(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 562 370 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
27.02.2013 Bulletin 2013/09

(51) Int Cl.:
F01D 25/14 *(2006.01)*

(21) Application number: **12181106.1**

(22) Date of filing: **20.08.2012**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(30) Priority: **25.08.2011 US 201113218224**

(71) Applicant: **Honeywell International Inc.**
Morristown, NJ 07962-2245 (US)

(72) Inventors:
- **Poon, Kin**
  Morristown, NJ 07962-2245 (US)
- **Howe, Jeff**
  Morristown, NJ 07962-2245 (US)
- **Barton, Michael T. Todd**
  Morristown, NJ 07962-2245 (US)
- **Mignano, Frank**
  Morristown, NJ 07962-2245 (US)
- **Mansour, Mahmoud**
  Morristown, NJ 07962-2245 (US)
- **Nolcheff, Nick**
  Morristown, NJ 07962-2245 (US)
- **Taylor, Scott**
  Morristown, NJ 07962-2245 (US)
- **Trzcinski, Steve**
  Morristown, NJ 07962-2245 (US)
- **Riahi, Ardeshir**
  Morristown, NJ 07962-2245 (US)
- **Guymon, Jeff**
  Morristown, NJ 07962-2245 (US)
- **Hemmingson, Alan**
  Morristown, NJ 07962-2245 (US)
- **Mirzamoghadam, Alex**
  Morristown, NJ 07962-2245 (US)

(74) Representative: **Houghton, Mark Phillip**
Patent Outsourcing Limited
1 King Street
Bakewell, Derbyshire DE45 1DZ (GB)

(54) Gas turbine engines with mid-impeller bleed cooling air

(57) Gas turbine engines and methods for cooling components thereof with mid-impeller bleed (MIB) cooling air having a pressure are provided. The gas turbine engine has a compressor (16) comprising an impeller body (56) and an impeller shroud (60) at least partially surrounding the impeller body. The impeller shroud has a plurality of MIB openings (61b) disposed therein. At least one edge treatment is provided thereto. The edge treatment substantially preserves pressure of the cooling air during entrance into and discharge out of the MIB opening. The plurality of MIB openings may be extended MIB openings in a thickened impeller shroud. The centerline of the MIB openings may be oriented to be substantially aligned with an averaged local absolute flow velocity vector of the cooling air at the inlet section of the MIB opening in order to extract cooling air in a direction that has a vector component in a tangential, an axial, and a radial flow direction.

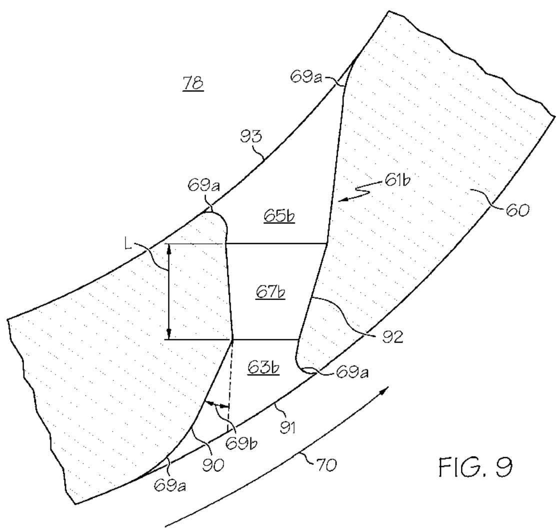

FIG. 9

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Description

TECHNICAL FIELD

[0001] The present invention generally relates to gas turbine engines, and more particularly relates to gas turbine engines and methods for cooling components thereof with mid-impeller bleed cooling air.

BACKGROUND

[0002] A gas turbine engine typically includes a compressor, a combustor, and a turbine. Airflow entering the compressor is compressed and directed to the combustor where it is mixed with fuel and ignited, producing hot combustion gases used to drive the turbine. Due to the high temperature of the combustion gases, the turbine must be cooled in order to maintain acceptable material temperatures for the turbine components. Typically, these turbine components are air cooled and cooling air is often channeled through a turbine cooling circuit to the turbine for use as a cooling source.

[0003] Extracting cooling air from the compressor may affect overall gas turbine engine performance. To minimize a reduction in engine performance, cooling air is typically extracted from the lowest compressor stage that has a sufficient pressure for the turbine. Generally, because the temperature of air flowing through the compressor increases at each stage of the compressor, utilizing cooling air extracted from the lowest feasible compressor stage results in a lower engine performance penalty. Furthermore, the turbine is cooled more effectively when the cooling air is extracted from a source having a lower temperature. In gas turbine engines including centrifugal compressors/impellers, cooling air is typically extracted at an inlet and/or exit of the centrifugal compressor/impeller. On one hand, cooling air extraction from the inlet of the centrifugal compressor may not have sufficient pressure for the turbine application for which it is intended. On the other hand, cooling air from the exit thereof is often at a higher pressure level than needed for turbine cooling. An associated engine performance loss results from utilizing cooling air at such an excessive pressure level. This is because additional work was done to compress such air making it thermodynamically expensive and furthermore cooling performance is adversely impacted because such air is at a higher temperature level. As a result, overall engine performance is affected and the turbine is ineffectively cooled.

[0004] It has been recognized that cooling air extraction from the middle of the centrifugal compressor/impeller (i.e., mid-impeller bleed ("MIB")) is thermodynamically less expensive than cooling air extracted from the exit of the centrifugal compressor, with cooler air, and better engine performance, but the pressure of the cooling air extracted mid-impeller is lower than at the exit. Pressure preservation is therefore an important aspect of a mid-impeller bleed system. In a conventional mid-impeller bleed (MIB) system, the cooling air is extracted from the engine flow path through substantially cylindrical bleed openings or slots (hereinafter a "conventional MIB opening") in a stationary impeller shroud of the centrifugal compressor. Conventional MIB openings are typically located between the inlet and exit of the impeller/centrifugal compressor at a constant radial distance from the engine centerline. Entrance and exit of cooling air into and out of conventional MIB openings result in pressure losses. Conventional bleed openings may have sharp edges at constant area inlet and outlet sections with a relatively short conical diffuser section between the inlet and outlet sections, contributing to such pressure losses. In addition, conventional MIB openings are oriented in the same plane normal to the direction of airflow permitting extraction of the larger tangential flow component only, while ignoring the smaller radial and axial flow components of the local velocity.

[0005] Accordingly, it is desirable to provide gas turbine engines and methods for cooling components thereof with mid-impeller bleed (MIB) cooling air. In addition, it is desirable to extract less thermodynamically expensive MIB cooling air while maximizing pressure, thereby preserving or recovering as much pressure as possible for subsequent applications. Furthermore, other desirable features and characteristics of the present invention will become apparent from the subsequent detailed description of the invention and the appended claims, taken in conjunction with the accompanying drawings and this background of the invention.

BRIEF SUMMARY

[0006] Methods are provided for cooling components of a gas turbine engine with mid-impeller bleed (MIB) cooling air having a pressure, according to exemplary embodiments of the present invention. The gas turbine engine has a compressor comprising an impeller body and an impeller shroud at least partially surrounding the impeller body. The impeller shroud has a plurality of MIB openings disposed therein. At least one edge treatment is provided to at least one MIB opening of the plurality of MIB openings in the impeller shroud. The at least one edge treatment substantially preserves the pressure of the MIB cooling air during entrance into, discharge out of, or both entrance into and discharge out of the at least one MIB opening.

[0007] A gas turbine engine is provided for cooling components thereof with cooling air in accordance with yet another exemplary embodiment of the present invention. The gas turbine engine includes a compressor that compresses intake air into intermediate pressure cooling air and high pressure air. The intermediate pressure cooling air is formed upstream of the high pressure air. The compressor comprises an impeller, an impeller shroud, and a plurality of MIB openings disposed in the impeller shroud. The plurality of MIB openings have a length co-terminating with a thickness of the impeller shroud, and an inlet section in flow communication with an engine flow path to extract the intermediate pressure cooling air therefrom, an outlet section in flow communication with a turbine, and a conical diffuser section between the inlet and outlet sections. The at least one MIB opening of the plurality of MIB openings has at least one edge treatment.

[0008] A compressor for a gas turbine engine is provided for cooling components thereof with cooling air in accordance with yet another exemplary embodiment of the present invention. The compressor comprises an impeller body having an exit and a thickened impeller shroud at least partially surrounding the impeller body. The thickened impeller shroud has a plurality of extended mid-impeller bleed (MIB) openings extending therethrough adapted to extract at least a portion of a tangential flow component, an axial flow component, and a radial flow component of cooling air from an engine flow path. The plurality of extended MIB openings is disposed at a distance from the exit of the impeller body. At least one extended MIB opening of the plurality of extended MIB openings has an inlet section, an outlet section, and an elongated conical diffuser section between the inlet and outlet sections. The inlet section has a leading edge and the outlet section has a trailing edge. The at least one extended MIB opening has a centerline orientation adapted to be substantially aligned with a local absolute flow velocity of the cooling air.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The present invention will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and

[0010] FIG. 1 is a flow diagram of a method for cooling components of a gas turbine engine, according to exemplary embodiments of the present invention;

[0011] FIG. 2 is a schematic diagram of a gas turbine engine for cooling components thereof with mid-impeller bleed ("MIB") cooling air;

[0012] FIG. 3 is a side cross-sectional view of a portion of the gas turbine engine of FIG. 2, illustrating an exemplary compressor thereof;

[0013] FIG. 4 is a side cross-sectional view of a conventional impeller shroud of the exemplary compressor of FIG. 3 superimposed over an exemplary thickened impeller shroud having an extended MIB opening, according to exemplary embodiments of the present invention;

[0014] FIG. 5 is schematic view of an exemplary impeller shroud/thickened impeller shroud, illustrating a plurality of MIB openings evenly spaced around the impeller shroud/thickened impeller shroud;

[0015] FIG. 6 is a top perspective view of an exemplary thickened impeller shroud;

[0016] FIG. 7 is a simplified two-dimensional cross-sectional view of a portion of the impeller shroud of FIG. 5 taken along line A-A thereof, illustrating a conventional MIB opening disposed therein and having exemplary edge treatments, according to exemplary embodiments;

[0017] FIG. 8 is a schematic view of a conventional MIB opening;

[0018] FIG. 9 is a simplified two-dimensional cross-sectional view of a portion of the thickened impeller shroud of FIG. 5 taken along line A-A thereof, illustrating an extended MIB opening disposed therein and having exemplary edge treatments, according to exemplary embodiments of the present invention;

[0019] FIG. 10 is a simplified two-dimensional sectional view similar to FIG. 9, according to other exemplary embodiments of the present invention;

[0020] FIG. 11 illustrates exemplary geometry of the plurality of extended MIB openings, according to exemplary embodiments of the present invention; and

[0021] FIGS. 12a-12c illustrate sequential angle orientations used in orienting a centerline of a MIB opening, according to exemplary embodiments of the present invention.

DETAILED DESCRIPTION

[0022] The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. As used herein, the word "exemplary" means "serving as an example, instance, or illustration." Thus, any embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments. All of the embodiments described herein are exemplary embodiments provided to enable persons skilled in the art to make or use the invention and not to limit the scope of the invention which is defined by the claims. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary, or the following detailed description.

[0023] Various exemplary embodiments are directed to gas turbine engines and methods for cooling components thereof with mid-impeller bleed (hereinafter "MIB") cooling air. Specially designed mid-impeller bleed openings (hereinafter "MIB openings") disposed in an impeller shroud of a compressor extract cooling airflow from an engine flow path and provide this cooling air to a plenum of the compressor for use in subsequently cooling the engine components. The dynamic pressure of the cooling airflow through the MIB openings is substantially recovered by providing the MIB openings with at least one edge treatment. Unless otherwise specified, the term "MIB openings" as used herein includes both conventional MIB openings and extended MIB openings according to exemplary embodiments, as hereinafter described. The extended MIB openings are disposed in a thickened impeller shroud according to exemplary embodiments, as hereinafter described. Unless otherwise specified, the term "impeller shroud" as used herein includes both a conventional impeller shroud and the thickened impeller shroud. As used herein, the term "dynamic pressure" means pressure associated with the kinetic energy of the airflow. The term "dynamic pressure recovery" or the like refers to a reduction of dynamic pressure with resultant increase in static pressure by reducing the velocity of the airflow in a manner that minimizes pressure losses, i.e., by gradually increasing flow area in the direction of flow. Thus, "dynamic pressure recovery" as used herein means the conversion of dynamic pressure into static pressure. The methods as described herein, according to exemplary embodiments, permit the preservation of dynamic pressure to maximize the amount thereof that can be converted to static pressure by, for example, minimizing pressure loss. The extended MIB openings are more effective at dynamic pressure recovery than conventional MIB openings. The centerline of the MIB openings may additionally or alternatively be oriented to be substantially aligned with an averaged local total flow velocity vector to extract tangential, radial, and axial flow components of the cooling airflow, thus also improving dynamic pressure recovery over conventional MIB openings that substantially ignore the radial and axial flow components.

[0024] Referring to FIGS. 1 and 2, in accordance with an exemplary embodiment, a method 10 for cooling components of a gas turbine engine with mid-impeller bleed (MIB) cooling air begins by forming an impeller shroud for use in a compressor of a gas turbine engine (step 100). In accordance with exemplary embodiments, the impeller shroud may be a thickened impeller shroud, as hereinafter described. FIG. 2 is a simplified schematic illustration of a gas turbine engine 12 including a compressor 16, a combustor 18, and a turbine 20. The compressor 16, combustor 18, and turbine 20 are in flow communication. Compressor 16 and turbine 20 are coupled by a shaft 22. Shaft 22 rotates about an axis of symmetry, which is the centerline of the shaft 22. In operation, air 15 flows through the compressor 16 and compressed inlet air 80 is supplied from compressor 16 to combustor 18 and is then mixed with fuel 17 provided by fuel nozzles (not shown) and ignited within the combustor 18 to produce hot combustion gases 19. The hot combustion gases 19 drive turbine 20. Intermediate pressure cooling air 76 flows from the compressor 16 to the turbine 20 through a cooling circuit 40 to cool the turbine components. It is to be understood that only one compressor and one turbine are shown for ease of illustration, but multiple compressors and turbines may be present in the gas turbine engine.

[0025] FIG. 3 is a side cross-sectional schematic illustration of a portion of the gas turbine engine 12 including an exemplary compressor 16. Compressor 16 includes a centrifugal compressor, or impeller 50, and the cooling circuit 40 (not shown in FIG. 3). The centrifugal compressor/impeller 50 includes an impeller inlet 62, an impeller exit 52, a hub 54, and a rotating impeller body 56 extending therebetween. As illustrated, the centrifugal compressor 50 also includes a non-rotating conventional impeller shroud 58 or thickened impeller shroud 60 (not shown in FIG. 3) that surrounds at least a portion of the impeller body 56, as hereinafter described. The impeller body 56 and impeller shroud 58 or 60 (impeller shroud 60 not shown in FIG. 3) extend radially outward from the impeller inlet 62 to the impeller exit 52. Impeller hub 54 is coupled circumferentially to a rotor shaft (not shown).

[0026] In FIG. 4, the conventional impeller shroud 58 of FIG. 3 is superimposed over an exemplary thickened impeller shroud 60 to illustrate an exemplary difference in thickness between the impeller shrouds. It is to be understood that the thickness of the thickened impeller shroud may be varied and other features of the thickened impeller shroud 60 may be adjusted to accommodate different embodiments of the gas turbine engine 12. For example, the conventional impeller shroud 58 may be .075 inches thick while the thickened impeller shroud 60 may be 0.280 inches thick, but other thicknesses for the conventional impeller shroud 58 and the thickened impeller shroud 60 may be used depending on operating conditions and performance requirements of the turbine engines in addition to geometry and manufacturing constraints, as known to one skilled in the art. For example, thickness may be a tradeoff between pressure recovery and impeller weight. Each engine has different tradeoff values depending on the relative importance of performance and weight. Other considerations include deflection and vibratory response of the impeller shroud. As for the adjustment of other features, for example, the thickened impeller shroud 60 illustrated in FIG. 4 has a lowered arm 59 to create the plenum 78, for purposes as hereinafter described. In addition, the configuration of the compressor 16 (FIG. 3) may vary to accommodate the thickened impeller shroud.

[0027] The step of forming the impeller shroud further comprises forming a plurality of MIB openings therein. The plurality of MIB openings is disposed in the impeller shroud at a distance from the impeller exit of the impeller body, as hereinafter described. The plurality of MIB openings may be conventional MIB openings 61a disposed in a conventional impeller shroud 58 (shown in dotted lines through the conventional impeller shroud 58 of FIG. 3) or, in accordance with exemplary embodiments, extended MIB openings 61b in the thickened impeller shroud 60 (one extended MIB opening 61b illustrated in FIG. 4). The plurality of MIB openings (both conventional and extended) have a length co-terminating with the thickness of the impeller shroud and may be evenly spaced around the impeller shroud (FIGS. 5 and 6). The number and size of the MIB openings may vary depending upon the impeller shroud as well as the density and flow magnitude of the MIB cooling air.

[0028] Referring again to FIG. 4, in accordance with exemplary embodiments, the thickened impeller shroud 60 may be thicker where the plurality of extended MIB openings 61b are disposed (i.e., localized thickening). While localized thickening has been described, it is to be understood that the thickened impeller shroud 60 may be thicker in additional portions thereof including the entire length thereof, but such additional thickening may undesirably result in adding excessive weight to the gas turbine engine. The thickened impeller shroud permits the extended MIB openings 61b disposed therein to be longer than the conventional MIB openings 61a in the conventional impeller shroud 58, as hereinafter described. The thickened impeller shroud also permits sufficient room for the desired MIB opening geometry (i.e., desired area ratio and angles (See FIGS. 12a-12c)).

[0029] Referring now to FIGS. 7 and 8, conventional MIB openings 61a are configured or formed with a cylindrical inlet section 63a, a cylindrical outlet section 65a, and a substantially conical diffuser section 67a between the cylindrical inlet and outlet sections. As illustrated in FIG. 7, the cylindrical inlet section 63a has conventional sharp edges 88 at an entrance 91 thereof. According to exemplary embodiment, a conventional MIB opening 61a may include at least one edge treatment, as hereinafter described. The cylindrical outlet section 65a of the illustrated conventional MIB opening 61a (FIG. 7) has exemplary edge treatments at an exit 93 thereof, as hereinafter described. The cylindrical inlet and outlet sections 63a and 65a have a constant area.

[0030] Referring now to FIGS. 9 through 11, the extended MIB openings 61b are more effective than conventional MIB openings 61a (FIGS. 7 and 8) at dynamic pressure recovery. In accordance with exemplary embodiments, the extended MIB openings 61b are configured or formed with an increased area inlet section 63b, an increased area outlet section 65b, and an elongated conical diffuser section 67b therebetween. The increased area inlet and outlet sections 63b and 65b of the extended MIB openings 61b have an increased area ratio (hereinafter described) relative to the cylindrical inlet and outlet sections 63a and 65a of the conventional MIB openings 61 a. The increased area inlet and outlet sections are alternatively referred to herein as "extended inlet and outlet sections."

[0031] Geometry of the MIB openings is defined in terms of the following dimensions (See, e.g., FIG. 8 (conventional MIB opening 61a) and FIG. 11 (extended MIB opening 61b)):

L=length of conical diffuser section

d_1=inlet section diameter

d_2=outlet section diameter

L/d_1=length of conical diffuser section/ inlet section diameter

Divergence cone angle=2θ

Area ratio= d_2^2/d_1^2

[0032] The area ratio = d_2^2/d_1^2 applies to MIB openings having a circular cross-section. While the MIB openings 61a and 61b are described with a circular cross-sectional area perpendicular to the bulk flow direction through the MIB opening and the same is shown through the accompanying figures, it is to be understood that MIB openings having a non-circular cross-section perpendicular to the bulk airflow through the MIB opening (i.e., a "non-circular cross-sectional flow area") may be used in other embodiments, in which case "diameter" is determined by the hydraulic diameter (Dh) defined by the following equation: Dh=4*(Flow Area)/(Wetted Perimeter)
wherein:

flow area=cross-sectional area perpendicular to the bulk airflow through the non-circular MIB opening; and

wetted perimeter=perimeter of the Flow Area in contact with the airflow.

[0033] The extended MIB openings 61b have a greater L/d_1 relative to the L/d_1 of conventional MIB openings 61a with a reasonable cone angle because of the greater length (L) of the extended MIB openings 61b. In accordance with exemplary embodiments, the thickened impeller shroud 60 creates room for the extended MIB openings 61b, providing additional area for the extended MIB openings 61b and for at least one edge treatment, as hereinafter described. An area ratio (d_2^2/d_1^2) of about 1 to about 3 is preferred, but higher or lower area ratios may be used. The thickened impeller shroud and the longer length (L) of the elongated conical diffuser section in the extended MIB openings 61b relative to the conical diffuser section in the conventional MIB openings 61a substantially ensures a reasonable cone angle at a given area ratio. In general, the longer the length (L) for a given area ratio, the more efficient the conical diffuser section is in converting inlet dynamic pressure into static pressure at an exit of the MIB opening. It is known that a higher L/d_1 provides improved pressure recovery, with less variability in diffuser area ratio and more consistent MIB opening performance. The divergence cone angle of the (elongated) conical diffuser section is generally between about 0 degrees and about 15 degrees, although it is to be understood that higher divergence cone angles may be used. For a given L, the higher the divergence cone angle, the higher the area ratio. With the thinner conventional impeller shroud 58, there may not be enough room for an optimal divergence cone angle. However, if the divergence cone angle of the conical diffuser section is too great, flow separation within the MIB opening may occur. The thickened impeller shroud 60 also makes it easier to substantially align a centerline of the extended MIB openings 61b with an averaged local absolute total flow velocity vector of the MIB cooling air at the MIB opening inlet, as hereinafter described. As noted above, the extended MIB openings 61b provide better dynamic pressure recovery than conventional MIB openings 61a.

[0034] In accordance with exemplary embodiments, the step of forming the impeller shroud further comprises orienting a centerline 94 of each of the MIB openings of the plurality of MIB openings to be substantially aligned with the averaged local absolute flow velocity of the MIB cooling air at the inlet of the MIB opening. While the orientation of extended MIB openings disposed in the thickened impeller shroud 60 is hereinafter described, conventional MIB openings 61a may have their centerline oriented in impeller shroud 58 in the same manner as noted below in order to extract tangential, axial, and radial flow components of the cooling air, unlike conventional MIB openings that do not have their centerline substantially aligned with the averaged local absolute flow velocity of the MIB cooling air at the inlet of the MIB opening. Without such centerline orientation, only a fraction of the tangential flow component is extracted and the axial and radial velocity components are ignored. Referring now to FIGS. 12a-12c, in accordance with exemplary embodiments, the centerline 94 of each of the extended MIB openings 61b in the thickened impeller shroud 60 is oriented to be substantially aligned with the averaged local absolute flow velocity (averaged local airflow velocity vector of the engine flow path (indicated by arrow 70) (FIGS. 9 and 10)) near the surface of the thickened impeller shroud 60 at the entrance of the increased area inlet section of the extended MIB openings. As used herein, the term "substantially" means within manufacturing constraints. The averaged absolute flow velocity vector includes tangential, axial, and radial flow components. The centerline orientation of the extended MIB openings enables extraction of tangential, axial, and radial flow components, unlike conventional MIB openings that extract only the tangential flow component. Each extended MIB opening 61b extends through the thickened impeller shroud 60 at a predetermined tangential angle, a predetermined axial angle, and a predetermined radial angle. As more than one flow component is extracted, the dynamic pressure recovery will increase. Two rotation angles β and γ are used to define the extended MIB opening centerline orientation to permit substantial alignment with the averaged local absolute flow velocity vector at the entrance of the extended MIB opening. The first angle is defined by the line 12c-12c in FIG. 12b and the tangential/circumferential direction at the entrance of the extended MIB opening. The second angle γ is formed by rotating line 12c-12c about point C on the plane formed by line 12c-12c and copy 3 in a direction such that the line 12c-12c intersects the exit plenum 78, as illustrated in FIG. 12c. Each of the extended MIB openings in the thickened impeller shroud has a different plane. The first angle β may be determined, for example, by Computational Fluid Dynamics (CFD) software. The second angle γ is a function of impeller shroud geometry, MIB opening location in the impeller shroud, as well as manufacturing constraints.

[0035] Referring specifically to FIG. 12a, the centerline 94 of the extended MIB opening 61b is first substantially aligned with the local absolute flow velocity in a perpendicular axis X to the flow path at the inlet to the extended MIB opening 61b. The centerline orientation is adapted to be substantially aligned with the averaged local absolute flow velocity vector. In FIG. 12a, a dimension d from the intersection I of datums A and B locates the perpendicular axis X. In general, dimension d varies from design to design and also engine to engine. Angle α from datum B represents the angular dimension that locates axis X. Point C is created at the intersection of that axis and the flow path. From that point, the axis is copied twice and rotated. One copy rotates 90 degrees counter clockwise and parallel to the drawing sheet, the other is rotated 90 degrees into the paper. These 2 copies form a plane that is perpendicular to the original axis and the plane of the paper. FIG. 12b is a view that looks directly at that plane. In FIG. 12b, there are two copies of the original perpendicular axis X (identified as "first copy" and "second copy" in FIG. 12b.) The second copy runs through Point C and is located by dimension d. For reference, the original axis X is perpendicular to the plane of the paper in section FIG. 12b. At this point, a copy of axis copy 1 ("copy 3") and axis copy 2 ("copy 4") are rotated a first rotation angle (angle β) through Point C. A planar cut is taken through copy 4 (perpendicular to the paper). This is FIG. 12c. Axis copy 3 extends from FIG. 12b to FIG. 12c. In FIG. 12c, 90 degrees clockwise from axis copy 3, a top view of axis copy 4 can be seen. From there, a copy of axis copy 4 is taken and rotated a second rotation angle (angle γ) counter clockwise. This becomes the centerline 94 of the extended MIB opening 61b. The second rotation angle enables the outlet section 65b of the extended MIB opening to break out into the plenum 78.

[0036] Once the centerline orientation of the first MIB opening in the impeller shroud has been determined as described above, the other MIB openings in the impeller shroud may be generated by rotating the impeller shroud to define a MIB opening pattern. The other MIB openings have substantially the same orientation relative to datums A and B as the first MIB opening therein. Alternatively, the centerline orientation of each of the MIB openings in the impeller shroud may be determined independently using the two rotation angles as described above.

[0037] Substantial alignment of the centerline 94 of the extended MIB opening with the averaged local airflow velocity vector is to maximize the capture of dynamic pressure of the cooling air and convert it into static pressure inside the plenum where the cooling air is collected for delivery to the cooling destinations in the turbine. The plenum 78 is a manifold of the compressor where cooling air from all MIB openings is collected, as hereinafter described.

[0038] EXAMPLE

[0039] The following example is provided for illustration purposes only, and is not meant to limit the various embodiments of the present invention in any way. In an exemplary thickened impeller shroud of 0.280 inches thick, the geometry and orientation of an exemplary extended MIB opening may be as follows, with reference to the figures as indicated:

Geometry (FIGS. 9-11)

d_1=0.097 inch diameter at inlet section

d_2=0.137 inch diameter at outlet section

L=0.329 inches

Θ=3.5° (half angle)

L/d_1=3.4

Area ratio=d_2^2/d_1^2=2.0

Centerline orientation (FIGS. 12a-12c)

angle (α) (FIG. 12a) =36°

First Rotation angle (β) (FIG. 12b) =20°

Second Rotation angle (γ) (FIG. 12c) =18°

Dimension x=2.8 inches

[0040] Referring again to FIG. 1 and to FIGS. 7, 9 and 10, in accordance with exemplary embodiments, method 10 continues by providing at least one edge treatment to at least one MIB opening of the plurality of MIB openings in the impeller shroud (step 200). The at least one edge treatment 69a and 69b substantially preserves the pressure of the MIB cooling air during entrance into or discharge out of the at least one MIB opening. It is to be understood that the term "entrance into or discharge out of" includes entrance into, discharge out of, or entrance into and discharge out of the at least one MIB opening. The plurality of MIB openings 61a and 61b may be provided with at least one edge treatment at one or both of a leading and a trailing edge 90 and 92 at the entrance 91 to the inlet section 63a and 63b and/or at the exit 93 of the outlet section 65a and 65b. The leading and/or trailing edges may be shaped to define the at least one edge treatment. The edge treatments help to reduce airflow entrance and exit pressure losses, thereby improving the amount of dynamic pressure recovery by the MIB openings. The leading edge and/or trailing edge at the entrance 91 to the inlet section may be shaped to direct and orient the flow of cooling air entering the inlet section of the MIB opening. The leading and/or trailing edge at the exit 93 of the outlet section may be shaped to enhance the discharge of cooling air from the outlet section of the MIB openings into the plenum 78, as hereinafter described. Edge treatments are where the MIB opening breaks through the impeller shroud. Edge treatments may include a rounded edge with a radius (hereinafter a "radial edge" 69a), a chamfered edge (hereinafter an "angled edge" 69b), or a combination thereof. The size of the radius is dependent on the thickness of the impeller shroud and may vary around the periphery of the MIB opening. A forward angled edge 69b at the leading edge 90 at the entrance 91 of the MIB opening reduces the amount of turning required for the cooling airflow to enter the MIB opening resulting in reduced pressure loss. The angled edge 69b at the leading 90 and/or trailing 92 edges at the entrance 91 and/or exit 93 may be from 0 to about 30 degrees, preferably about 15 degrees. However, an angled edge 61b greater than 30 degrees may be used in other embodiments. Conventional sharp edges 88 may be used at the leading and/or trailing edges at the entrance and exit of the MIB openings where there are no edge treatments. Referring again to FIG. 7, the leading edge of the illustrated conventional MIB opening 61a has exemplary conventional sharp edges 88 at the leading and trailing edges 90 and 92 at the entrance 91 to the cylindrical inlet section 63a. The leading and trailing edges 90 and 92 at the exit 93 of the cylindrical outlet section 65a have exemplary radial edges 69a.

[0041] Referring specifically to FIG. 9, the leading edge 90 at the entrance 91 to the illustrated extended MIB opening 61b has both a radial edge 69a and a forward angled edge 69b, and the trailing edge 92 at the entrance has a radial edge 69a. The leading and trailing edges 90 and 92 at the exit 93 both have exemplary radial edges 69a. The dotted line in FIG. 9 indicates a conventional sharp edge at the entrance 91 to the cylindrical inlet section 63a of a conventional MIB opening 61 a for comparison purposes.

[0042] Referring specifically to FIG. 10, the leading edge 90 at the entrance 91 to the illustrated extended MIB opening 61b has both a radial edge 69a and a forward angled edge 69b, and the trailing edge 92 at the entrance has a radial edge 69a in the same manner as FIG. 9. The leading edge 90 at the exit 93 has an exemplary radial edge 69a. The trailing edge 92 at the exit 93 of the extended MIB opening 61b terminates with an angled edge 69b, with the outlet section 65b continued from the elongated conical diffuser section 67b, as indicated by arrow C. The outline of the conventional MIB opening with a constant area cylindrical inlet and outlet sections is shown in dotted lines. While particular edge treatments at the leading and/or trailing edges of the entrance to the inlet section and/or at the leading and/or trailing edges at the exit of the outlet section of MIB openings have been described, it is to be understood that edge treatments other than those illustrated may be used or no edge treatments at all (thus having sharp edges). It is to be understood that edge treatments of a conventional MIB opening 61a will be constrained by the smaller thickness of the conventional impeller shroud relative to edge treatments of an extended MIB opening 61b in the thickened impeller shroud. It is also to be understood that all or at least one of the plurality of MIB openings in the impeller shroud are/is configured to include the at least one edge treatment, if at all.

[0043] The impeller shroud may be formed prior to or substantially simultaneously with the step of providing at least one edge treatment. In addition, while "formation" of an impeller shroud is described, it is to be understood that the at least one edge treatment may be provided to at least one MIB opening in a commercially available impeller shroud having a plurality of MIB openings disposed therein.

[0044] Referring again to FIGS. 2 and 3, the plurality of MIB openings 61a or 61b (MIB openings 61b not shown in FIG. 3) disposed in the impeller shroud 58 or 60 between the impeller inlet 62 and impeller exit 52 are at a constant radial distance 74 from an engine centerline 26 and upstream from the impeller exit 52. The radial distance 74 varies in different embodiments of gas turbine engine 12 based on pressure level requirements for turbine 20, such requirements known to one skilled in the art. As known in the art, the plurality of MIB openings is disposed as forward as possible in the impeller shroud to enable extraction of the less thermodynamically expensive cooling air, as hereinafter described.

[0045] The cooling circuit 40 of the compressor is in flow communication with both the centrifugal compressor 50 and turbine 20 (not shown in FIG. 3). Cooling circuit 40 includes a plurality of piping (not shown) extending between the compressor 16 and the turbine 20 and permits a portion of the intermediate pressure cooling air 76 to be directed to cool components of the turbine 20. A coupling (not shown) permits the cooling circuit piping to attach to the compressor 16 in flow communication with the plenum 78 and the plurality of MIB openings 61a and/or 61b, i.e., the plenum is in flow communication between the cooling circuit and the plurality of MIB openings.

[0046] The combustor 18 (not shown in FIG. 3) is positioned downstream from the compressor 16 and the turbine 20 (not shown in FIG. 3) is coupled coaxially with compressor 16 downstream from combustor 18. The turbine 20 is in flow communication with the combustor 18. The impeller exit 52 is in flow communication with a diffuser 82. Diffuser 82 is positioned radially outward from the centrifugal compressor 50 and includes a diffuser inlet 84 and a diffuser outlet 85. Diffuser inlet 84 is adjacent the impeller exit 52 and permits compressed inlet air 80 to exit centrifugal compressor/impeller 50 serially into diffuser 82. A deswirl cascade 86 is in flow communication with diffuser 82 and extends from diffuser outlet 85.

[0047] During operation of the gas turbine engine, as illustrated in FIG. 3, inlet air 15 (FIG. 2) enters compressor 16 and is compressed by the plurality of compressor stages (not shown) prior to entering the centrifugal compressor 50. As the impeller body rotates, compressed inlet air 80 enters impeller from an engine flow path (indicated by arrow 70) and is channeled towards the diffuser 82. Compressed inlet air 80 exiting diffuser 82 passes serially through the deswirl cascade 86 to mix with fuel 17 (FIG. 2) provided by fuel nozzles (not shown) and ignited within the combustor 18 (FIG. 2) to produce hot combustion gases 19 (FIG. 2). The resulting hot combustion gases drive the turbine 20 (FIG. 2). Simultaneously, a portion of the compressed inlet air 80 is extracted from the impeller to the cooling circuit 40 (FIG. 2) through the plurality of MIB openings 61a or 61b. The compressed inlet air 80 is extracted where the MIB openings intersect the engine flow path. The plurality of MIB openings permits intermediate pressure cooling air 76 to exit the impeller into the plenum 78. The inlet section of each MIB opening is adapted to receive the compressed inlet air 80 from the impeller and the outlet section is configured to discharge intermediate pressure cooling air 76 into the plenum 78. The plenum 78 is in flow communication with the plurality of MIB openings and the cooling circuit and is disposed adjacent impeller body 56 upstream from impeller exit 52. The plenum 78 collects the intermediate pressure cooling air 76 and provides a uniform, uninterrupted flow of intermediate pressure cooling air 76 to cooling circuit 40 (FIG. 2). The compressed inlet air 80 from the compressor has a tangential vector component, an axial vector component, and a radial vector component. The (elongated) conical diffuser section converts dynamic pressure at the inlet section into static pressure at the outlet section of each of the MIB openings. Thus, the airflow dynamic pressure is converted into static pressure inside the MIB openings and inside the plenum 78.

[0048] The gas turbine engine components are cooled with MIB cooling air supplied to the turbine (not shown in FIG. 3) from the cooling circuit. The MIB cooling air 76 that is extracted or discharged from the plurality of MIB openings is "intermediate pressure cooling air". The pressure of the intermediate pressure air is lower than that of the high pressure compressed inlet air 80 extracted from the impeller exit 52. The lower compression work required helps minimize the impact of a mid-impeller bleed on overall turbine engine efficiency. Additionally, the temperature of the intermediate pressure cooling air 76 will be cooler than the high pressure compressed inlet air 80 extracted from the impeller exit 52 as less compression work has been done on it. The intermediate pressure cooling air will cool the turbine more effectively than the high pressure compressed inlet air 80 that exits through the impeller exit 52.

[0049] The cooling circuit piping (not shown) channels the intermediate pressure cooling air 76 aftward to the turbine 20. The intermediate pressure cooling air 76 reduces turbine temperatures which improves mechanical capability and rotor durability. The desired temperature and pressure of cooling air 76 extracted mid-impeller are determined by the temperature and pressure requirements of the application for which the cooling air is to be used. While the cooling air is shown in FIG. 2 as cooling a turbine, it is to be understood that there are multiple other uses for MIB cooling air. One skilled in the art with knowledge of the application can determine the required temperature and pressure of the cooling air, depending on its intended use.

[0050] From the foregoing, it is to be appreciated that the gas turbine engines and methods for cooling components thereof with mid-impeller bleed (MIB) cooling air according to exemplary embodiments of the present invention provide improved pressure recovery by extracting cooling air through MIB openings having a configuration, geometry, and orientation according to exemplary embodiments as described herein. The MIB openings according to exemplary embodiments maximize pressure of the cooling air and reduce pressure losses thereof associated with cooling airflow entrance into and/or exit therefrom, thereby providing sufficient pressure for the turbine application for which the cooling air is intended and permitting use of thermodynamically less expensive cooling air, resulting in improving overall engine performance and effectively cooling the components of the gas turbine engine.

[0051] While at least one exemplary embodiment has been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention. It being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

Claims

1. A method (10) for cooling components of a gas turbine engine with mid-impeller bleed (MIB) cooling air having a pressure, the gas turbine engine having a compressor comprising an impeller body and an impeller shroud at least partially surrounding the impeller body, the method comprising:

   providing at least one edge treatment to at least one MIB opening of a plurality of MIB openings disposed in the impeller shroud, the at least one edge treatment substantially preserving the pressure of the MIB cooling air during entrance into, discharge out of, or both entrance into and discharge out of the at least one MIB opening (200).

2. The method of claim 1, further comprising the step (100) of forming an impeller shroud comprising forming the plurality of MIB openings disposed therein, each MIB opening of the plurality of MIB openings having an inlet section, an outlet section, and a conical diffuser section between the inlet and outlet sections, the entrance into the at least one MIB opening at the inlet section and the exit out of the at least one MIB opening at the outlet section.

3. The method as claimed in any one of claims 1 to 2, wherein the step (100) of forming the impeller shroud comprises forming a thickened impeller shroud and wherein the plurality of MIB openings comprise a plurality of extended MIB openings disposed in the thickened impeller shroud each having an extended inlet section, an extended outlet section, and an elongated conical diffuser section between the extended inlet and outlet sections.

4. The method as claimed in any one of claims 1 to 3, wherein the step (200) of providing at least one edge treatment comprises providing the at least one edge treatment at one or both of a leading edge and a trailing edge of one or both of an entrance into and an exit out of the at least one MIB opening and wherein the step of providing at least one edge treatment comprises providing a radial edge, an angled edge, or a combination thereof.

5. The method as claimed in any one of claims 1 to 4, wherein the step (100) of forming the impeller shroud comprises orienting a centerline of each MIB opening of the plurality of MIB openings to be substantially aligned with an averaged local absolute flow velocity vector of the MIB cooling air at the inlet section of each MIB opening.

6. The method as claimed in any one of claims 1 to 5, wherein the step (100) of forming the impeller shroud comprises orienting the plurality of MIB openings to extend through the impeller shroud at a predetermined tangential angle, a predetermined axial angle, and a predetermined radial angle to extract the MIB cooling air in a direction that has a vector component in a tangential, an axial, and a radial flow direction.

7. A gas turbine engine including a compressor that compresses inlet air into intermediate pressure cooling air and high pressure air, the intermediate pressure cooling air formed upstream of the high pressure air, the compressor comprising
   an impeller;
   an impeller shroud; and
   a plurality of MIB openings disposed in the impeller shroud and having a length co-terminating with a thickness of the impeller shroud, and each MIB opening of the plurality of MIB openings having an inlet section in flow communication with an engine flow path to extract the intermediate pressure cooling air therefrom, an outlet section in flow communication with a turbine, and a conical diffuser section between the inlet and outlet sections, at least one MIB opening of the plurality of MIB openings having at least one

edge treatment, wherein the at least one edge treatment is at one or both of a leading edge and a trailing edge of one or both of an entrance into the inlet section and an exit of the outlet section and the at least one edge treatment comprises a radial edge, an angled edge, or a combination thereof.

8. The gas turbine engine of claim 7, wherein a centerline orientation of each MIB opening of the plurality of MIB openings is substantially aligned with an averaged local absolute flow velocity vector of the intermediate pressure cooling air to extract tangential, axial, and radial velocity flow components therefrom.

9. A compressor for a gas turbine engine, the compressor comprising:

an impeller body having an impeller exit;
a thickened impeller shroud at least partially surrounding the impeller body and having a plurality of extended mid-impeller bleed (MIB) openings extending therethrough adapted to extract at least a portion of a tangential flow component, an axial flow component, and a radial flow component of cooling air from an engine flow path and disposed at a distance from the impeller exit, the plurality of extended MIB openings each having:

an inlet section, an outlet section, and an elongated conical diffuser section between the inlet and outlet sections, the inlet section having a leading edge and a trailing edge at an entrance thereof and the outlet section having a leading edge and a trailing edge at an exit thereof;
a centerline orientation adapted to be substantially aligned with an averaged local absolute flow velocity vector of the cooling air at the inlet section of the extended MIB opening.

10. The compressor of claim 9, wherein one or both of the leading and trailing edges at one or both of the entrance and exit of the extended MIB opening is shaped to define at least one edge treatment, the at least one edge treatment comprising a radial edge, an angled edge, or a combination thereof.

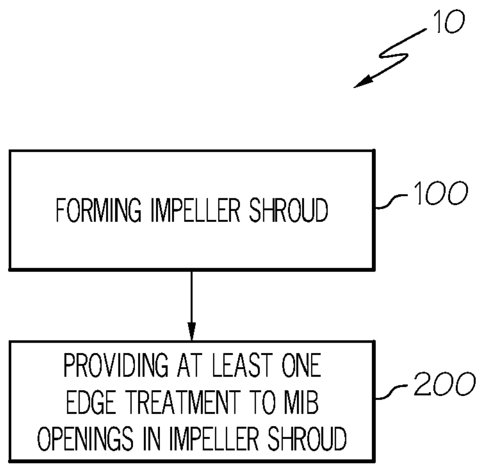
10
FORMING IMPELLER SHROUD
100
PROVIDING AT LEAST ONE EDGE TREATMENT TO MIB OPENINGS IN IMPELLER SHROUD
200

FIG. 1

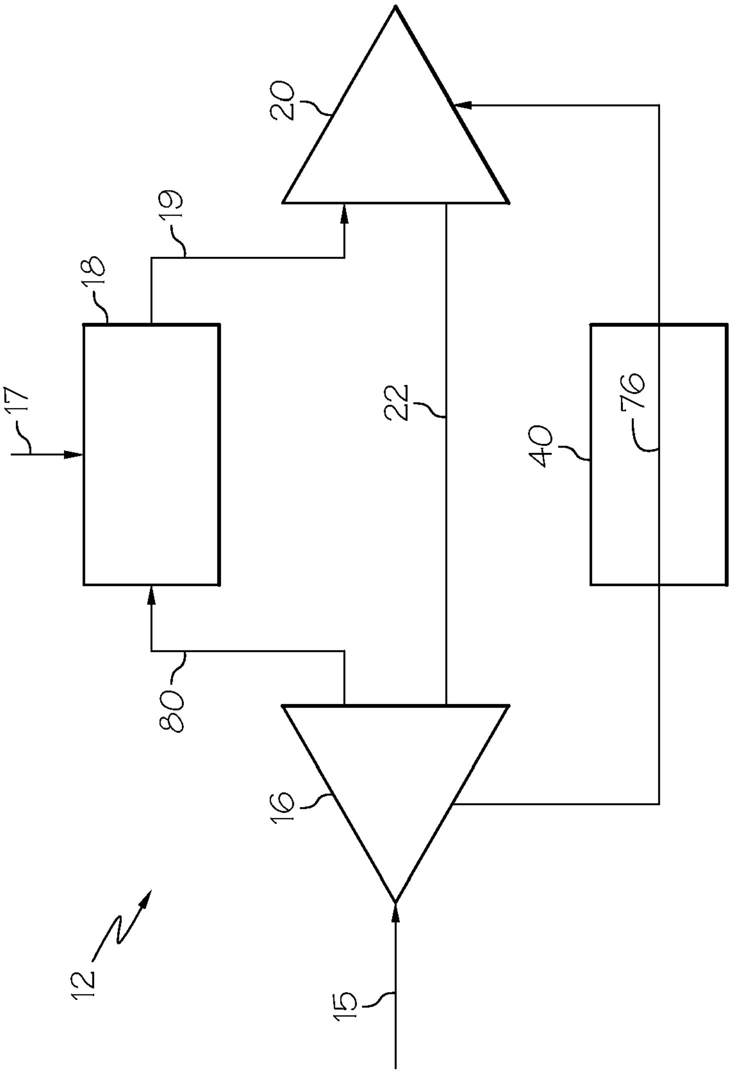

FIG. 2

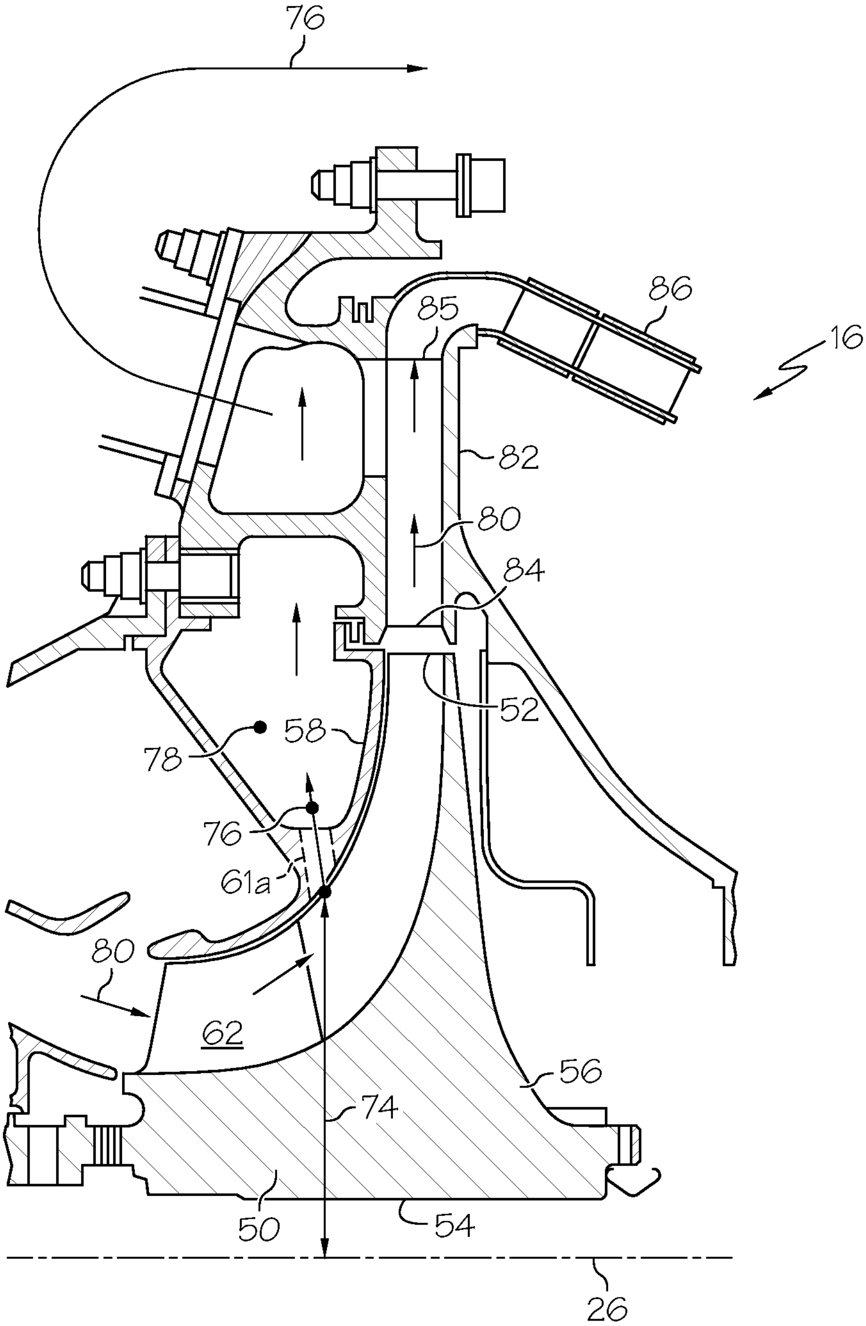

FIG. 3

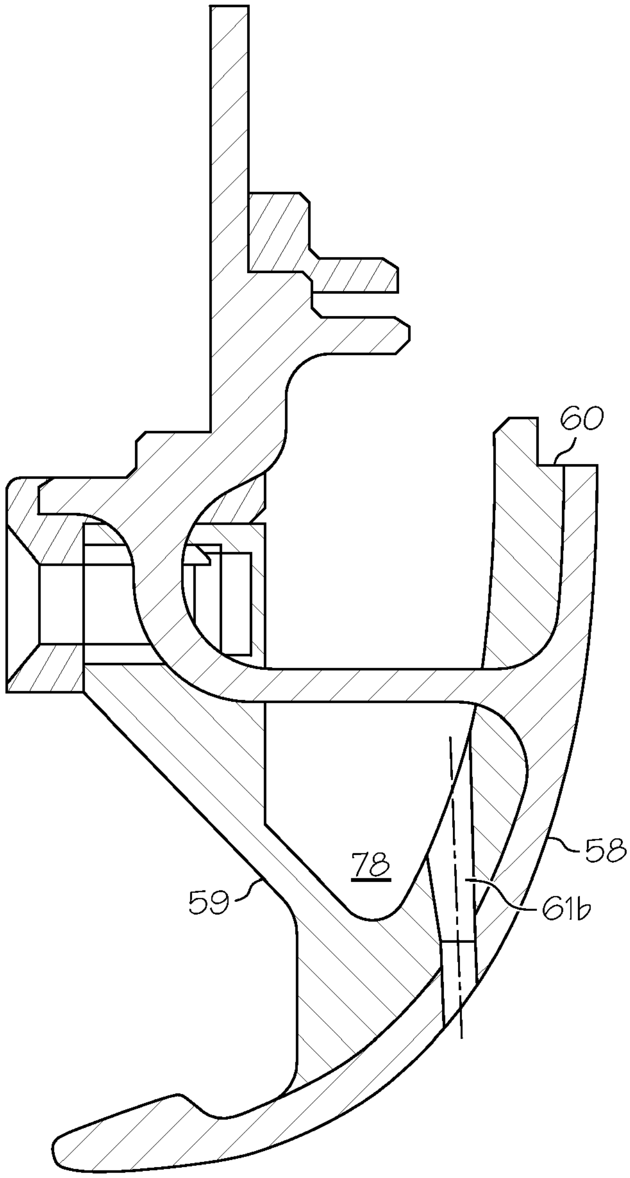

FIG. 4

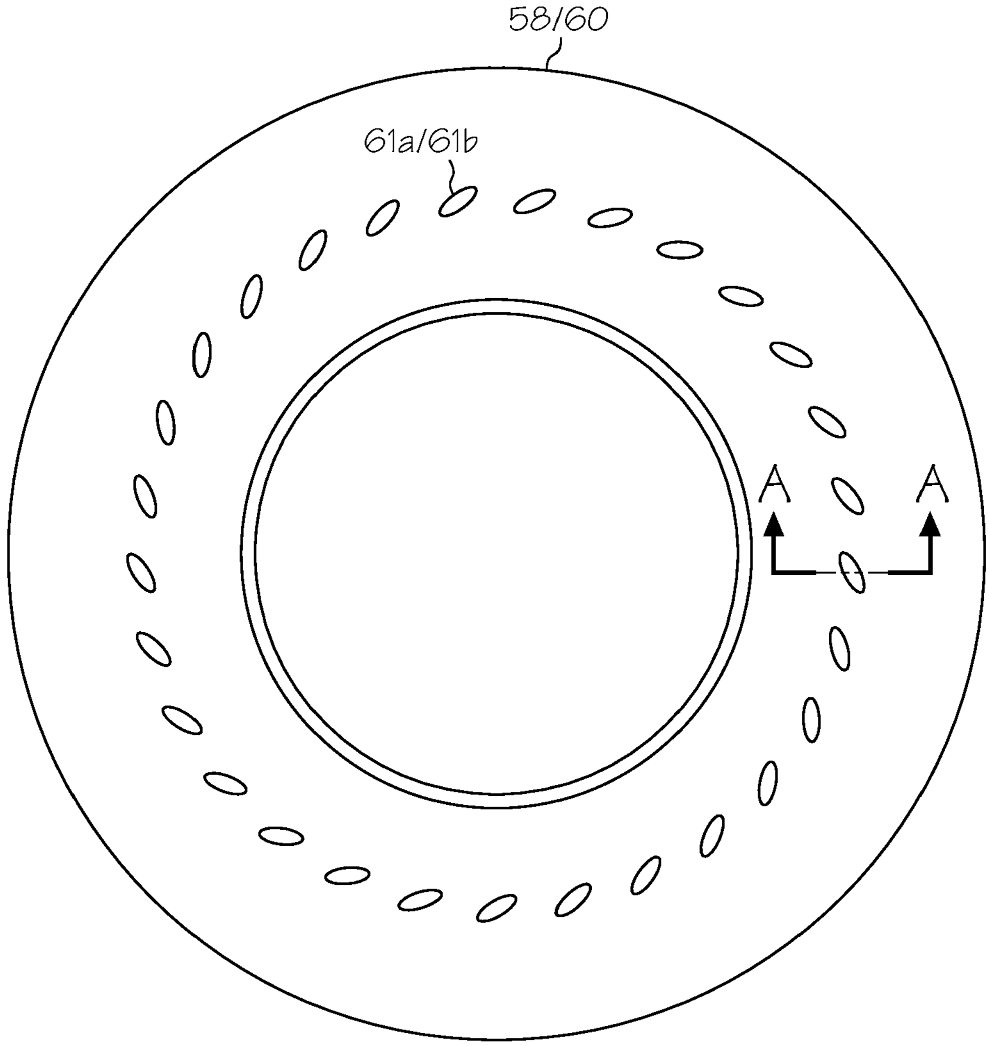

FIG. 5

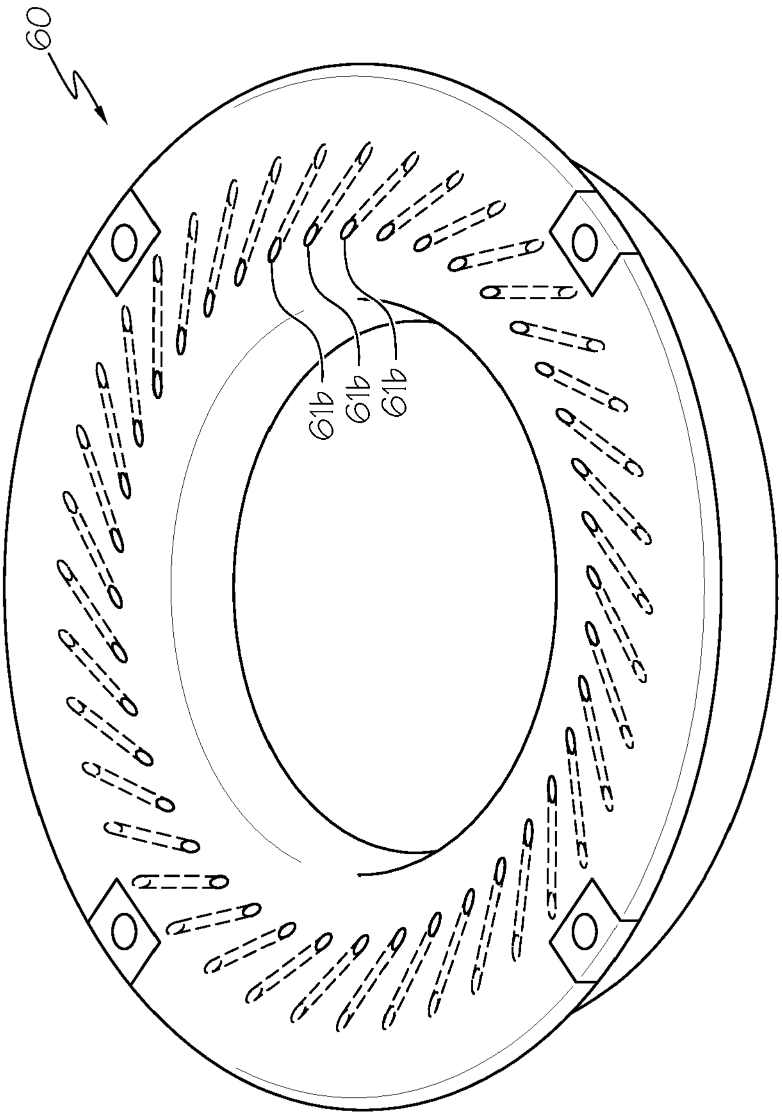

FIG. 6

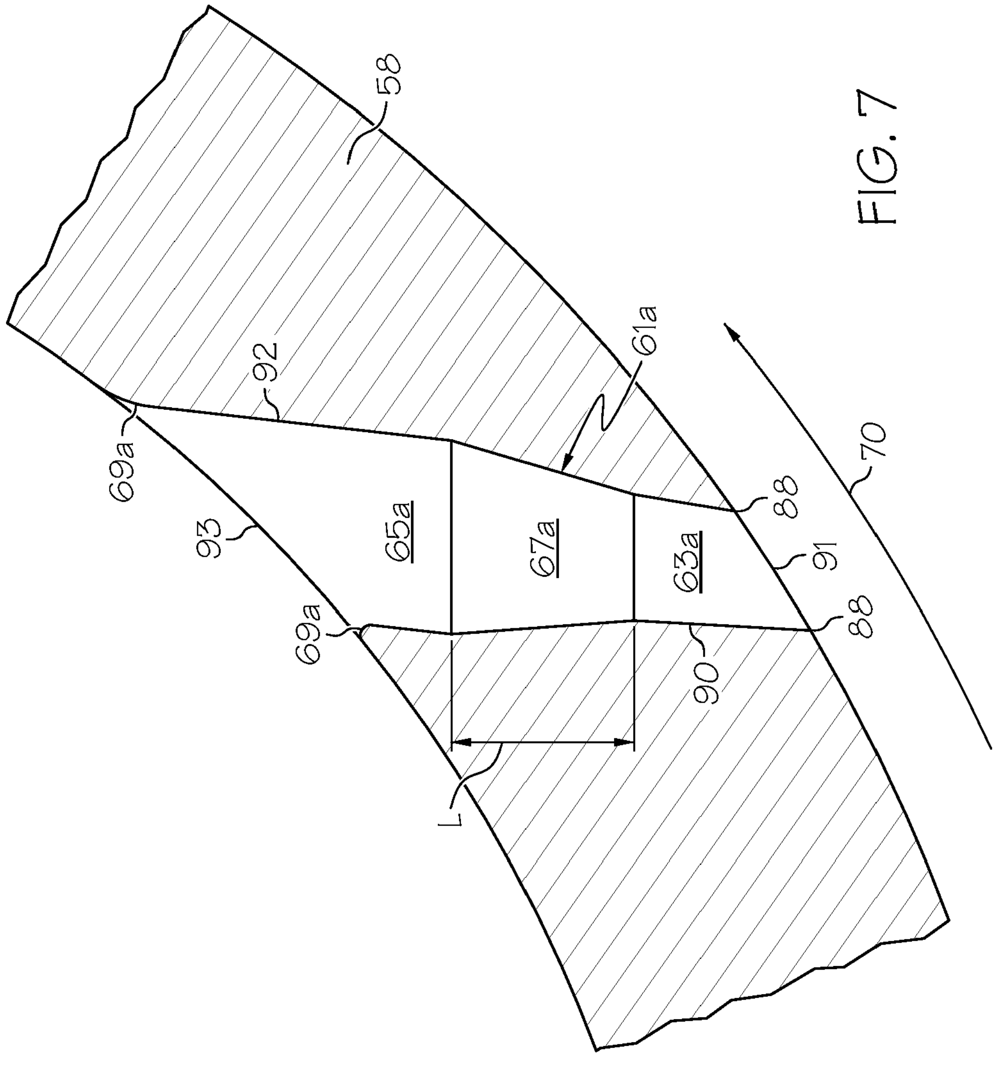

FIG. 7

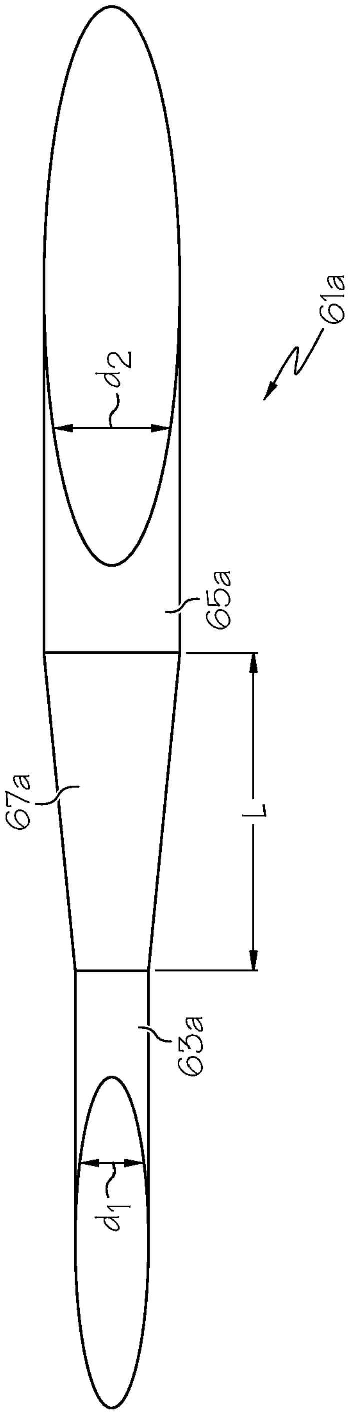

FIG. 8

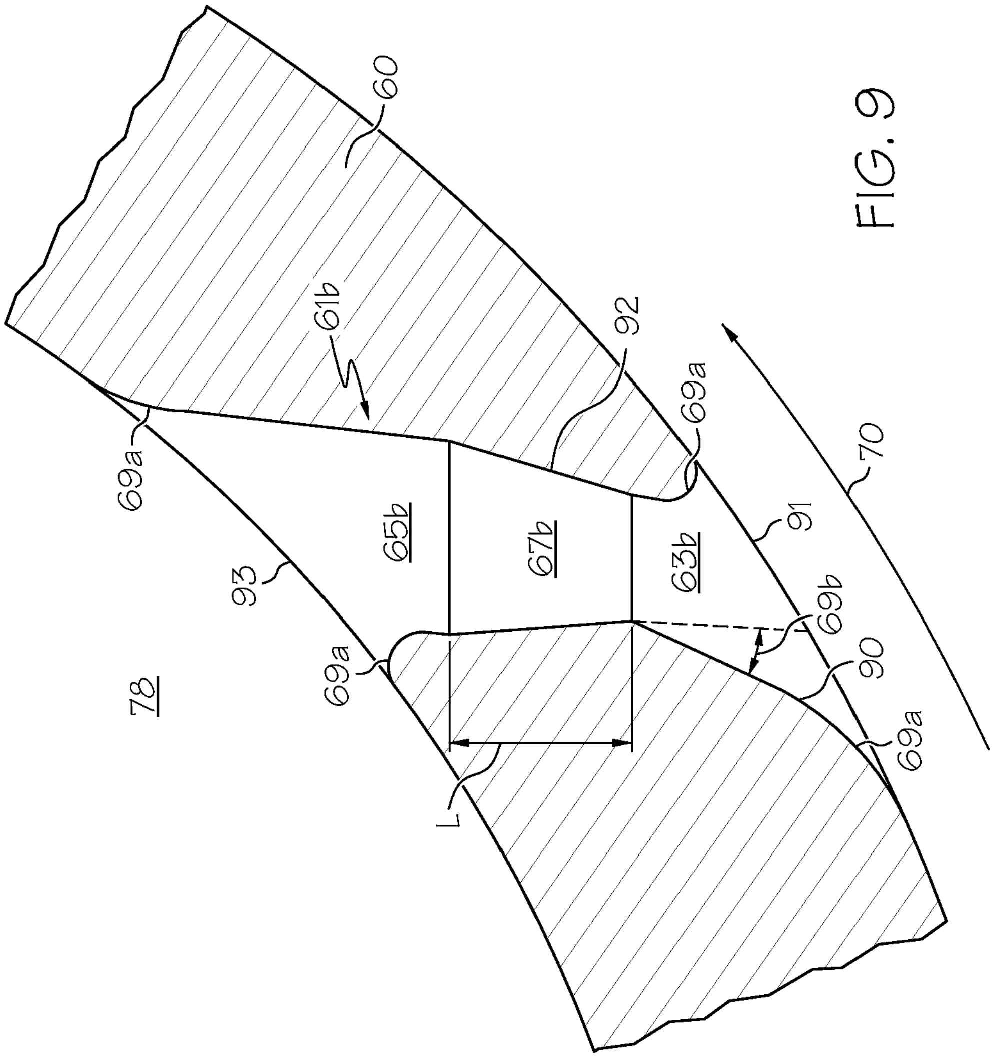

FIG. 9

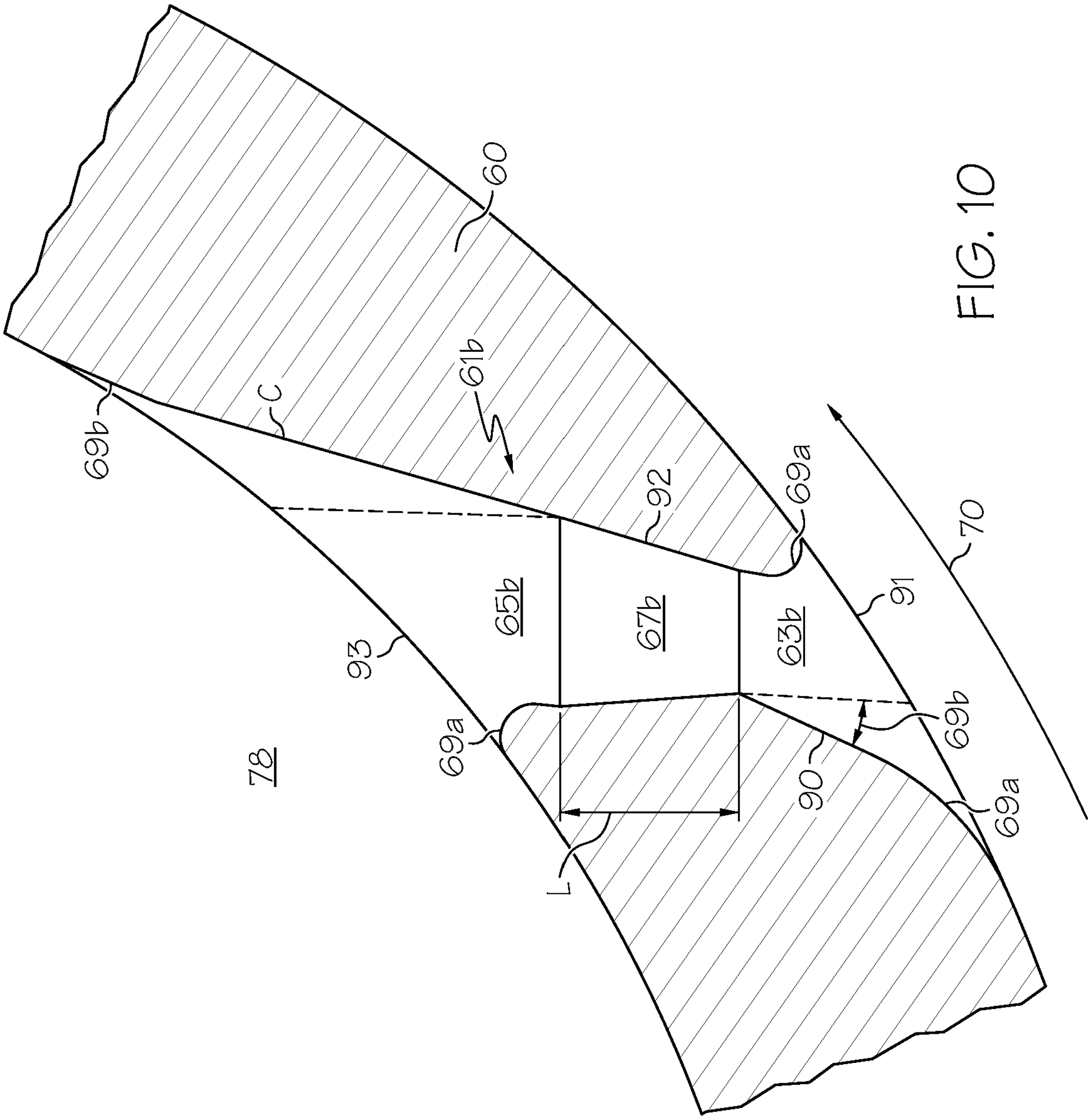

FIG. 10

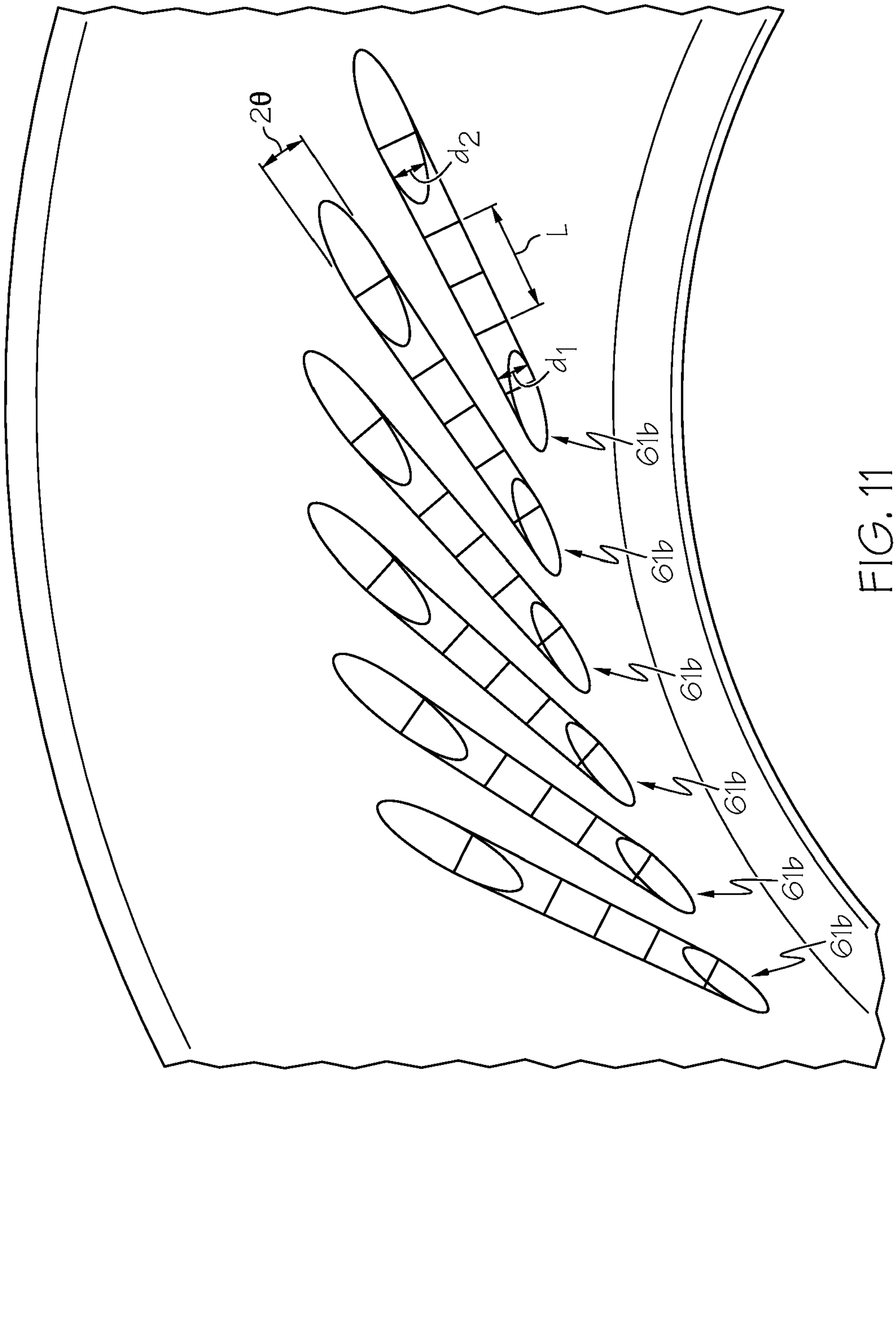

FIG. 11

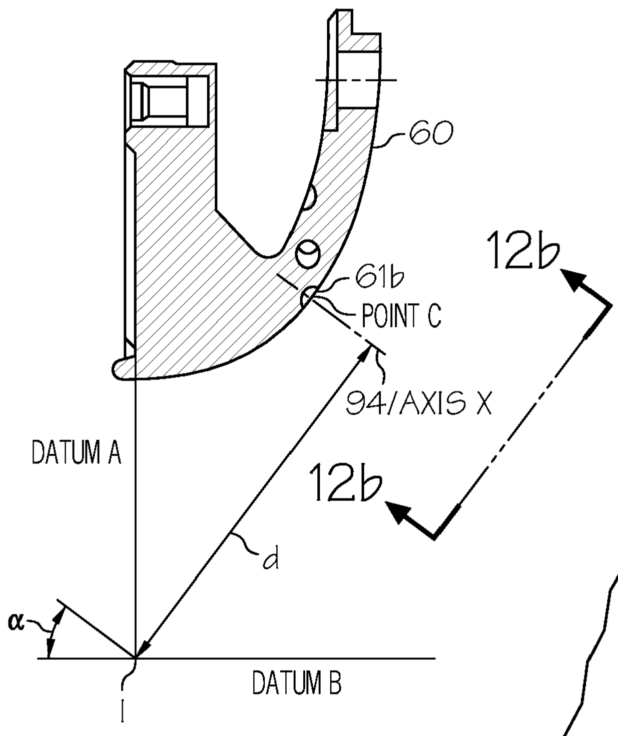

FIG. 12a

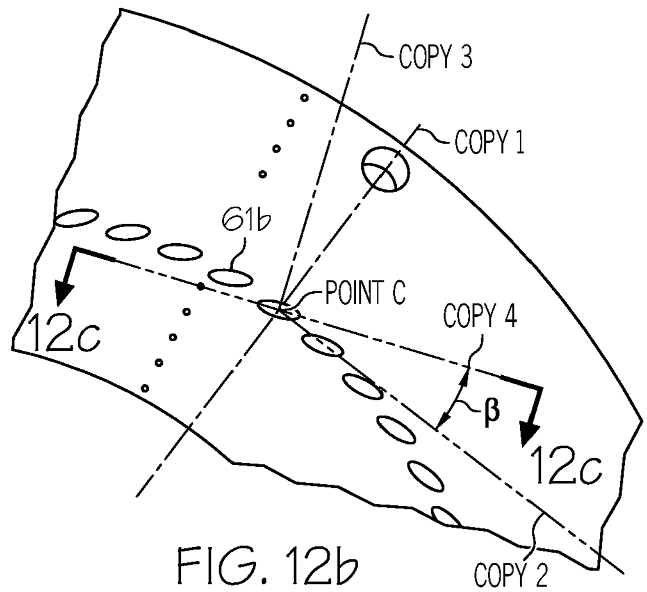

FIG. 12b

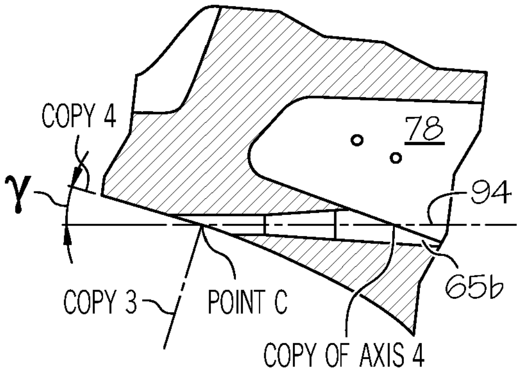

FIG. 12c