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(54) Hole for rotating component cooling system

(57) A rotor (31A) for a gas turbine engine (10) comprises an annular body (38) and a plurality of holes (40). The annular body (38) is configured to rotate in a circumferential direction (ω) about an axis (CL) extending through a center of the annular body (38). The annular body (38) comprises an outer diameter surface (60B) and an inner diameter surface (60A). The plurality of holes (40) extends through the annular body (38). Each of the holes (40) comprises an elongate profile in the circumferential direction, and a side wall (58) extending between the outer diameter surface and the inner diameter surface. The side wall (58) is slanted in the circumferential direction (ω).

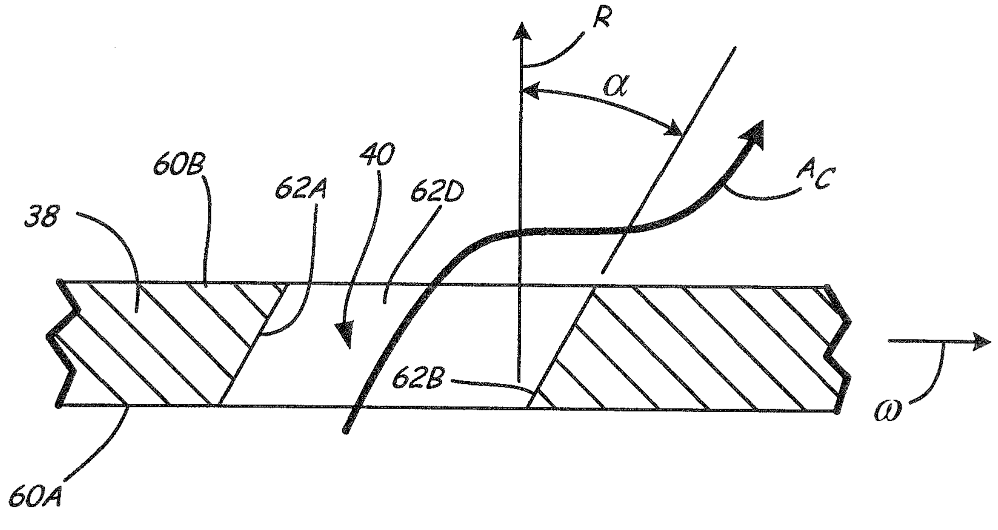

FIG.4B

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Description

BACKGROUND

[0001] Gas turbine engines operate by passing a volume of high energy gases through a plurality of stages of vanes and blades, each having an airfoil, in order to drive turbines to produce rotational shaft power. The shaft power is used to drive a compressor to provide compressed air to a combustion process to generate the high energy gases. Additionally, the shaft power is used to drive a generator for producing electricity. In order to produce gases having sufficient energy to drive the compressor or generator, it is necessary to combust the air at elevated temperatures and to compress the air to elevated pressures, which again increases the temperature. Thus, the vanes and blades are subjected to extremely high temperatures, often times exceeding the melting point of the alloys comprising the airfoils.

[0002] In order to maintain the airfoils at temperatures below their melting point it is necessary to, among other things, cool the airfoils with a supply of relatively cooler air, typically bleed from the compressor. This siphoned compressor air must be routed from the compressor to the vanes and, as such, must pass through rotating components. For example, cooling air is often drawn from the radial outer ends of the high pressure compressor vanes and routed radially inward via plumbing to the high pressure shaft where the cooling air must pass through support struts and the high pressure turbine rotor to be directed radially outward for passing into roots of the turbine vanes in the rotor. Routing of the cooling air in such a manner incurs aerodynamic losses that reduce the cooling effectiveness of the air and overall gas turbine engine efficiency. There is, therefore, a continuing need to improve aerodynamic efficiencies in cooling systems involving rotating components.

SUMMARY

[0003] The present invention is directed toward a rotor for a gas turbine engine. The rotor comprises an annular body and a plurality of holes. The annular body is configured to rotate in a circumferential direction about an axis extending through a center of the annular body. The annular body comprises an outer diameter surface and an inner diameter surface. The plurality of holes extends through the annular body. Each of the holes comprises an elongate profile in the circumferential direction, and a side wall extending between the outer diameter surface and the inner diameter surface. The side wall is slanted in the circumferential direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004]

FIG. 1 shows a gas turbine engine including a turbine section having a rotor in which the slanted racetrack holes of an embodiment of the present invention are used.

FIG. 2 is a cross-sectional view of the second stage turbine rotor of FIG. 1 having a hub through which the slanted racetrack holes extend.

FIG. 3 is a perspective view of the second stage turbine rotor of FIG. 2 showing the configuration of the slanted racetrack holes in the hub.

FIG. 4A is a top view of a slanted racetrack hole of FIG. 3 showing a profile of the racetrack shape.

FIG. 4B is a cross-sectional view of the slanted racetrack hole as taken at section 4B-4B of FIG. 4A showing a radial angle of the slanted walls of the racetrack hole.

FIG. 4C is an alternative cross-sectional view of the slanted racetrack hole as taken at section 4B-4B of FIG. 4A showing a contoured shape of the slanted walls of the racetrack hole.

DETAILED DESCRIPTION

[0005] FIG. 1 shows gas turbine engine 10, in which the slanted racetrack holes of an embodiment of the present invention can be used. Gas turbine engine 10 comprises a dual-spool turbofan engine having fan 12, low pressure compressor (LPC) 14, high pressure compressor (HPC) 16, combustor section 18, high pressure turbine (HPT) 20 and low pressure turbine (LPT) 22, which are each concentrically disposed around longitudinal engine centerline CL. Fan 12 is enclosed at its outer diameter within fan case 23A. Likewise, the other engine components are correspondingly enclosed at their outer diameters within various engine casings, including LPC case 23B, HPC case 23C, HPT case 23D and LPT case 23E such that an air flow path is formed around centerline CL. Although depicted as a dual-spool turbofan engine in the disclosed nonlimiting embodiment, it should be understood that the concepts described herein are not limited to use with turbofans as the teachings may be applied to other types of turbine engines, such as three-spool turbine engines and geared turbine fan engines.

[0006] Inlet air A enters engine 10 and it is divided into streams of primary air Ap and bypass air A_B after it passes through fan 12. Fan 12 is rotated by low pressure turbine 22 through shaft 24 (directly or via a transmission (not shown, also known as a gear box) to accelerate bypass air A_B through exit guide vanes 26, thereby producing a major portion of the thrust output of engine 10. Shaft 24 is supported within engine 10 at ball bearing 25A, roller bearing 25B and roller bearing 25C. Primary air A_P (also known as gas path air) is directed first into low pressure compressor (LPC) 14 and then into high pressure compressor (HPC) 16. LPC 14 and HPC 16 work together to incrementally step up the pressure of primary air Ap. HPC 16 is rotated by HPT 20 through shaft 28 to provide compressed air to combustor section 18. Shaft 28 is supported within engine 10 at ball bearing 25D and roller bearing

25E. The compressed air is delivered to combustors 18A and 18B, along with fuel through injectors 30A and 30B, such that a combustion process can be carried out to produce the high energy gases necessary to turn turbines 20 and 22. Primary air A_P continues through gas turbine engine 10 whereby it is typically passed through an exhaust nozzle to further produce thrust.

[0007] HPT 20 and LPT 22 each include a circumferential array of blades extending radially from rotors 31 A and 31B connected to shafts 28 and 24, respectively. Similarly, HPT 20 and LPT 22 each include a circumferential array of vanes extending radially from HPT case 23D and LPT case 23E, respectively. In this specific example, HPT 20 comprises a two-stage turbine having blades 32A and 32B extending from rotor disks 34A and 34B of rotor 31A. Vane 34A extends radially inward from case HPT case 23E between blades 34A and 34B. Blades 32A and 32B include internal passages into which compressed cooling air A_C from, for example, HPC 16 is directed to provide cooling relative to the hot combustion gasses of primary air Ap. Rotor disks 34A and 34B include holes to permit cooling air A_C (also known as secondary air) into roots of blades 32A and 32B. Specifically, as shown in FIG. 2, rotor disk 34B includes a hub having racetrack cooling holes with angled wall of an embodiment of the present invention.

[0008] FIG. 2 is a cross-sectional view of second stage turbine rotor disk 34B of FIG. 1 having disk 36 and hub 38 through which slanted racetrack holes 40 extend. Disk 36 includes outer diameter end 42 (shown in FIG. 3) into which a plurality of slots 44 extend. Disk 36 also includes inner diameter end 46 through which engine centerline CL (FIG. 1) extends. Hub 38 extends axially from disk 36 at inner diameter end 46 to form an annular body surrounding centerline CL. Rotor disk 34B also includes mini-disk 48, which includes axially extending portion 48A and radially extending portion 48B. Mini-disk 48 forms cooling passage 50 along rotor disk 34B. Mini-disk 48 is coupled to hub 38 at lap joint 52, which comprises a pair of overlapping flanges from hub 38 and axially extending portion 48A. Mini-disk 48 adjoins outer diameter end 42 at face seal 54, which comprises a flat, sealed plate that abuts slots 44 and roots of blade 32B. Rotor disk 34B, when rotated during operation of engine 10 via high pressure shaft 28, rotates into the plane of the page of FIG. 2. Low pressure shaft 24 rotates within high pressure shaft 28. Rotor disk 34B is coupled to high pressure shaft 28 such that cooling passage 56 is provided therebetween. Cooling air A_C from HPC 16 (FIG. 1) is routed into cooling passage 56 where, due to pressure differentials within engine 10, the air turns to enter holes 40. Within holes 40, the air is bent by the rotation of hub 38 and distributed into cooling passage 50. From cooling passage 50, cooling air A_C flows toward face seal 54, which prevents cooling air A_C from escaping rotor disk 34B, and into slots 44. From slots 44 cooling air A_C enters inner diameter cooling channels of blade 32B to cool blade 32B relative to primary air Ap. Holes 40 are shaped to facilitate the turning and bending of cooling air A_C and reduce pressure losses within engine 10.

[0009] FIG. 3 is a perspective view of second stage turbine rotor 34B of FIG. 2 showing the configuration of slanted racetrack holes 40 in hub 38. As discussed, rotor disk 34B include disk 36 and hub 38, through which holes 40 extend. Disk 36 includes outer diameter end 42 into which slots 44 extend. Slots 44 include dovetail or fir tree grooves, as are known in the art, to receive root portions of turbine blades. The bottom, or radially inner portions, of slots 44 receive cooling air A_C from holes 40 to cool the turbine blades. Holes 40 each include walls 58 that produce an elongate profile in the circumferential direction and that are slanted or angled in the circumferential direction into the direction of rotation. In the shown embodiment, holes 40 have a racetrack profile, although other shapes may be used. Holes 40 are disposed in a circumferential row spaced evenly about hub 38. Holes 40 reduce the surface area of hub 38, thereby increasing the area through which cooling air A_C is able to pass and reducing the pressure loss generated by rotor disk 34B.

[0010] In conventional rotors, cooling air is delivered through straight circular holes. The cooling air thus needs to turn ninety degrees to pass through the straight holes, which produces pressure loss. Additionally, circular holes limit swirl ratio to unity. The swirl ratio comprises the swirl velocity of the cooling air divided by the speed of the rotor, which is a product of the rotational speed ω of the rotor and the distance of the hole from the engine centerline. Holes 40 of the present invention reduce pressure loss, as compared to straight circular holes, by slanting the holes in a flow rotating direction to reduce the flow turning loss, and elongating the shape of the holes in the flow rotating direction to increase the swirl ratio.

[0011] FIG. 4A is a top view of slanted racetrack hole 40 of FIG. 3 showing a profile of the racetrack shape. FIG. 4B is a cross-sectional view of slanted racetrack hole 40 as taken at section 4B-4B of FIG. 4A showing radial angle α of slanted walls 58 of racetrack hole 40. FIGS. 4A and 4B are discussed concurrently. Holes 40 extend from inner diameter surface 60A to outer diameter surface 60B of hub 38. Hole 40 includes leading edge wall 62A, trailing edge wall 62B, first side wall 62C and second side wall 62D. Rotor disk 34B rotates in the circumferential direction, indicated by arrow ω. Cooling air A_C flows downstream with respect to engine 10 (FIG. 1) in an axial direction, then turns generally radially outward in radial direction R before bending in the circumferential direction ω.

[0012] In the depicted embodiment, holes 40 are racetrack shaped such that leading edge wall 62A and trailing edge wall 62B are semi-circular, and side walls 62C and 62C extend straight between walls 62A and 62B parallel to each other. However, in other embodiments leading edge wall 62A and 62B may have some other arcuate shape. In yet other embodiments, the leading and trailing edge walls may be straight or flat. In any embodiment, the distance between leading edge and trailing edge side walls 62A and 62B (width) is greater than the distance between side walls 62C and 62D (length) such that holes 40 are elongate in circumferential direction ω. In the disclosed embodiment, hole 40 is approximately twice as wide as it is long, with reference to FIG. 4A. As mentioned above, widening or elongating of holes 40, as compared to conventional circular holes, increases the area through which cooling air A_C is able to flow, increasing the swirl ratio. The denominator of the swirl ratio (rotor speed) remains the same as compared to circular holes. The numerator (swirl velocity), however, increases because the cooling air is less restricted by hub material, which slows the swirling of the cooling air. Experimentation has shown that the slanted racetrack cooling holes of the present invention can increase the swirl ratio from unity for straight circular holes to approximately 1.25.

[0013] Walls 58, which include walls 62A-62D, are angled in circumferential direction ω with respect to radial direction R. In the depicted embodiment, leading edge wall 62A and trailing edge wall 62B are angled in the circumferential direction ω by about thirty degrees to form angle α. In other embodiments, angle α can be anywhere from approximately fifteen degrees to approximately seventy-five degrees, with higher angles typically being used in rotors that rotate at higher speeds. As such, leading edge wall 62A angles toward the interior of hole 40, while trailing edge wall 62B angles away from hole 40. Side walls 62C and 62D extend straight between outer diameter surface 60B and inner diameter surface 62A. Angling of the walls of hole 40, particularly walls 62A and 62B, reduces pressure loss generated by rotor disk 34B. Specifically, as shown in FIG. 4B, cooling air A_C is shown as having to bend approximately sixty degrees to bend from the angle of hole 40 to the circumferential direction. Thus, in embodiments where angle α rages from about twenty degrees to about fifty degrees, cooling air A_C has to bend about seventy to about forty degrees. By comparison, in straight circular holes, the cooling air has to bend ninety degrees to change from the true radial direction of the hole to the circumferential direction. As such, pressure losses are reduced by reducing the amount of redirection cooling air A_C must undergo to move from cooling passage 56 to cooling passage 50 (FIG. 2).

[0014] FIG. 4C is an alternative cross-sectional view of slanted racetrack hole 40 as taken at section 4B-4B of FIG. 4A showing a contoured shape of slanted walls 64A and 64B of racetrack hole 40. Sidewall 64C extends between leading edge wall 64A and trailing edge wall 64B. As shown, hole 40 is positioned between inner diameter surface 60A and outer diameter surface 60B of hub 38, as in the embodiment of FIG. 4B. However, in FIG. 4C, hole 40 includes leading edge wall 64A and trailing edge wall 64B which are contoured in the radial direction as well as being slanted in the radial direction. In other words, hole 40 extends through hub 38 at a varying angle α which still results in an overall slanted configuration. In the depicted embodiment, walls 64A and 64B extend over single smooth arcs such that angle α increases, resulting in a convex inflection point between inner diameter surface 60A and outer diameter surface 60B of wall 64B and a concave inflection point on wall 64A. In other embodiments, walls 64A and 64B may have other contoured or arcuate configurations, such bending or inflecting closer to either inner diameter surface 60A or outer diameter surface 60B. In yet other embodiments, wall 64A may be convex and wall 64B may be concave, or vice versa. Sidewall 66C and an opposing equivalent sidewall connect slanted walls 64A and 64B. In the disclosed embodiments, the sidewall are parallel and extend straight between walls 64A and 64B. As configured in FIG. 4C, cooling air A_C bends within hole 40 before passing along disk 36 (FIG. 2), thus further reducing pressure losses.

[0015] Some of the benefits of the present invention in rotating annular bodies include reduction in pressure loss through holes, and increase in the swirl ratio through holes. This is achieved by elongating the hole to a racetrack configuration and slanting the hole in a radial direction about thirty to about forty degrees, in one embodiment. These qualities increase flow area, reduce flow vector turning and overall pressure loss, as compared to straight circular holes. The swirl ratio of cooling air for the present invention is greater than one, whereas circular holes are limited to swirl ratios of unity. Thus, the swirl ratio can be increased to 1.2 or more, a 20% or more increase as compared to the straight circular holes.

[0016] While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. A rotor (31A) for a gas turbine engine (10), the rotor (31A) comprising:

an annular body (38) configured to rotate in a circumferential direction (ω) about an axis (CL) extending through a center of the annular body (38), the annular body (38) comprising:

an outer diameter surface (60B); and
an inner diameter surface (60A); and

a plurality of holes (40) extending through the annular body (38), each of the holes (40) comprising:

an elongate profile in the circumferential direction (ω); and
a side wall (58) extending between the outer diameter surface (60B) and the inner diameter surface, the side wall (58) being slanted in the circumferential direction (ω).

2. The rotor (31A) of claim 1, wherein the elongate profile of each of the plurality of holes (40):

is racetrack shaped; and/or
includes a width in the circumferential direction (ω) that is approximately twice as large as a length in the axial direction.

3. The rotor (31A) of claim 1 or 2, wherein the side wall (58) of each of the plurality of holes (40) includes arcuate leading and trailing edge segments (62A, 62B;64A,64B) that are angled in the circumferential direction (ω) with respect to a radial direction (R).

4. The rotor (31A) of claim 3, wherein the side walls (62A,62B) are angled between approximately fifteen degrees and approximately seventy-five degrees, or optionally between approximately thirty degrees and approximately forty degrees.

5. The rotor (31A) of any preceding claim, wherein the elongate profile of each of the plurality of holes (40) comprises:

an arcuate leading edge (62A;64A);
an arcuate trailing edge (62B;64B);
a first side edge (62D;64D) extending straight between the arcuate leading and trailing edges; and
a second side edge (62C;64C) extending straight between the arcuate leading and trailing edges.

6. The rotor (31A) of claim 5, wherein the first side edge (62D;64D) and the second side edge (62C;64C) are parallel to each other.

7. The rotor (31A) of claim 5 or 6, wherein the arcuate leading edge (62A;64A) and the arcuate trailing edge (62B;64B):

are circular;
extend straight between the inner diameter surface (60A) and the outer diameter surface (60B);
extend arcuately between the inner diameter surface (60A) and the outer diameter surface (60B); and/or
are angled in the circumferential direction with respect to a radial direction.

8. The rotor (31A) of any preceding claim, wherein the rotor further comprises:

a disk (34B) comprising:

an outer diameter edge (42) having slots (44) for receiving airfoils (32B); and
an inner diameter bore (46) surrounding the axis (CL); and

a hub (38) extending from the inner diameter bore (46) of the disk (34B) to form the annular body, the plurality of holes (40) being positioned on the hub (38), and optionally wherein said rotor further comprises a mini-disk (48) disposed opposite the outer diameter surface (60B) to form a cooling channel (50), the mini-disk (48) comprising:

an axially extending portion (48A) extending opposite the hub (38); and

a radially extending portion (48B) extending along the disk (34B); wherein cooling air (Ac) directed into the hole from the inner diameter surface (60A) flows along the hub (38) and along the disk (34B) to the slots (44), and optionally wherein said mini-disk (48) further comprises:

a lap joint (52) coupling the axially extending portion (48A) to the hub (38); and
a face seal (54) adjoining the radially extending portion (48B) with the slots (44) of the outer diameter edge (42) of the disk (34B).

9. A rotor (31 A) for a gas turbine engine (10) configured to rotate in a circumferential direction (ω) about an axis (CL) extending through a center of the rotor (31 A), the rotor (31 A) comprising:

a disk (34B) comprising:

an outer diameter edge (42) having slots (44) for receiving airfoils (32B); and
an inner diameter bore (46) surrounding the axis (CL);

a hub (38) extending from the inner diameter bore (46) of the disk (34B) to form an annular body;
a plurality of holes (40) extending through the hub (38), each of the plurality of holes (40) comprising:

an arcuate leading edge (62A;64A);
an arcuate trailing edge (62B;64B); and
first and second elongate side edges (62C, 62D;64C,64D) extending between the arcu-

ate leading and trailing edges (62A,62B; 64A,64B), wherein the first and second elongate side edges (62C,62D;64C,64D) are parallel and wherein the arcuate leading edge and the arcuate trailing edge are angled with respect to a radial direction.

10. The rotor (31A) of claim 9, wherein:

the arcuate leading edge (62A;64A) and arcuate trailing edge (62B;64B) define a width that is approximately twice as large as a distance between the first and second elongate side edges (62C,62D;64C,64D); and
the arcuate leading edge (62A;64A) and the arcuate trailing edge (62B;64B) are angled approximately fifteen to approximately seventy-five degrees.

11. The rotor (31 A) of claim 9 or 10, and further comprising a mini-disk disposed opposite the rotor (31A) to form a cooling channel (50) therebetween, the mini-disk (48) comprising:

an axially extending portion (48A) extending opposite the hub (38); and
a radially extending portion (48B) extending along the disk (34B) wherein cooling air (Ac) directed into the hole (40) from the inner diameter bore (46) flows along the hub (38) and along the disk (34B) to the slots (44).

12. The rotor (31A) of any of claims 9 to 11, wherein the arcuate leading edge (62A;64A) and the arcuate trailing edge (62B;64B) are countoured radially as they pass through the hub (38).

13. The rotor (31A) of any preceding claim, wherein the plurality of holes (40) is arranged in a circumferential row spaced evenly about the outer diameter surface (60B) or the hub (38).

14. The rotor (31A) of any preceding claim, wherein the plurality of holes (40) increases the swirl ratio across the hub (38) or the annular body (38) while decreasing pressure loss when the annular body (38) or the rotor (31A) is rotating about the axis (CL).

15. A method of passing flowing cooling air (Ac) through a rotating annular body (38), the method comprising:

rotating an annular body (38) about an axis (CL) in a circumferential direction (ω);
passing cooling air (Ac) through the annular body (38) in an axial direction;
turning the cooling air (Ac) in a radial direction (R) to pass through a plurality of holes (40) in the annular body (38) that are wider in the circumferential direction (ω) than in the axial direction; and
bending the cooling air (Ac) in a circumferential direction (ω) by passing over angled walls (58) of the plurality of holes (40), wherein optionally:

the holes (40) are angled into the direction of rotation (ω) approximately thirty to approximately forty degrees;
each of the cooling holes (40) has a racetrack shape profile; and/or
turning and bending of the cooling air (Ac) with the plurality of holes (40) increases the swirl ratio across the annular body (38) and decreases pressure loss with respect to holes (40) having circular profiles and unangled walls.

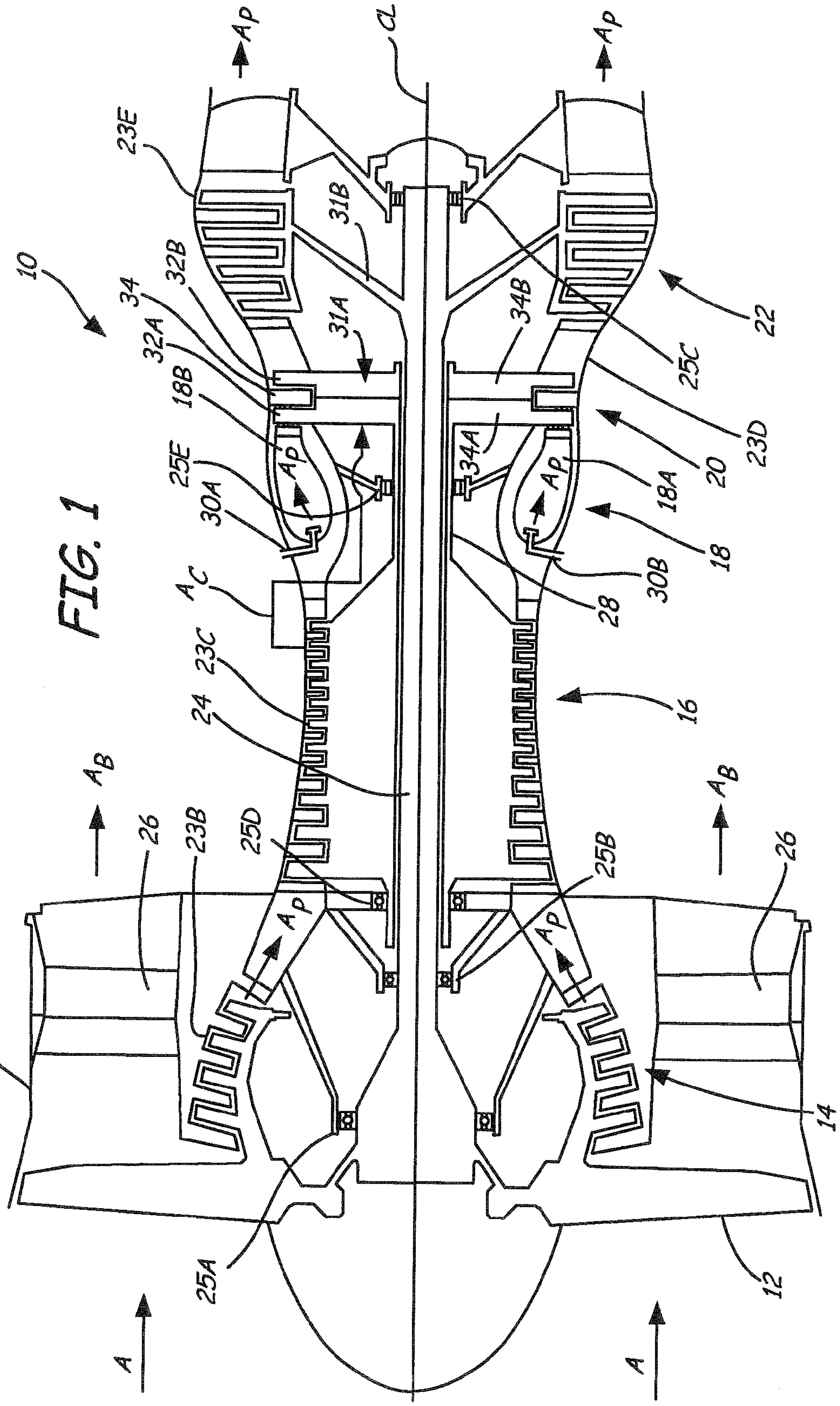
FIG. 1
10
A
A
AB
AB
AP
AP
AP
AP
AP
AP
AC
CL
12
14
16
18
18A
18B
20
22
23A
23B
23C
23D
23E
24
25A
25B
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32B
34
34A
34B

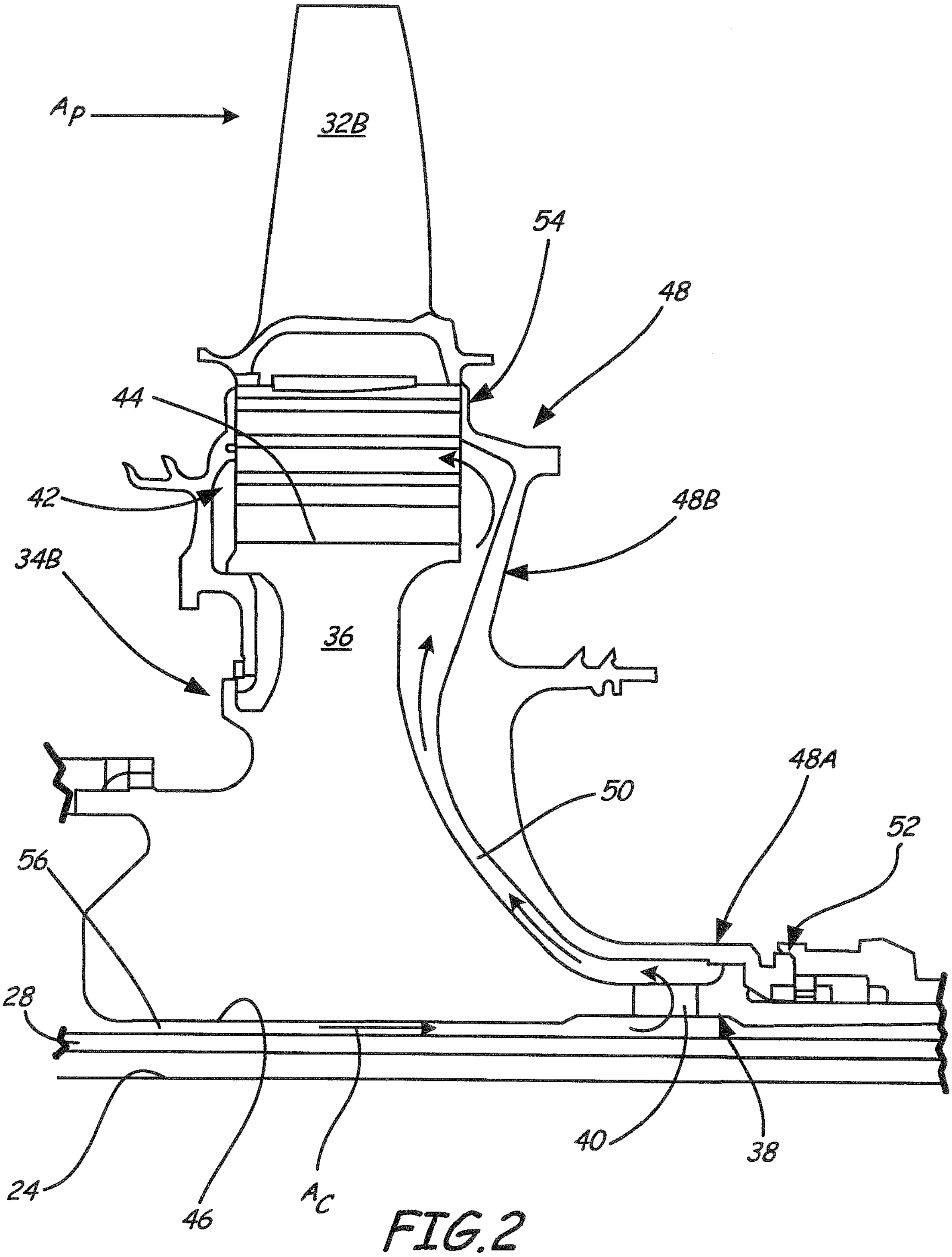

FIG.2

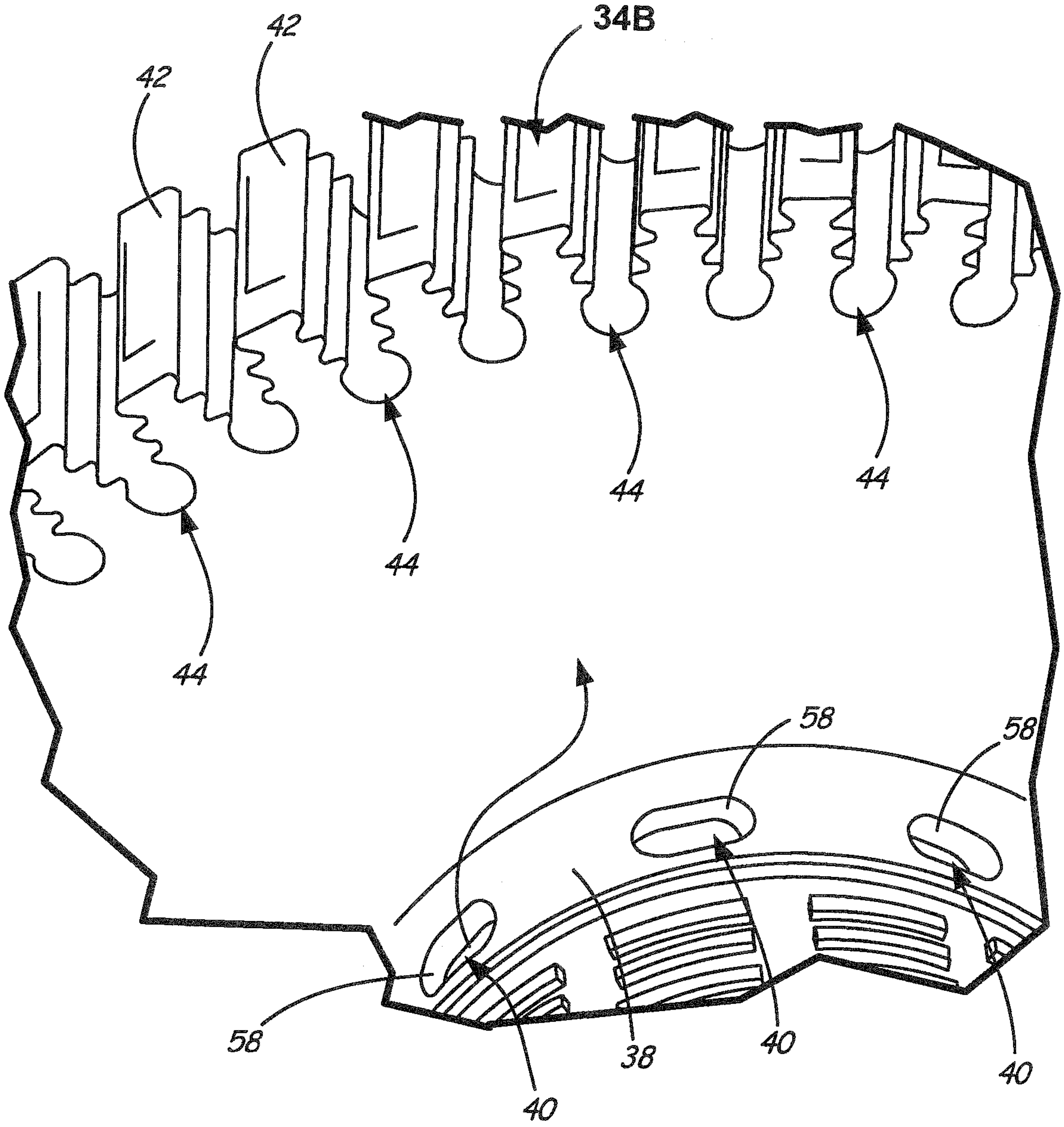

FIG.3

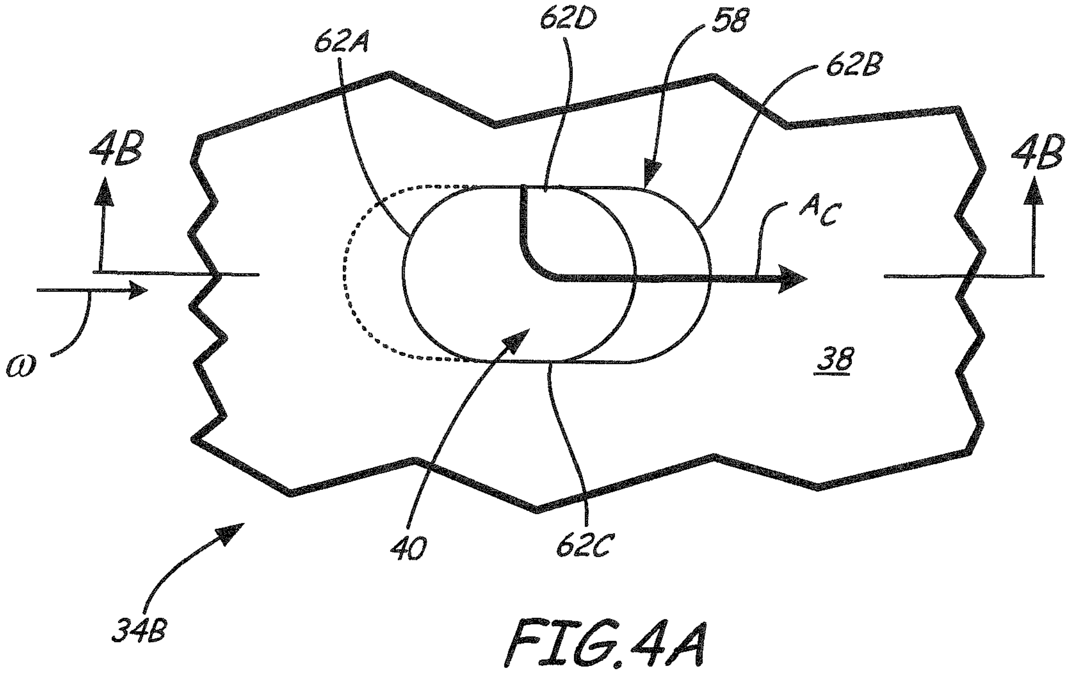
62A
62D
58
62B
4B
4B
A_C
ω
38
40
62C
34B

FIG.4A

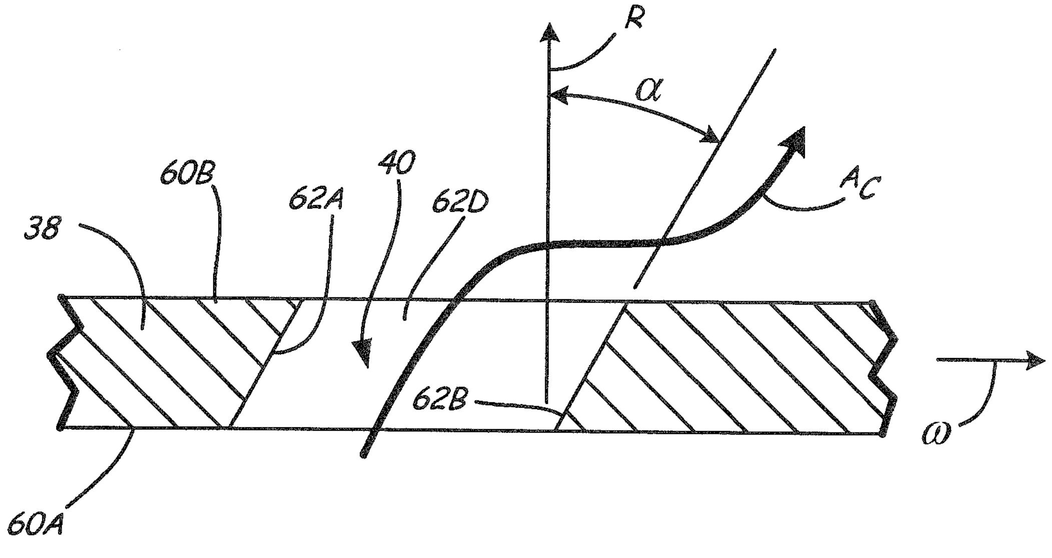
R
α
40
60B
62A
62D
A_C
38
62B
ω
60A

FIG.4B

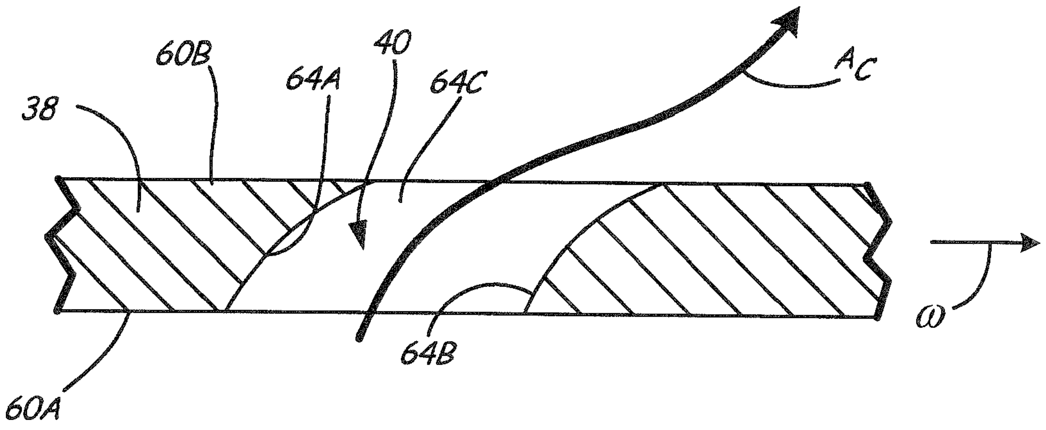

FIG.4C