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(54) BOUNDARY LAYER TURBOMACHINE AND CORRRESPONDING OPERATING METHOD

(57) A boundary layer turbomachine is disclosed and described. The boundary layer turbomachine can include a housing defining an interior space and having an inlet opening and an outlet opening to facilitate movement of a fluid through the housing. The boundary layer turbomachine can also include partition circumferentially dividing the interior space into an outer chamber and a rotor chamber located radially inward of the outer chamber. The partition can have partition openings such that fluid is movable through the partition between the outer chamber and the rotor chamber. Additionally, the boundary layer turbomachine can include a rotor assembly disposed in the rotor chamber and configured to rotate about an axis of rotation. The rotor assembly can have a plurality of disks spaced apart along the axis of rotation and defining an interior opening along the axis of rotation. The fluid can pass through gaps between the disks and the interior opening as the fluid moves through the housing. A corresponding method of operating the boundary layer turbomachine is also provided.

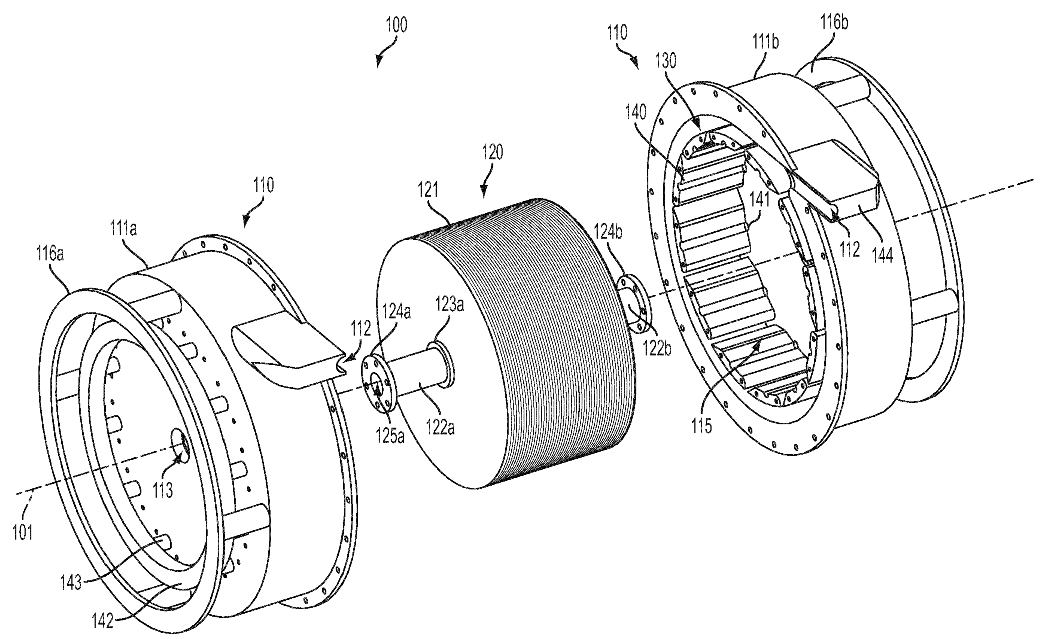

FIG. 2A

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Description

Technical **field**

[0001] The present invention relates to boundary layer machines and rotor assemblies therefor.

BACKGROUND

[0002] Transfer of motive force between stacked rotating disks and a fluid is described by Tesla in U.S. Patent Nos. 1,061,142 and 1,061,206. According to these disclosures, fluid drags on closely spaced rotating disks due to viscosity and adhesion of a surface layer of the fluid, which subjects the fluid to two forces, one acting tangentially in the direction of rotation and the other acting radially outward. The combined effect of these tangential and centrifugal forces is to propel the fluid with continuously increasing velocity in a spiral path until it reaches a suitable peripheral outlet from which it is ejected.

[0003] The design described by Tesla can be used as a pump or as a motor. Such devices take advantage of the properties of a fluid when in contact with the rotating surfaces of the disks. If the disks are driven by the fluid, then as the fluid passes between the spaced apart disks, the movement of the fluid causes the disks to rotate thereby generating power which can be transmitted external to the device via a shaft to provide motive force for various applications. Accordingly, such devices function as a motor or turbine. On the other hand, if the fluid is essentially static, rotation of the disks will cause the fluid to commence rotating in the same direction as the disks and to thus draw the fluid through the device, thereby causing the device to function as a pump or a fan. In this disclosure, all such devices, whether used as a motor or as a pump or fan, are referred to generically as "boundary layer turbomachines."

[0004] Despite numerous improvements to the original design by Tesla, such machines have found limited practical application due to various drawbacks such as reliability and costs. A typical boundary layer turbomachine has several shortcomings. The thin disks of a typical boundary layer turbomachine tend to deflect under operating loads, which can cause contact with other disks and/or other structures, such as a housing that encloses the disks. To minimize this potentially destructive contact, some boundary layer turbomachines include features such as dimples incorporated into the housing or through-bolts which act as spacers. In addition, efficiencies of typical boundary layer turbomachines can be limited. Accordingly, improvements in boundary layer turbomachine design continue to be sought.

SUMMARY

[0005] Aspects of the present invention are set out in the independent claims. Further, optional features of specific embodiments are set out in the dependent claims.

[0006] A boundary layer turbomachine is disclosed herein that can minimize or eliminate disk deflections that tend to cause contact between adjacent disks and/or a housing. In one aspect, principles are disclosed herein that also provide increased efficiency of the boundary layer turbomachine. The boundary layer turbomachine can include a housing defining an interior space and having an inlet opening and an outlet opening to facilitate movement of a fluid through the housing. The boundary layer turbomachine can also include a partition circumferentially dividing the interior space into an outer chamber and a rotor chamber located radially inward of the outer chamber. The partition can have partition openings such that fluid is movable through the partition between the outer chamber and the rotor chamber. The boundary layer turbomachine can also include a rotor assembly disposed in the rotor chamber and configured to rotate about an axis of rotation. The rotor assembly can have a plurality of disks spaced apart along the axis of rotation and defining an interior opening along the axis of rotation. The fluid can pass through gaps between the disks and the interior opening as the fluid moves through the housing.

[0007] In one aspect, a rotor assembly for a boundary layer turbomachine is disclosed. The rotor assembly can include a plurality of disks spaced apart along an axis of rotation and defining an interior opening along the axis of rotation such that fluid passes through gaps between the disks and the interior opening as the fluid moves through the rotor assembly. A plurality of spacers can be disposed between adjacent disks to space the disks apart along an axis of rotation. The rotor assembly can also include a base coupled to the plurality of disks to facilitate coupling the rotor assembly to a housing of the boundary layer turbomachine.

[0008] Specifically, the following aspects and embodiments are disclosed:

1. A boundary layer turbomachine, comprising:

    a housing defining an interior space and having an inlet opening and an outlet opening to facilitate movement of a fluid through the housing; and

    a rotor assembly disposed in the housing and configured to rotate about an axis of rotation, the rotor assembly having a plurality of disks spaced apart along the axis of rotation and defining an interior opening along the axis of rotation, wherein the fluid passes through gaps between the disks and the interior opening as the fluid moves through the housing, wherein the turbomachine is configured such that fluid moving through the housing is guided into or from the gaps at a plurality of locations around outer edges of the disks.

2. A boundary layer turbomachine, comprising:

a housing defining an interior space and having an inlet opening and an outlet opening to facilitate movement of a fluid through the housing;
a partition circumferentially dividing the interior space into an outer chamber and a rotor chamber located radially inward of the outer chamber, the partition having partition openings such that fluid is movable through the partition between the outer chamber and the rotor chamber; and
a rotor assembly disposed in the rotor chamber and configured to rotate about an axis of rotation, the rotor assembly having a plurality of disks spaced apart along the axis of rotation and defining an interior opening along the axis of rotation, wherein the fluid passes through gaps between the disks and the interior opening as the fluid moves through the housing.

3. The boundary layer turbomachine of item 1 or 2, wherein the plurality of disks are oriented perpendicular to the axis of rotation.

4. The boundary layer turbomachine of any preceding item, wherein the axis of rotation extends through the interior opening.

5. The boundary layer turbomachine of any preceding item, wherein outer edges of the disks are tapered.

6. The boundary layer turbomachine of any preceding item, wherein the interior opening is defined at least in part by a helical baffle to facilitate movement of the fluid through the rotor assembly.

7. The boundary layer turbomachine of any preceding item, wherein the rotor assembly includes an extension member to couple the rotor assembly to the housing and facilitate rotation of the rotor assembly about the axis of rotation.

8. The boundary layer turbomachine of item 7, wherein the extension member includes a vent port extending therethrough in fluid communication with the interior opening.

9. The boundary layer turbomachine of item 8, wherein the vent port is oriented along the axis of rotation and wherein the vent port is defined at least in part by a helical baffle to facilitate movement of the fluid through the vent port.

10. The boundary layer turbomachine of any preceding item, wherein the inlet opening is associated with the outer chamber such that the outer chamber serves as an expansion chamber for the fluid.

11. The boundary layer turbomachine of any preceding item, wherein the fluid is a gas, a liquid, or a combination thereof.

12. The boundary layer turbomachine of any preceding item, wherein the partition openings are defined by two or more partition members.

13. The boundary layer turbomachine of any preceding item, the turbomachine comprising
a partition circumferentially dividing the interior space into an outer chamber and a rotor chamber located radially inward of the outer chamber, wherein the rotor assembly is disposed in the rotor chamber, the partition having partition openings spaced circumferentially around the partition such that fluid is movable through the partition between the outer chamber and the rotor chamber at the plurality of locations.

14. The boundary turbomachine of any preceding item with the proviso that it does not comprise: a partition circumferentially dividing the interior space into an outer chamber and a rotor chamber located radially inward of the outer chamber, wherein the rotor assembly is disposed in the rotor chamber, the partition having partition openings spaced circumferentially around the partition such that fluid is movable through the partition between the outer chamber and the rotor chamber at the plurality of locations; or the boundary turbomachine of item 2.

15. The boundary layer turbomachine of any preceding item , wherein the inlet opening is associated with the outer chamber such that the outer chamber serves as an expansion chamber for the fluid.

16. The boundary layer turbomachine of any preceding item, wherein the partition openings have a tangential cross-sectional area that increases in a radially inward direction.

17. The boundary layer turbomachine of any preceding item, wherein the partition openings comprise a venturi configuration.

18. The boundary layer turbomachine of any preceding item, wherein the partition openings are equally spaced circumferentially around the partition.

19. The boundary layer turbomachine of any preceding item, wherein the turbomachine is configured such that fluid moving through the housing is guided into the gaps at a plurality of locations circumferentially spaced around the rotor assembly at an angle in the range of 40° to 60°, optionally 45° to 55°, for example 51° or 52° relative to a radius of the discs.

20. The boundary layer turbomachine of any preced-

ing item, further comprising a debris trap.

21. The boundary layer turbomachine of item 20, wherein the debris trap is formed by a groove along an inner radial surface of a portion of the partition.

22. The boundary turbomachine of any preceding item, wherein the interior opening defines a central void centred on the axis of rotation.

23. The boundary turbomachine of any preceding item, wherein the interior opening defines a fluid flow path coinciding with the axis of rotation.

24. The boundary layer turbomachine of any preceding item, wherein the disks are spaced apart by a plurality of spacers.

25. The boundary layer turbomachine of item 24, wherein the disks are permanently coupled to one another by the plurality of spacers.

26. The boundary layer turbomachine of any preceding item, wherein the disks are permanently coupled to one another with a resin.

27. The boundary layer turbomachine of item 24, wherein the spacers have an airfoil cross-section.

28. The boundary layer turbomachine of item 24, wherein the disks and spacers form a monolithic structure.

29. The boundary layer turbomachine of item 24 or 28, wherein the spacers are arranged in a ring configuration across each disk.

30. The boundary layer turbomachine of item 29, wherein the ring configuration comprises a plurality of rings concentric about the axis of rotation.

31. The boundary layer turbomachine of item 30, wherein a radial relationship of the plurality of rings corresponds to the Fibonacci ratio or the Golden ratio.

32. The boundary layer turbo machine of any of items 24-31, wherein the spacers are arranged with a longitudinal axis at an angle in the range of 40° to 60°, optionally 45° to 55°, for example 51° or 52° relative to a radius of the discs.

33. The boundary layer turbomachine of any preceding item, wherein the interior opening defines a helical baffle to facilitate movement of the fluid through the rotor assembly.

34. The boundary layer turbomachine of any preceding item, wherein the rotor assembly includes an extension member to couple the rotor assembly to the housing and facilitate rotation of the rotor assembly about the axis of rotation, the extension member defining a fluid port extending therethrough in fluid communication with the interior opening.

35. A method of operating the boundary layer turbomachine of any preceding item, the method comprising feeding a mixture of gas and liquid through the one or more inlet openings to drive the boundary layer turbomachine.

36. A rotor assembly for a boundary layer turbomachine, comprising:

a plurality of disks; and
a plurality of spacers disposed between adjacent disks to space the disks apart along an axis of rotation,
wherein the disks define an interior opening along the axis of rotation such that fluid passes through gaps between the disks and the interior opening as the fluid moves through the rotor assembly.

37. The rotor assembly of item 36, wherein the interior opening defines a central void centred on the axis of rotation.

38. The rotor assembly of item 36 or 37, wherein the interior opening defines a fluid flow path coinciding with the axis of rotation.

39. The rotor assembly of item 36, 37 or 38, wherein the plurality of disks are oriented perpendicular to the axis of rotation.

40. The rotor assembly of any of items 36-39, wherein the disks are permanently coupled to one another by the plurality of spacers.

41. The rotor assembly of any of items 36-40, wherein the disks are permanently coupled to one another with a resin.

42. The rotor assembly ofany of items 36-41, wherein the discs and spacers form a monolithic fibre composite structure..

43. The rotor assembly of any of items 36-42, wherein the discs and spacers are formed of basalt fibre composite or carbon fibre composite.

44. The rotor assembly of any of items 36-43, wherein the spacers have an airfoil cross-section.

45. The rotor assembly of any of items 36-44, where-

in the spacers are arranged in a ring configuration across each disk, wherein the ring configuration comprises a plurality of rings concentric about the axis of rotation.

46. The rotor assembly of item 45, wherein a radial relationship of the plurality of rings corresponds to the Fibonacci ratio or the Golden ratio.

47. The rotor assembly of any of items 36-46, wherein the axis of rotation extends through the interior opening.

48. The rotor assembly of any of items 36-47, wherein the spacers are arranged in a configuration comprising one or more rings centred on the axis of rotation.

49. The rotor assembly of item 48, wherein the configuration comprises a plurality of rings and a radial relationship of the plurality of rings corresponds to the Fibonacci ratio or the Golden ratio.

50. The rotor assembly of any of items 36-49, wherein the spacers are arranged with a longitudinal axis at an angle in the range of 40° to 60°, optionally 45° to 55°, for example 51° or 52° relative to a radius of the discs.

51. The rotor assembly of any of items 36-50, wherein outer edges of the disks are tapered.

52. The rotor assembly of any of items 36-51, wherein the interior opening is defined at least in part by a helical baffle to facilitate movement of the fluid through the rotor assembly.

53. The rotor assembly of any of items 36-52, wherein the rotor assembly includes an extension member to couple the rotor assembly to a portion of the turbomachine and facilitate rotation of the rotor assembly about the axis of rotation.

54. The rotor assembly of item 53, wherein the extension member includes a vent port extending therethrough in fluid communication with the interior opening.

55. The rotor assembly of item 54, wherein the vent port is oriented along the axis of rotation and wherein the vent port is defined at least in part by a helical baffle to facilitate movement of the fluid through the vent port.

56. The rotor assembly of any of items 36-55, wherein the interior opening defines a helical baffle to facilitate movement of the fluid through the rotor assembly.

57. The rotor assembly of any of items 36-56, wherein the rotor assembly includes an extension member to couple the rotor assembly to a portion of the turbomachine and facilitate rotation of the rotor assembly about the axis of rotation, the extension member defining a fluid port extending therethrough in fluid communication with the interior opening.

58. A boundary layer turbomachine, comprising:

a housing defining an interior space and having an inlet opening and an outlet opening to facilitate movement of a fluid through the housing; and

a rotor assembly as set out in any of items 36-57disposed in the housing to rotate about the axis of rotation, wherein the fluid passes through gaps between the disks and the interior opening as the fluid moves through the housing.

59. A boundary layer turbomachine as set out in item 58, wherein the turbomachine is configured such that fluid moving through the housing is guided into the gaps at a plurality of locations circumferentially spaced around the rotor assembly.

60. A boundary layer turbomachine as set out in item 58 or 59, comprising a partition circumferentially dividing the interior space into an outer chamber and a rotor chamber located radially inward of the outer chamber, the partition having partition openings such that fluid is movable through the partition between the outer chamber and the rotor chamber, wherein the rotor assembly is disposed in the rotor chamber.

61. A boundary layer turbomachine as set out in any of items 1-34 and 58-60, with a rotor as set out in any of items 36-57.

[0009] There have thus been outlined some features so that the detailed description that follows may be better understood. Other features will become clearer from the following detailed description taken with the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

FIG. 1 is a perspective view of a boundary layer turbomachine in accordance with an example of the present disclosure.

FIGS. 2A and 2B are exploded views of the boundary layer turbomachine of FIG. 1.

FIG. 3A is a cross-sectional view of the boundary layer turbomachine of FIG. 1 taken between housing portions with a rotor assembly omitted.

FIG. 3B is a cross-sectional view of the boundary layer turbomachine of FIG. 1 taken between housing portions showing a rotor assembly.

FIG. 4 is a side view of a disk of a rotor assembly in accordance with an example of the present disclosure.

FIG. 5 is a detail view of disk edges of a rotor assembly having a tapered zone in accordance with an example of the present disclosure.

FIG. 6 is a cross-sectional view of a portion of a rotor assembly in accordance with an example of the present disclosure.

FIG. 7 is a cross-sectional view of a portion of a rotor assembly showing an optional helical baffle within the interior opening in accordance with another example of the present disclosure.

FIGS. 8A and 8B illustrate a computer model showing the fluid volume in an interior space of a boundary layer turbomachine in accordance with an example of the present disclosure.

[0011] These drawings are provided to illustrate various aspects of the disclosure and are not intended to be limiting of the scope in terms of dimensions, materials, configurations, arrangements or proportions.

DETAILED DESCRIPTION

[0012] While embodiments are described in what follows, by way of example, in sufficient detail to enable those skilled in the art to practice the invention, it should be understood that other embodiments may be realized and that various changes to the invention may be made without departing from the spirit and scope of the present invention. Thus, the following more detailed description of the embodiments of the present invention is not intended to limit the scope of the invention, as claimed, but is presented for purposes of illustration only and not limitation to describe the features and characteristics of the present invention, to set forth the best mode of operation of the invention, and to sufficiently enable one skilled in the art to practice the invention. Accordingly, the scope of the present invention is to be defined solely by the appended claims.

Definitions

[0013] In describing and claiming the present invention, the following terminology will be used.

[0014] The singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a disk" includes reference to one or more of such disks and reference to "the spacer" refers to one or more of such spacers, unless the context indicates otherwise.

[0015] As used herein with respect to an identified property or circumstance, "substantially" refers to a degree of deviation that is sufficiently small so as to not measurably detract from the identified property or circumstance. The exact degree of deviation allowable may in some cases depend on the specific context.

[0016] As used herein, "adjacent" refers to the proximity of two structures or elements. Particularly, elements that are identified as being "adjacent" may be either abutting or connected. Such elements may also be near or close to each other without necessarily contacting each other. The exact degree of proximity may in some cases depend on the specific context.

[0017] As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a *de facto* equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary.

[0018] As used herein, the term "at least one of" is intended to be synonymous with "one or more of." For example, "at least one of A, B and C" explicitly includes only A, only B, only C, or combinations of each.

[0019] Numerical data may be presented herein in a range format. It is to be understood that such range format is used merely for convenience and brevity and should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. For example, a numerical range of about 1 to about 4.5 should be interpreted to include not only the explicitly recited limits of 1 to about 4.5, but also to include individual numerals such as 2, 3, 4, and sub-ranges such as 1 to 3, 2 to 4, etc. The same principle applies to ranges reciting only one numerical value, such as "less than about 4.5," which should be interpreted to include all of the above-recited values and ranges. Further, such an interpretation should apply regardless of the breadth of the range or the characteristic being described.

[0020] Any steps recited in any method or process claims may be executed in any order and are not limited to the order presented in the claims. Means-plus-function or step-plus-function limitations will only be employed where for a specific claim limitation all of the following conditions are present in that limitation: a) "means for" or "step for" is expressly recited; and b) a corresponding function is expressly recited. The structure, material or acts that support the means-plus function are expressly recited in the description herein. Accordingly, the scope of the invention should be determined solely by the appended claims and their legal equivalents, rather than by the descriptions and examples given herein.

Boundary Layer Turbomachine

[0021] With reference to FIG. 1, a boundary layer turbomachine 100 is illustrated in accordance with an example of the present disclosure. FIGS. 2A-2B illustrate exploded views of the boundary layer turbomachine 100 for further reference. The boundary layer turbomachine can include a housing 110, which can include complimentary housing portions 111a, 111b. The housing can also have an inlet opening 112 and an outlet opening 113 to facilitate movement of a fluid (i.e., a gas and/or a liquid) through the housing. The outlet opening 113 can be located at or near a rotational axis 101 of a rotor assembly 120 while the inlet opening 112 can be located on the housing 110 radially outward from the rotational axis 101. Although reference numbers 112, 113 have identified an inlet opening and an outlet opening of the housing 110, respectively, it should be recognized that in some embodiments opening 113 can be an inlet opening and opening 112 can be an outlet opening based on operation of the boundary layer turbomachine. In one aspect, the boundary layer turbomachine can be designed and operated as "directional" in that the flow of fluid always enters the housing via the same inlet opening and exits the housing via the same outlet opening. In another aspect, the boundary layer turbomachine can be designed and operated as "bidirectional" in that the flow of fluid can be switched to enter the housing via either opening 112, 113 and exit the housing via the other opening to obtain forward and reverse fluid flow. In addition, the housing can include an opening 114 (FIG. 2B) that can also serve as an inlet and/or an outlet similar to the opening 113. When both openings 113, 114 are utilized they will typically have the same function. Thus, opening 112 can serve as an inlet opening, and opening 113 and/or opening 114 can serve as outlet openings. On the other hand, opening 113 and/or opening 114 can serve as inlet openings, and opening 112 can serve as an outlet opening. In some embodiments, multiple openings, which can serve as inlet and/or outlet openings, can be located on the housing 110 radially outward from the rotational axis similar to opening 112.

[0022] As illustrated in FIGS. 2A and 2B, the housing 110 can define an interior space 115 to accommodate a rotor assembly 120. The rotor assembly can be configured to rotate about the axis of rotation 101. The rotor assembly can have a plurality of disks 121 spaced apart along the axis of rotation. In one aspect, the disks can be substantially planar and oriented perpendicular to the axis of rotation, although any suitable disk configuration can be utilized, such as a conical disk configuration. Regardless, the disks can be substantially parallel to one another throughout. Furthermore, any suitable number of disks can be utilized (e.g., depending on power requirements). As described in more detail hereinafter, the plurality of disks 121 can define an interior opening (internal to the plurality of disks 121 and hidden from view) along the axis of rotation. Thus, fluid can pass through gaps between the disks and the interior opening as the fluid moves through the housing from the inlet opening 112 to the outlet opening 113 and/or 114. As will be appreciated, the interior opening is free of any structural material as there is not shaft extending through the interior opening to facilitate rotation. As a result, the interior opening provides a central void centred on the axis of rotation and defines a fluid flow path through the interior opening that coincides with the axis of rotation. This can facilitate laminar flow through the gaps and the interior opening, since there are no structural parts that would be needed to fix a shaft in the opening (and which would hence rotate about the shaft) interfering with the flow.

[0023] The rotor assembly 120 can also include an extension member 122a, 122b to couple the rotor assembly to the housing 110 and facilitate rotation of the rotor assembly about the axis of rotation 101. For example, the extension members 122a, 122b can be attached to the plurality of disks 121 opposite one another and substantially inline to facilitate rotation of the rotor assembly about the axis 101. The extension members 122a, 122b can be attached to the plurality of disks 121 using an adhesive, fasteners, or any other suitable substance or device. For example, the extension member can include a flange 123a, 123b to interface with the plurality of disks 121 (more specifically the flange 123a, 123b can interface with a respective adjacent one of the plurality of disks 121) and facilitate coupling with the disks. The extension members 122a, 122b can be mounted on bearings when coupled to the housing 110 to provide low friction rotational interface. In one aspect, the extension members 122a, 122b can include vent ports 125a, 125b extending through the extension members in fluid communication with the interior opening formed by the plurality of disks 121. Thus fluid can exit or enter the housing via the extension member vent ports 125a, 125b, which extend through the housing openings 113, 114, respectively. In some arrangements where only a single housing opening 113, 114 is desired, one of the extension members 122a, 122b can be designed as a blank closing the interior opening at one end, so that fluid exits or enters through the other one of the extension members 122a, 122b.

[0024] Although the various components of the boundary layer turbomachine 100 can be constructed of any suitable material, in one aspect the rotor assembly 120 (i.e., the plurality of disks 121, the extension member 122a, and/or the extension member 122b) and/or the housing 110 (i.e., the housing portion 111a and/or the housing portion 111b) can be made in whole or in part from carbon fiber composite (e.g., Toray T800S), basalt fibre composite or any other suitable lightweight structural material. As a general guideline, the rotor assembly 120 is designed to provide a low mass to volume ratio. In some cases, the rotor assembly 120 can be provided as a complete unit as a replacement of a damaged or worn rotor assembly.

[0025] In one aspect, the extension member 122a, 122b can facilitate coupling the rotor assembly 120 to a generator or a motor. For example, the extension member 122a, 122b can include a flange 124a, 124b to interface with a generator shaft or a motor shaft and facilitate coupling the rotor assembly 120 to the generator or motor, such as utilizing fasteners, etc. A generator (e.g., an electric generator or a pump) can be coupled to the rotor assembly 120 to generate power as the fluid moves through the housing 110. A motor can be coupled to the rotor assembly 120 to cause rotation of the rotor assembly, thereby causing movement of the fluid through the housing 110 and utilizing the boundary layer turbomachine 100 as a pump. The extension member 122a, 122b can therefore serve as a mechanical transfer coupling for the rotor assembly 120 to an external device, such as a generator or a motor. Any suitable generator or motor can be utilized with the boundary layer turbomachine 100. In one aspect, each housing portion 111a, 111b can be coupled to a generator or a motor. For example, the housing portions 111a, 111b can include mounting features 116a, 116b, respectively, to interface with a generator or a motor and facilitate coupling the housing 110 to the generator or motor, such as utilizing fasteners, welds, etc. In one aspect, the mounting feature 116a, 116b can extend at least as far as the extension member 122a, 122b to facilitate directly attaching the housing 110 to a generator or motor without interference from the extension member 122a, 122b. In addition, the boundary layer turbomachine 100 can be operated with the axis of rotation 101 in any suitable orientation, such as vertical or horizontal.

[0026] When utilizing the boundary layer turbomachine 100 with a generator, the boundary layer turbomachine can be powered by steam from a number of different sources, such as capturing waste heat from a boiler, injecting water directly into the exhaust stream of a liquid fuel generator by replacing the muffler, or by generating its own heat content from a combustor. Each of these configurations can utilize many of the same components, such as a feedwater tank, pumps, sensors, computers, and other electronic components. Thus, water can enter the boundary layer turbomachine 100 as steam and can exit as a liquid, although any fluid within a wide range of pressures and temperatures may be used, which can depend on the material and resin properties when boundary layer turbomachine components are constructed of a carbon or basalt fiber composite.

[0027] In one aspect, the boundary layer turbomachine 100 can include a partition 130. As more clearly illustrated in FIGS. 3A and 3B, the partition 130 can circumferentially divide the interior space 115 into an outer chamber 116 and a rotor chamber 117 located radially inward of the outer chamber. The outer chamber 116 can be an annular volume having an inner radial dimension 102 of 80 to 95% of a radius 103 of the interior space 115. As shown in FIG. 3B, the rotor assembly 120 can be disposed in the rotor chamber 117. Although the illustration shows the rotor assembly engaged with an inner edge of partition members 132, actual contact can create undesirable friction. Therefore, an outer edge of the rotor assembly can be spaced a rotor gap distance apart from the inner edge of partition members 132. The rotor gap can generally be 85 to 95% of a rotor chamber radius measured to the inner edge. Despite the rigidity of most materials used for the rotor disks 121, the associated rate of spin during operation can often result in radial elongation of from 1% to 5%. The rotor gap can vary depending on size, but is often from 1 mm to 2 cm at a resting condition. Accordingly, the rotor gap can be designed to accommodate such disk stretching. Notably, operating speeds can vary considerably. However, in many cases the rotor assembly can operate at speeds of 10,000 rpm up to 100,000 rpm.

[0028] The partition 130 can have partition openings 131 such that fluid is movable through the partition between the outer chamber 116 and the rotor chamber 117. In one aspect, the opening 112 can be associated with the outer chamber 116 such that the outer chamber serves as an expansion chamber for the fluid when the opening 112 is an inlet opening. Typically, although not required, the inlet can also be oriented to produce tangential flow within the expansion chamber. The partition openings 131 can be spaced (e.g., equally) circumferentially around the partition 130 so as to allow fluid to move from the outer chamber 116 into the rotor chamber 117 and, thus, into gaps between the disks of the rotor assembly 120, at multiple locations around the outer edge of the disks. This configuration offering multiple access ports from the outer chamber 116 to the rotor assembly 120 disks can increase the efficiency of the turbomachine, particularly when the partition openings 131 are equally spaced from one another.

[0029] In some embodiments is configured such that fluid moving through the housing is guided into or from the gaps at a plurality of locations around the outer edges of the disks (into when then opening 112 is an inlet opening and from if the opening 112 is an outlet opening). The partition 130 and partition openings 131 an embodiments of how this can be implemented with a single inlet opening, for example opening 112. Other such embodiments connect a single inlet (or outlet) opening to a different kind of manifold, for example a conduit conduit around the perimeter of the turbomachine with ports and/or branch conduits providing fluid flow paths to guide fluid into or from the plurality of locations. In some embodiments, the turbomachine has a plurality of inlet (or outlet) openings, each providing a flow path into (or from) the gaps at respective ones of the plurality of locations. In some embodiments, one or more openings are associated with two or more of the plurality of locations via respective manifolds.

[0030] In one aspect, the partition openings 131 can be defined by two or more partition members 132 or formed in a single partition member. As shown in FIG. 3B, the partition members 132 can be arranged in a circular configuration with an internal diameter sized to accommodate the rotor assembly 120 disks (i.e., larger than the outer diameter of the disks). The partition 130 (i.e., partition members 132) can be an individual component which is secured in place, or integrally formed with the housing, such as housing portion 111a. In the embodiment illustrated in FIG. 3A and 3B, the partition members 132 illustrated are merely one-half of the partition 130, with a complimentary set of partition members secured to the opposite housing portion 111b. Alternatively, the partition can be formed as a single set of partition members in order to avoid misalignment of complimentary partition members.

[0031] In one aspect, the partition openings 131 can comprise a venturi configuration. The term "venturi" is used herein to generally define a configuration wherein the partition opening 131 formed by two complimenting surfaces 133, 134 of adjacent partition members 132 converges and/or diverges such that fluid passing through the partition opening reaches enhanced speed while concurrently developing a significantly reduced pressure producing an effect similar to the Venturi effect. Any suitable venturi configuration can be utilized. For example, the cross-section of the partition opening 131 normal to the direction of flow through the partition opening 131 can increase in the direction of flow. In one aspect, the partition openings 131 can have an angle 104 of 25 to 55 degrees. In another aspect, the partition openings 131 can have a radial dimension 105 of 5 mm to 5 cm. In yet another aspect, the partition openings 131 can have an outer circumferential dimension 106 of 5 mm to 5 cm and an inner circumferential dimension 107 of 1 cm to 10 cm. The angle 104, radial dimension 105, outer circumferential dimension 106, and inner circumferential dimension 107 can vary depending on the fluid type, size, and application of the turbomachine. In some embodiments, the angle 104 is in the range of 40° to 60°, more specifically 45° to 55°, for example 51.5° or 51° or 52°, which has been found to result in efficient energy transfer.In one aspect, the partition openings 131 can be reconfigured during use to facilitate bidirectional flow of fluid through the housing. For example, the configuration (i.e., the angle 104, radial dimension 105, outer circumferential dimension 106, and/or inner circumferential dimension 107) of the partition openings 131 can be controlled by manipulating one or more partition members 132 via a motor, which can be actuated by one or more switches to achieve suitable flow characteristics through the partition openings in two directions.

[0032] In a steady operational state where fluid enters the housing via the opening 112, the fluid circulates around the outer chamber 116 and maintains a relatively constant pressure regime within the outer chamber. The fluid passes through the partition openings 131 into the rotor chamber 117 and enters the spaces or gaps between the individual disks 121 within the rotor assembly 120. By adhesive and viscous action on the surfaces of the disks the fluid causes the disks to rotate. As the rotational speed of the disks increases, the fluid between the disks is acted upon by both centrifugal force and the pressure difference maintained between the outer chamber 116 and the partition openings 131, which causes the fluid to be retained within the disks. This increased residence of the fluid between the disks enables the fluid to continue to transfer energy and do work by imparting further rotation in the form of torque, which increases efficiency and allows the turbomachine to convert more thermal energy to mechanical work.

[0033] In one aspect, a debris trap 140 can be included to gather and expel heavier particles thrown to the outer edges of the rotor assembly 120 disks by centrifugal force. For example, a portion of the partition 130 can form the debris trap 140 as shown in FIGS. 3A and 3B in the shape of a channel or groove along an inner radial surface of one or more of the partition members 132. The debris trap 140 can convey the particles from the interior space 115 via an opening 141, which can lead to a debris receptacle 142 external to the housing 110 via a conduit 143, as shown in FIGS. 1 and 2A. The illustrated debris trap includes openings 141 at each end, although a single opening may be suitable. The debris receptacle 142 can be easily serviced and cleaned utilizing steam pressure and gravity. The debris trap 140 can therefore capture particles from the fluid and prevent the particles from leaving the turbomachine as emissions. In certain applications this can dramatically reduce the environmentally negative emissions associated with typical existing technologies.

[0034] In one aspect, the opening 112 can be configured as an adaptive inlet port to provide the optimal efficiency intake pressure and/or flow pattern for the fluid. For example, as shown in FIG. 3B, a modular, replaceable inlet fitting 118 can optionally be used to provide different orifice or inlet opening sizes as desired to affect the intake pressure and/or flow pattern of the fluid. Alternatively, the inlet manifold 144 can include replaceable inserts across a width of the manifold.

[0035] FIG. 4 illustrates a disk 250 that can be utilized in a rotor assembly in accordance with an example of the present disclosure. As shown in the figure, the disk 250 can include a plurality of fluid guides 251. The fluid guides can have any suitable cross-section such as, but not limited to, airfoil, elliptical, circular, diamond, and the like. However, an airfoil cross-section as illustrated can be particularly effective. For example, the airfoil shape can be symmetric about a longitudinal central axis of the airfoil, in some arrangement. The fluid guides 251 can be arranged in a ring configuration 252a, 252b, and/or 252c across the disk 250. In one aspect, the ring configuration can comprise multiple rings 252a-c concentric about the axis of rotation 201. Although three such rings are illustrated, from about three to about eight rings can often be suitable depending on the size and design operating parameters. In another aspect, a radial relationship of the rings 252a-c can correspond to the Fibonacci ratio (1.61618) or the Golden ratio (1.61803) to maximize the efficiency of the fluid as the fluid follows a spiral flow path along the disk 250. However, other radial relationships can be used such as equidistant, or ratios of 1.2 to 2, for example. As the fluid first encounters the fluid guides 251 a pressure wave is formed, which upon passing forms a low pressure vortex area that adds further impulse in the form of mechanical transfer of energy to the (rotating) disk in addition to the force(s) already present (e.g., adhesion and viscous forces acting on the rotating rotor assembly). When using airfoil shaped fluid guides, an inclination angle can be adjusted based on desired operating parameters. As a general guideline, the inclination angle 254 (i.e. an angle between a rotor radius 256 and central longitudinal airfoil axis 258) can be from about 20° to about 75°, and in some cases 30° to 55°. In some embodiments, the inclination angle is in the range of 40° to 60°, more specifically 45° to 55°, for example 51.5°, which has been found to result in efficient energy transfer. In some embodiments, the inclination angle 254 and the angle 104 are substantially the same. The number, geometric design, and location of the fluid guides 251 on the disk 250 can be optimized based on the size of the disk, the inlet pressure, and the design speed of rotation of the rotor assembly. In one aspect, a venturi configuration of a partition opening (see FIGS. 3A and 3B) can control the fluid flow between the concentric rings 252a-c. As the rotational velocity of the rotor assembly increases, fluid flow increases towards the center of the disks. At lower rotational velocity, fluid flow tends towards the outer edges of the disks.

[0036] FIG. 5 illustrates adjacent disks 350a, 350b of a rotor assembly in accordance with an example of the present disclosure oriented to show a gap between the disks. The disks 350a, 350b of a rotor assembly are typically relatively thin (e.g., a thickness 353 of approximately 1.45 mm) and typically have a gap 354 or space between the disks of a distance 355 equal to or less than the disk thickness 353. Generally, disk thickness can range from about 0.5 mm to about 5 mm, and in some cases from about 0.8 mm to about 2 mm. In one aspect, the outer edges of the disks 350a, 350b can be tapered by an angle 356 to a thinner edge of small radius to provide a tapered zone that can lessen turbulence and facilitate a smooth transition of fluid flow into or out of the rotor assembly.

[0037] FIG. 6 illustrates a cross-section of a portion of a rotor assembly 420 in accordance with an example of the present disclosure. The rotor assembly 420 includes a plurality of disks 421 (identified individually as disks 450a-n) that defines a central hollow interior opening 426 along an axis of rotation, which extends through the interior opening. The disks 450a-n include a plurality of spacers 451a-n disposed between adjacent disks to space the disks apart along the axis of rotation to provide gaps 454a-m between the disks. Thus, fluid can pass through the gaps 454a-m between the disks 450a-n and the interior opening 426 as the fluid moves through the rotor assembly 420.

[0038] In one aspect, the disks 450a-n can be permanently coupled to one another by the plurality of spacers 451a-n, such as using an adhesive. In one example, the adhesive is a common resin binder used to form the entire assembly, in particular in embodiments where the assembly is formed from a fibre composite material (i.e. composite of fibrous material, for example provided as a felt or other matted material and a resin binder). In some embodiments, the discs 450a-n and respective adjacent spacers 451a-n are assembled together before the resin binder is fully cured, so that the resin binder in the discs 450a-n and respective adjacent spacers 451a-n fuses and then fully cures, resulting in some embodiments in a monolithic fiber composite structure. In some embodiments, the resin permeates the fibrous material of adjacent layers of the assembly and fuses the entire structure into a monolithic assembly with no discernible interfaces between the layers. Fusing of the resin in adjacent layers and/or the subsequent full curing is facilitated by appropriate timing and/or heat treatment during the manufacturing process. In some embodiments, the assembly is manufactured using carbon fibres carbon fiber composite (e.g., Toray™ T800S) and an appropriated resin binder and hardener. In some embodiments the assembly is manufactured using basalt fibres in combination with a suitable resin binder and hardener. An example of basalt fibres used in some embodiments is a weave with weight 6.8oz/yds^2 (34g/m^2) and fiber thickness 9.8mils (0.25nm). For example a bismaleimide two-component system such as Matrimid® 5292 A-2 resin and Matrimid ® 5292 B hardener available commercially from Huntsman Corporation, TX, see also US Patent No. 4,100,140, incorporated herein by reference in its entirety, can be used with either carbon or basalt fibres. With no solid central shaft to hold the disks together, this configuration can be termed shaftless. As shown in FIG. 6, the spacers 451a-n can be integrally formed with the disks 450a-n. Thus, by utilizing such built-in spacers 451a-n to couple the disks 450a-n to one another, no other parts are needed to complete the disk assembly.

[0039] In one aspect, the spacers 451 a-n can have an airfoil configuration and can therefore also serve as fluid guides as discussed above with reference to FIG. 4. The spacers 451a-n can be configured in accordance with the above description of fluid guides 251. In some arrangements, the fluid guides 251 and spacers 451a-n are identical and the disks 450a-n are spaced apart by the fluid guides 251 described above, that is in some arrangements, the spacers 451a-n are the fluid guides 251.

[0040] As illustrated in FIG. 6, the disks 450a-n can be flat on one side and can have spacers projecting from an opposite side, which can be set out or arranged in a ring configuration as discussed above, for example with reference to the fluid guides 251 and/or Figure 4. Thus, the spacers 451a-n can ensure precise and proper spacing of the disks 450a-n from one another and contribute rigidity to the rotor assembly 420 structure under operating loads by providing multiple, geometrically and radially distributed coupling locations to interlock adjacent disks.

In addition, utilizing adhesive to bond the spacers 451a-n to adjacent disks provides a fixed attachment condition in all degrees of freedom that increases stiffness over a simpler attachment condition without fixity in all degrees of freedom, such as a bolted coupling. Typically, the rotor assembly 420 will include from 60 to 200 disks having gap distances of 0.5 mm to 5 mm, although any suitable number and spacing of disks can be utilized. Although the number of disks within a rotor assembly can vary, as a general guideline, from 50 to 500 disks, and in some cases from 75 to 200 disks can be included. In some embodiments, identical disks can be used to construct the entire rotor assembly 420 (including outer end disks), thus simplifying construction. In other embodiments, disks of different configurations can be incorporated into the rotor assembly, such as disks having different spacer/fluid guide configurations. In one example, a "smooth" disk can be used to "cap" an end of the rotor assembly disks, thus providing smooth exposed disk faces on opposite ends of the rotor assembly.

[0041] In one aspect, the disks of the rotor assembly can be constructed of lightweight carbon fiber composite material, which can provide a high surface area with less mass compared to typical designs that rely heavily on a "flywheel" effect to preserve momentum, unlike a turbomachine of the present disclosure.

[0042] FIG. 7 illustrates a cross-section of a portion of a rotor assembly 520 in accordance with another example of the present disclosure. As with FIG. 6, the rotor assembly 520 includes a plurality of disks 521 that define a central hollow interior opening 526 along an axis of rotation, which extends through the interior opening. Accordingly, fluid moving through gaps between adjacent disks can freely enter or exit the interior opening 526 directly from the gaps. In this case, however, the interior opening 526 is also defined at least in part by a helical baffle 527 to facilitate directional flow or movement of fluid through the rotor assembly 520 for venting fluid from the rotor assembly. In some embodiments, the helical baffle 527 can be formed by a feature or protrusion on each disk such that when the disks are assembled the baffle is formed with gaps in the baffle between adjacent disks. In other embodiments, the helical baffle 527 can be a separate component added to the disk assembly such that the baffle extends across the gaps between adjacent disks.

[0043] An extension member 522 is also shown attached to the plurality of disks 521. The extension member 522 can be attached to the plurality of disks 521 using an adhesive, fasteners, or any other suitable substance or device. For example, the extension member 522 can include a flange 523 to interface with the plurality of disks 521 and facilitate coupling with the disks. The extension member 522 also includes a vent port 525 oriented along the axis of rotation. The vent port 525 can extend through the extension member 525 in fluid communication with the interior opening 526 formed by the plurality of disks, thus effectively forming an extension of the interior opening. Although a diameter of the vent port 525 is illustrated as being different than a diameter of the interior opening 526, it should be recognized that the vent port and the interior opening can have substantially the same diameter to facilitate unrestricted fluid flow between the interior opening and the vent port.

[0044] The helical baffle optionally extends across an extension member 522. In one aspect, the vent port 525 can be defined at least in part by a helical baffle 528 to facilitate movement of the fluid through the vent port 525. As with the helical baffle 527 of the internal opening 526, the helical baffle 528 can be a protruding internal surface feature integrally formed with the substrate or included as a separate component. The helical baffles 527, 528 can be continuous through the interior opening 526 and the vent port 525 such that the interfacing ends of the baffles align with one another to maintain the flow or movement of fluid through the rotor assembly 520 for venting fluid from the rotor assembly. Although interior opening 526 and the vent port 525 are shown with the helical baffles 527, 528, it should be recognized that the interior opening and the vent port can have smooth or featureless boundaries, which can simplify construction of the rotor assembly 520.

[0045] FIGS. 8A and 8B illustrate a computer model showing the fluid volume in an interior space of a boundary layer turbomachine in accordance with an example of the present disclosure. These figures show fluid in the inlet opening, the outer chamber, the partition openings, the rotor chamber, the interior opening, and the vent port.

[0046] The foregoing detailed description describes the invention with reference to specific exemplary embodiments. However, it will be appreciated that various modifications and changes can be made without departing from the scope of the present invention as set forth in the appended claims. The detailed description and accompanying drawings are to be regarded as merely illustrative, rather than as restrictive, and all such modifications or changes, if any, are intended to fall within the scope of the present invention as described and set forth herein.

Claims

1. A boundary layer turbomachine, comprising:

a housing defining an interior space and having an inlet opening and an outlet opening to facilitate movement of a fluid through the housing; and

a rotor assembly disposed in the housing and configured to rotate about an axis of rotation, the rotor assembly having a plurality of disks spaced apart along the axis of rotation and defining an interior opening along the axis of rotation, wherein the fluid passes through gaps between the disks and the interior opening as the fluid moves through the housing, wherein the turbomachine is configured such that fluid moving through the housing is guided into or from the gaps at a plurality of locations around outer edges of the disks.

2. The boundary layer turbomachine of claim 1, the turbomachine comprising
a partition circumferentially dividing the interior space into an outer chamber and a rotor chamber located radially inward of the outer chamber, wherein the rotor assembly is disposed in the rotor chamber, the partition having partition openings spaced circumferentially around the partition such that fluid is movable through the partition between the outer chamber and the rotor chamber at the plurality of locations.

3. The boundary turbomachine of claim 1 with the proviso that it does not comprise: a partition circumferentially dividing the interior space into an outer chamber and a rotor chamber located radially inward of the outer chamber, wherein the rotor assembly is disposed in the rotor chamber, the partition having partition openings spaced circumferentially around the partition such that fluid is movable through the partition between the outer chamber and the rotor chamber at the plurality of locations; or the boundary turbomachine of claim 2.

4. The boundary layer turbomachine of claim 2 or 3, wherein theinlet opening is associated with the outer chamber such that the outer chamber serves as an expansion chamber for the fluid.

5. The boundary layer turbomachine of claim 2, 3 or 4, wherein the partition openings have a tangential cross-sectional area that increases in a radially inward direction.

6. The boundary layer turbomachine of claim 2, 3 or 4, wherein the partition openings comprise a venturi configuration.

7. The boundary layer turbomachine of any one of claims 2 to 6, wherein the partition openings are equally spaced circumferentially around the partition.

8. The boundary layer turbomachine of any preceding claim, wherein the turbomachine is configured such that fluid moving through the housing is guided into the gaps at a plurality of locations circumferentially spaced around the rotor assembly at an angle in the range of 40° to 60°, optionally 45° to 55°, for example 51° or 52° relative to a radius of the discs.

9. The boundary layer turbomachine of any preceding claim, further comprising a debris trap.

10. The boundary layer turbomachine of claim 9, wherein the debris trap is formed by a groove along an inner radial surface of a portion of the partition.

11. The boundary layer turbomachine of any preceding claim, wherein the interior opening defines a central void centred on the axis of rotation.

12. The boundary layer turbomachine of any one claims claim 1 to 11, wherein the interior opening defines a fluid flow path coinciding with the axis of rotation.

13. The boundary layer turbomachine of any preceding claim, wherein the disks are spaced apart by a plurality of spacers.

14. The boundary layer turbomachine of claim 13, wherein the disks and spacers form a monolithic structure.

15. The boundary layer turbomachine of claim 13 or 14, wherein the spacers are arranged in a ring configuration across each disk.

16. The boundary layer turbo machine of claim 13, 14 or 15, wherein the spacers are arranged with a longitudinal axis at an angle in the range of 40° to 60°, optionally 45° to 55°, for example 51° or 52° relative to a radius of the discs.

17. The boundary layer turbomachine of any preceding claim, wherein the interior opening defines a helical baffle to facilitate movement of the fluid through the rotor assembly.

18. The boundary layer turbomachine of any preceding claim, wherein the rotor assembly includes an extension member to couple the rotor assembly to the housing and facilitate rotation of the rotor assembly about the axis of rotation, the extension member defining a fluid port extending therethrough in fluid communication with the interior opening.

19. A method of operating the boundary layer turbomachine of any preceding claim, the method comprising feeding a mixture of gas and liquid through the one or more inlet openings to drive the boundary layer turbomachine.

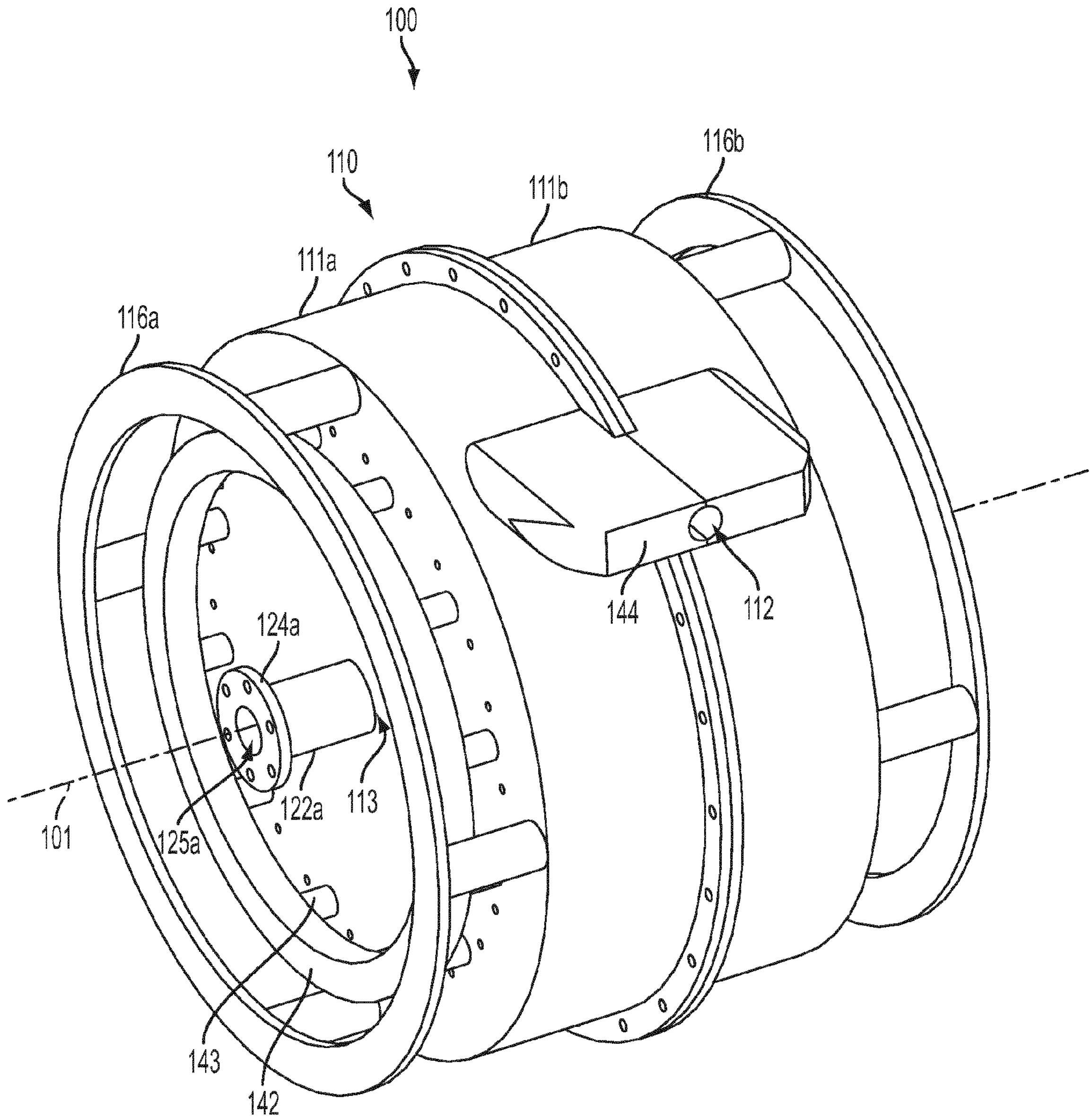
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FIG. 1

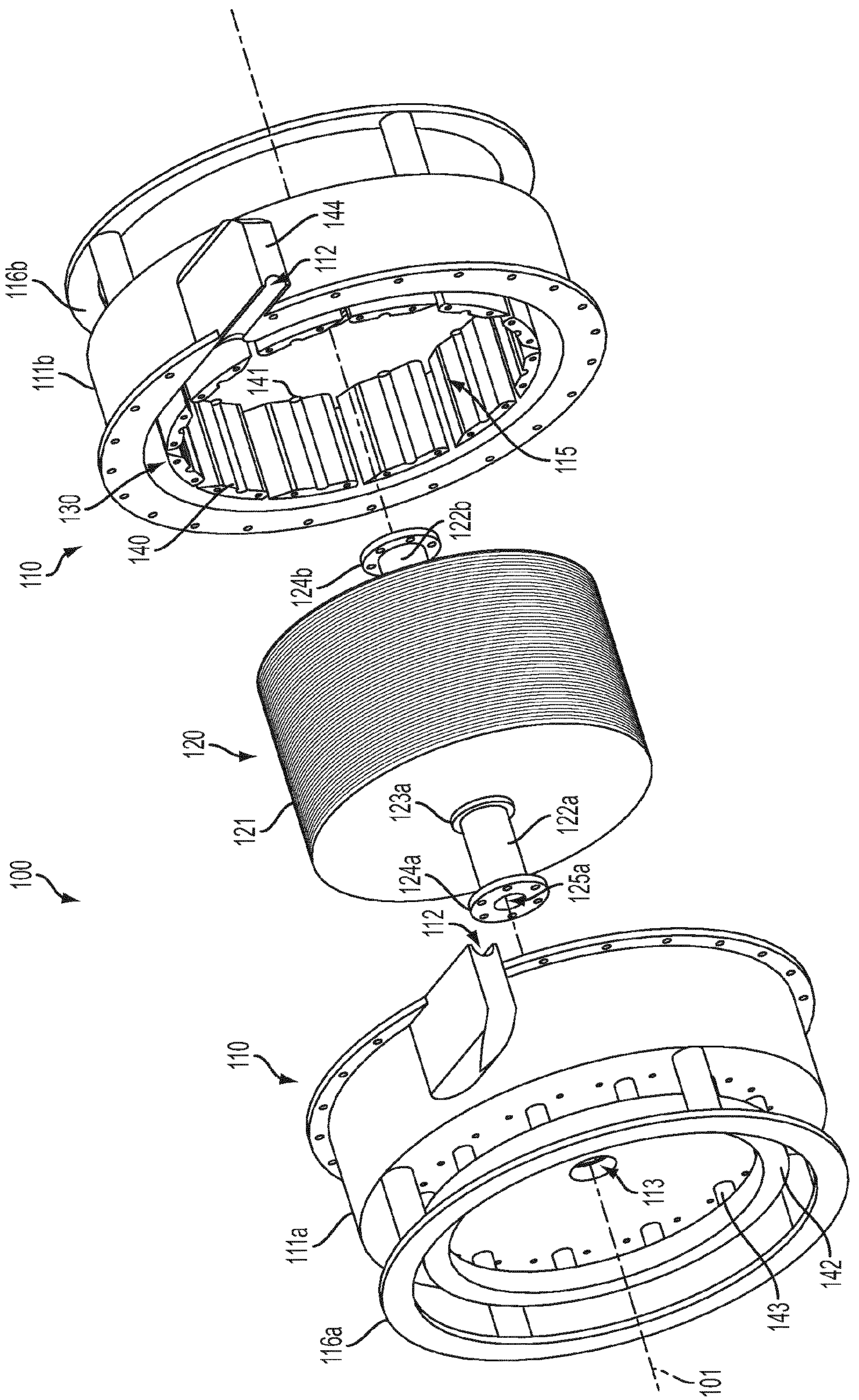
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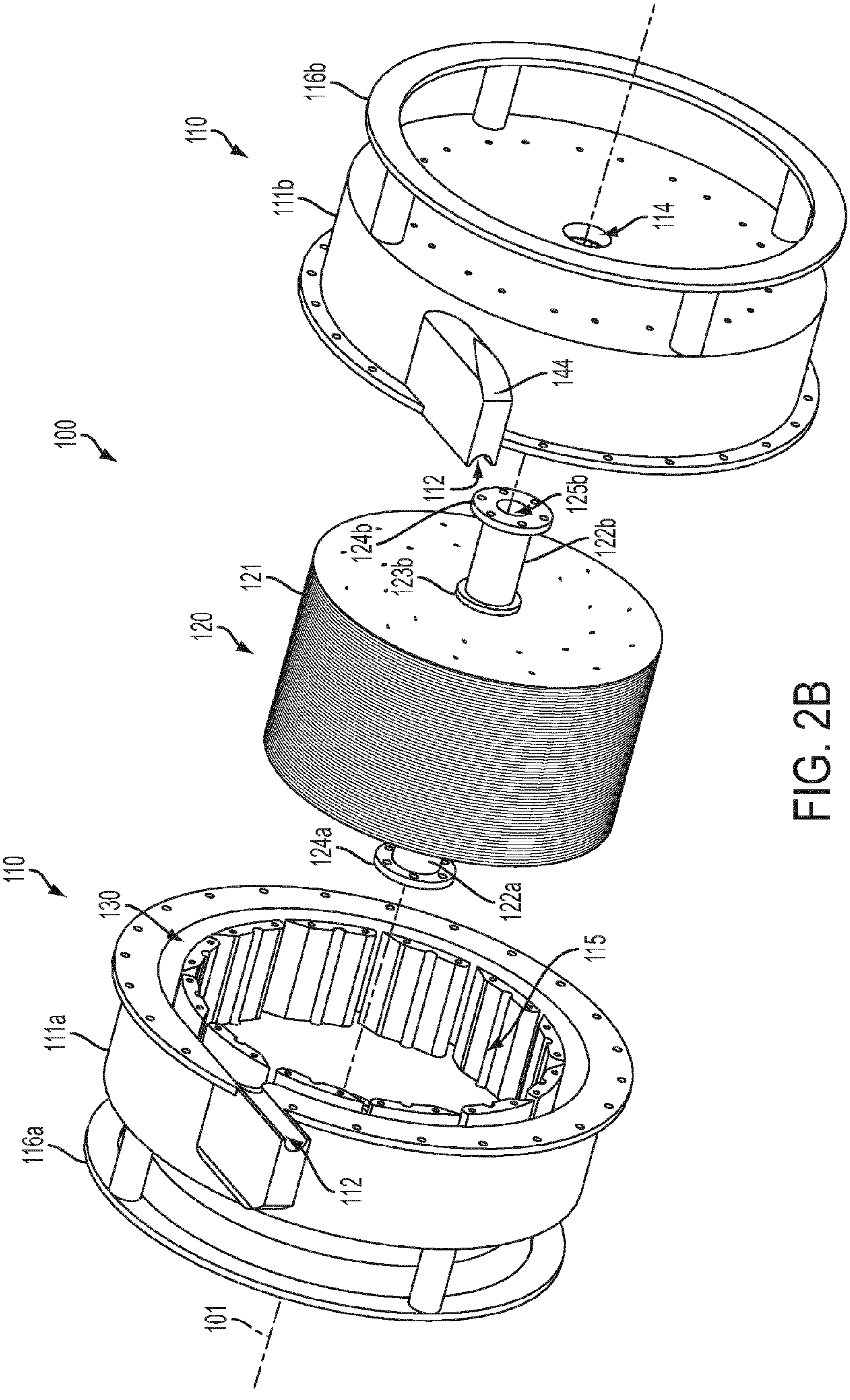
FIG. 2A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116a
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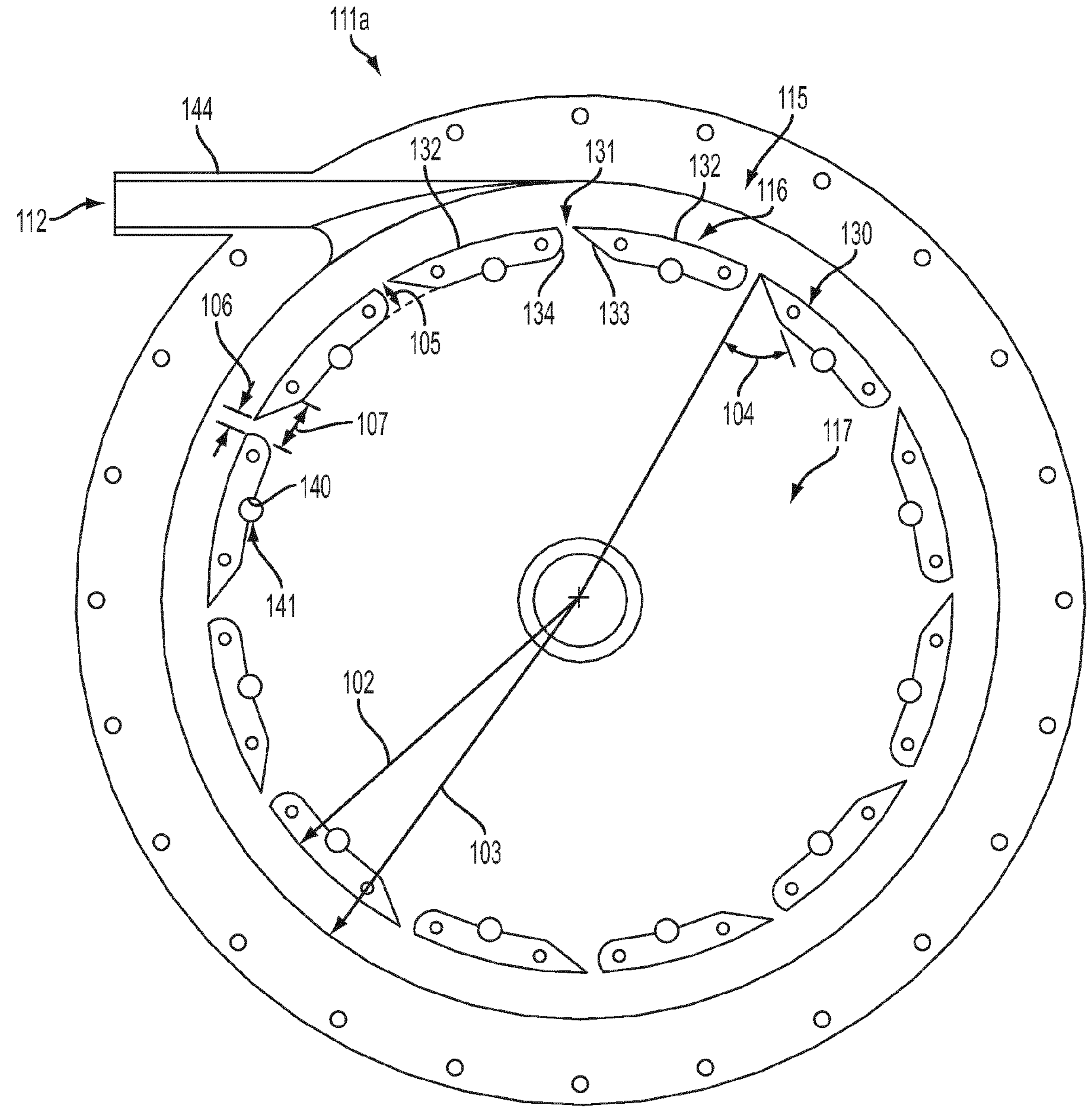
101

FIG. 2B


111a
144
112
132
131
132
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133
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104
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141
102
103

FIG. 3A

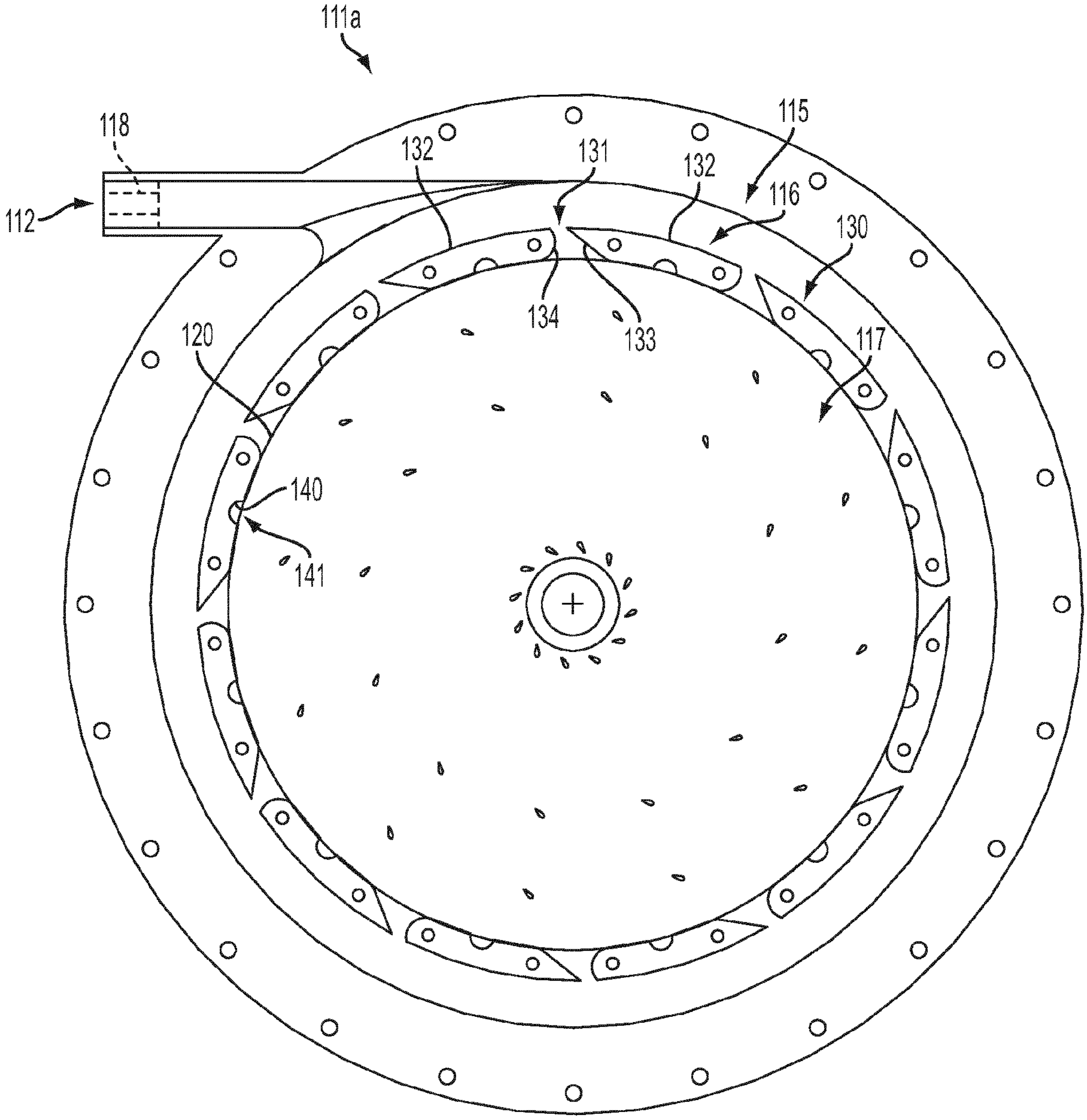
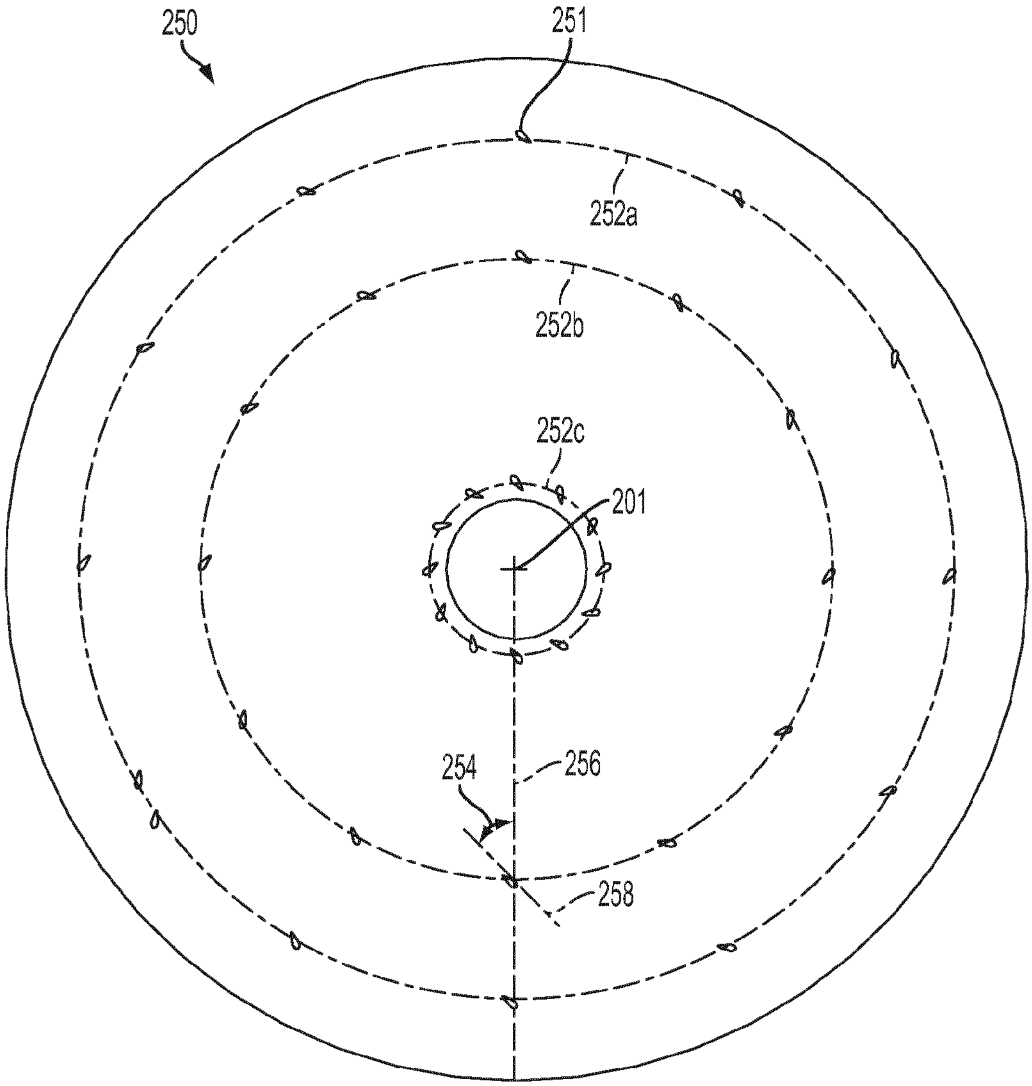


FIG. 3B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252a
252b
252c
201
254
256
258

FIG. 4

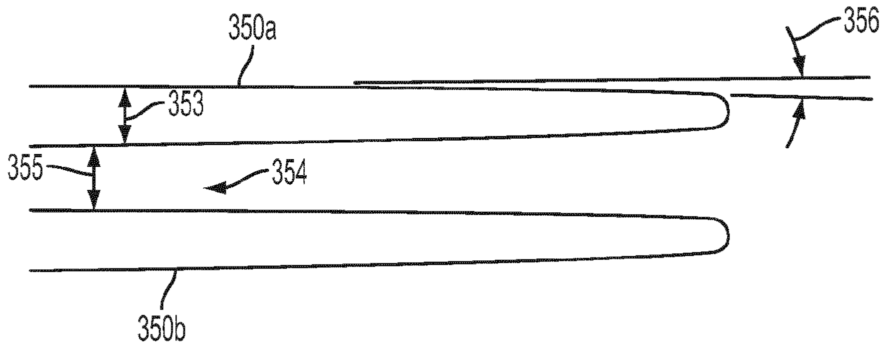
350a
356
353
355
354
350b

FIG. 5

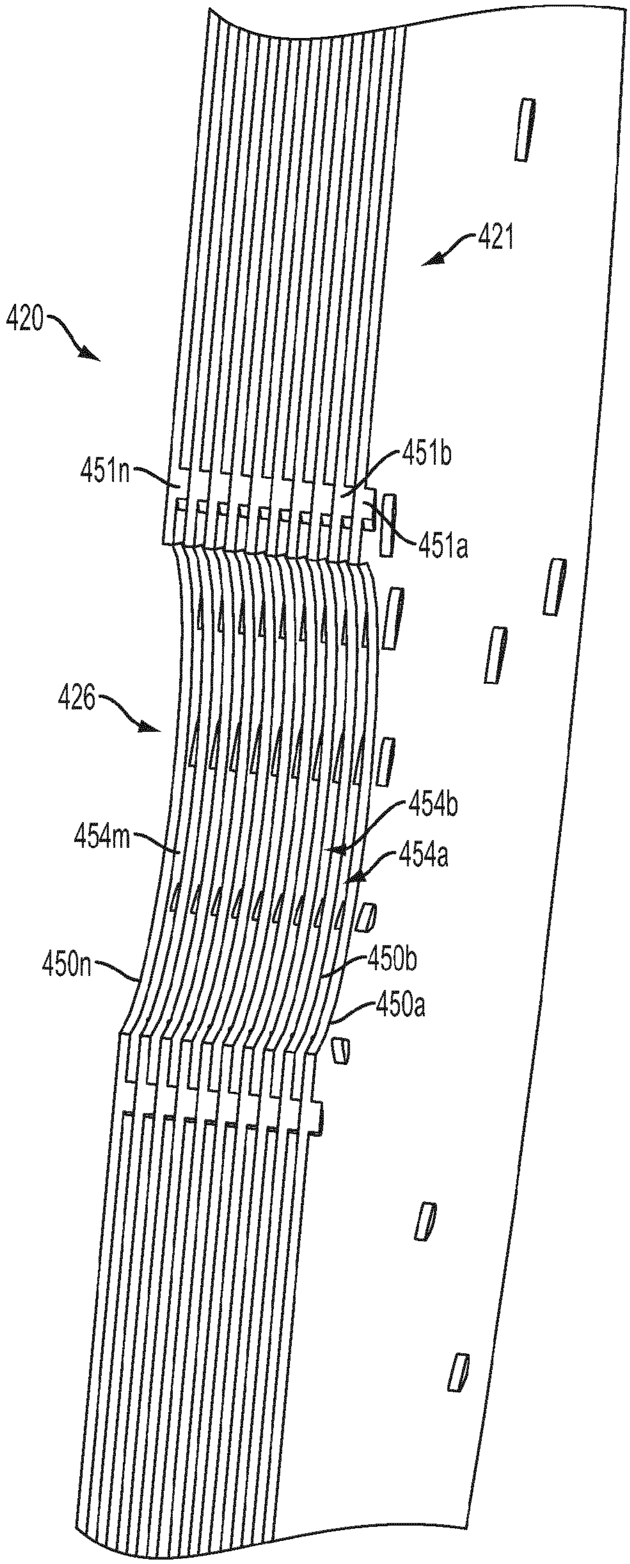

FIG. 6

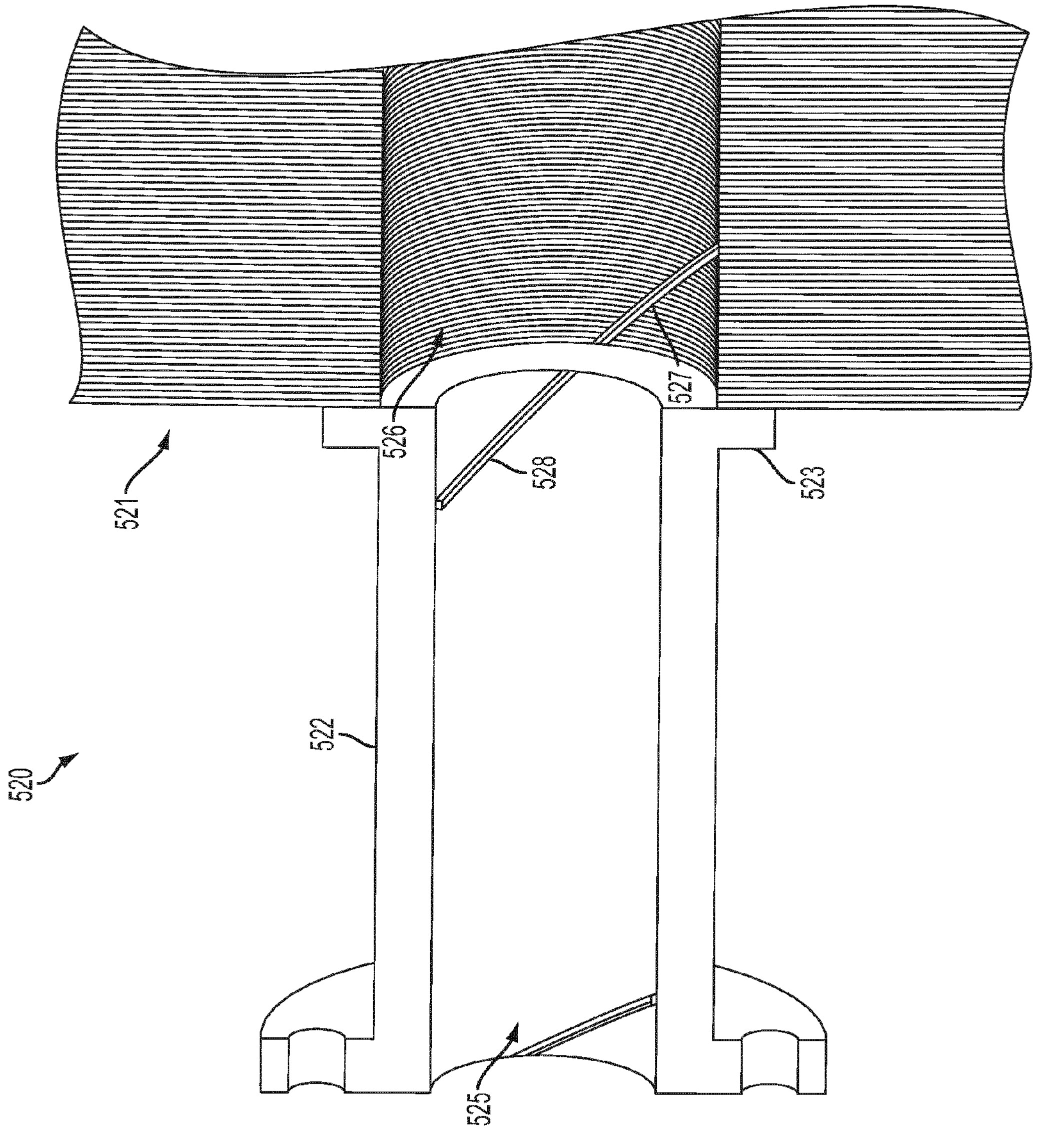

FIG. 7

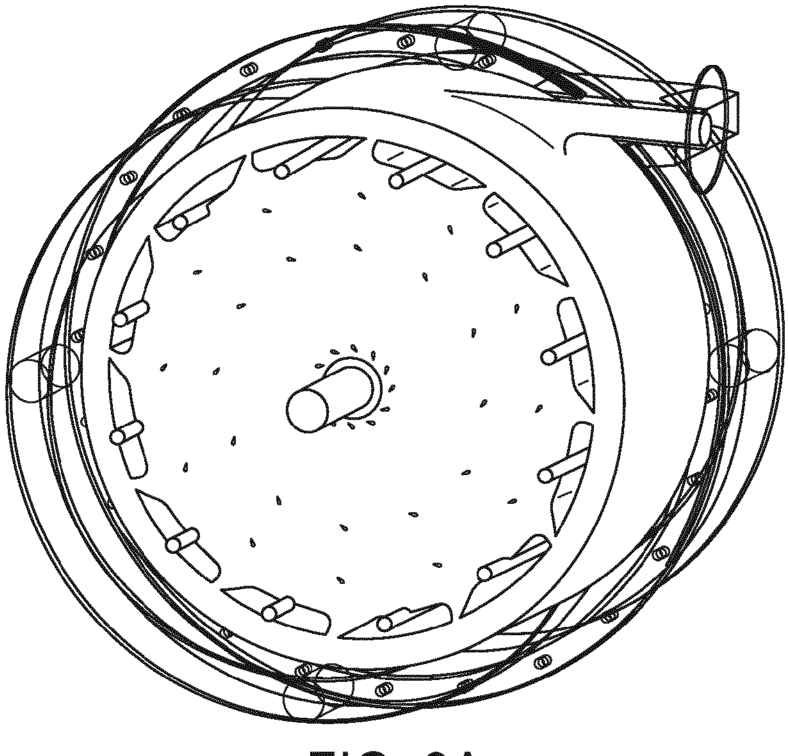

FIG. 8A

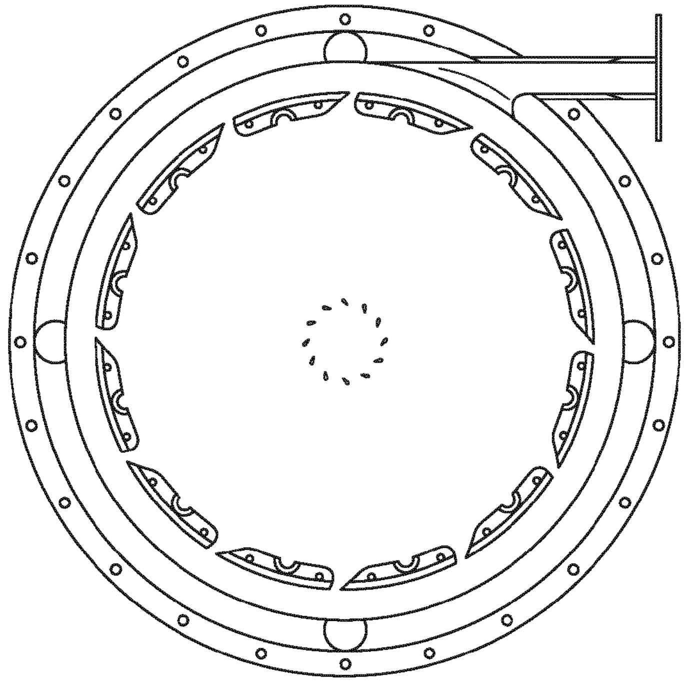

FIG. 8B

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EUROPEAN SEARCH REPORT

Application Number
EP 15 17 1530

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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Y	WO 2008/070369 A2 (FULLER HOWARD J [US]) 12 June 2008 (2008-06-12) * figures 1-3 *	16	
Y	WO 2005/081766 A2 (GRANDE SALVATORE F III [US]; DRAPER DAVID R [US]) 9 September 2005 (2005-09-09) * figures 1, 2, 8, 9 * * page 14, line 20 - page 15, line 16 *	17	TECHNICAL FIELDS SEARCHED (IPC)
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	10 March 2016	Lutoschkin, Eugen

CATEGORY OF CITED DOCUMENTS

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