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(54) **Title:** PUMPING STAGE OF A VACUUM PUMP

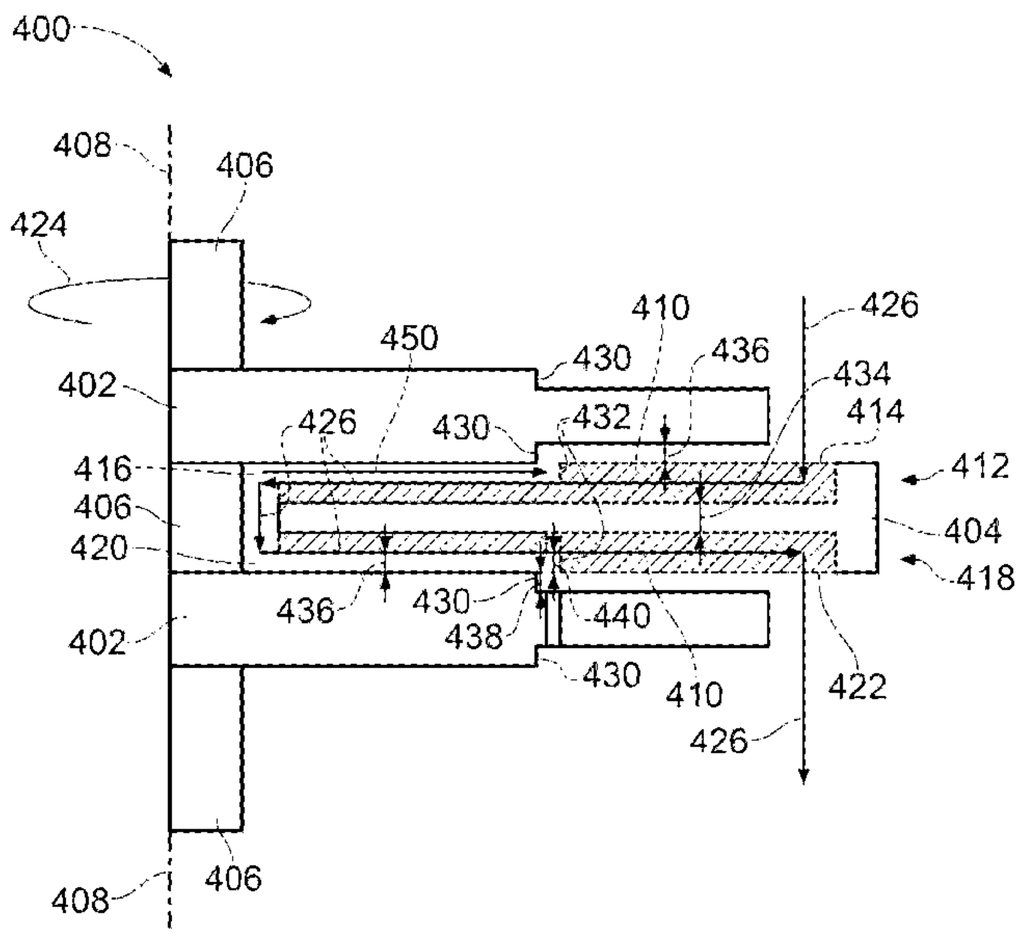


FIG. 4

(57) **Abstract:** A Siegbahn or Holweck stage of a pump (400) comprising: a rotor (402) configured to be rotated about an axis of rotation (408); a stator (404) mounted in proximity to the rotor (402) such that a side of the rotor (402) faces a side of the stator (404); wherein at least one of the stator (404) or the rotor (402) includes at least one open channel (410) on the side of the stator (404) or the rotor (402) that faces the other of the stator (404) or the rotor (402); and the facing sides of the rotor (402) and the stator (404) each comprise at least one step (430, 432).

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PUMPING STAGE OF A VACUUM PUMP

FIELD OF THE INVENTION

The present invention relates to Siegbahn stages and Holweck stages of vacuum pumps.

BACKGROUND

Vacuum pumps are used in various technical processes to create a vacuum for the respective process.

Molecular drag vacuum pumps (or “friction pumps”) pump gases by momentum transfer from a fast-moving surface directly to gas molecules. Typically, molecular drag vacuum pumps include rotating rotor and stationary stator surfaces. Typically, the stator comprises several channels between an inlet and an outlet. Collisions of gas molecules with the moving rotor cause gas in the channels to be pumped from the inlet to the outlet. In some molecular drag vacuum pumps, the channels are located in the rotor as opposed to the stator.

An example of a molecular drag vacuum pump is the Siegbahn pump.

Figure 1 is a schematic illustration (not to scale) showing a cross section through two stages of a conventional Siegbahn-type pump 100.

The Siegbahn-type pump 100 comprises rotor discs 102 and a stator disc 104.

Figure 2 is a schematic illustration (not to scale) showing a perspective view of a stator disc 104 of the Siegbahn-type pump 100.

The rotor discs 102 are fixed to a shaft 106 such that a longitudinal axis 108 of the shaft is aligned with the axes of the rotor discs 102.

The stator disc 104 comprises spiral channels 110 that extends from an outer periphery of the stator 104 toward a centre portion of the disc. In a first, or inward stage 112, the channels 110 of the stator disc 104 comprise first inlets 114 located at the outer periphery of the disc and first outlets 116 located near

the centre of the disc. In a second, or outward stage 118, the channels 110 of the stator disc 104 comprise second inlets 120 near the centre of the disc and second outlets 122 at the outer periphery of the disc.

In operation, the shaft 106 and rotors 102 are rotated about the axis 108, as indicated in Figure 1 by an arrow and the reference numeral 124. Collisions of gas molecules with the moving rotors 102 cause gas in the channels 110 to be moved, in the first stator stage 112, from the first inlet 114 to the first outlet 116, and, in the second stator stage 118, from the second inlet 120 to the second outlet 122. Movement of gas through the Siegbahn-type pump 100 is indicated in Figure 1 by arrows and the reference numeral 126.

SUMMARY OF THE INVENTION

The present inventors have realised that a maximum compression ratio achievable in a Siegbahn-type drag pumping stage is limited by back leakage from the outlets towards the inlets. One of the key limiting leaks occurs in the clearance between the spinning rotor disc and the tip of the thread of the stator disc, whereby gas can leak back directly from an outlet to an inlet. In the case of 'inward pumping' stages, this tends to be exacerbated by the centrifugal forces imparted on the gas from the rotor disc.

The present inventors have further realised that this compression limiting leakage may be reduced, minimised, or eliminated by introducing at least one step to the rotors and stators. Preferably, such a step is of a height greater than or equal to the clearance between the rotor and stator. This tends to eliminate the line of sight leakage path between an outlet and an inlet. That is, the step tends to reduce gas flow through the clearance gap between the spinning rotor and the stator.

In an aspect, there is provided a Siegbahn-stage of a vacuum pump comprising a rotor configured to be rotated about an axis of rotation, and a stator mounted in proximity to the rotor such that a side of the rotor faces a side of the stator. At least one of the stator or the rotor includes at least one open channel

on the side of the stator or the rotor that faces the other of the stator or the rotor. The facing sides of the rotor and the stator each comprise at least one step.

A thickness of the rotor in a direction parallel to the axis may decrease step-wise in a radial direction from a central portion of the rotor to a peripheral edge of the rotor. A thickness of the stator in a direction parallel to the axis may increase step-wise in a radial direction from a central portion of the stator to a peripheral edge of the stator. A depth of the at least one open channel may increase step-wise in a radial direction from a central portion of the stator to a peripheral edge of the stator.

The at least one open channel may be on the side of the stator that faces the rotor. The at least one open channel defines a first vacuum pumping stage. The stator may further include at least one further open channel on a further side of the stator, the further side of the stator being opposite to the side of the stator that faces the rotor, the at least one further open channel defining a second vacuum pumping stage.

The Siegbahn-stage of the vacuum pump may further comprise a further rotor configured to be rotated about an axis of rotation. The stator may be mounted in proximity to the further rotor such that a side of the further rotor faces the further side of the stator. The further side of the stator and the side of the rotor that faces the further side of the stator may each comprise at least one further step.

In a further aspect, there is provided a Holweck-stage of a vacuum pump comprising a rotor configured to be rotated about an axis of rotation and a stator mounted in proximity to the rotor such that a side of the rotor faces a side of the stator. At least one of the stator or the rotor includes at least one open channel on the side of the stator or the rotor that faces the other of the stator or the rotor. The facing sides of the rotor and the stator each comprise at least one step.

The stator may comprise the at least one open channel on the side of the stator that faces the rotor. The step of the stator may partition the stator into a first portion at a first side of the step of the stator and second portion at a second side of the step of the stator. The at least one open channel may be formed in

the side of the stator that faces the rotor of both the first portion of the stator and the second portion of the stator. The step of the rotor may partition the rotor into a first portion at a first side of the step of the rotor and second portion at a second side of the step of the rotor. A side of the first portion of the rotor may face a side of the first portion of the stator. A side of the second portion of the rotor may face a side of the second portion of the stator.

The Holweck-stage of the vacuum pump may further comprise a pumping stage inlet and a pumping stage outlet, An axial length of the rotor may be defined as a length of the rotor in an axial direction between the inlet and the outlet. The axial direction may be parallel to the axis of rotation. An axial length of the stator may be defined as a length of the stator in the axial direction between the inlet and the outlet. A distance from the inlet to the step of the rotor along the axial direction may be between 10% and 90% of the axial length of the rotor. A distance from the inlet to the step of the stator along the axial direction may be between 10% and 90% of the axial length of the stator.

In any aspect, the at least open channel may comprise at least one curved, spiral, helical or involute channel.

In any aspect, a size of at least one of the steps may be greater than or equal to a clearance distance between the facing sides of the rotor and the stator.

In any aspect, a size of at least one of the steps may be greater than or equal to about 200μm-500μm, or greater than about 1mm.

In any aspect, a clearance distance between the facing sides of the rotor and the stator may be about 200μm-500μm, or greater than about 1mm.

In any aspect, a clearance distance between the facing sides of the rotor and the stator may be substantially uniform.

In a further aspect, there is provided a vacuum pumping method comprising providing a pumping stage in accordance with any aspect, and rotating the rotor about the axis.

In a further aspect, there is provided a molecular drag pumping apparatus for use in a vacuum pump, the molecular drag pumping apparatus comprising: a

rotor configured to be rotated about an axis of rotation, the axis of rotation defining an axial direction parallel thereto and a radial direction perpendicular thereto; and a stator mounted in proximity to the rotor such that a side of the rotor faces a side of the stator; wherein at least one of the stator or the rotor includes an open channel; the open channel is a radially extending open channel or an axially extending open channel and is recessed in the side of the stator or the rotor that faces the other of the stator or the rotor; and the open channel defines a flow path, the flow path, if formed by the radially extending open channel, being a radial flow path for a pumped fluid or, if formed by the axially extending open channel, being an axial flow path for a pumped fluid; the facing sides of the rotor and the stator each comprise a step, such that the flow path, if a radial flow path, includes a step in the radial direction or the flow path, if an axial flow path, includes a step in the axial direction. Each of the facing sides of the rotor and the stator may extend from both sides of the step formed therein, such that the distance from an end of the flow path to the step of the flow path is between 10% and 90% of the length of the open channel.

In a further aspect, there is provided a molecular drag pumping apparatus comprising a rotor configured to be rotated about an axis of rotation and a stator mounted in proximity to the rotor such that a side of the rotor faces a side of the stator. At least one of the stator or the rotor includes at least one open channel on the side of the stator or the rotor that faces the other of the stator or the rotor. The facing sides of the rotor and the stator each comprise at least one step. Each step may be a substantially circular step. The steps may be concentric. The steps may define concentric circles. The circles defined by the steps may be centred about the axis of rotation. Each step may be a circumferential step.

The molecular drag pumping apparatus may be an apparatus selected from the group of apparatuses consisting of: a Siegbahn-type pump, a Holweck-type pump, a Siegbahn stage of a turbomolecular pump, a Holweck stage of a turbomolecular pump, a turbomolecular pump, a magnetic levitation turbomolecular pump, and a mechanical bearing molecular drag pump.

A dimension (e.g. a thickness) of the rotor in a direction parallel to the axis may decrease step-wise in a radial direction from a central portion of the rotor to

a peripheral edge of the rotor. A dimension (e.g. a thickness) of the stator in a direction parallel to the axis may increase step-wise in a radial direction from a central portion of the stator to a peripheral edge of the stator. A dimension (e.g. a depth) of the at least open channel may increase step-wise in a radial direction from a central portion of the stator to a peripheral edge of the stator.

The at least open channel may comprise at least one curved, spiral, or involute channel.

A size of at least one of the steps may be greater than or equal to a clearance distance between the facing sides of the rotor and the stator. A size of at least one of the steps may be greater than or equal to about 200μm-500μm, or greater than about 1mm. A clearance distance between the facing sides of the rotor and the stator may be about 200μm-500μm, or greater than about 1mm. A clearance distance between the facing sides of the rotor and the stator may be substantially uniform.

The at least one open channel may be on the side of the stator that faces the rotor. The at least one open channel may define a first vacuum pumping stage. The stator may further include at least one further open channel on a further side of the stator, the further side of the stator being opposite to the side of the stator that faces the rotor, the at least one further open channel defining a second vacuum pumping stage.

The molecular drag pumping apparatus may further comprise a further rotor configured to be rotated about an axis of rotation. The stator may be mounted in proximity to the further rotor such that a side of the further rotor faces the further side of the stator. The further side of the stator and the side of the rotor that faces the further side of the stator may each comprise at least one further step. Each further step may be a substantially circular step. The further steps may be concentric. The further steps may define concentric circles. The circles defined by the further steps may be centred about the axis of rotation. Each further step may be a circumferential step.

In a further aspect, there is provided a vacuum pumping method comprising providing a molecular drag pumping apparatus in accordance with any preceding aspect, and rotating the rotor about the axis.

In a further aspect, there is provided a molecular drag vacuum pumping apparatus comprising a rotor and a stator. The rotor and stator are positioned facing each other. The stator and/or the rotor includes an open channel on its side that faces the other of the stator or the rotor. A gap between the facing sides of the rotor and the stator comprises a step.

In a further aspect, there is provided a molecular drag vacuum pumping apparatus comprising: a rotor configured to be rotated about an axis of rotation; and a stator mounted in proximity to the rotor such that a side of the rotor faces a side of the stator. The stator or the rotor includes at least one open channel on its side that faces the other of the stator or the rotor. A maximum thickness of the rotor either decreases or increases step-wise in a direction from a central portion of the rotor to a peripheral edge of the rotor; and/or a maximum thickness of the stator either decreases or increases step-wise in a direction from a central portion of the stator to a peripheral edge of the stator. The maximum thickness dimension may be measured in an axial direction, i.e. in a direction parallel with the axis of rotation.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic illustration (not to scale) showing a cross section through two stages of a conventional Siegbahn-type pump;

Figure 2 is a schematic illustration (not to scale) showing a perspective view of a stator disc of the conventional Siegbahn-type pump;

Figure 3 is a schematic illustration (not to scale) showing a cross section through two stages of a conventional Siegbahn-type pump and illustrating a gas leakage path;

Figure 4 is a schematic illustration (not to scale) showing a cross section through two stages of a pump; and

Figure 5 is a schematic illustration (not to scale) showing a cross section through a further pump.

DETAILED DESCRIPTION

It will be appreciated that relative terms such as above and below, horizontal and vertical, top and bottom, front and back, and so on, are used herein merely for ease of reference to the Figures, and these terms are not limiting as such, and any two differing directions or positions and so on may be implemented rather than truly above and below, horizontal and vertical, top and bottom, and so on.

Figure 3 is a schematic illustration (not to scale) showing a cross section through two stages of the conventional Siegbahn pump or Siegbahn-type pump 100 of Figure 1. Figure 3 illustrates the problem of leakage between the inlet and outlet of a Siegbahn-type pump 100. In addition to the elements shown in Figure 1 and described in more detail earlier above (where like reference numerals refer to like elements), Figure 3 further shows a first gas leakage path 301 and a second gas leakage path 302.

The first gas leakage path 301 occurs in the clearance between the stator disc 104 and the preceding rotor disk 102. More specifically, in the orientation of Figure 3, the first gas leakage path 301 is between an upper surface (i.e. a thread tip) of the first stage 112 of the stator disc 104 and a lower surface of the rotor disk 102 that is above the stator disc 104 in the pump 100. The first gas leakage path 301 is a gas path via which gas may travel back from the first outlet 116 to the first inlet 114.

For the first stage 114, gas leakage via the first gas leakage path 301 tends to be caused or exacerbated, at least in part, by centrifugal forces imparted on the gas from the rotating rotor discs 102.

The second gas leakage path 302 occurs in the clearance between the stator disc 104 and the following rotor disk 102. More specifically, in the orientation of Figure 3, the second gas leakage path 302 is between a lower

surface (i.e. a thread tip) of the second stage 118 of the stator disc 104 and an upper surface of the rotor disk 102 that is below the stator disc 104 in the pump 100. The second gas leakage path 302 is a gas path via which gas may travel back from the second outlet 122 to the second inlet 120.

The clearances between the stator disc 104 and the rotor discs 102 that define the gas leakage paths 301, 302 may be approximately 200μm-500μm, for example for mechanical turbo pumps. However, it will be appreciated by those skilled in the art that the clearance may have different values. For example, larger clearances of, for example, greater than or equal to 1mm (e.g. 1mm-2mm, or about 1.5mm) may be present, for example in magnetic levitation (i.e. "maglev") turbomolecular pumps.

The depths of the channels 110 (i.e. the depth of the thread of the stator disc 104) may be approximately 2mm-4mm. However, it will be appreciated by those skilled in the art that the depths may be deeper or shallower, for example, depending upon the pump type and/or characteristic performance required. These depths are indicated in Figure 3 by double-headed arrows and the reference numerals 304. In some embodiments, the channel depth of one or more channels may vary along the channel. The depth of a channel may vary continuously, or in a discrete, step-wise fashion. For example, the depth of a channel may be tapered from inlet to outlet. This may provide improved performance characteristics.

A distance between the floors of opposite channels 110 (i.e. channels 110 on opposite sides of the stator disc 104) may be approximately 2mm-4mm. This distance is indicated in Figure 3 by a double-headed arrow and the reference numeral 306. In pumps where the channel depth of one or more channels varies between inlet and outlet, the stator disc thickness between the channels may also vary to accommodate the tapered channels whilst keeping the thread tips of the channels in a constant plane.

Stator and/or rotor thickness and/or channel depth may vary stage by stage in the pump 100. Stator and/or rotor thickness and/or channel depth may depend upon the pump type and/or characteristic performance required. By way

of example, in maglev turbomolecular pumps, channel depth may vary stage in the pump by e.g. a series of stages may have the following series of channel depths: about 10mm, about 7mm, about 5mm, about 3-4mm, and less than or equal to about 1mm.

Gas leakage via the gas leakage paths 301, 302 tends to result in lower pumping performance in terms of both compression ratio and pumping speed.

Figure 4 is a schematic illustration (not to scale) showing a cross section through two stages of an embodiment of a pump 400. The pump stages shown in Figure 4 may be considered to be Siegbahn stages of the pump 400. Figure 4 illustrates steps 430, 432 which tend to address the problem of leakage between the inlet and outlet of a Siegbahn-type pump 100.

In this embodiment, the pump 400 comprises rotors in the form of rotor discs 402, and a stator in the form of a stator disc 404.

The rotor discs 402 are fixed to a shaft 406 such that a longitudinal axis 408 of the shaft is aligned with the axes of the rotor discs 402.

The stator disc 404 comprises curved, spiral, or involute channels 410 that extend from an outer periphery of the stator disc 404 toward a centre portion of the stator disc 404.

In a first or inward stage 412 of the stator disc 404, the channels 410 of the stator disc 404 comprise first inlets 414 located at the outer periphery of the stator disc 404 and first outlets 416 located near the centre of the stator disc 404.

In a second or outward stage 418, the channels 410 of the stator disc 404 comprise second inlets 420 near the centre of the stator disc 404 and second outlets 422 at the outer periphery of the stator disc 404.

In this embodiment, each side of each rotor disc 402 comprises a respective step 430. For a rotor disc 402, the steps 430 on opposite sides of that rotor disc 402 are opposite each other (i.e. aligned in a direction parallel to the axis 408). In this embodiment, a thickness of each rotor disc 402 (defined as the distance between opposite sides of the rotor disc 402 in a direction parallel to the

axis 408) decreases step-wise in a radial direction from a centre portion of the rotor disc 402 to a peripheral edge of the rotor disc 402.

In this embodiment, each side of the stator disc 404 comprises a respective step 432. The steps 432 on opposite sides of the stator disc 432 are opposite each other (i.e. aligned in a direction parallel to the axis 408). In this embodiment, a maximum thickness of the stator disc 404 (defined as the maximum distance between opposite sides of the stator disc 404 in a direction parallel to the axis 408) increases step-wise in a radial direction from a centre portion of the stator disc 404 to a peripheral edge of the stator disc 404.

In this embodiment, a depth of each of the channels 410 of the stator disc 404 increases step-wise in a radial direction from a centre portion of the stator disc 404 to a peripheral edge of the stator disc 404. Equivalently, in the first stage 412, the depths of the channels 410 decrease in a step-wise manner between the first inlets 414 and the first outlets 416. Also, in the second stage 418, the depths of the channels 410 increase in a step-wise manner between the second inlets 420 and the second outlets 422. In this embodiment, a distance 434 between the floors of opposite channels 410 (i.e. channels 410 on opposite sides of the stator disc 404) may be substantially uniform in the radial direction.

In this embodiment, the stator disc 404 and the rotor discs 402 are arranged such that the steps 432 of the stator disc 404 are radially outwards of the steps 430 of the rotor discs. This advantageously tends to facilitate installation and/or assembly/disassembly of the pump 400.

In this embodiment, the stator disc 404 and the rotor discs 402 are arranged such that a clearance 436 between the stator disc 404 and a rotor disc 402 is substantially uniform in the radial direction. In this embodiment, the steps 430, 432 of the rotors and stator 402, 404 are arranged such that an substantially uniform clearance distance between the opposing faces of the rotors and stator 402, 404 is maintained in the axial direction.

The size (e.g. a height or a depth) of a step 430 of a rotor disc 402 is indicated in Figure 4 by a double-headed arrow and the reference numeral 438.

The size (e.g. a height or a depth) of a step 432 of the stator disc 404 is indicated in Figure 4 by a double-headed arrow and the reference numeral 440.

In this embodiment, the size 438 of the step 430 in a side of a rotor disc 402 is substantially the same as the size 440 of the step 432 in the side of the stator disc 404 that faces that side of the rotor disc 402. In some embodiments, the sizes of all steps 430 in rotors 402 and all steps 432 in stators 404 are substantially equal.

In this embodiment, the size 438 of the step 430 in a side of a rotor disc 402 and the size 440 of the step 432 in the side of the stator disc 404 that faces that side of the rotor disc 402 are greater than or equal to the clearance distance 436 between that rotor disc 402 and the stator disc 404. In some embodiments, the sizes of the steps 430 in the rotor discs 402 and the sizes of the steps 432 in the stators 404 are greater than or equal to clearance distances 436. By way of example, clearance distances 436 between adjacent rotors and stators may be around 200μm-500μm in mechanical bearing pumps (or greater in, for example, maglev turbomolecular pumps) and the sizes 438, 440 of the steps 430, 432 may be greater than this distance.

In operation, the shaft 406 and rotor discs 402 are rotated about the axis 408, as indicated in Figure 4 by an arrow and the reference numeral 424. Collisions of gas molecules with the moving rotor discs 402 cause gas in the channels 410 to be moved, in the first stator stage 412, from the first inlet 414 to the first outlet 416, and, in the second stator stage 418, from the second inlet 420 to the second outlet 422. This movement of gas through the pump 400 is indicated in Figure 4 by arrows and the reference numeral 426.

At relatively low pressures (e.g. at or below about 0.001mbar, though this may be application dependent) the pump may operate in molecular flow (or free molecular flow). In this operating state, gas molecules tend to move in substantially straight lines uninterrupted until they collide with a surface of the pump. The stepped surfaces of the rotors and stators advantageously tend to eliminate the straight leak path (i.e. a line of sight) between the outlet and inlet of a stage. (For example, a straight gas leak path 450 does not extend from the first

outlet 416 to the first inlet 414 as it is interrupted by the steps 430, 432.) Thus, leakage tends to be reduced and the pumping efficiency improved.

At relatively higher pressures (e.g. between 0.001mbar and about 1mbar, though this may be application dependent), the pump may operate in transitional flow (i.e. transitioning between molecular flow and viscous flow) the gas molecules tend to maintain an element of free molecular flow but start to act additionally with some level of fluidity. In this case, the stepped surfaces and the rotors and stators provides a series of 'bends' in the flow path which tends to reduce conductance of the leak path and improves performance of the pump.

Advantageously, the above described pumping apparatus tends to provide efficiency benefit when operating in molecular, transitional, and viscous flow.

Advantageously, the stepped surfaces 430, 432 of the rotor discs 402 and the stator disc 404 tends to provide that the gas leakage paths between the rotor discs 402 and the stator disc 404 are meandering or convoluted. This tends to make it more difficult for gas to travel back along leakage paths in a stator stage from outlets to inlets. Thus, the pump 400 tends to provide for improved pumping efficiency. The stepped surfaces 430, 432 may be considered complementary, matched, or mirrored surfaces. The stepped surfaces 430, 432 may be considered arranged approximately opposite or opposing each other, e.g. such that the stepped surfaces 430, 432 face each other to some extent.

Advantageously, the step sizes 438, 440 being greater than or equal to the clearance 436 between the rotor discs 402 and the stator 402 tends to provide that there is no line-of-sight along the gas leakage paths. This tends to further reduce gas leakage and provide for more efficient gas pumping.

Advantageously, the rotor thickness decreasing in the radial direction tends to reduce or minimise stresses in the rotor component.

Advantageously, the above-described pumping apparatus tend to be capable of being implemented in pumps at any or all stage types in any or all pressure regime and for any or all gas species.

In an embodiment of a Siegbahn stage for use in a turbomolecular pump, shown in Figure 4, corresponding steps 430, 432 in the respective surfaces of the rotor disc 402 and the stator disc 404 form a step in the radial direction in the clearance 436 (i.e. a step in the pumping direction or direction of majority or bulk gas flow), thereby to create a convoluted gas leakage path extending radially between the first inlet 414 at a radially peripheral region of the rotor disc 402 and the first outlet 416 at a radially inner region of the rotor disc 402. A convolution in the gas leakage path 450 restricts the radial flow of fluid counter to the radial movement of gas 426, thereby to improve pumping efficiency.

In the above embodiments, the pumping apparatus is a Siegbahn pump or a Siegbahn-type pump. However, in other embodiments, the pumping apparatus may be a different type of molecular drag pump. The pumping apparatus may, for example, be an apparatus selected from the group of apparatuses consisting of: a Siegbahn pump, a Siegbahn-type pump, a Siegbahn stage of a pump, a Siegbahn stage of a vacuum pump, a Siegbahn stage of a turbomolecular pump, a Holweck pump, a Holweck-type pump, a Holweck stage of a pump, a Holweck stage of a vacuum pump, a Holweck stage of a turbomolecular pump, a turbomolecular pump, a magnetic levitation turbomolecular pump, and a mechanical molecular drag pump.

What will now be described with reference to Figure 5 is an embodiment in which the pumping apparatus is a Holweck pump, Holweck-type pump, or Holweck stage of a pump.

Figure 5 is a schematic illustration (not to scale) showing a cross section through a further embodiment of a pump stage 500. The pump stage 500 shown in Figure 5 may be considered to be a Holweck stage of a pump. Figure 5 illustrates steps 530, 532 which tend to address the problem of leakage between the inlet and outlet of a pump.

In this embodiment, the pump 500 comprises a rotor 502 in the form of a cylindrical, tubular or sleeve rotor, and a stator 504 in the form of a substantially cylinder jacket or tubular jacket.

The rotor 502 is fixed to a shaft 506 such that a longitudinal axis 508 of the shaft 506 is aligned with the axis of rotation of the rotor 502.

The radially outer surface of the rotor 502 (i.e. a jacket surface of the rotor 502) and a radially inner surface of the stator 504 (i.e. a jacket surface of the stator 504) form the surfaces of the pump stage provided with pump activity, and are disposed opposite one another while forming a narrow gap 509. The gap 509 may be referred to as a Holweck gap.

The stator 504 comprises one or more helical channels 510, or thread grooves, formed on the radially inner surface of the stator 504. The channel(s) 510 extend helically in the axial direction. The oppositely disposed surface of the rotor 502, i.e. the radially outer surface of the rotor 502, may be substantially smooth.

In this embodiment, the rotor 502 comprises a step 530 in the axial direction, i.e. in the pumping direction or direction of majority or bulk gas flow. In particular, the diameter of the rotor 502 increases in a step-wise fashion in the axial direction, thereby to form a step or stepped surface 530. In other embodiments, a step 530 may be formed by the rotor 502 decreasing in a step-wise fashion in the axial direction.

The step 530 is located on the rotor 502 between a pumping stage inlet 524 and a pumping stage outlet 526. Preferably, the step 530 is located along the rotor length such that portions of the rotor 502 at both sides of the step 530 are disposed opposite to at least part of the helical channels 510 formed in the radially inner surface of the stator 504. Similarly, at least part of the helical channels 510 are formed in the stator 504 at both sides of the step 532. Preferably, the distance from the inlet 524 to the step 530 along axial direction is between 10% and 90% of the axial length of the rotor 502 (the axial length of the rotor 502 being the length of the rotor 502 in the axial direction between the inlet 524 and the outlet 526). More preferably, the distance from the inlet 524 to the step 530 along axial direction is between 20% and 80% of the axial length of the rotor 502. More preferably, the distance from the inlet 524 to the step 530 along axial direction is between 30% and 70% of the axial length of the rotor 502. More

preferably, the distance from the inlet 524 to the step 530 along axial direction is between 40% and 60% of the axial length of the rotor 502. More preferably, the distance from the inlet 524 to the step 530 along axial direction is approximately 50% of the axial length of the rotor 502.

In this embodiment, the stator 504 comprises a step 532 in the axial direction, i.e. in the pumping direction or direction of majority or bulk gas flow. In particular, an inner diameter of the stator 504, defined by tips or radially innermost surfaces of the stator thread, increases in a step-wise fashion in the axial direction, thereby to form a step or stepped surface 532. In other embodiments, a step 532 may be formed by the stator 504 decreasing in a step-wise fashion in the axial direction.

The step 532 is located on the stator 504 between the pumping stage inlet 524 and the pumping stage outlet 526. Preferably, the step 532 is located along the stator length such that the helical channels 510 are formed in the stator 502 at both sides of the step 532. Preferably, the distance from the inlet 524 to the step 532 along axial direction is between 10% and 90% of the axial length of the stator 504 (the axial length of the stator 504 being the length of the stator 504 in the axial direction between the inlet 524 and the outlet 526). More preferably, the distance from the inlet 524 to the step 532 along axial direction is between 20% and 80% of the axial length of the stator 504. More preferably, the distance from the inlet 524 to the step 532 along axial direction is between 30% and 70% of the axial length of the stator 504. More preferably, the distance from the inlet 524 to the step 532 along axial direction is between 40% and 60% of the axial length of the stator 504. More preferably, the distance from the inlet 524 to the step 532 along the axial direction is approximately 50% of the axial length of the stator 504.

In this embodiment, the rotor 502 and the stator 504 are arranged such that the step 530 of the rotor is closer, in the axial direction, to the outlet 526 than the step 532 of the stator 504.

In this embodiment, the rotor 502 and the stator 504 are arranged such that a first clearance 536 between the rotor 502 and the surface defined by tips or radially innermost surfaces of the stator thread in a region between the inlet

524 and the step 532 is substantially uniform in the axial direction. Also, the rotor 502 and the stator 504 are arranged such that a second clearance 537 between the rotor 502 and the surface defined by tips or radially innermost surfaces of the stator thread in a region between the step 530 and the outlet 526 is substantially uniform in the axial direction. The first and second clearances 536, 537 may be substantially equal.

The size (e.g. a height or a depth) of the step 530 of the rotor 502 is indicated in Figure 5 by a double-headed arrow and the reference numeral 538.

The size (e.g. a height or a depth) of the step 532 of the stator 504 is indicated in Figure 5 by a double-headed arrow and the reference numeral 540.

In this embodiment, the size 538 of the step 530 is substantially the same as the size 540 of the step 532.

In this embodiment, the size 538 of the step 530 and the size 540 of the step 532 are greater than or equal to the clearances 536, 537 between the rotor 502 and the stator 504.

In operation, the shaft 506 rotates about the axis 508, thereby to rotate the rotor 502 about the axis 508, as indicated by an arrow and the reference numeral 520. This rotating movement of the rotor 502 causes gas molecules within the pump stage 500 to move along the helical channels 510 and thereby be conveyed in the axial direction. This axial movement of gas is indicated in Figure 5 by arrows and the reference numeral 522. In this way, gas is pumped from the inlet 524 of the pump stage 500 to the outlet 526 of the pump stage 500.

In some embodiments, webs formed between the channels 510 seal the channels 510 and prevent or reduce an outflowing or a backflowing of the gas molecules against the pumping direction.

Similarly to the Siegbahn stage of the pump shown in Figure 4 and described in more detail earlier above, in this embodiment the stepped surfaces 530, 532 of the rotor 502 and the stator 504 advantageously tend to eliminate the straight leak path (i.e. a line of sight) in a direction from the outlet 526 and the

inlet 524 of the Holweck stage of the pump. Thus, leakage tends to be reduced and the pumping efficiency improved.

Advantageously, the above described pumping apparatus 500 tends to provide efficiency benefits when operating in molecular, transitional, and viscous flow.

Advantageously, the stepped surfaces 530, 532 of the rotor 502 and the stator 504 tend to provide that the gas leakage paths between the rotor 502 and the stator 504 are meandering or convoluted. This tends to make it more difficult for gas to travel back along leakage paths from outlets to inlets. Thus, the pump 500 tends to provide for improved pumping efficiency. The stepped surfaces 530, 532 may be considered complementary, matched, or mirrored surfaces. The stepped surfaces 530, 532 may be considered arranged approximately opposite or opposing each other, e.g. such that the stepped surfaces 530, 532 face each other to some extent.

Advantageously, the step sizes 538, 540 being greater than or equal to the clearance 536 between the rotor 502 and the stator 504 tends to provide that there is no line-of-sight along the gas leakage paths. This tends to further reduce gas leakage and provide for more efficient gas pumping.

In an embodiment of a Holweck stage for use in a turbomolecular pump, shown in Figure 5, corresponding steps 530, 532 in the respective surfaces of the rotor 502 and the stator 504 form a step in the axial direction in the clearance 536 (i.e. a step in the pumping direction or direction of majority or bulk gas flow), thereby to create a convoluted gas leakage path extending axially between the inlet 524 and the outlet 526. A convolution in the gas leakage path restricts the axial flow of gas counter to the axial movement of gas 522, thereby to improve pumping efficiency.

In the above embodiments, the channels are located in opposite side of the stator disc (or stator tube for Holweck-type pump). However in other embodiments, the channels are located at a different location. For example, in some embodiments in which the channels are located in a stator disc, the channels may be located in only one side of the stator disc. In some

embodiments, one or more channels are located in one or both sides of one or more of the rotor discs instead of or in addition to one or both sides of the stator disc.

In the above embodiments, each side of each rotor disc comprises a single respective step. However, in other embodiments, one or more sides of one or more rotor discs comprises multiple steps. Also, in some embodiments, one or more sides of one or more rotor discs omits a step.

In the above embodiments, a thickness of each rotor disc decreases step-wise in a radial direction from a centre portion of that rotor disc to a peripheral edge of that rotor disc. However, in other embodiments, a thickness of one or more of the rotor discs does not decrease step-wise in a radial direction from a centre portion of that rotor disc to a peripheral edge of that rotor disc. For example, in some embodiments, a thickness of one or more of the rotor discs increases step-wise in a radial direction from a centre portion of that rotor disc to a peripheral edge of that rotor disc.

In the above embodiments, each side of the stator disc 404 comprises a respective step. However, in other embodiments, one or more sides of one or more stator discs comprises multiple steps. Also, in some embodiments, one or more sides of one or more stator discs omits a step.

In the above embodiments, a thickness of each stator disc increases step-wise in a radial direction from a centre portion of that stator disc to a peripheral edge of that stator disc. However, in other embodiments, a thickness of one or more of the stator disc does not increase step-wise in a radial direction from a centre portion of that stator disc to a peripheral edge of that stator disc. For example, in some embodiments, a thickness of one or more of the stator discs decreases step-wise in a radial direction from a centre portion of that stator disc to a peripheral edge of that stator disc.

In the above embodiments, a depth of each of the channels of the stator disc increases step-wise in a radial direction from a centre portion of the stator disc to a peripheral edge of the stator disc. However, in other embodiments, a depth of one or more of the channels of the stator disc does not increases step-

wise in a radial direction from a centre portion of the stator disc to a peripheral edge of the stator disc. For example, a depth of a channel may decrease step-wise, or be stepped so as to remain constant, in the outwardly radial direction.

In the above embodiments, a distance between the floors of opposite channels of the stator disc is substantially uniform in the radial direction. However, in other embodiments, a distance between the floors of opposite channels of the stator disc is not substantially uniform in the radial direction, for example it may increase or decrease step-wise. Also, for example, the stator disc may have a variable thickness e.g. in the case of tapered channel depths.

In the above embodiments, the steps of the stator disc are radially outwards of the steps of the rotor discs. However, in other embodiments, the steps of the stator disc are radially inwards of the steps of the rotor discs.

In the above embodiments, a clearance between a stator disc and an adjacent rotor disc is substantially uniform in the radial direction. However, in other embodiments, a clearance between a stator disc and an adjacent rotor disc is not uniform in the radial direction. Further, in other embodiments where the rotor disc comprises a plurality of steps, the stator disc may comprise steps which mirror the steps of the rotor disc. The steps of the rotor disc may mirror the steps of the stator disc such that a constant gap is maintained between adjacent radial and adjacent axial surfaces of the steps. There may be a radial gap between radially adjacent surfaces, radially adjacent surfaces being in a plane perpendicular to the axis of rotation. There may be an axial gap between axially adjacent surfaces, axially adjacent surfaces being parallel to the axis of rotation. The radial gap and axial gap may be the same. The radial gap and axial gap may be different. For example, the axial gap may be greater than the radial gap, for example to accommodate axial movement of the stator disc relative to the rotor disc.

In the above embodiments, the step sizes are greater than or equal to the clearance distance between the rotor discs and the stators. However, in other embodiments, one or more of the step sizes are less than the clearance distance.

REFERENCE NUMERAL KEY

100 - conventional Siegbahn-type pump;

102 - rotor disc;

104 - stator disc;

106 – shaft;

108 - longitudinal axis;

110 - spiral channels;

112 - inward stage;

114 - first inlets;

116 - first outlets;

118 - outward stage;

120 - second inlets;

122 - second outlets;

124 – rotation direction;

126 – movement of gas;

301 - first gas leakage path;

302 - second gas leakage path;

304 – depth dimension;

306 - distance between floors of opposite channels;

400 – pump;

402 - rotor discs;

404 - stator disc;

406 – shaft;

408 - longitudinal axis;

410 – channels;

412 - inward stage;

414 - first inlets;

416 - first outlets

418 - outward stage;

420 - second inlets;

422 - second outlets

424 – direction of rotation;

426 – movement of gas

430 – step;

432 – step;

434 - distance between floors of opposite channels;

436 – clearance;

438 - size of a step 430;

440 - size of a step 432;

450 - gas leak path;

500 – pump;

502 - rotor;

504 - stator;

506 – shaft;

508 - longitudinal axis;

509 – gap;

510 – helical channels;

520 – direction of rotation;

522 – movement of gas;

524 – inlet;

526 – outlet;

530 – step;

532 – step;

536 – first clearance;

537 – second clearance;

538 - size of a step 530;

540 - size of a step 532.

CLAIMS

1. A Siegbahn-stage of a vacuum pump comprising:

a rotor configured to be rotated about an axis of rotation; and

a stator mounted in proximity to the rotor such that a side of the rotor faces a side of the stator; wherein

at least one of the stator or the rotor includes at least one open channel on the side of the stator or the rotor that faces the other of the stator or the rotor; and

the facing sides of the rotor and the stator each comprise at least one step.

2. The Siegbahn-stage of a vacuum pump of claim 1, wherein a thickness of the rotor in a direction parallel to the axis decreases step-wise in a radial direction from a central portion of the rotor to a peripheral edge of the rotor.

3. The Siegbahn-stage of a vacuum pump of claims 1 or 2, wherein a thickness of the stator in a direction parallel to the axis increases step-wise in a radial direction from a central portion of the stator to a peripheral edge of the stator.

4. The Siegbahn-stage of a vacuum pump of any of claims 1 to 3, wherein a depth of the at least one open channel increases step-wise in a radial direction from a central portion of the stator to a peripheral edge of the stator.

5. The Siegbahn-stage of a vacuum pump of any of claims 1 to 4, wherein:

the at least one open channel is on the side of the stator that faces the rotor, and the at least one open channel defines a first vacuum pumping stage; and

the stator further includes at least one further open channel on a further side of the stator, the further side of the stator being opposite to the side of the stator that faces the rotor, the at least one further open channel defining a second vacuum pumping stage.

6. The Siegbahn-stage of a vacuum pump of any of claims 1 to 5, further comprising:

a further rotor configured to be rotated about an axis of rotation; wherein

the stator is mounted in proximity to the further rotor such that a side of the further rotor faces the further side of the stator; wherein

the further side of the stator and the side of the rotor that faces the further side of the stator each comprise at least one further step.

7. A Holweck-stage of a vacuum pump comprising:

a rotor configured to be rotated about an axis of rotation; and

a stator mounted in proximity to the rotor such that a side of the rotor faces a side of the stator; wherein

at least one of the stator or the rotor includes at least one open channel on the side of the stator or the rotor that faces the other of the stator or the rotor; and

the facing sides of the rotor and the stator each comprise at least one step.

8. The Holweck-stage of a vacuum pump of claim 7, wherein:

the stator comprises the at least one open channel on the side of the stator that faces the rotor;

the step of the stator partitions the stator into a first portion at a first side of the step of the stator and second portion at a second side of the step of the stator;

the at least one open channel is formed, in the side of the stator that faces the rotor, of both the first portion of the stator and the second portion of the stator;

the step of the rotor partitions the rotor into a first portion at a first side of the step of the rotor and second portion at a second side of the step of the rotor;

a side of the first portion of the rotor faces a side of the first portion of the stator; and

a side of the second portion of the rotor faces a side of the second portion of the stator.

9. The Holweck-stage of a vacuum pump of claim 7 or 8, further comprising:

a pumping stage inlet; and

a pumping stage outlet; wherein

an axial length of the rotor is defined as a length of the rotor in an axial direction between the inlet and the outlet, the axial direction being parallel to the axis of rotation;

an axial length of the stator is defined as a length of the stator in the axial direction;

a distance from the inlet to the step of the rotor along the axial direction is between 10% and 90% of the axial length of the rotor; and

a distance from the inlet to the step of the stator along the axial direction is between 10% and 90% of the axial length of the stator.

10. The pumping stage of any preceding claims, wherein the at least open channel comprises at least one curved, spiral, helical or involute channel.

11. The pumping stage of any preceding claim, wherein a size of at least one of the steps is greater than or equal to a clearance distance between the facing sides of the rotor and the stator.

12. The pumping stage of any preceding claim, wherein a size of at least one of the steps is greater than or equal to about 200μm-500μm, or greater than about 1mm.

13. The pumping stage of any preceding claim, wherein a clearance distance between the facing sides of the rotor and the stator is about 200μm-500μm, or greater than about 1mm.

14. The pumping stage of any preceding claim, wherein a clearance distance between the facing sides of the rotor and the stator is substantially uniform.

15. A vacuum pumping method comprising:

providing a pumping stage in accordance with any of claims 1 to 14; and

rotating the rotor about the axis.

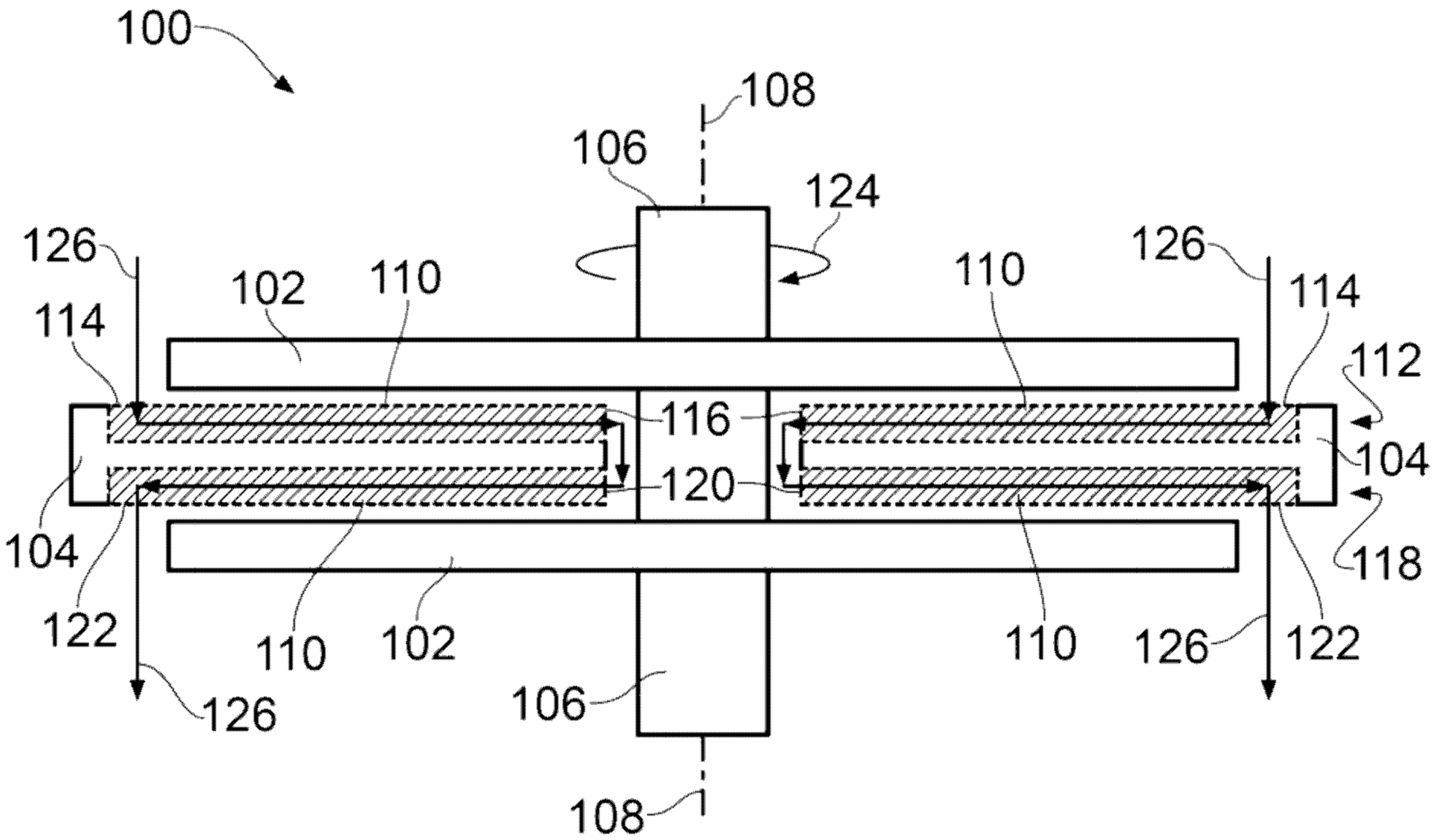


FIG. 1 (Prior Art)

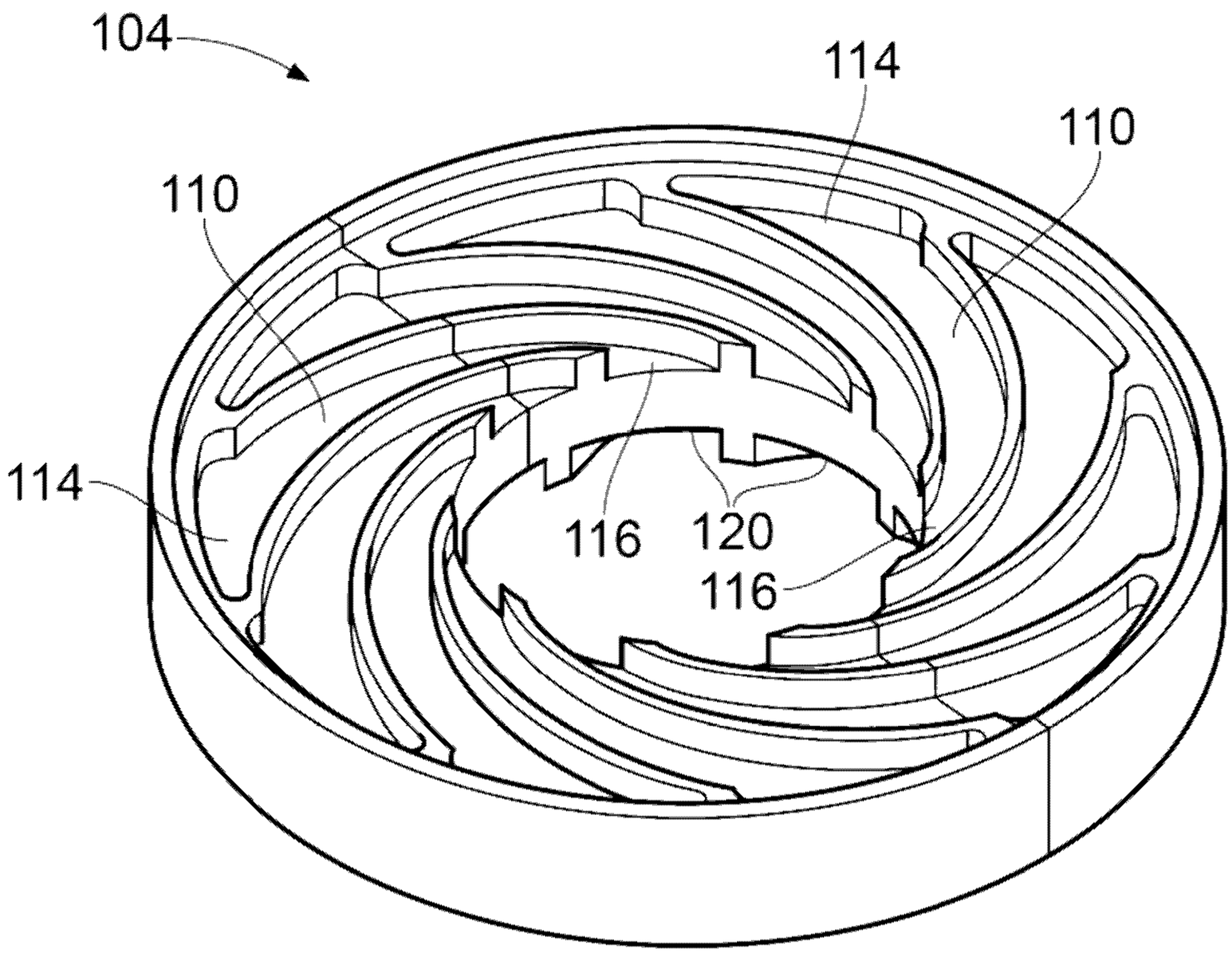


FIG. 2 (Prior Art)

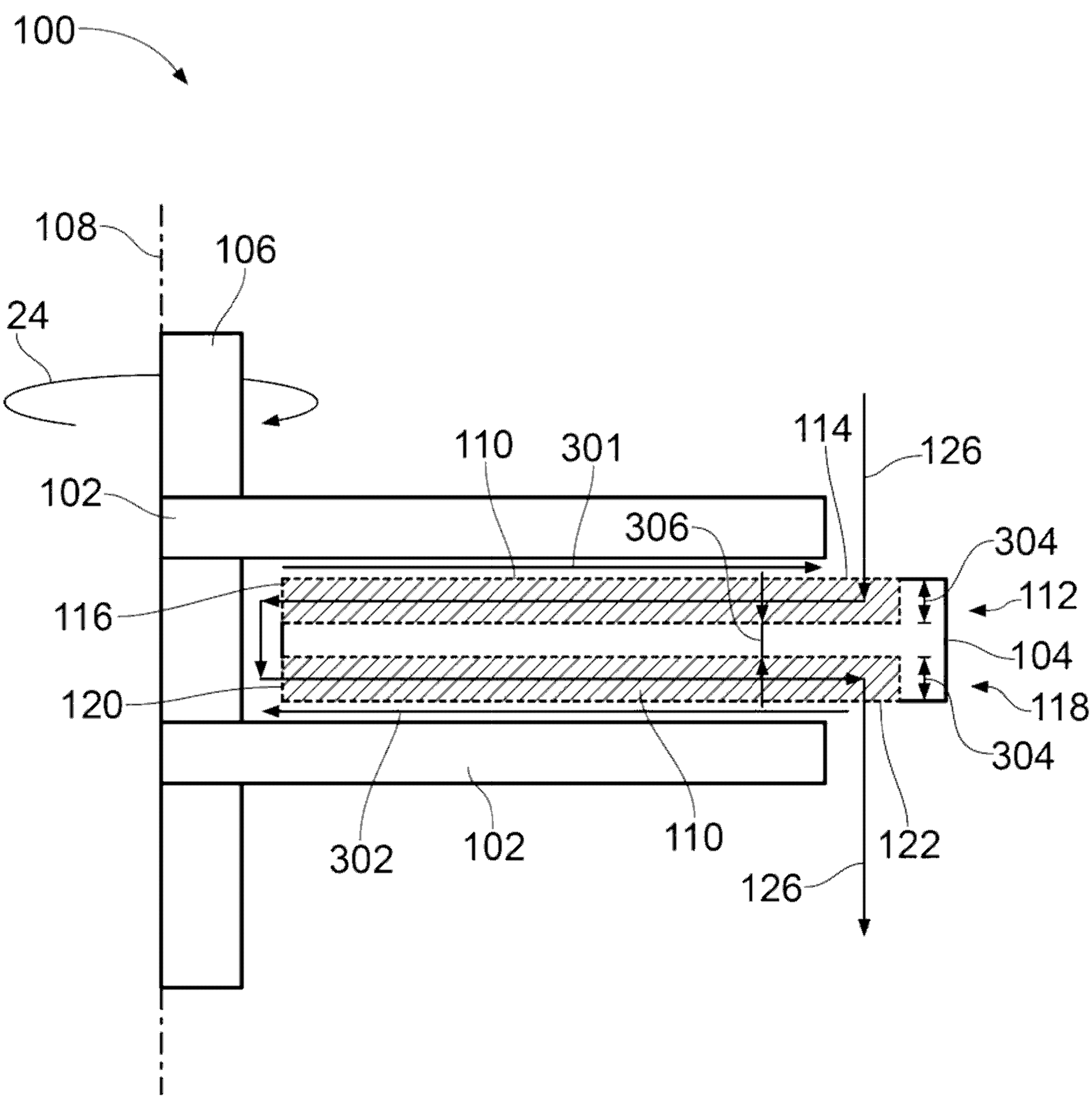

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FIG. 3

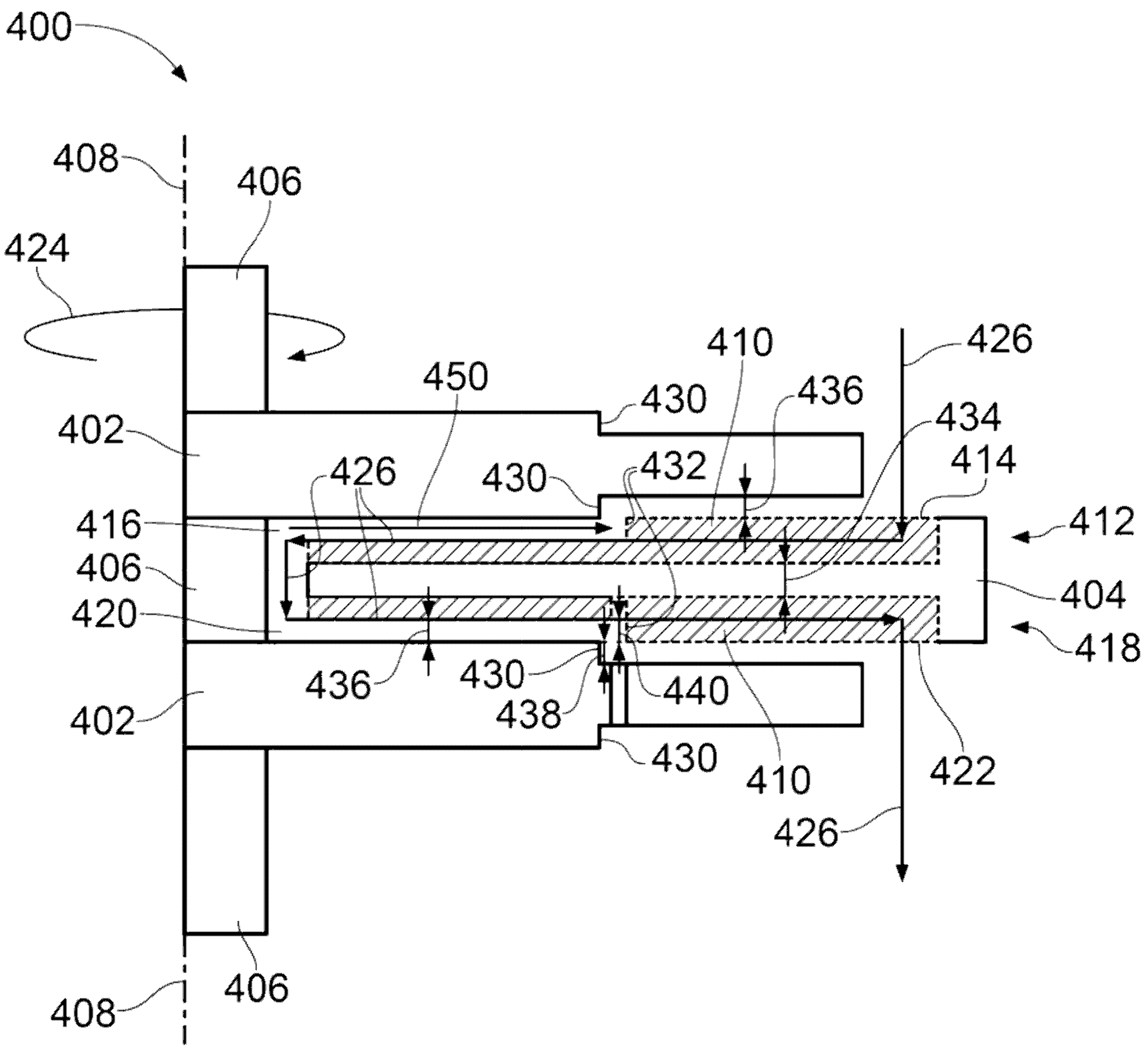

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FIG. 4

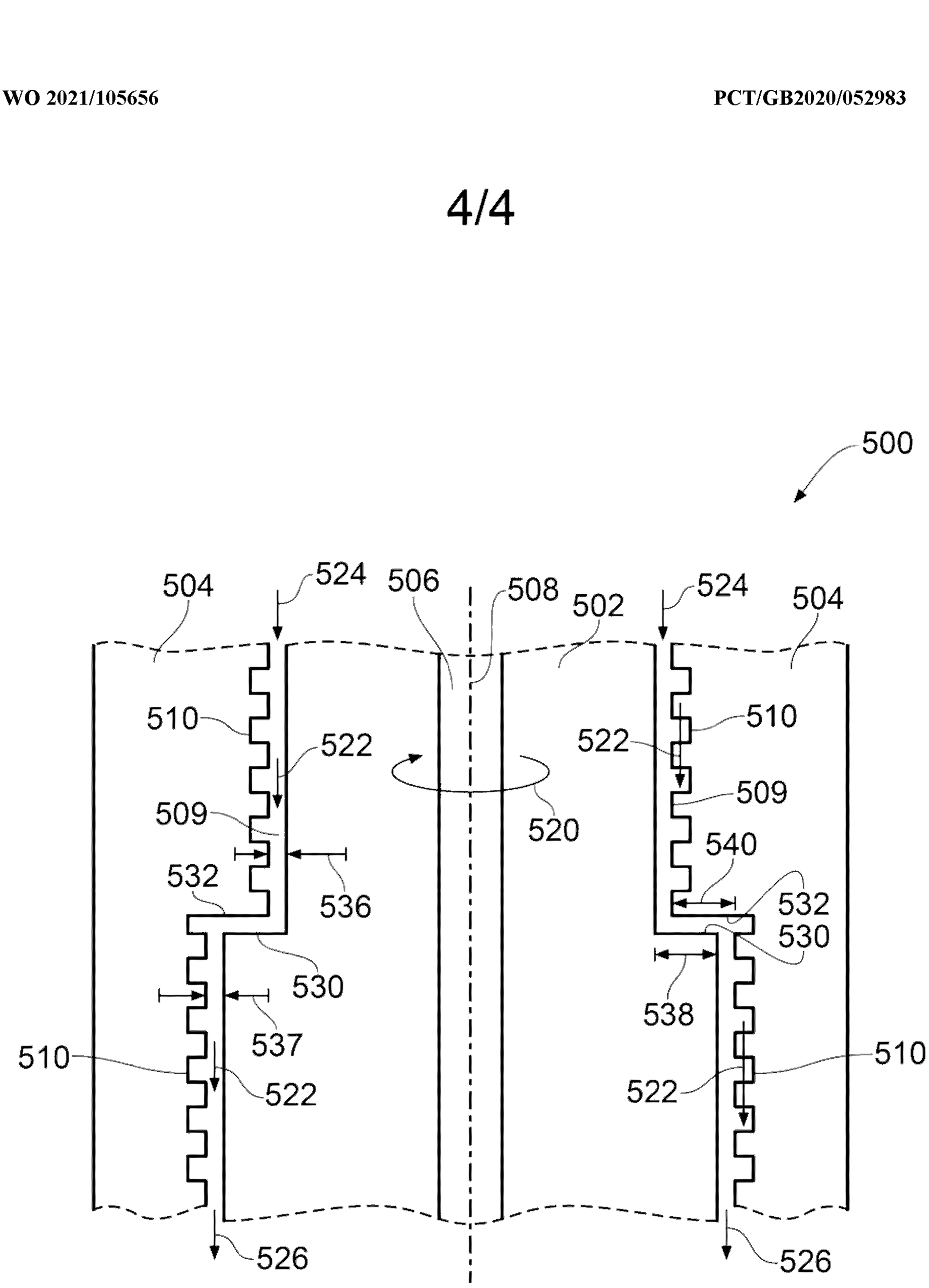

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FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2020/052983

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04D17/16 F04D19/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 160 250 A (IKEGAMI TATSUJI [JP] ET AL) 3 November 1992 (1992-11-03) column 14, line 10 - column 16, line 50; figures 15-22, 39-49 column 6, line 5 - line 46 abstract -----	1-6
X	JP H02 264197 A (SHIMADZU CORP) 26 October 1990 (1990-10-26) paragraph [0001] - paragraph [0003]; figures 4,5 abstract -----	7-15
A	EP 3 051 141 A1 (PFEIFFER VACUUM GMBH [DE]) 3 August 2016 (2016-08-03) paragraph [0030] - paragraph [0032]; figure 1 abstract -----	1-6

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 February 2021	23/02/2021

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Hermens, Sjoerd

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2020/052983

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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