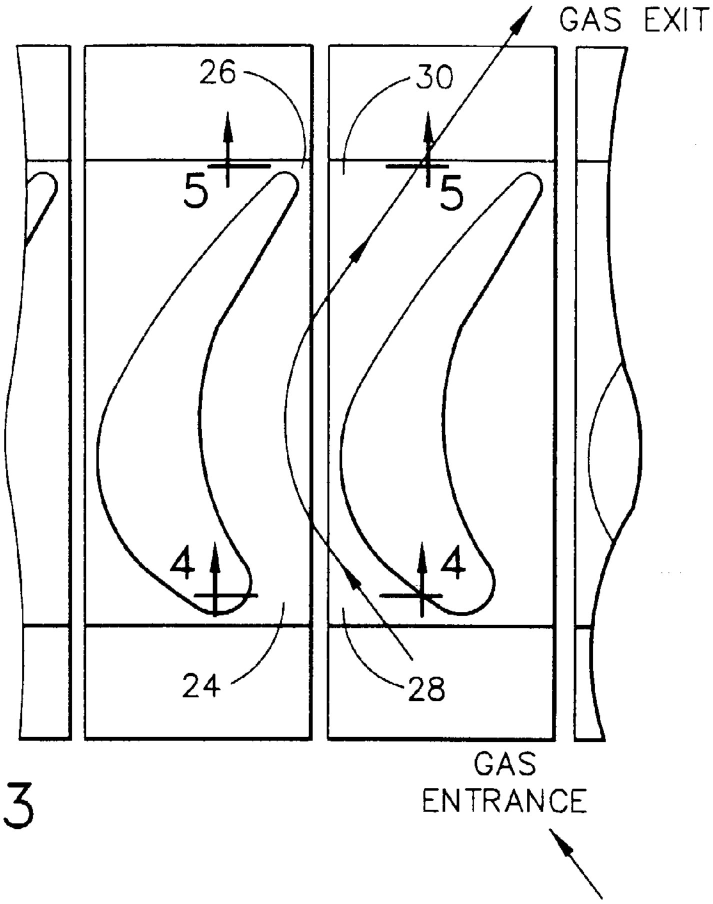

FIG. 3

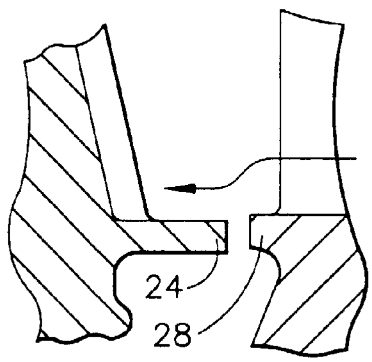

FIG. 4

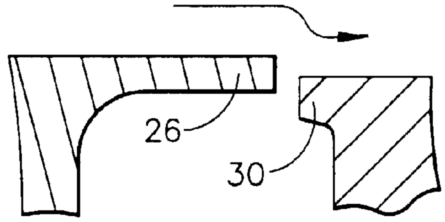

FIG. 5

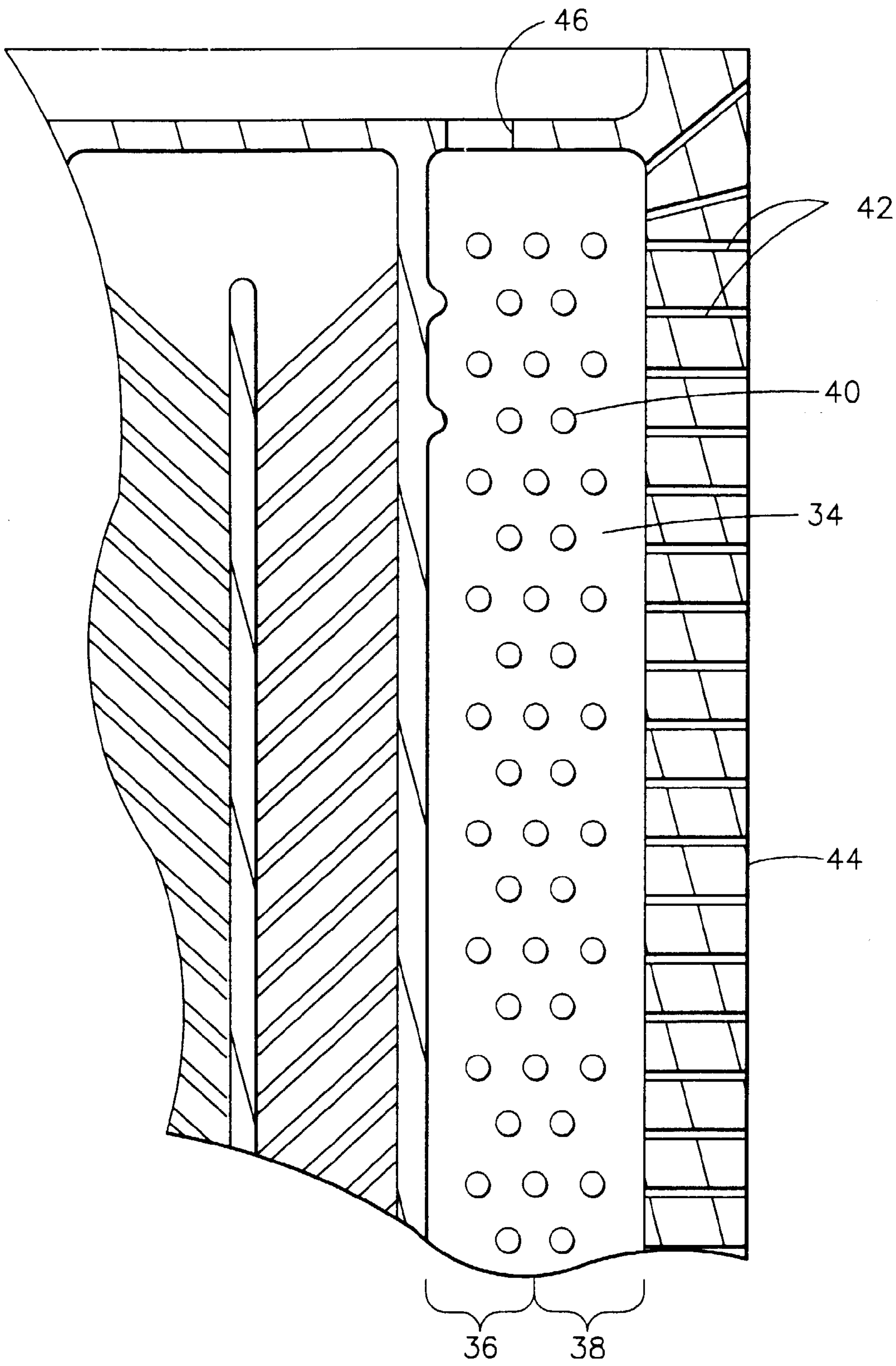

FIG. 6