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(54) RETENTION RING FOR HYDRAULIC APPARATUS

(57) In summary, there is provided a hydraulic apparatus comprising an eccentric rotatable about an axis, a plurality of piston feet arranged around a running surface of the eccentric and wherein each piston foot is configured to reciprocate by rotation of the eccentric. In addition there is provided a retention ring having an inner surface which defines therein at least one depression, an outer surface defined by the outer circumference of the retention ring; and first and second lateral surfaces each extending between the inner surface and the outer surface. The piston feet each have a seat portion and a lateral flange, and at least two of the piston feet have a protrusion that is sized and shaped in relation to the size and shape of the depression, such that the protrusion can move from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, when the protrusion is in a first position with respect to the depression, such that the retention ring then surrounds both the lateral flange and the eccentric.

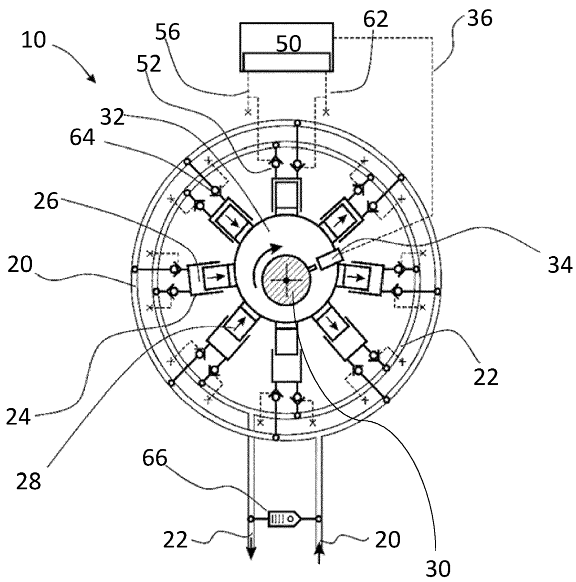

Fig. 1

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Description

Field of the invention

[0001] The present invention relates to a retention ring for hydraulic apparatus, for example a hydraulic vehicle, to a hydraulic apparatus comprising the same, and to a method and kit of parts, each for manufacturing the same.

Background to the invention

[0002] In a hydraulic machine, a shaft having an eccentric cam surface is rotated. Typically, a plurality of pistons are in contact with the eccentric cam surface at a radially inner end and have a radially outer end received in a piston cylinder. The outer end moves cyclically inwards and outwards in the piston cylinder, varying a volume of a piston working chamber. The inner end slides over the eccentric cam surface and remains in contact therewith. One or more retention rings are typically used to each hold the inner end of each of the plurality of pistons at the eccentric cam surface.

[0003] It is challenging to manufacture such hydraulic machines, particularly where a retention ring must be used to retain multiple pistons.

[0004] It is in this context that the present disclosure has been devised.

Summary of the invention

[0005] According to a first aspect of the invention, there is provided a hydraulic apparatus comprising:

an eccentric rotatable about an axis;
a plurality of piston feet arranged around a running surface of the eccentric, each piston foot being configured to reciprocate by rotation of the eccentric; and
a retention ring having: an inner surface, the inner surface defining therein at least one depression; an outer surface defined by the outer circumference of the retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface,

wherein each piston foot comprises a seat portion and a lateral flange, and wherein at least two (e.g. each) of the piston feet comprise a protrusion sized and shaped relative to the size and shape of the depression such that the protrusion can move from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, when the protrusion is in a first position relative to the depression,
wherein the inner surface surrounds the running surface of the eccentric and the piston foot whereby the retention ring is configured to restrict radial movement of the piston foot away from the running surface of the eccentric, and wherein the protrusion is configured to restrict movement of the retention ring laterally away from the piston foot when the protrusion is in a second position, different to the first position, relative to the depression.

[0006] It will be understood that the axis is an axis of rotation of a shaft (sometimes referred to as a crankshaft or a camshaft). Accordingly, it will be understood that where an axial direction is referred to, this direction is substantially parallel to the axis. Similarly, where a lateral direction is referred to, this direction is substantially parallel to the axis. Where a radial direction is referred to, this direction is substantially perpendicular to the axis. Where a circumferential direction is referred to, this direction is around the circumference of the eccentric and perpendicular to the axial direction.

[0007] It will be understood that a protrusion that is sized and shaped relative to the size and shape of a depression is arranged such that the protrusion is small enough to be passed through the depression. For example, the protrusion may extend from the lateral flange by a distance no greater than the distance that the depression extends from the inner surface of the retention ring towards the outer surface of the retention ring. In other words, the protrusion may be no taller than the protrusion is deep. The protrusion may have a breadth in a circumferential direction no greater than the distance that the depression extends around the inner surface of the retention ring. In other words the protrusion may be no wider than the depression is wide.

[0008] The first position is any position of a protrusion relative to a depression of the retention ring which allows for the protrusion to move past the first lateral surface of the retention ring and towards the second lateral surface of the retention ring, e.g. when the piston foot is engaged with the eccentric and the inner circumference of the retention ring surrounds the running surface of the eccentric. As such, the first position should be understood as a first circumferential position on the eccentric. Where a first position is referred to, it should be understood that there is also a second position different to the first position. The second position is any position of a protrusion relative to a depression of the retention ring which does not allow for the protrusion to move past the first lateral surface of the retention ring and towards the second lateral surface of the retention ring, e.g. when the piston foot is engaged with the eccentric and the inner circumference of the retention ring surrounds the running surface of the eccentric. As such, the first position should be understood as a first circumferential position on the eccentric. Accordingly, the skilled person will appreciate that there are at least as many first positions as there are depressions.

[0009] By providing depressions in the retention rings to accommodate a corresponding protrusion of each piston foot, which extends from the respective lateral flange, it is possible to easily slide the piston foot relative to the retention ring (i.e. to mount the ring onto the piston foot via the protrusion and lateral flange) during assembly and then also to use the protrusion to ensure the retention ring remains in the required lateral mounted position on the lateral flange. As a result, no additional components such as springs or clips are required to maintain the ring in a mounted position (e.g. during hydraulic machine operation). Manufacturing and/or assembly of such hydraulic machines is thus less complex and less time consuming.

[0010] In addition, by using the protrusions to ensure the retention ring is laterally retained (in a direction to restrict movement away from the respective piston foot) on the lateral flange of the piston foot, no additional components need be provided further radially spaced from the eccentric (higher up the piston foot). As a result, the overall height of the piston foot (radial extent) can be reduced, meaning the size of the hydraulic apparatus, and a hydraulic machine assembled using the described apparatus, can also be reduced.

[0011] In operation, the retention ring may move laterally on the piston foot, between the seat portion and the protrusion.

[0012] The apparatus may be understood to have an operative configuration and an assembly configuration. When the apparatus is in the operative configuration, each piston foot is typically engaged with the running surface of the eccentric and the inner surface of the retention ring surrounds the running surface and each piston foot, and is thus broadly configured to displace fluid when the shaft is turned. When the apparatus is in the assembly configuration, the hydraulic machine is typically being assembled or disassembled, (assembly and disassembly including mounting, or dismounting pistons, rings, etc.) to allow the machine to reach an assembled or disassembled condition.

[0013] The protrusion typically extends from the lateral flange in a direction having a component that is perpendicular to and radially away from the axis. Accordingly, when the apparatus is the in operative configuration, at least the first lateral surface of the retention ring is positioned between the protrusion and the seat portion.

[0014] The lateral flange may be a first lateral flange. The protrusion may be a first protrusion. The retention ring may be a first retention ring.

[0015] Each piston foot may be part of a respective piston. The hydraulic apparatus may be a hydraulic machine, the hydraulic machine comprising a housing, the housing defining therein a cavity for each cylinder for each respective piston, and each cylinder forming a working chamber with a piston, wherein each working chamber has a volume which varies cyclically with rotation of the eccentric.

[0016] One or more of the piston feet may comprise a second lateral flange, the second lateral flange extending from the piston foot in a direction having a component in parallel to the axis, and the second lateral flange comprising a protrusion, wherein the protrusion is sized and shaped such that the protrusion can move from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, when the protrusion is in a first position relative to the depression. Each piston foot may comprise a second lateral flange and at least two (e.g. each) of the piston feet may comprise a second protrusion, each being sized and shaped relative to the size and shape of a respective depression such that the second protrusion can move from the first lateral surface of the (e.g. first or second) retention ring towards the second lateral surface of the (e.g. first or second) retention ring, via the (e.g. any one) depression, when the second protrusion is in a first position relative to the said depression. Accordingly, either protrusion may be moved from a first lateral surface of a retention ring towards a second lateral surface of the retention ring, via the depression, such that the retention ring surrounds both the lateral flange and the eccentric. Therefore, movement of the piston foot away from the running surface of the eccentric may be restricted by a retention ring surrounding either the first lateral flange and the eccentric, or surrounding the second lateral flange and the eccentric. This provides more flexibility when assembling a hydraulic apparatus.

[0017] It will be understood that a (e.g. first or second) lateral flange of a piston foot is a flange which extends away from the seat portion, in a direction having a component in parallel to the axis when the piston foot is engaged around the running surface of the eccentric and that a second lateral flange extends away from the first lateral flange and the seat portion in a direction having a component in parallel to the axis when the piston foot is engaged around the running surface of the eccentric. Typically, the second lateral flange extends from the seat portion, opposite to the first lateral flange. The protrusion (e.g. the first or second protrusion) will be understood as a protrusion extending from a respective lateral flange in a direction having a component that is perpendicular to the axis when the piston foot is engaged around the perimeter of the eccentric.

[0018] It will be understood that a protrusion (e.g. a first or second protrusion) is substantially any extension from a lateral flange (e.g. a first or second lateral flange) which can prevent movement of a retention ring (e.g. provided between the protrusion and the seat portion of the piston foot) past the protrusion, when the protrusion is in a second position different to the first position, relative to the depression. It will be understood that restriction of movement of the (e.g. first or second) retention ring laterally away from the respective piston foot is restriction of movement away from the piston foot in a direction parallel to the axis when the piston foot is engaged around the running surface of the eccentric. Typically, the (e.g. first or second) lateral flange can be considered to extend in a lateral direction, the lateral direction being substantially the same as the axial direction (in use).

[0019] The running surface of the eccentric is the surface on which the piston feet are engaged. The eccentric may be a cam, even an eccentric cam.

[0020] Similarly, it will be understood that a depression is substantially any deviation from a circle otherwise defined by the inner surface of the retention ring, such that a protrusion on that circle could pass from the inner surface of the retention ring towards the outer surface of the retention ring, through the depression. In this way, it can be appreciated that while the depression may extend all the way through the retention ring in an axial direction, aligned with a central axis of the retention ring, this need not be the case and the depression may extend only partially through the retention ring in an axial direction, aligned with a central axis of the retention ring. For example, the depression may extend in an axial direction, aligned with the retention ring, from the first lateral surface to an intermediate point between the first lateral surface and the second lateral surface. It may be that from that intermediate point the depression extends in a circumferential direction parallel to the inner surface of the retention ring to a second intermediate point between the first lateral surface and the second lateral surface and optionally may then extends towards the (and optionally intersect with) the second lateral surface.

[0021] The apparatus may comprise a second retention ring, the second retention ring having: an inner surface, the inner surface defining therein a plurality of depressions; an outer surface defined by the outer circumference of the second retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface,

wherein each piston foot comprises a second lateral flange and at least two (e.g. each) of the piston feet may comprise a second protrusion sized and shaped relative to the size and shape of a respective depression such that any one second protrusion can move from the first lateral surface of the second retention ring towards the second lateral surface of the second retention ring via any one depression of the plurality of depressions (e.g. any one depression of the second retention ring) when the second protrusion is in a first position relative to the said depression.

[0022] Accordingly, the inner surface of the second retention ring may surround the running surface of the eccentric and the (e.g. first or second) lateral flange of the piston foot whereby the second retention ring is configured to restrict movement of the piston foot away from the running surface of the eccentric, and

wherein the second protrusion is configured to restrict movement of the second retention ring laterally away from the piston foot when the second protrusion is in a second position, different to the first position, relative to the said depression.

[0023] The apparatus may comprise a plurality of retention rings. The or each retention ring may have an inner surface, the inner surface defining therein a depression. The inner surface may define therein a plurality of depressions. Each retention ring may have an inner surface defining the same number of depressions as the or each other retention ring, however this is not required.

[0024] The inner surface of the or each retention ring may define therein a plurality of depressions. At least the second retention ring may define therein at least as many depressions as there are second protrusions. The inner surface of the second retention ring may define therein more depressions than second protrusions. For example, the inner surface of the second retention ring may define (e.g. at least) one more depression than there are second protrusions.

[0025] A second retention ring with at least as many depressions as there are second protrusions, makes the apparatus easier to assemble, as the protrusion of each piston foot can be located in a first position with respect to a respective depression and therefore each protrusion can be moved from a first lateral surface of the second retention ring towards the second lateral surface of the second retention ring, via the depressions of the second retention ring, simultaneously.

[0026] Advantageously, a retention ring wherein the inner surface defines more depressions than there are protrusions provided would typically make it difficult if not impossible to align all of the protrusions with a respective depression during assembled operation of the hydraulic apparatus, ensuring that the retention ring is retained on the lateral flanges and therefore that the apparatus has good reliability.

[0027] The plurality of depressions may be distributed (e.g. evenly) around the inner surface of the or each retention ring. The plurality of depressions may be spaced apart at equal distances around the inner surface of the or each retention ring.

[0028] In the operative configuration, at least one retention ring typically surrounds both the running surface and a lateral flange of each piston foot, and each piston is typically retained in a respective cylinder, with each cylinder in place in a respective cavity of the machine body of the housing. Accordingly, the person skilled in the art will appreciate that in the operative configuration, the distance between adjacent depressions on the ring, relative to the time-varying distance (i.e. as the eccentric rotates during operation), particularly the minimum distance between protrusions of adjacent pistons, is important as a key determinant of alignment of protrusions and depressions during operation and will be a function of various aspects of the machine design. As such, the depressions of the inner surface of each retention ring (e.g. of each retention ring having an inner surface defining therein more than one depression) may be arranged relative to the minimum distance between protrusions of adjacent pistons such that only one protrusion can be in the first position with respect to any one depression, when the retention ring surrounds the eccentric and a lateral flange of each piston foot. The depressions of the inner surface of the second retention ring may be arranged such that no more than two protrusions can be in the first position with respect to any two respective depressions, when the retention ring surrounds the eccentric and a lateral flange of each piston foot. Advantageously, where only one, or no more than two protrusions can be in the first position with respect to a depression, this means that the apparatus is more stable, as the retention ring is more stably laterally restricted by the protrusions. The depressions of the inner surface of each retention ring (e.g. of each retention ring having an inner surface defining therein more than one depression) may be arranged such that at least one protrusion, possibly two protrusions, cannot be in the first position with respect to any one of the respective depressions, when the retention ring surrounds the eccentric and a lateral flange of each piston foot as in the operative configuration. However, if only one protrusion is not in the first position, misalignment of the retention ring becomes more likely.

[0029] A number of piston protrusions may be non-aligned such that the ring is stably retained in an axial direction. In the operative configuration, a greater number of non-alignments for more of the combinations of eccentric rotational position, and ring rotation positions, promotes ring stability. At the same time, these relative absolute distances and distribution of the protrusions and depressions, allow assembly to take place by aligning piston protrusions with a ring depression, and pushing pistons axially into their correct positions.

[0030] The (e.g. plurality of) depressions of the inner surface of the second retention ring may be arranged, or distributed, such that the ring has at least two positions of rotational symmetry. The depressions of the inner surface of the second retention ring may be arranged such that said ring has at least four positions of rotational symmetry. Said rotational symmetry refers to rotation about the central axis of the ring.

[0031] The or each depression is typically defined by one or more depression regions of the inner surface of the retention ring. A cross-section of the or each depression region of the inner surface may have an arcuate shape, however this is not required, and the or each depression region may be substantially any shape in cross-section. The or each depression region may be shaped such that it forms a section of a circle or ellipse in cross-section. The cross-sectional shape of the or each depression is typically constant throughout the thickness of the retention ring, however this is not required and the cross-sectional shape of the or each depression may vary throughout the thickness of the retention ring. The size of the cross-section of the or each depression may be substantially constant throughout the thickness of the retention ring, however this is not required and the size of the cross-section of the or each depression may vary throughout the thickness of the retention ring.

[0032] It will be understood that the inner surface of the retention ring is the surface defined by the inner circumference of the retention ring and the depressions defined therein. Typically, the retention ring has an outer surface defined by the outer circumference of the said retention ring. Thus, the inner surface is radially inward of the outer surface. Typically, the retention ring has two lateral surfaces; a first lateral surface and a second lateral surface, wherein each lateral surface extends between the inner surface and the outer surface. The first lateral surface may be a seat portion facing surface. For example, the first lateral surface may be configured to face the seat portion when the retention ring surrounds the eccentric and the lateral flange. The second lateral surface may be a protrusion facing surface. For example, the second lateral surface may be configured to face the protrusion when the retention ring surrounds the eccentric and the lateral flange. At least one of the two lateral surfaces may define a depression chamfer adjacent to and meeting the or each depression, optionally on each side of the or each depression. The depression chamfer may be between the first lateral surface and the inner surface. The first (e.g. seat portion facing) lateral surface may define a depression chamfer adjacent to and meeting the or each depression. The first (e.g. seat portion facing) lateral surface may define a depression chamfer adjacent to and meeting the or each depression on each side of the or each depression. The or each depression chamfer may be angled from the respective (e.g. first) lateral surface towards the other (e.g. second) lateral surface. The depression chamfer may border the inner surface.

[0033] Advantageously, the provision of a depression chamfer (a sort of 'lead in') reduces stress due to contact between the retention ring and the protrusion during use, as where a depression chamfer is provided, the angle between the (e.g. second, e.g. protrusion facing) lateral face and the edge of the depression is reduced. Furthermore, because a depression chamfer is provided between the (e.g. second, e.g. protrusion facing) lateral surface, the depression and the inner surface, the frictional forces between the protrusion and the retention ring at the boundary of the depression will be reduced if and when the protrusion is moved past the depression (e.g. when the retention ring is rotated around the eccentric), thereby reducing wear of the retention ring and/or the protrusion.

[0034] The or each depression chamfer may be angled at at least 4 degrees from a plane defined transverse to a central axis of the retention ring. The or each depression chamfer may be angled at at least 15 degrees from a plane defined transverse to a central axis of the retention ring. The or each depression chamfer may be angled at at least 30 degrees from a plane defined transverse to a central axis of the retention ring. The or each depression chamfer is typically angled by no more than 80 degrees from a plane defined transverse to a central axis of the retention ring. The or each depression chamfer is typically angled by no more than 70 degrees from a plane defined transverse to a central axis of the retention ring. The or each depression chamfer is typically angled by no more than 60 degrees from a plane defined transverse to a central axis of the retention ring.

[0035] Each depression chamfer may be angled from a plane defined transverse to a central axis of the retention ring by the same angle as the or each other depression chamfer, however this is not required, and each depression chamfer may be angled from a plane defined transverse to a central axis of the retention ring by a different angle to that of the or each other depression chamfer.

[0036] The or each depression may each extend around at least 2 degrees of the retention ring, in a plane perpendicular to the central axis of the retention ring. The or each depression may each extend around at least 5 degrees. The or each depression may each extend around at least 10 degrees. The or each depression may each extend around 15 degrees. Preferably the or each depression extends around no more than 20 degrees. Preferably the or each depression extends around no more than 25 degrees. Preferably the or each depression extends around no more than 30 degrees.

[0037] The or each depression may extend around at least 5 millimetres of the inner surface of the respective retention ring. The or each depression may extend around at least 50 millimetres of the inner surface of the respective retention ring. The or each depression may extend around 250 millimetres around the inner surface of the respective retention ring. The or each depression may extend by no more than 400 millimetres around the inner surface of the respective retention ring.

[0038] The or each depression is typically defined in the inner surface and both the first and second lateral surfaces of the retention ring. The or each retention ring may have one or more further chamfers. For example, the or each retention ring may have one or more inner peripheral chamfers, the inner peripheral chamfers being defined at the boundary between the inner surface and the first lateral surface and/or at the boundary between the inner surface and the second lateral surface. The or each retention ring may have an outer peripheral chamfer, the outer peripheral chamfer being defined at the boundary between the outer surface and the first lateral surface and/or at the boundary between the outer surface and the second lateral surface. It will be understood that the inner surface of the retention ring is the surface defined by the inner circumference of the retention ring and the depressions therein.

[0039] For example, there may be an outer peripheral chamfer defined at the boundary between the outer surface and the first (e.g. seat portion facing) lateral surface. There may be an outer peripheral chamfer defined at the boundary between the outer surface and a lateral surface in which no depression chamfers are defined. Advantageously, this will mean that the apparatus (e.g. hydraulic machine) can be smaller because the overall height (radial extent) of the retention ring closest to the piston foot is reduced. Where no outer peripheral chamfer is defined at the boundary between the outer surface and the second (e.g. protrusion facing) lateral surface the retention ring is relatively rigid and has relatively high strength (e.g. in comparison to where outer peripheral chamfers are defined at both the boundary between the outer surface and the second (e.g. protrusion facing) lateral surface) and at the boundary between the outer surface and the first (e.g. seat portion facing) lateral surface).

[0040] The or each inner peripheral chamfer may extend around the full inner perimeter of the retention ring (for example, excluding where such a chamfer is interrupted by the or each depression), however this is not required and the or each inner peripheral chamfer may extend around only a part of the full perimeter of the retention ring. The or each outer peripheral chamfer may extend around the full perimeter of the retention ring, however this is not required and the or each outer peripheral chamfer may extend around only a part of the full perimeter of the retention ring.

[0041] The or each inner peripheral chamfer may be angled at at least 4 degrees from the respective lateral surface towards the inner surface. The or each inner peripheral chamfer may be angled at at least 15 degrees from the respective lateral surface towards the inner surface. The or each inner peripheral chamfer may be angled at at least 30 degrees from the respective lateral surface towards the inner surface. The or each inner peripheral chamfer is typically angled by no more than 80 degrees from the respective lateral surface towards the inner surface. The or each inner peripheral chamfer is typically angled by no more than 70 degrees from the respective lateral surface towards the inner surface. The or each inner peripheral chamfer is typically angled by no more than 60 degrees from the respective lateral surface towards the inner surface.

[0042] Each inner peripheral chamfer may be angled from the respective lateral surface towards the inner surface by the same angle as the or each other inner peripheral chamfer, however this is not required, and each inner peripheral chamfer may be angled from the respective lateral surface towards the inner surface by a different angle to that of the or each other depression chamfer.

[0043] The or each outer peripheral chamfer may be angled at at least 5 degrees from the respective lateral surface towards the outer surface. The or each outer peripheral chamfer may be angled at at least 15 degrees from the respective lateral surface towards the outer surface. The or each outer peripheral chamfer may be angled at at least 30 degrees from the respective lateral surface towards the outer surface. The or each outer peripheral chamfer is typically angled by no more than 80 degrees from the respective lateral surface towards the outer surface. The or each outer peripheral chamfer is typically angled by no more than 70 degrees from the respective lateral surface towards the outer surface. The or each outer peripheral chamfer is typically angled by no more than 60 degrees from the respective lateral surface towards the outer surface.

[0044] The or each outer peripheral chamfer may be angled such that the shape of the retention ring corresponds to and cooperates with the shape of the cylinder when the piston reaches top dead centre. For example, the or each outer peripheral chamfer may be angled at a first angle from the respective lateral surface towards the outer surface and the cylinder may have a cylinder chamfer angled from an interior perimeter of the cylinder towards an outer perimeter of the cylinder at the cylinder opening, where the cylinder chamber is angled at a second angle which is the same as the first angle. Advantageously, this prevents the cylinder from making contact with the retention ring during operation of the apparatus.

[0045] Where the region of the piston foot at the boundary between the seat portion and the lateral flange and/or the region of the piston foot at the boundary between the lateral flange and the protrusion, includes a partially filled-in portion (such as defining a shape having an arcuate region in a cross-section in a plane intersecting the axis and the piston foot), it may be that providing the inner peripheral chamfers at one or both lateral surfaces reduces stress on the retention ring. Furthermore, an inner peripheral chamfer can act as a guide to centralise the retention ring at the point of contact between the retention ring and the lateral flange.

[0046] The seat portion of the piston foot may be spaced apart from the or each protrusion by a separation distance, the separation distance defined by the respective lateral flange. This separation distance can provide a convenient space which a retention ring can occupy.

[0047] The protrusion is typically defined by at least one surface. The at least one surface may comprise a first surface portion which faces the seat portion. The at least one surface may comprise a second surface portion which faces away from the seat portion. The at least one surface may comprise a lateral surface portion extending from the second surface portion towards the seat portion in a direction having a component that is parallel to the direction in which the lateral flange extends away from the seat portion.

[0048] The at least one surface of the protrusion may define a substantially prismatic shape. For example, the at least one surface of the protrusion may define an (e.g. generally) frustrated triangular prism shape (e.g. with the sloped sides extending in the same direction as the lateral flange). The at least one surface of the protrusion may define an (e.g. generally) frustoconical shape. The at least one surface of the protrusion may define a (e.g. generally) cubic or cuboidal shape, optionally a frustrated cubic or cuboidal shape. The at least one surface of the protrusion may define a (e.g. generally) cylindrical shape, optionally where the radius of the cylinder is greater than its length and further optionally where the uppermost surface portion of the protrusion is domed.

[0049] Advantageously, where the at least one surface of the protrusion is cylindrical in shape, due to the curvature of the protrusion it is easier to move the protrusion from the first lateral surface of the retention ring towards the second lateral surface, via the depression, when the protrusion is in the first position.

[0050] In one protrusion embodiment, the at least one surface of the protrusion defines a transected cylinder with a domed head, where the transection dividing the cylinder in two parts is in a plane approximately parallel to the axis of the cylinder. (e.g. parallel to the length dimension of the cylinder rather than to the radius or circumference dimensions), such that the divided face faces away from the piston.

[0051] In one protrusion embodiment, the at least one surface of the protrusion defines a conical frustum, but divided in two along a plane approximately parallel to the conical frustum centre axis of rotation, such that the divided face faces away from the piston.

[0052] Although the shape of the protrusion may be prismatic, this is not necessarily the case. For example, the first and/or second surfaces of the protrusion may be (e.g. smoothly) curved into each other. Alternatively, one or more intermediate surfaces may be provided between the first and second surfaces. The protrusion may be hemispherical in shape. The protrusion may have an irregular hemisphere shape.

[0053] The protrusion may be integrally formed with the flange. The protrusion may be a separate component which is connected to (or connectable to) the flange. The protrusion may be a pin or dowel configured to cooperate with and be retained by a pin or dowel receiving recess in the flange.

[0054] Where the first and/or second surface of the protrusion comprises a first surface portion which is curved, it may be curved in such a way that the surface contact area between the second lateral surface of the retention ring and the protrusion at the boundaries of the or each depression is greater than it would be if the first surface portion were not curved. This reduces stress in use.

[0055] The or each protrusion may have one or more protrusion chamfers. For example, there may be a protrusion chamfer at any boundary between adjacent surfaces on or near the protrusion.

[0056] It is well known that that the use of chamfers reduces stress which results from sharp corners, vertices, and/or edges, when contacting and moving relative to another part. As such, the use of chamfers reduces stress on the protrusion and the boundaries of the depression.

[0057] In some embodiments the inner surface of the retention ring may define a channel between the first and second lateral surfaces of the retention ring, said channel being sized and shaped relative to the size and shape of the protrusion, such that the channel may receive and retain the protrusion. The depression may intersect with the channel. For example, the channel may extend into the retention ring from the inner surface of the retention ring towards the outer surface of the retention ring by a distance as least as great as the distance the protrusion extends from the lateral flange. In other words, the channel may be at least as deep as the protrusion is tall. The channel may have a breadth extending from the first lateral surface towards the second lateral surface that is at least as great as the lateral extent of the protrusion. In other words the channel may be at least as wide as the protrusion is wide. The channel may extend around the full inner surface of the retention ring. Alternatively, the channel may extend only around part (i.e. a number of non-overlapping sectors) of the inner surface of the retention ring. The channel may be positioned at an equal distance between the first and second lateral faces of the retention ring, or may be positioned closer to one lateral face than to the other lateral face. The position of the channel relative to each lateral face may vary along the length of the channel. Accordingly, it should be understood that in some embodiments the protrusion is contained within the channel of the retention ring, in the operative configuration. Advantageously, where the inner surface defines such a channel, the faces of the channel interact with the corresponding faces of the protrusion and therefore the retention ring cannot travel axially relative to the protrusion unless the protrusion is in the first position relative to the depression.

[0058] Although the channel may be defined in the retention ring and the protrusion may extend from the lateral flange, it will be understood that this could be the other way around. In other words, there may be one or more protrusions extending from the inner surface of the retention ring towards the central rotational axis of the retention ring, and there may be a depression and/or a channel defined in the lateral flange, where the depression and/or channel are sized and shaped relative to the size and shape of the protrusion such that the protrusion of the retention ring can be moved axially along the lateral flange via the depression and/or channel.

[0059] The or each retention ring may be resiliently deformable. For example, part of the or each retention ring may be resiliently dilatable, such that it may be dilated to fit over a protrusion.

[0060] The or each retention ring may comprise a relatively resilient ring portion that is resiliently dilatable. The relatively resilient portion may comprise a resilient polymer. This makes it easier to pass a protrusion from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, even when the protrusion is not perfectly aligned with the said depression (e.g. not precisely in the first position relative to the said depression). The or each retention ring may comprise a relatively rigid ring portion that is relatively less resiliently deformable than the relatively resiliently deformable ring portion. The relatively rigid ring portion may comprise a metal (e.g. a metal section that is less deformable than the resilient polymer where the relatively resilient ring portion comprises a resilient polymer). The relatively rigid ring portion acts to constrain the relatively resilient ring portion, thus preventing the retention ring from expanding sufficiently that it is no longer reliably restrained by the protrusions (when depressions and protrusions are non-aligned).

[0061] For example, the retention ring may be defined by: a relatively resilient ring portion that extends from the inner surface towards the outer surface of the retention ring; and a relatively rigid ring portion that extends from the outer surface of the retention ring towards the relatively resilient ring portion. Alternately, it may be that where the inner surface of the retention ring defines a channel, some surfaces of the channel are defined by the relatively resilient ring portion and other surfaces of the channel are defined by the relatively rigid ring portion. It may be that the first lateral surface of the retention ring and the surfaces of the channel closest to the first lateral surface are defined by the relatively resilient ring portion and the second lateral surface of the retention ring and the surfaces of the channel closest to the second lateral surface are defined by the relatively rigid ring portion. This makes it easier to move the protrusion from the first lateral surface towards the second lateral surface and thus into the channel.

[0062] The or each retention ring may have an (e.g. substantially continuous) interior protrusion extending from the inner surface radially inwards. The interior protrusion may be configured to cooperate with a groove in the or each lateral flange. Advantageously, this provides lateral guidance to the retention ring and provides a lateral restraining force to restrict movement towards and/or away from the piston. The interior protrusion may be (e.g. generally) square or rectangular in cross section. The groove may define a (e.g. generally) square or rectangular depression, optionally with lateral faces.

[0063] Typically, the or each retention ring is integrally formed. However, this is not required and the or each retention ring may comprise two or more part-rings, wherein the two or more part-rings are configured to form a retention ring when combined. The two or more part-rings may be combined to form a retention ring by joining the two or more part-rings together, for example using fasteners, such as screws, or by welding.

[0064] The or each lateral flange typically extends from the seat portion in a direction having a component in parallel to the axis when the piston foot is engaged around the running surface of the eccentric, by a protrusion separation distance. In other words, the protrusion should be understood to be spaced apart from the seat portion by a protrusion separation distance that is defined by the length of the lateral flange.

[0065] The protrusion separation distance is typically sized such that a retention ring may be retained between the seat portion and the protrusion, with a clearance of at least 0.1 millimetres. For example, the clearance may be at least 0.2 millimetres. The clearance may be at least 0.45 millimetres. Typically, the clearance is no more than 1 millimetre. The clearance may be no more than 0.8 millimetres. The clearance may be no more than 0.6 millimetres. The clearance may be between 0.4 and 0.6 millimetres, or between 0.45 and 0.55 millimetres, or between 0.45 and 0.5 millimetres.

[0066] According to a further aspect of the invention, there is provided a method of manufacturing a hydraulic apparatus according to any one preceding claim, the method comprising:

a. providing:

an eccentric rotatable about an axis;
a retention ring having: an inner surface, the in-

ner surface defining therein at least one depression; an outer surface defined by the outer circumference of the retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface; and

a plurality of piston feet for engagement around a running surface of the eccentric, each piston foot comprising a seat portion, a lateral flange, and at least two (e.g. each) of the piston feet comprising a protrusion sized and shaped relative to the size and shape of the depression such that the protrusion can move from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, when the protrusion is in a first position relative to the depression;

b. sliding the retention ring over the eccentric, such that the inner surface of the retention ring surrounds the running surface of the eccentric;

c. locating a piston foot on the outer surface of the eccentric at the running surface of the eccentric; and

d. moving the protrusion into the first position relative to the depression and moving the protrusion from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, such that the inner surface of the retention ring surrounds both the running surface of the eccentric and the piston foot.

[0067] It will be understood that manufacturing may comprise assembling.

[0068] The method may comprise repeating steps c and d with each of the remaining piston feet in turn. The method may comprise rotating the retention ring relative to the piston foot, around the running surface of eccentric such that the protrusion is in a second position, different to the first position, relative to the depression.

[0069] Advantageously, the method is a convenient and time-efficient way to manufacture/assemble an apparatus wherein a retention ring restricts movement of piston feet away from the running surface of an eccentric. The protrusion ensures that the retention ring remains in the required lateral position on the lateral flange. As a result, it may be that fewer or even no additional components such as springs or clips are required.

[0070] The method may comprise providing a plurality of pistons, each piston extending from a respective piston foot. The method may further comprise providing a housing, the housing defining therein a cylinder for each piston. The method may comprise positioning the eccentric, the piston feet, the pistons, and the retention ring in the housing. The housing may be in two or more parts. This leads to a particularly convenient configuration for hydraulic apparatuses.

[0071] Each piston foot may comprise a second lateral flange. At least two (e.g. each) of the piston feet may comprise a second protrusion.

The method may further comprise:

providing a second retention ring having: an inner surface, the inner surface defining therein at least as many depressions as there are second protrusions; an outer surface defined by the outer circumference of the second retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface, wherein the second protrusions are each sized and shaped, relative to the size and shape of a respective depression of the second retention ring, such that any one second protrusion can move from a first lateral surface of the second retention ring towards the second lateral surface of the second retention ring, via any one depression of the second retention ring, when the said second protrusion is in a first position relative to the said depression;

sliding the second retention ring over the eccentric on the opposite side of the piston feet to the first retention ring, such that the inner surface of the second retention ring surrounds the running surface of the eccentric; and

moving the second protrusion into a first position relative to a respective depression of the second retention ring and moving each second protrusion from the first lateral surface of the second retention ring towards the second lateral surface of the second retention ring, via the said respective depression, such that the inner surface of the second retention ring surrounds both the running surface of the eccentric and each piston foot.

[0072] The method may comprise providing a piston foot alignment jig, the piston foot alignment jig being configured to hold each piston foot such that each protrusion is in a first position relative to a respective depression of a retention ring (e.g. a second retention ring and/or one or more further retention rings). The method may comprise holding each piston foot such that each protrusion is in a first position relative to a respective depression of a retention ring (e.g. a second retention ring), for example after the protrusion of each piston foot has been passed from the first lateral surface of a first retention ring towards the second lateral surface of the first retention ring via a depression of the first retention ring. The method may comprise holding each piston foot such that each protrusion is in the said first position with the piston foot alignment jig. The use of a piston foot alignment jig to hold the piston feet such that each protrusion is in the said first position makes the method easier to carry out than is the case where no piston foot alignment jig is used. The piston foot alignment jig may sometimes be referred to as a piston whip. The piston alignment jig may sometimes be referred to as a piston whip.

[0073] The method may comprise rotating the retention ring (e.g. first or second retention ring) relative to each piston foot, such that each protrusion (e.g. first or second protrusion) is in a second position, different to the first position, relative to the respective depression. The method may comprise rotating the second retention ring relative to each piston foot, such that at least one protrusion is in the second position relative to a depression of the second retention ring. The method may comprise rotating the second retention ring relative to each piston foot, such that no more than one (e.g. first or second) protrusion is in the first position relative to any one depression of the second retention ring. By rotating the retention ring relative to each piston foot such that the protrusions are in the second position relative to the depressions, the risk of the retention ring slipping off the lateral flange is reduced or even completely eliminated.

[0074] The method may comprise assembling a housing around the eccentric, the or each retention ring and the plurality of piston feet.

[0075] It will be understood that manufacturing includes assembling.

[0076] It will be appreciated that the steps of the method may be completed in any order unless inherently incompatible. In some examples, one or more of the steps of the method may be completed simultaneously.

[0077] According to a further aspect of the invention, there is provided a kit of parts for manufacturing an apparatus, the kit of parts comprising:

an eccentric rotatable about an axis;
a retention ring having: an inner surface, the inner surface defining therein at least one depression; an outer surface defined by the outer circumference of the retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface;
a plurality of piston feet for engaging around a running surface of the eccentric, each piston foot comprising a seat portion, a lateral flange, and at least two (e.g. each) of the piston feet comprising a protrusion sized and shaped relative to the size and shape of the depression such that the protrusion can move from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, when the protrusion is in a first position relative to the depression.

[0078] Advantageously, the kit of parts can be used to manufacture the hydraulic apparatus described above. In which case, the retention ring will restrict the movement of the piston foot away from the running surface of the eccentric, without the need for additional components such as springs or clips.

[0079] The kit of parts may comprise a plurality of pistons, wherein each piston extends from a respective piston foot. The kit of parts may comprise a housing, the housing defining therein a cylinder for each piston, such that each cylinder can form a working chamber with a respective piston, wherein each working chamber has a volume which varies cyclically with rotation of the eccentric.

[0080] The kit may comprise a second retention ring. One or more (e.g. each) of the piston feet may comprise a second lateral flange. One or more (e.g. each) of the piston feet may comprise a second protrusion. Typically, the second protrusion is sized and shaped relative to the size and shape of the depression such that the second protrusion can move from the first lateral surface of the second retention ring towards the second lateral surface of the second retention ring, via a respective depression, when the second protrusion is in a first position relative to the said depression. Accordingly, either protrusion may be moved from a first lateral surface of a retention ring towards a second lateral surface of the retention ring via a depression of the retention ring, such that the retention ring surrounds the lateral flange, from which the protrusion extends, and the eccentric. Therefore, movement of the piston foot away from the running surface of the eccentric may be restricted by a retention ring surrounding either the first lateral flange and the eccentric, or the second lateral flange and the eccentric. This provides more flexibility in assembling a hydraulic apparatus using the kit of parts.

[0081] Furthermore, because the piston foot comprises a second protrusion and the apparatus comprises a second retention ring that surrounds the running surface of the eccentric and the piston foot to thereby restrict movement of the piston foot away from the eccentric, this has the advantage that the movement of the piston foot away from the eccentric is restricted at at least two points, and the piston foot therefore stays in contact with the running surface of the eccentric more consistently as the eccentric rotates. Further to this, the resulting machine is better balanced than is the case where only one retention ring is provided.

[0082] The kit of parts may comprise a piston foot alignment jig. The kit of parts may comprise a piston alignment jig. The piston foot alignment jig may be a piston alignment jig. The piston foot alignment jig may be configured to hold each piston foot such that each protrusion is in a first position relative to a respective depression of a retention ring or a second retention ring. The piston foot alignment jig may be configured to hold each piston such that each protrusion is in a first position relative to a respective depression of a retention ring or a second retention ring. The provision of a piston foot alignment jig configured to hold the piston feet such that each protrusion is in the said first position makes it easier to manufacture a hydraulic apparatus using the kit of parts than is the case where no piston foot alignment jig is provided.

[0083] The piston foot alignment jig typically comprises at least one piston foot holding segment, wherein each piston foot holding segment is configured to releasably hold at least one piston foot. Typically, the piston foot alignment jig comprises two end segments. It may be that the two end segments can be reversibly brought into contact with each other. Each piston foot holding segment is typically connected to an adjacent piston foot holding segment and/or to an end segment via a hinge joint. Accordingly, each piston foot holding segment may be pivotably rotatable with respect to at least one (e.g. two) adjacent piston foot holding segment(s) and/or at least one end segment via the respective hinge joint. Because of the hinged connections of the piston foot holding segments and the end segments, the piston foot alignment jig can be positioned such that it surrounds an eccentric at a distance which corresponds to the length of each respective piston foot. The or each piston foot can therefore be arranged on the running surface of the eccentric, whilst held in position by the piston foot alignment jig.

[0084] The two end segments may be configured to be brought into contact and/or connected with each other (in which case they may be thought of as connecting segments). This provides one way in which the piston foot alignment jig can hold each piston foot in position around the running surface of the eccentric without the respective piston feet moving (e.g. radially) away from the running surface of the eccentric, however the skilled person will appreciate that this could be achieved in other ways.

[0085] The or each piston foot holding segment may be connected to at least one adjacent piston foot holding segment and/or to at least one connecting segment via a hinge joint, wherein the hinge joint defines a slot and a shaft which passes through the slot, whereby the shaft may travel along the length of the slot and may rotate around an axis that is perpendicular to the length of the slot and parallel to the length of the shaft. Accordingly, it may be that the or each piston foot holding segment is connected to at least one adjacent piston foot holding segment and/or to at least one connecting segment via a hinge joint, such that each piston foot holding segment may be rotated relative to at least one adjacent piston foot holding segment and/or relative to at least one connecting segment and/or may travel with respect to at least one adjacent piston foot holding segment and/or relative to at least one connecting segment, via the hinge joint.

[0086] The or each piston foot holding segment may be a piston holding segment.

[0087] In an alternative aspect there is provided a hydraulic apparatus comprising:

an eccentric cam rotatable about an axis;
a plurality of piston feet arranged around a running surface of the eccentric cam, each piston foot being configured to reciprocate by rotation of the eccentric cam; and
a retention ring having: an inner surface defined by the inner circumference of the retention ring with at least one protrusion extending therefrom towards a central rotational axis of the retention ring; an outer surface defined by the outer circumference of the retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface,

wherein each piston foot comprises a seat portion, and a lateral flange, and wherein the lateral flange defines therein a depression sized and shaped relative to the size and shape of the protrusion such that the depression can receive and retain the protrusion,
whereby the retention ring is configured to restrict radial movement of the piston foot away from the running surface of the eccentric cam, and
wherein the protrusion is configured to restrict movement of the retention ring laterally away from the piston foot when the protrusion is retained by the depression.

[0088] Although the first and second lateral surfaces are typically substantially planar surfaces, this need not be the case. For example, the first lateral surface may be a planar lateral surface while the second lateral surface may vary sinusoidally in its axial distance from the first lateral surface around the circumference of the retention ring. In other words, the second lateral surface may have a waved profile. Where the second lateral surface has waved profile, the or each depression may be defined in a wave trough, i.e. at a location corresponding to a point where the second lateral surface is closest to the first lateral surface. Alternatively, both the first and second lateral surfaces may have correspondingly waved profiles in the axial direction. In which case, the distance between the first and second lateral surfaces is equal around the circumference of the retention ring, but each lateral surface varies in distance from a lateral plane arranged perpendicularly to the central rotational axis of the retention ring, around the circumference of the retention ring.

[0089] This provides the advantage that, where the retention ring surrounds both the eccentric and more than one lateral flange, and where at least one first protrusion is not in the first position relative to any one depression, even if any other protrusion is in the first position relative to any one depression, the said other protrusion cannot move towards the first lateral surface of the retention ring via the depression. This is because the first protrusion will be in contact with a peak of the wave of the second lateral surface, and thus the other said protrusion will be spaced apart from the second lateral surface of the retention ring by a distance defined by the difference in spacing between the peaks and troughs of the second lateral surface.

[0090] The retention ring itself is believed to be novel and so, in a further aspect of the invention, there is provided a retention ring for a hydraulic apparatus, the hydraulic apparatus comprising:

an eccentric rotatable about an axis; and
a plurality of piston feet arranged around a running

surface of the eccentric, each piston foot being configured to reciprocate by rotation of the eccentric, and comprising a seat portion, a lateral flange, and wherein two (e.g. each) piston foot comprises a protrusion,

the retention ring having an inner surface configured to surround the running surface of the eccentric and the piston foot, and to restrict movement of the piston foot away from the running surface of the eccentric, and defining therein at least one depression, arranged such that the retention ring can move past the protrusion and onto the lateral flange via the depression when the depression is in a first position relative to the protrusion. The protrusion may be configured to restrict movement of the retention ring laterally away from the piston foot when the protrusion is in a second position, different to the first position, relative to the protrusion.

[0091] The retention ring may have an outer surface defined by the outer circumference of the retention ring. The retention ring may have first and second lateral surfaces each extending between the inner surface and the outer surface, wherein the second lateral surface defines a depression chamfer adjacent to and meeting the or each depression on each side of the or each depression, each depression chamfer being angled from the second lateral surface towards the first lateral surface. Such a retention ring provides a particularly convenient way of restricting movement of piston feet away from the running surface of an eccentric.

[0092] Although the features described above are described in relation to a first and/or second retention ring and a group of piston feet which are arranged around the running surface of an eccentric, the skilled person will appreciate that this may be extended to more than one first retention ring, more than one second retention ring, and one or more further groups of piston feet arranged around the running surface of the (e.g. same) eccentric. For example, a first group of piston feet may be associated with a first and second retention ring, and a second group of piston feet may be associated with a third and fourth retention ring, e.g. where more than one bank of pistons is arranged on the eccentric. Additionally or alternatively, one or more banks of pistons may be positioned around an eccentric without said first and/or second retention rings according to the invention.

[0093] It will be understood that any features described above in relation to the retention ring according to any other aspect of the invention are optional features of the retention ring.

Description of the Drawings

[0094] An example embodiment of the present invention will now be illustrated with reference to the following Figures in which:

Figure 1 is a schematic diagram of a hydraulic machine;

Figure 2A is a front elevation diagram of a retention ring according to an aspect of the invention; Figure 2B is a back elevation diagram of the retention ring of Figure 2A; Figure 2C is a perspective view diagram of the retention ring of Figures 2A and 2B;

Figure 3A is a perspective view diagram of a piston according to an aspect of the invention and Figure 3B a further perspective view diagram of the piston of Figures 3A;

Figure 4 is a perspective view diagram of an example of a protrusion according to an aspect of the invention;

Figure 5 is a perspective view diagram of an example of a protrusion according to an aspect of the invention;

Figure 6 is a perspective view diagram of a retention ring retaining several pistons on an eccentric, according to an aspect of the invention;

Figure 7A is a diagram of a piston alignment jig when holding pistons before the pistons are arranged around the running surface of an eccentric, according to an aspect of the invention; Figure 7B is a perspective view diagram of the piston alignment jig of Figure 7A, when holding pistons in position around the running surface of an eccentric; Figure 7C is a detail view of the piston alignment jig of Figures 7A and 7B;

Figure 8 is a flow chart indicating steps in a method according to an aspect of the invention; and

Figure 9 is a flow chart indicating further optional steps in the method of Figure 7.

Detailed Description of an Example Embodiment

[0095] It will be understood by those skilled in the art that any dimensions and relative orientations such as lower and higher, above and below, and directions such as vertical, horizontal, upper, lower, longitudinal, axial, radial, lateral, circumferential, etc. referred to in this description refer to, and are within expected structural tolerances and limits for, the technical field (here including hydraulic apparatuses and retention rings for hydraulic apparatuses) and the hydraulic apparatus and methods described, and these should be interpreted with this in mind.

[0096] Figure 1 is a schematic diagram of part a hydraulic apparatus in the form of a hydraulic machine 10 and shows a single group of working chambers currently connected to one or more actuators through a high-pressure manifold 20. The hydraulic machine 10 has a plurality of working chambers (eight are shown) having cylinders 24 which have working volumes 26 defined by the interior surfaces of the cylinders 24 and pistons 28 which are driven from a rotatable shaft 30 by an eccentric 32 and which reciprocate within the cylinders 24 to cyclically vary the working volume of 24 the cylinders. The rotatable shaft 30 is firmly connected to and rotates with a drive shaft.

[0097] In the example of a hydraulic machine 10 depicted in Figure 1, a shaft position and speed sensor 34 determines the instantaneous angular position and speed of rotation of the shaft, and through a signal line 36 informs a machine controller 50, which enables machine controller 50 to determine the instantaneous phase of the cycles of each cylinder. The working chambers are each associated with Low-Pressure Valves (LPVs) in the form of electronically actuated face-sealing poppet valves 52, which each have an associated working chamber and are operable to selectively seal off a channel extending from the working chamber to a low-pressure hydraulic fluid manifold 22, which may connect one or several working chambers (or indeed all as is shown in the example depicted in Figure 1) to the low-pressure hydraulic fluid manifold of the hydraulic machine. The LPVs 52 are normally-open solenoid-actuated valves which open passively when the pressure within the working chamber is less than or equal to the pressure within the low-pressure hydraulic fluid manifold (i.e. during an intake stroke) to bring the working chamber into fluid communication with the low-pressure hydraulic fluid manifold, but are selectively closable under the active control of the machine controller 50 via LPV control lines 56 to bring the working chamber out of fluid communication with the low-pressure hydraulic fluid manifold. The valves 52 may alternatively be normally closed valves.

[0098] The working chambers are each further associated with a respective High-Pressure valve (HPV) 64, each HPV 64 in the form of a pressure-actuated delivery valve. The HPVs 64 open outwards from their respective working chambers and are each operable to seal off a respective channel extending from the working chamber to a high-pressure hydraulic fluid manifold 20, which may connect one or several working chambers (or indeed all as is shown in the example depicted in Figure 1). The HPVs 64 function as normally-closed pressure-opening check valves which open passively when the pressure within the working chamber exceeds the pressure within the high-pressure hydraulic fluid manifold 20. The HPVs 64 also function as normally-closed solenoid actuated check valves which the machine controller 50 may selectively hold open via HPV control lines 62 once a respective HPV 64 is opened by pressure within the associated working chamber. Typically, the HPVs 64 are not openable by the machine controller 50 against pressure in the high-pressure hydraulic fluid manifold 20. The HPVs 64 may additionally be openable under the control of the machine controller 50 when there is pressure in the high-pressure hydraulic fluid manifold 20, but not in the working chamber.

[0099] In a pumping mode, the machine controller 50 selects the net rate of displacement of hydraulic fluid from the working chamber to the high-pressure hydraulic fluid manifold 20 by a hydraulic motor by actively closing one or more of the LPVs 52 near the point of maximum volume in the associated working chamber's cycle, i.e. on a cycle-by-cycle basis, closing the path to the low-pressure hydraulic fluid manifold 22 and thereby directing hydraulic fluid out through the associated HPV 64 on the subsequent contraction stroke (but does not actively hold open the HPV 64). The machine controller 50 selects the number and sequence of LPV 52 closures and HPV 64 openings to produce a flow or create a shaft torque or power to satisfy a selected net rate of displacement.

[0100] In a motoring mode of operation, the machine controller 50 selects the net rate of displacement of hydraulic fluid, displaced by the hydraulic machine 10, via the high-pressure hydraulic fluid manifold 20, actively closing one or more of the LPVs 52 shortly before the point of minimum volume in the associated working chamber's cycle, closing the path to the low-pressure hydraulic fluid manifold 22 which causes the hydraulic fluid in the working chamber to be compressed by the remainder of the contraction stroke. The associated HPV 64 opens when the pressure across it equalises and a small amount of hydraulic fluid is directed out through the said associated HPV 64, which is held open by the machine controller 50. The machine controller 50 then actively holds open the said associated HPV 64, typically until near the maximum volume in the associated working chamber's cycle, admitting hydraulic fluid from the high-pressure hydraulic fluid manifold 20 to the working chamber and applying a torque to the rotatable shaft.

[0101] As well as determining whether or not to close or hold open the LPVs 52 on a cycle-by-cycle basis, the machine controller 50 is operable to vary the precise phasing of the closure of the HPVs 64 with respect to the varying working chamber volume and thereby to select the net rate of displacement of hydraulic fluid from the high-pressure hydraulic fluid manifold 20 to the low-pressure hydraulic fluid manifold 22 or vice versa.

[0102] Arrows on the low-pressure fluid manifold connection, and the high-pressure fluid manifold connection indicate the direction of flow of hydraulic fluid in the motoring mode. In the pumping mode the flow is reversed.

[0103] A pressure relief valve 66 may protect the hydraulic machine 10 from damage.

[0104] In normal operation, the hydraulic machine 10 intersperses active and inactive cycles of working chamber volume to meet the demand indicated by a received demand signal.

[0105] Figure 2A is a front elevation diagram of a retention ring 100 according to an aspect of the invention. Figures 2B and 2C are a back elevation diagram and a perspective view diagram of the same retention ring.

[0106] The retention ring 100 has an inner surface 102, an outer surface 106 defined by the outer circumference of the retention ring, a first lateral surface 110 and a second lateral surface 108. The retention ring 100 has six depressions 104a, 104b, 104c, 104d, 104e, 104f defined in the inner surface 102. The inner surface 102 should thus be understood to be defined by the combination of the inner circumference of the retention ring 100 and the six depressions. The cross-section of each depression region of the inner surface 102 is generally of an arcuate shape.

[0107] The depressions are equally spaced around the inner surface 102 of the retention ring 100. Each depression extends around 4 percent of the total perimeter of the inner surface 102 of the retention ring 100.

[0108] The retention ring 100 has two depression chamfers 112a, 112b, adjacent to and on either side of each of the six depressions. Each depression chamfer 112a, 112b is defined in the first lateral surface 110 and is angled towards the respective depression and towards the second lateral surface 108 of the retention ring 100. Each depression chamfer 112a, 112b defines an angle between the first lateral surface 110 towards the second lateral surface 108 of 45 degrees.

[0109] The retention ring 100 also has first and second inner peripheral chamfers 114, 116 and an outer peripheral chamfer 117. The first inner peripheral chamfer 114 is at the boundary between the inner surface 102 and the first lateral surface 110 and the second inner peripheral chamfer 116 is at the boundary between the inner surface 102 and the second lateral surface 108. The outer peripheral chamfer 117 is at the boundary between the inner surface 106 and the second lateral surface 108. The first inner peripheral chamfer 114 defines an angle of 45 degrees between the inner surface 102 towards the first lateral surface 110. The second inner peripheral chamfer 116 defines an angle of 45 degrees between the inner surface 102 towards the second lateral surface 108. The outer peripheral chamfer 117 defines an angle of 60 degrees between the outer surface 106 towards the second lateral surface 108.

[0110] Figure 3A is a perspective view diagram of a piston 150 according to an aspect of the invention. Figure 3D is a further perspective view diagram of the piston 150 of Figure 3A.

[0111] The piston 150 has a piston head 152 and a piston foot 154. The piston foot 154 has a seat portion 164, an eccentric engaging surface 156, two lateral surfaces 158a, 158b, two side walls 160a, 160b, and a first and second protrusions 166a, 166b. The eccentric engaging surface 156 is concave and has a radius of curvature such that is it generally conformal with the running surface of the eccentric 32. The piston foot 154 further has first and second lateral flanges 162a, 162b each extending from a respective lateral surface 158a, 158b in opposite directions away from the seat portion 164. The first and second protrusions 166a, 166b extend from the first and second lateral flanges 162a, 162b respectively, in a direction that is substantially perpendicular to the direction in which the flanges 162a, 162b extend from the lateral surfaces 158a, 158b. Each protrusion 166a, 166b is sized and shaped relative to the size and shape of the depressions, such that a protrusion 166a, 166b can be passed through the retention ring 100 by moving the protrusion 166a, 166b from the first lateral surface 110 of the retention ring 100 towards the second lateral surface 108 of the retention ring 100 via any one of the depressions 104a, 104b, 104c, 104d, 104e, 104f when the protrusion 166a, 166b is in a first position relative to a said depression. The protrusion 166a, 166b cannot be passed through a retention ring 100 when the piston foot 154 is located on the running surface of the eccentric 32 if the protrusion 166a, 166b is not in the first position relative to a depression.

[0112] Figure 4 is a detail perspective cut-away view diagram showing a protrusion 166a extending from a lateral flange 162a. Each protrusion 166a, 166b of a single flange is spaced apart from the piston head 152 and the seat portion 164 of the piston foot 154 by a distance defined by the dimensions of the lateral flange 162a, 162b.

[0113] The protrusion 166a of Figure 4 (also shown in Figures 3A to 3D) has: a seat portion facing surface 168 which faces towards the seat portion 164 and the piston head 152; an opposite surface 170 which faces away from the seat portion 164 and the piston head 152; first and second side surfaces 172a, 172b which extend in the same direction as the respective lateral flange 162a, 162b, away from the seat portion 164 and the piston head 152; and an uppermost top surface 174. The top surface 174 extends between the seat portion facing surface 168, the opposite surface 170 (not shown in Figure 4), and also between the first and second side surfaces 172a, 172b. The top surface 174 is generally parallel to a surface of the seat portion 164.

[0114] The seat portion facing surface 168 is convexly curved, such that the areas of the seat portion facing surface that are closest to the respective first and second side surfaces 172a, 172b are further from the seat portion 164 than the areas of the seat portion facing surface that are furthest from the respective first and second side surfaces 172a, 172b. The opposite surface is a flat surface extending generally upwards in a direction that is substantially perpendicular to the direction of extension of the lateral flange 162a, 162b. The first and second side surfaces 172a, 172b are flat surfaces and are angled towards each other. The top surface 174 is a flat surface.

[0115] First and second protrusion chamfers 176a, 176b are provided at the boundaries between the first and second side surfaces 172a, 172b and the seat portion facing surface 168. The first and second inner protrusion chamfers 176a, 176b each define an angle of 45 degrees between the seat portion facing surface 168 and the respective side surfaces 172a, 172b.

[0116] Figure 5 is a perspective view diagram of a further example of a protrusion 167 according to an aspect of the invention. The protrusion 167 extends from a lateral flange 162, which in turn extends from the seat portion 164 of a piston foot 154, and a piston 150 extends from the piston foot 164. The protrusion 167 has a curved outer surface 169 defining its perimeter and a flat upper surface 171 arranged perpendicular to the curved outer surface 169. The protrusion 167 is substantially cylindrical in shape having a radius that is greater than its height. The protrusion 167 is sized and shaped such that the protrusion 167 can be passed through a retention ring 100 by moving the protrusion from the first lateral surface 110 of the retention ring 100 towards the second lateral surface 108 of the retention ring 100 when the protrusion 167 is in a first position relative to a depression, such that the retention ring 100 is passed onto the lateral flange 162.

[0117] Figure 6 is a diagram of a retention ring retaining several pistons 150 on an eccentric 32, according to an aspect of the invention. In this example, there are four pistons 150a, 150b, 150c, 150d, provided. Each piston is held in place with a first retention ring 100a at a first side of the 150a, 150b, 150c, 150d and a second retention ring (not shown) at the opposite side of the pistons. Only one eccentric is shown populated with pistons, for clarity of viewing various components.

[0118] As the eccentric 32 rotates around the axis (A), each piston, reciprocates in a respective cylinder (not shown). During such rotation, each piston is kept in contact with the running surface of the eccentric 32 by the retention rings 100 which are sized and shaped such that the pistons stay on or close to the eccentric surface. Each retention ring 100 is prevented from travelling away from the respective pistons (e.g. by travelling in parallel to the axis A) by the protrusions 166 of the lateral flanges 162.

[0119] The inner peripheral chamfers 114, 116 of the retention ring reduce stress between the lateral flange 162 and the retention ring 100. The outer peripheral chamfer 117 is angled to cooperate with a chamfer in the surfaces defining the opening of the cylinder when the piston 150 is at top dead centre.

[0120] Figure 7A is a diagram of a piston alignment jig 180 when holding pistons 150, before the pistons 150 are arranged around the running surface of an eccentric 32, according to an aspect of the invention. In this instance, five pistons 150a, 150b, 150c, 150d, 150e are provided. The piston alignment jig 180 has several piston holding segments 182, each of which can hold a respective piston 150. The piston alignment jig 180 also has two end segments in the form of connecting segments 186. The piston holding segments 182 are joined by hinges 184 to adjacent piston holding segments 182, or to an adjacent connecting segment 186. Accordingly, each piston holding segment 182 can move pivotably with respect to its respective adjacent piston holding segments 182 or with respect to an adjacent connecting segment 186.

[0121] Figure 7B is a perspective view diagram of the piston alignment jig 180 of Figure 7A, when holding pistons 150 in position around the running surface of an eccentric 32. Here it can be seen that because each piston-holding segment 182 can move pivotably with respect to its adjacent piston-holding segments 182, and because the connecting segments 186 can move pivotably with respect to their respective adjacent piston-holding segments 182, the piston alignment jig 180 can be configured to surround an eccentric in a circular fashion, with the two connecting segments 186 in contact with each other or simply pulled towards one another. Each piston-holding segment 182 is then spaced apart from the eccentric 32 by a distance defined by the length of the respective piston 150 and the engaging surface of each respective piston 150 is in contact with the running surface of the eccentric 32. It will be understood that while a piston jig 180 is a convenient tool with which to assemble an apparatus according to the invention, specifically to hold the piston against a respective eccentric, such that the ring can be slid onto the respective lateral flange of a set of pistons, the use of such a piston jig 180 is not required. When the connecting segments 186 are brought into contact with each other, or are simply pulled towards each other so as to apply an inwards force around the jig, they can be secured together, such that the pistons 150 cannot leave the running surface of the eccentric 32 (e.g. until, in the event of disassembly of the apparatus, the connecting segments 186 are later separated).

[0122] When the piston alignment jig 180 holds the pistons 150 and is arranged around the eccentric 32 in this way, a retention ring 100 can be conveniently passed over each protrusion 166 of each lateral flange 162 simultaneously, via a respective depression 104. The retention ring 100 will then surround both the eccentric 32 and each lateral flange 162 and will thereby restrict movement of the piston away from the running surface of the eccentric 32. The piston holding segments 182 can then be disconnected from the respective pistons 150 and the piston alignment jig 180 can be removed, leaving the pistons 150 and the retention ring 100 in position around the eccentric 32. An alternate method of manually holding the pistons against the cam surface not using such a jig, whilst sliding the ring over the protrusions, and rotating the pistons around the cam to align with the depressions, is a difficult operation.

[0123] Figure 7C is a detail view of the piston alignment jig 180 of Figures 7A and 7B. The piston holding segments 182 can both be rotated pivotably with respect to an adjacent piston holding segment 182 and/or with respect to an adjacent connecting segment 186 via the hinges 184. However, each hinge 184 also defines a slot 190 in which the hinge pin may travel, such that each piston holding segment 182 can travel relative to an adjacent piston holding segment 182 and/or with respect to an adjacent connecting segment 186, in the direction shown by arrow 188. The slot assists insertion of the jig into the pistons, as well as allowing for the piston alignment jig 180 to be used with pistons 150 and/or eccentrics 32 having a range of dimensions.

[0124] In use, each retention ring 100 surrounds both the eccentric 32 and a lateral flange 162a, 162b of each piston 150. Because the retention ring 100 surrounds both the eccentric 32 and the lateral flange 162a, 162b, the piston foot 154 cannot leave (or cannot move far from) the running surface of the eccentric 32. Accordingly, the eccentric engaging surface 156 each piston foot 154 stays substantially in contact with the running surface the eccentric 32 during machine operation.

[0125] The protrusions 166a, 166b are sized and shaped relative to the size and shape of the depressions, such that a protrusion 166a, 166b and part of the respective lateral flange 162a, 162b can be passed through a retention ring 100 via any one of the depressions 104a, 104b, 104c, 104d, 104e, 104f, and such that the protrusion 166a, 166b and the lateral flange 162a, 162b cannot be passed through a retention ring 100 when the piston foot 154 is located on the running surface of the eccentric 32 if the protrusion 166a, 166b is in a second position, different to the first position, with respect to a depression 104a, 104b, 104c, 104d, 104e, 104f. As a result, the protrusions 166a, 166b restrict the movement of the retention ring 100 away from the piston 100 in a direction parallel to the axis of rotation of the eccentric 32.

[0126] Figure 8 is a flow chart indicating steps in a method 200 of manufacturing a hydraulic apparatus according to an aspect of the invention. The steps of the method 200 are as follows:

providing 202 an eccentric 32 rotatable about an axis, at least one retention ring 100a, 100b having six depressions 104, and six pistons 150, each piston 150 having a piston foot 154, first and second lateral flanges 162a, 162b, each lateral flange 162a, 162b having a protrusion 166a, 166b;

sliding 204 the retention ring 100a over the eccentric 32 so that the retention ring surrounds the eccentric 32;

locating 206 the piston foot 154 of a first piston 150 on the running surface of the eccentric 32;

moving 208 a protrusion 166a of a lateral flange 162a of the piston foot of the first piston 150 into a first position with respect to a depression 104 of the retention ring 100a; and

passing 210 the said protrusion 166a through the retention ring 100a via the said depression 104 such that the retention ring 100a surrounds both the eccentric 32 and the piston foot 154 of the piston 150.

The locating 206, moving 208 and passing 210 steps of the above-described method 200 are then repeated with each of the remaining pistons 150 in turn, until all of the pistons 150 are located on the running surface of the eccentric 32 and the retention ring surrounds the eccentric 32 and each piston foot 154.

[0127] Although described as passing the protrusion through the ring, this is merely a relative motion to encompass moving the piston whilst the ring is static, or moving the ring whilst the piston is static.

[0128] Figure 9 is a flow chart indicating further optional steps in the method 200. The further optional steps of the method 200 are as follows:

sliding 212 a second retention ring 100b over the eccentric 32, on the opposite side of the piston feet 154 to that of the first retention ring 100a, so that the second retention ring 100b surrounds the eccentric 32;

moving 214 each protrusion 166b of the other lateral flange 162a of each respective piston foot 154of each piston 150 into a first position with respect to a respective depression 104 of the second retention ring 100b; and

passing 216 each said protrusion 166b through the second retention ring 100b via each said depression 104 such that the second retention ring 100b surrounds both the running surface of the eccentric 32 and each piston foot 154 of each piston 150.

[0129] It will be understood that the retention ring and the piston may be formed in a number of different ways and the skilled person is able to select a suitable manufacturing process to provide the required component properties.

[0130] The retention rings 100, 100a, 100b restrict the movement of the piston feet 154 of the pistons 150 away from the running surface of the eccentric 32. Advantageously, the piston feet 154 therefore tend to stay in contact with the running surface of the eccentric 32 more reliably than would be the case without the retention rings 100, 100a, 100b and without the need to provide additional components such as springs or clips.

[0131] Furthermore, because the protrusions 166a, 166b restrict the movement of the two retention rings 100, 100a, 100b laterally away from the piston feet 154, the retention rings cannot move completely away from the pistons 150 (by moving at least in part in a direction in parallel to the axis) and the retention rings 100, 100a, 100b therefore stay in position surrounding the lateral flanges 162 and the eccentric 32 and are less likely to fall off the lateral flanges 162 of the piston feet 154 than would be the case if the piston feet 154 did not have protrusions 166a, 166b.

[0132] Because chamfers 112a, 112b are provided on either side of each depression 104a, 104b, 104c, 104d, 104e, 104f there is an improved deflection action when the depression chamfer contacts the protrusion 166 during operation, deflecting the ring away from the protrusion lateral surface 168. For example, where there is misalignment of the protrusion 168 and a respective depression the protrusion may contact a surface of the retention ring 100 (e.g. a chamfer 112a, 112b, the edge of a chamfer, or the first lateral surface 110) rather than being directly passed through the depression 104a, 104b, 104c, 104d, 104e, 104f. With the provision of the chamfers, the protrusion 168 is better deflected from such a surface to more smoothly guide the protrusion relative to the depression, helping to reduce the chance of the protrusion accidentally passing through the depression.

[0133] Although in the above-described examples, the retention rings 100 have six depressions 104, this need not be the case. In some examples a first retention ring 100 has one depression 104 and the second retention ring 100 has a plurality of depressions 104. The second retention ring 100 is then provided with at least as many depressions 104 as there are pistons 150, for example, the second retention ring 100 may be provided with one more depression 104 than there are pistons 150. Where the second retention ring 100 defines therein at least as many depressions 104 as there are pistons 150, this makes the hydraulic apparatus 10 easier to manufacture, as each protrusion 166a, 166b can be moved from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via a respective depression 104, and thereby passed through the retention ring 100, simultaneously. In addition, where a retention ring 100 has more depressions 104 than there are pistons 150 provided, it is not possible for one depression 104 positioned with respect to a protrusion 166a, 166b of one piston 150 such that the said protrusion could move from the second lateral surface of the retention ring towards the first lateral surface of the retention ring, at the same time as each other depression 104 is so positioned with the protrusion 166a, 166b of each other piston 150.

[0134] In summary, there is provided a hydraulic apparatus comprising an eccentric (32) rotatable about an axis, a plurality of piston feet (154) arranged around a running surface of the eccentric (32), each piston foot (154) being configured to reciprocate by rotation of the eccentric (32). In addition there is provided a retention ring (100) having an inner surface (102) which defines therein at least one depression (104); an outer surface defined by the outer circumference of the retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface. The piston feet (154) each have a seat portion (164) and a lateral flange (162) and at least two of the piston feet have a protrusion (166) that is sized and shaped in relation to the size and shape of the depression (104), such that the protrusion(166) can move from the first lateral surface of the retention ring (100) towards the second lateral surface of the retention ring, via the depression (104), when the protrusion (166) in a first position with respect to the depression (104), such that the retention ring (100) then surrounds both the lateral flange (162) and the eccentric (32).

[0135] Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of them mean "including but not limited to", and they are not intended to and do not exclude other components, integers, or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

[0136] Features, integers, characteristics, or groups described in conjunction with a particular aspect, embodiment, or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. A hydraulic apparatus comprising:

an eccentric rotatable about an axis;
a plurality of piston feet arranged around a running surface of the eccentric, each piston foot being configured to reciprocate by rotation of the eccentric; and
a retention ring having: an inner surface, the inner surface defining therein at least one depression; an outer surface defined by the outer circumference of the retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface,

wherein each piston foot comprises a seat portion and a lateral flange, and wherein at least two of the piston feet comprise a protrusion sized and shaped relative to the size and shape of the depression such that the protrusion can move from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, when the protrusion is in a first position relative to the depression, wherein the inner surface surrounds the running surface of the eccentric and the piston foot whereby the retention ring is configured to restrict radial movement of the piston foot away from the running surface of the eccentric, and
wherein the protrusion is configured to restrict movement of the retention ring later-

ally away from the piston foot when the protrusion is in a second position, different to the first position, relative to the depression.

2. A hydraulic apparatus according to claim 1,

wherein the lateral flange is a first lateral flange and the protrusion is a first protrusion, and wherein each piston foot comprises a second lateral flange and at least two of the piston feet comprise a second protrusion and wherein the retention ring is a first retention ring and the apparatus comprises a second retention ring, the second retention ring having: an inner surface, the inner surface defining therein at least as many depressions as there are second protrusions; an outer surface defined by the outer circumference of the second retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface,

the second protrusions each being sized and shaped relative to the size and shape of a respective depression such that any one second protrusion can move from the first lateral surface of the second retention ring towards the second lateral surface of the second retention ring, via any one depression of the second retention ring when the said second protrusion is in a first position relative to the said depression,

wherein the inner surface of the second retention ring surrounds the running surface of the eccentric and the lateral flange of the piston foot whereby the second retention ring is configured to restrict movement of the piston foot away from the running surface of eccentric, and

wherein the second protrusion is configured to restrict movement of the second retention ring laterally away from the piston foot when the second protrusion is in a second position, different to the first position, relative to the said depression.

3. A hydraulic apparatus according to claim 2, wherein the inner surface of the second retention ring defines therein more depressions than there are second protrusions.

4. A hydraulic apparatus according to claim 2 or claim 3, wherein the depressions of the inner surface of the second retention ring are arranged such that the second retention ring has at least two positions of rotational symmetry.

5. A hydraulic apparatus according to any one of claims 2 to 4, wherein the depressions of the inner surface of the second retention ring are arranged such that only one protrusion can be in the first position with respect to any one depression, when the retention ring surrounds the eccentric and a lateral flange of each piston foot.

6. A hydraulic apparatus according to any one preceding claim, wherein:

the inner surface of the retention ring is the surface defined by the inner circumference of the said retention ring and the depressions defined therein,

and the first lateral surface defines a depression chamfer adjacent to and meeting the or each depression, wherein the depression chamfer is between the first lateral surface and the inner surface and is angled from the first lateral surface towards the second lateral surface.

7. A hydraulic apparatus according to any one preceding claim, wherein there is an outer peripheral chamfer defined at the boundary between the outer surface and the first lateral surface.

8. A hydraulic apparatus according to any one preceding claim, wherein the protrusion extends substantially normal to the lateral flange.

9. A hydraulic apparatus according to any one preceding claim, wherein the or each lateral flange extends from the seat portion in a direction having a component in parallel to the axis when the piston foot is engaged around the running surface of the eccentric by a protrusion separation distance, wherein the protrusion separation distance is sized such that a retention ring may be retained between the seat portion and the protrusion with a clearance of no more than 1 millimetre.

10. A method of manufacturing a hydraulic apparatus according to any one preceding claim, the method comprising:

a. providing:

an eccentric rotatable about an axis;

a retention ring having: an inner surface, the inner surface defining therein at least one depression; an outer surface defined by the outer circumference of the retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface; and

a plurality of piston feet for engagement around a running surface of the eccentric, each piston foot comprising a seat portion, a lateral flange, and at least two of the piston feet comprising a protrusion sized and shaped relative to the size and shape of the depression such that the protrusion can move from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, when the protrusion is in a first position relative to the depression;

b. sliding the retention ring over the eccentric, such that the inner surface of the retention ring surrounds the running surface of the eccentric;
c. locating a piston foot on the outer surface of the eccentric at the running surface of the eccentric; and
d. moving the protrusion into the first position relative to the depression and moving the protrusion from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, such that the inner surface of the retention ring surrounds both the running surface of the eccentric and the piston foot;

repeating steps c and d with each of the remaining piston feet in turn.

11. A method according to claim 10, wherein the lateral flange is a first lateral flange, the protrusion is a first protrusion, and the retention ring is a first retention ring, and wherein each piston foot comprises a second lateral flange and at least two of the piston feet comprise a second protrusion, the method further comprising:

providing a second retention ring having: an inner surface, the inner surface defining therein at least as many depressions as there are second protrusions; an outer surface defined by the outer circumference of the second retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface, wherein the second protrusions are each sized and shaped, relative to the size and shape of a respective depression of the second retention ring, such that any one second protrusion can move from a first lateral surface of the second retention ring towards the second lateral surface of the second retention ring, via any one depression of the second retention ring, when the said second protrusion is in a first position relative to the said depression;
sliding the second retention ring over the eccentric on the opposite side of the piston feet to the first retention ring, such that the inner surface of the second retention ring surrounds the running surface of the eccentric; and
moving the second protrusion into a first position relative to a respective depression of the second retention ring and moving each second protrusion from the first lateral surface of the second retention ring towards the second lateral surface of the second retention ring, via the said respective depression, such that the inner surface of the second retention ring surrounds both the running surface of the eccentric and each piston foot.

12. A method according to claim 10 or claim 11, wherein the method further comprises:
rotating the retention ring relative to each piston foot, such that each protrusion is in a second position, different to the first position, relative to the respective depression.

13. A kit of parts for manufacturing an apparatus according to any one of claims 1 to 9, the kit of parts comprising:

an eccentric rotatable about an axis;
a retention ring having: an inner surface, the inner surface defining therein at least one depression; an outer surface defined by the outer circumference of the retention ring; a first lateral surface; and a second lateral surface, wherein the first and second lateral surfaces each extend between the inner surface and the outer surface;
a plurality of piston feet for engagement around a running surface of the eccentric, each piston foot comprising a seat portion, a lateral flange, and at least two of the piston feet comprising a protrusion sized and shaped relative to the size and shape of the depression such that the protrusion can move from the first lateral surface of the retention ring towards the second lateral surface of the retention ring, via the depression, when the protrusion is in a first position relative to the depression.

14. A kit of parts according to claim 13, wherein the kit of parts further comprises a piston foot alignment jig, the piston foot alignment jig being configured to hold each piston foot such that each protrusion is in the first position;
or a method according to any one of claims 10 to 12, wherein the method further comprises:

providing a piston foot alignment jig, the piston foot alignment jig being configured to hold each piston foot such that each protrusion is in the first position; and
holding each piston foot such that each protrusion is in the first position with the piston foot alignment jig.

15. A retention ring for a hydraulic apparatus, the hydraulic apparatus comprising:

an eccentric rotatable about an axis; and
a plurality of piston feet arranged around a running surface of the eccentric, each piston foot being configured to reciprocate by rotation of the eccentric, and comprising a seat portion, a lateral flange, and at least two of the piston feet comprising a protrusion,

the retention ring having an inner surface configured to surround the running surface of the eccentric and the piston foot, and to restrict movement of the piston foot away from the running surface of the eccentric, and defining therein at least one depression, arranged such that the retention ring can move past the protrusion and onto the lateral flange via the depression when the depression is in a first position relative to the protrusion,
and wherein the retention ring has an outer surface defined by the outer circumference of the retention ring and first and second lateral surfaces each extending between the inner surface and the outer surface, wherein the second lateral surface defines a depression chamfer adjacent to and meeting the or each depression on each side of the or each depression, each depression chamfer being angled from the second lateral surface towards the first lateral surface.

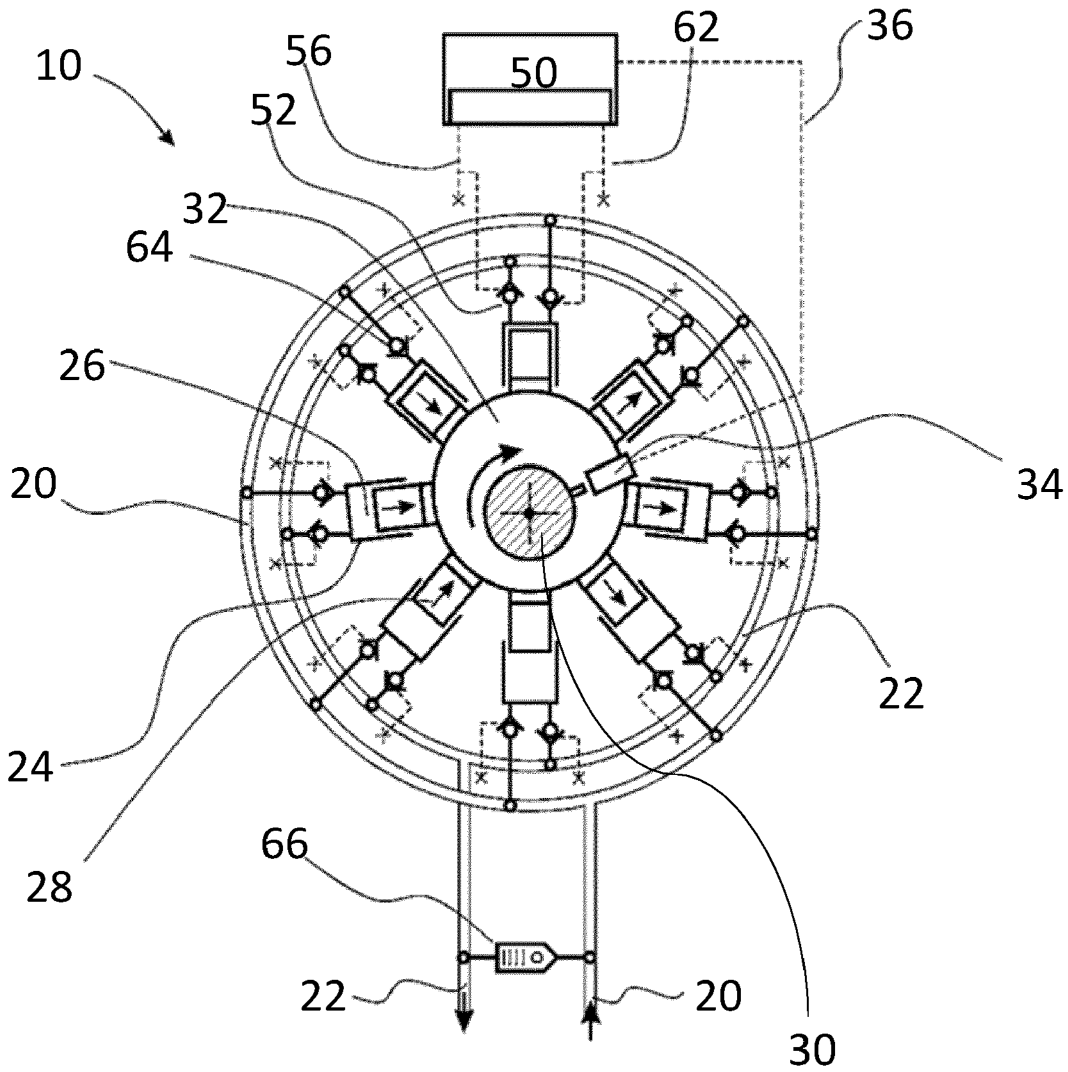

Fig. 1

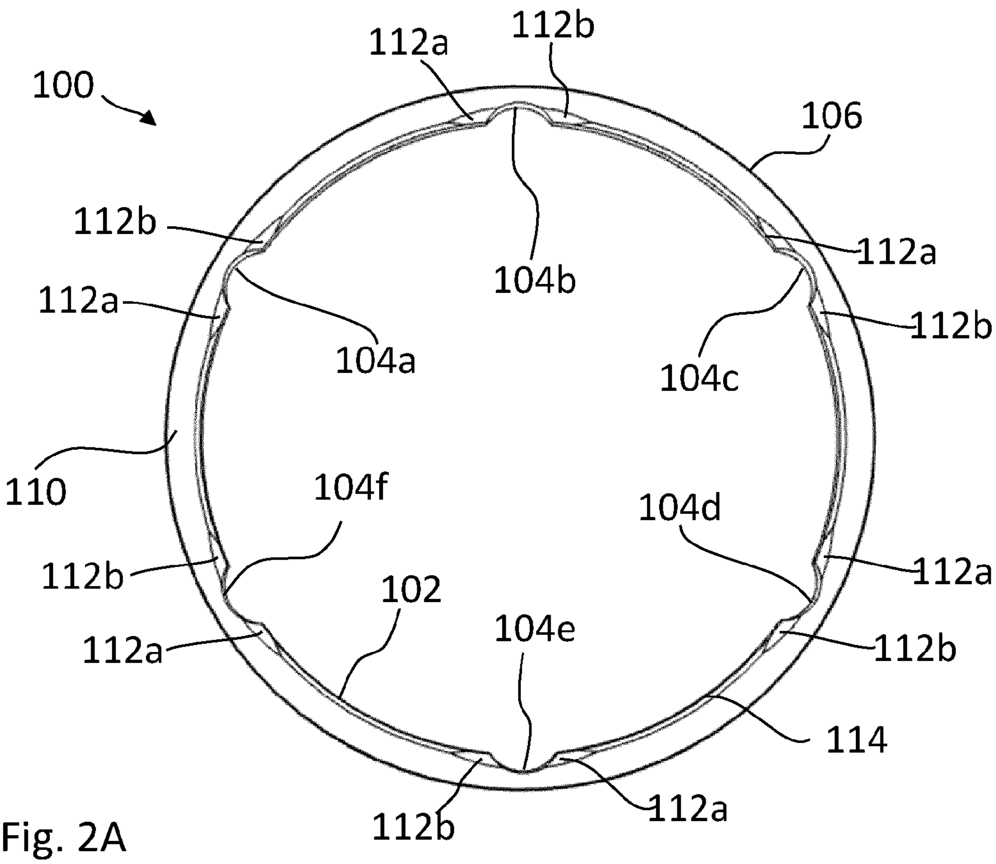
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Fig. 2A

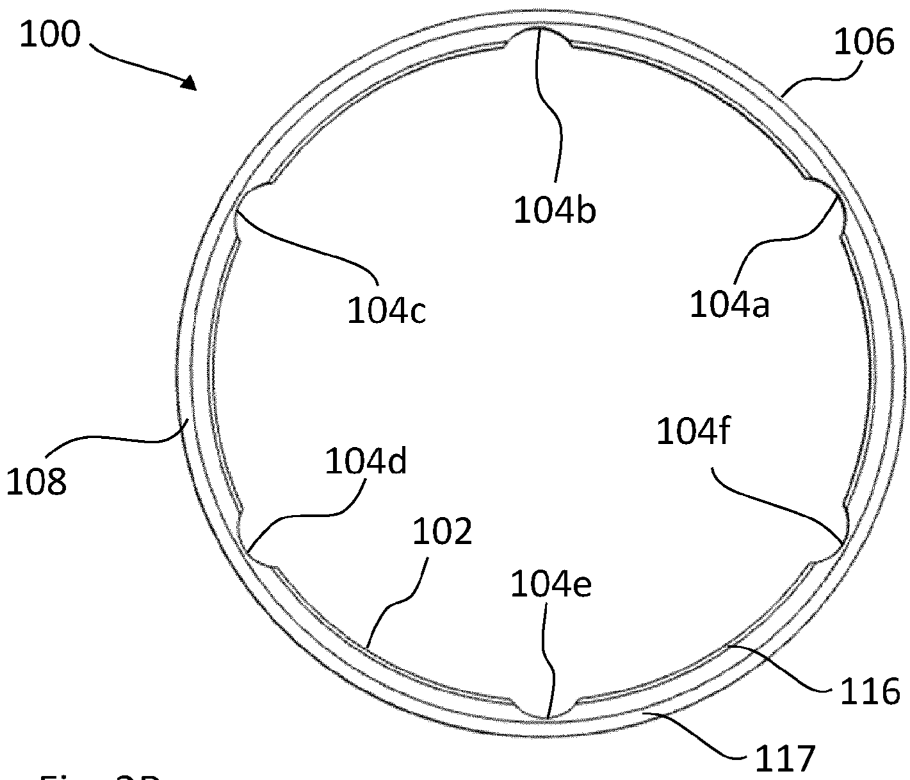
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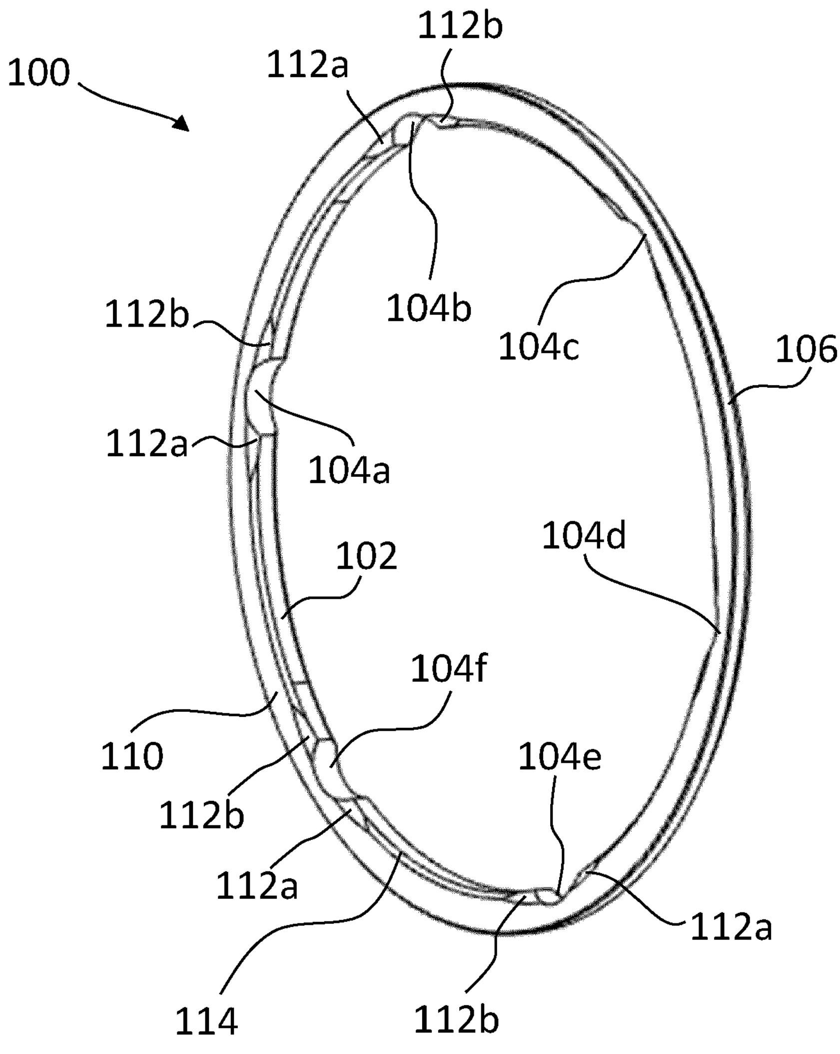
Fig. 2B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112b

Fig. 2C

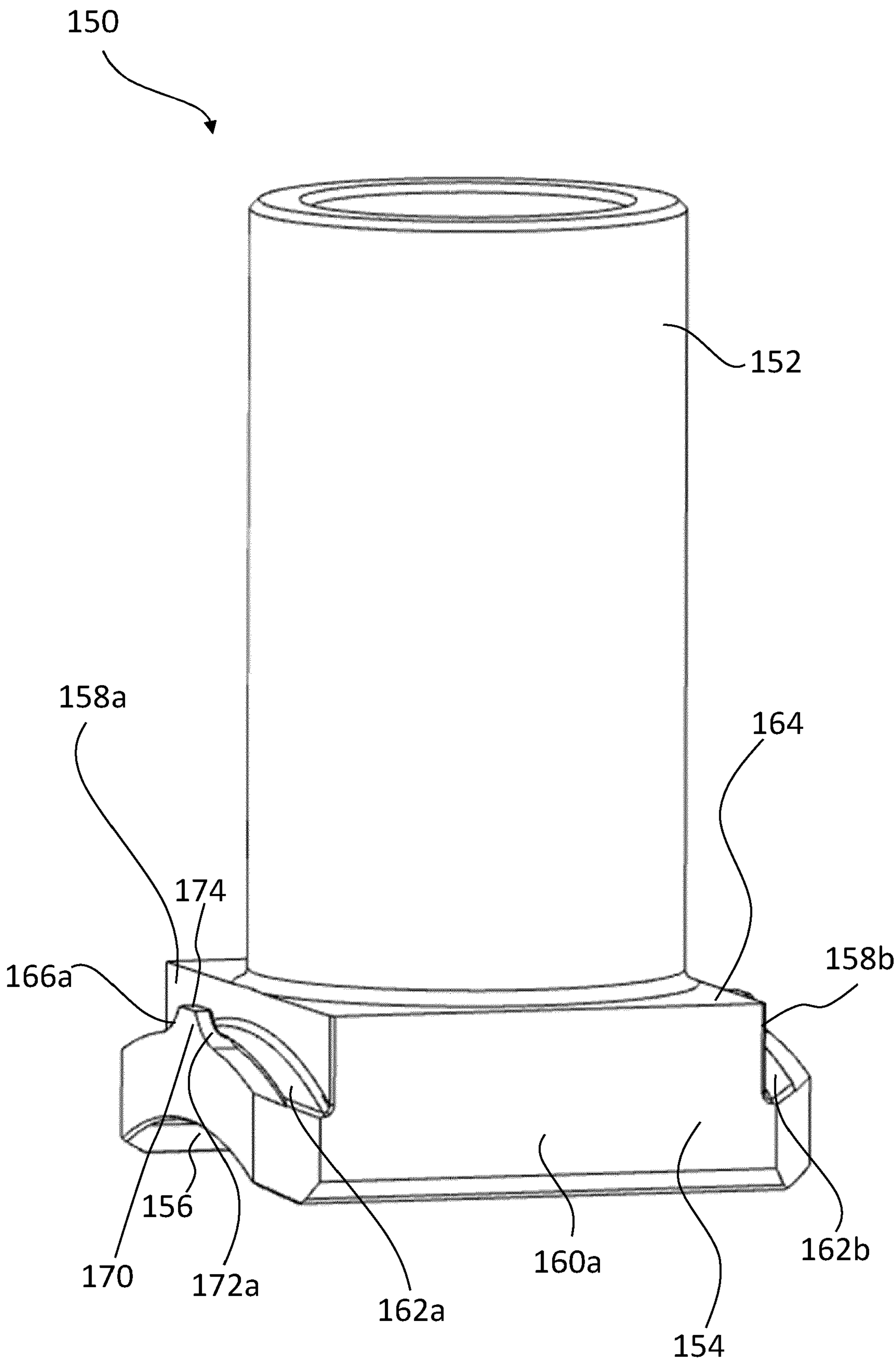


Fig. 3A

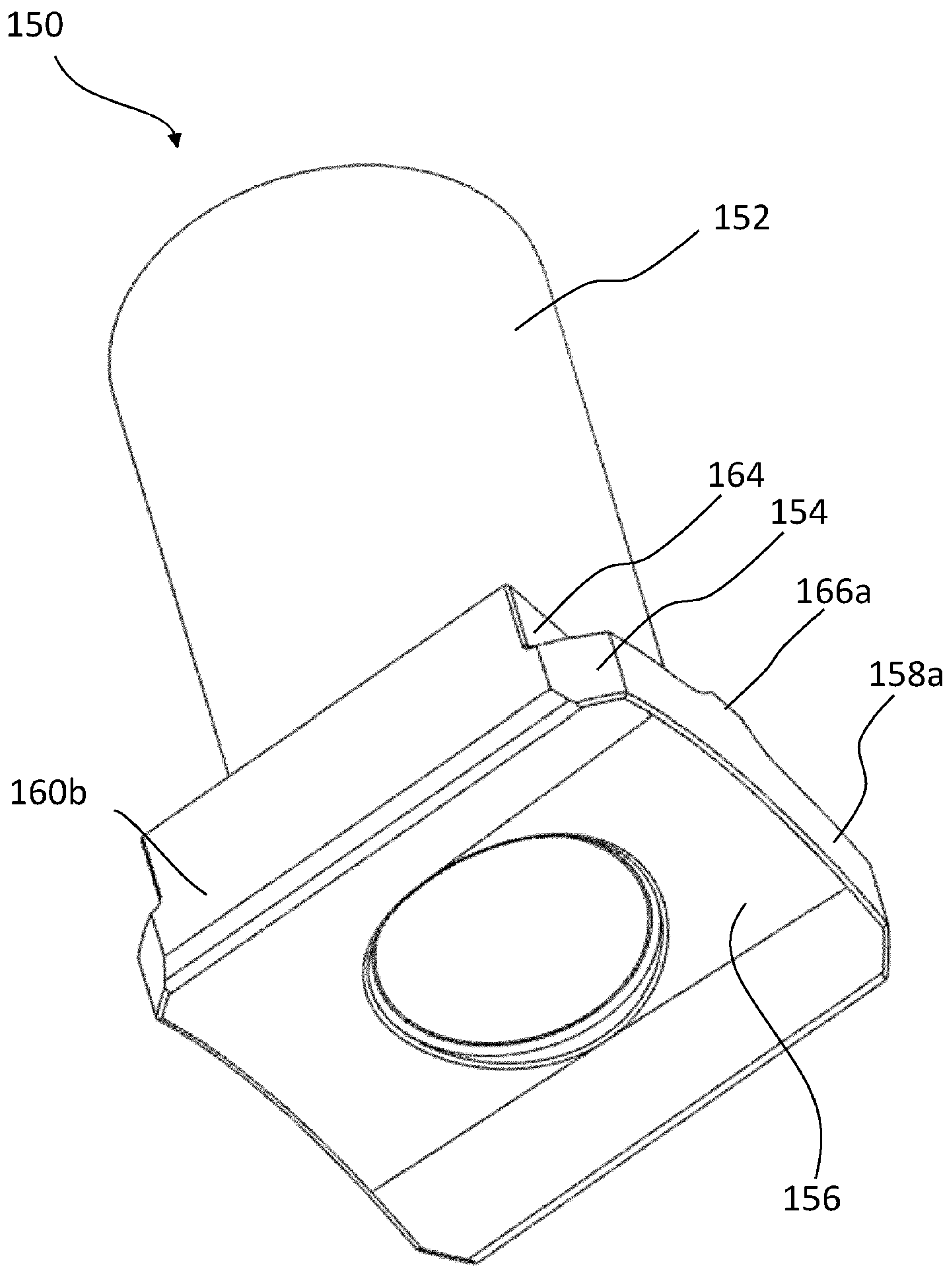


Fig. 3B

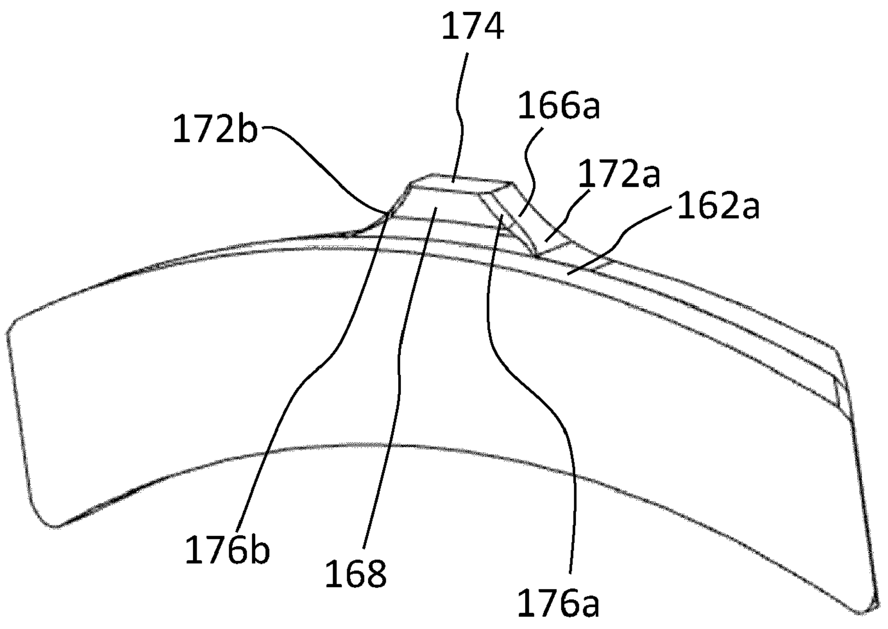


Fig. 4

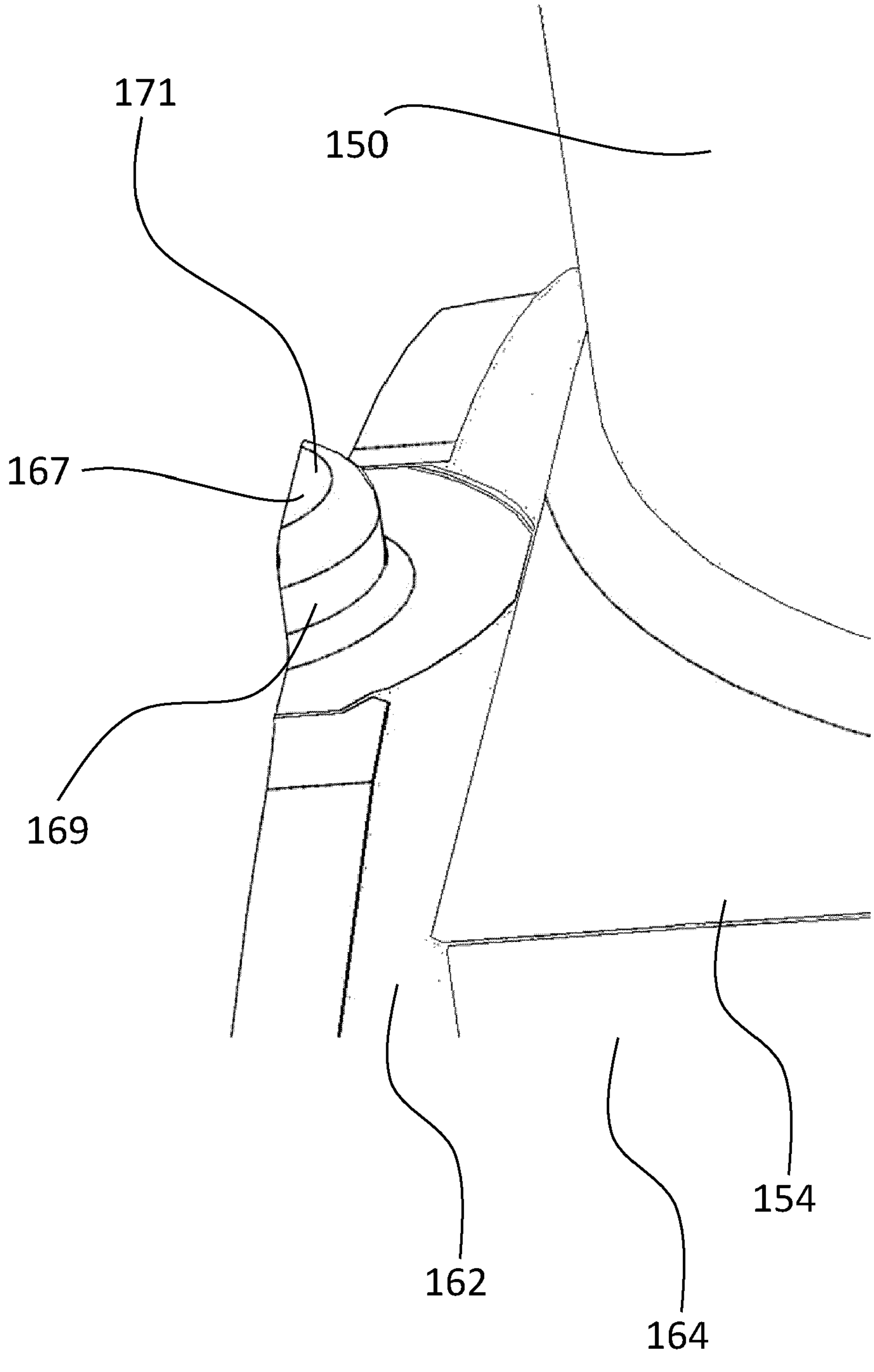


Fig. 5

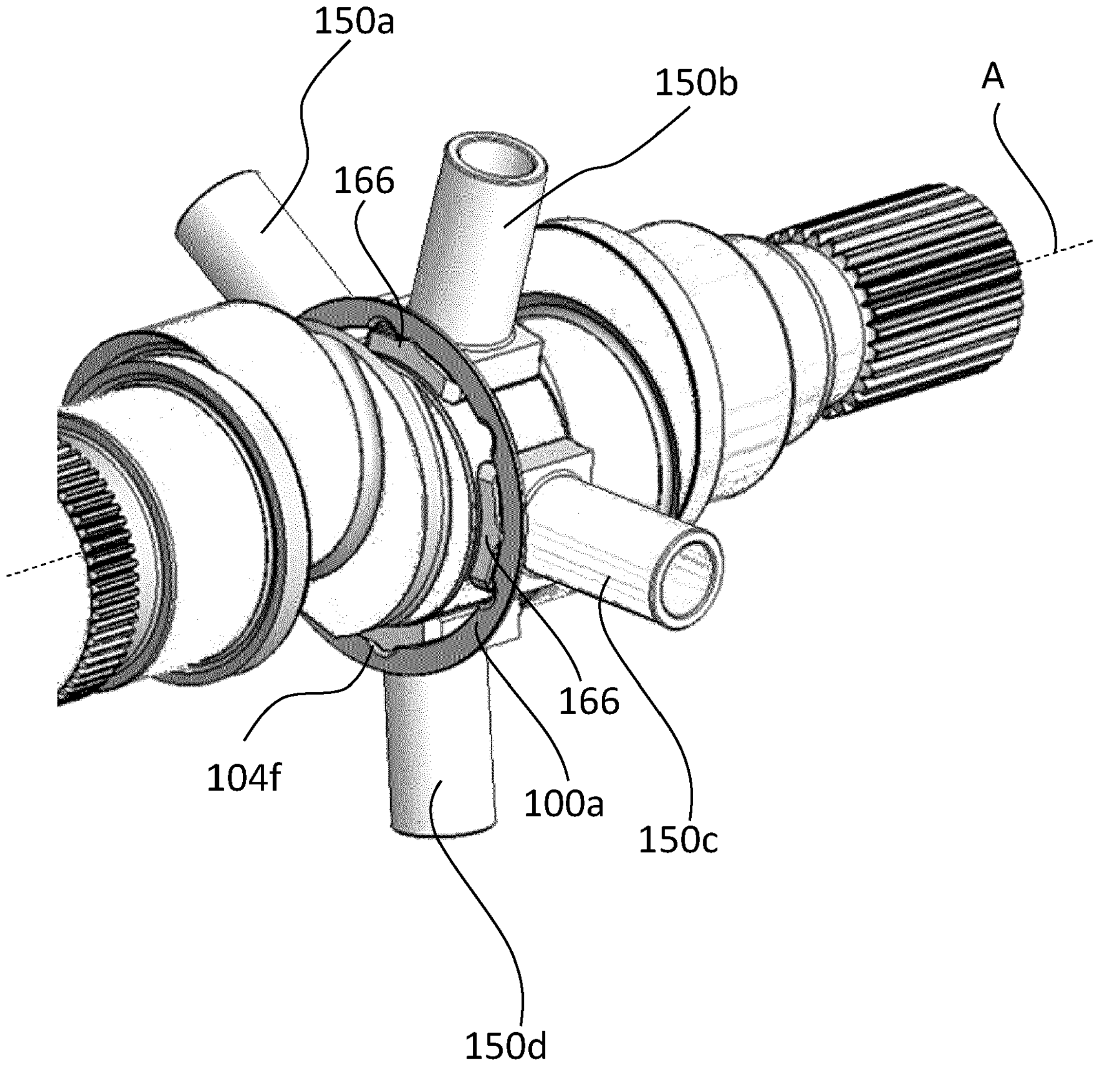
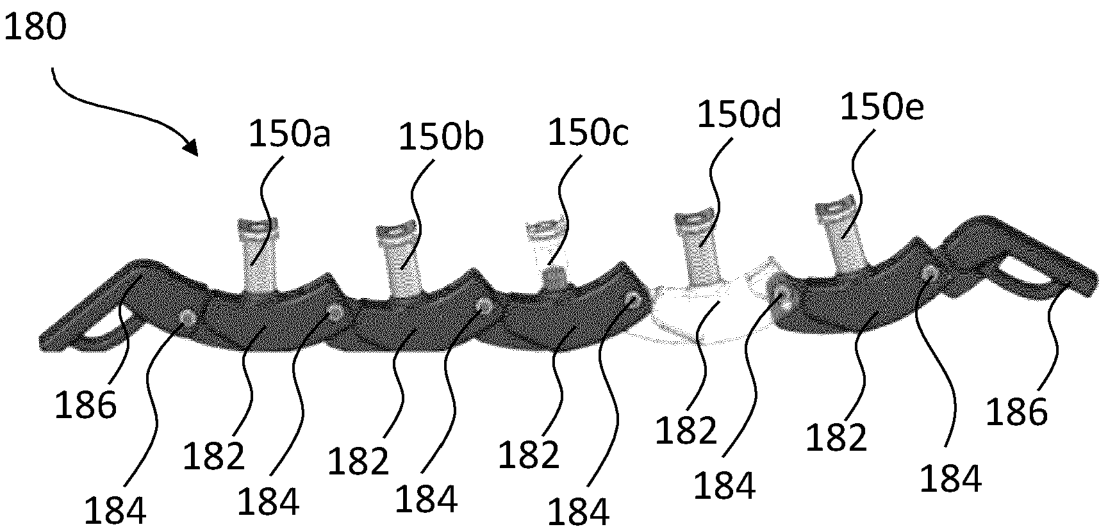


Fig. 6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150a
150b
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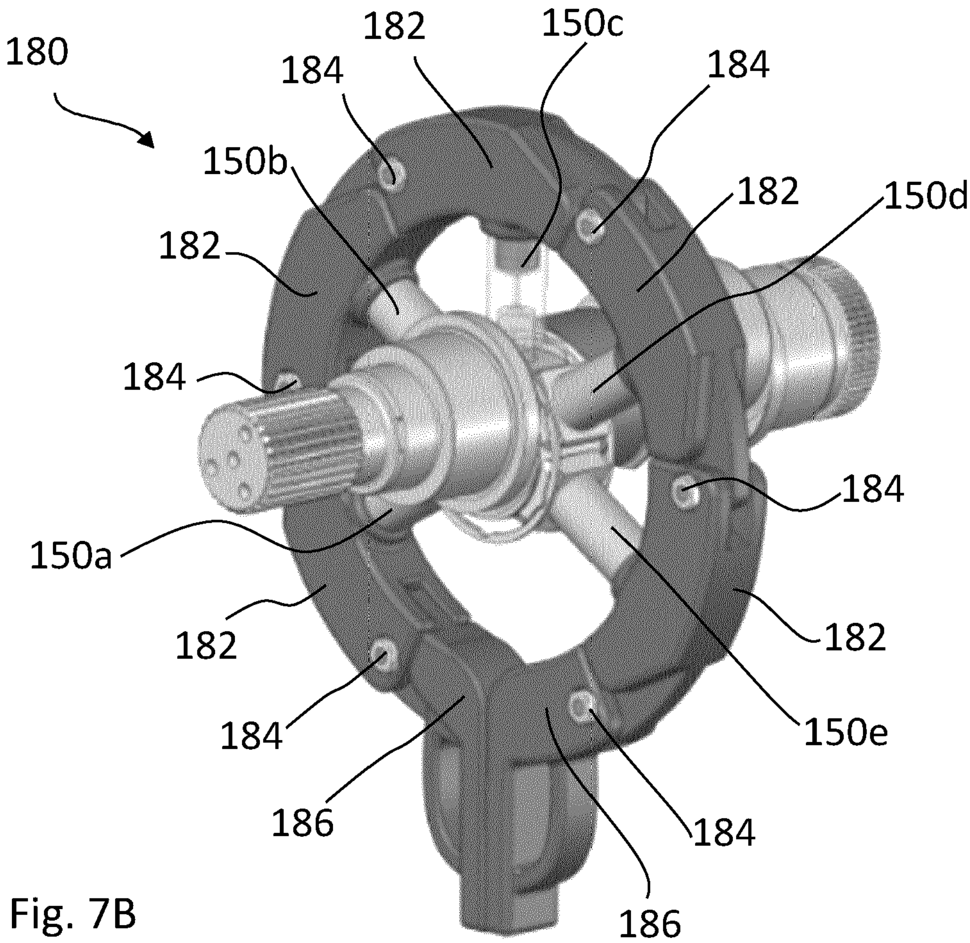
Fig. 7A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186

Fig. 7B

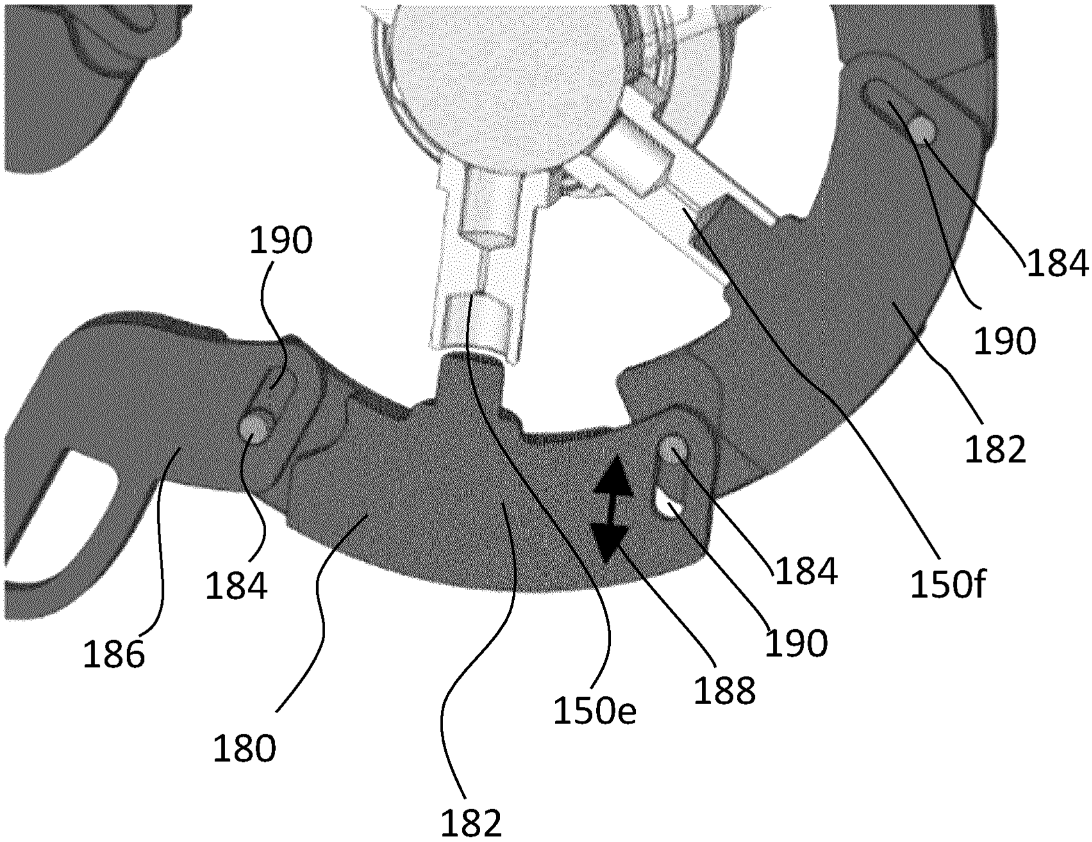

Fig. 7C

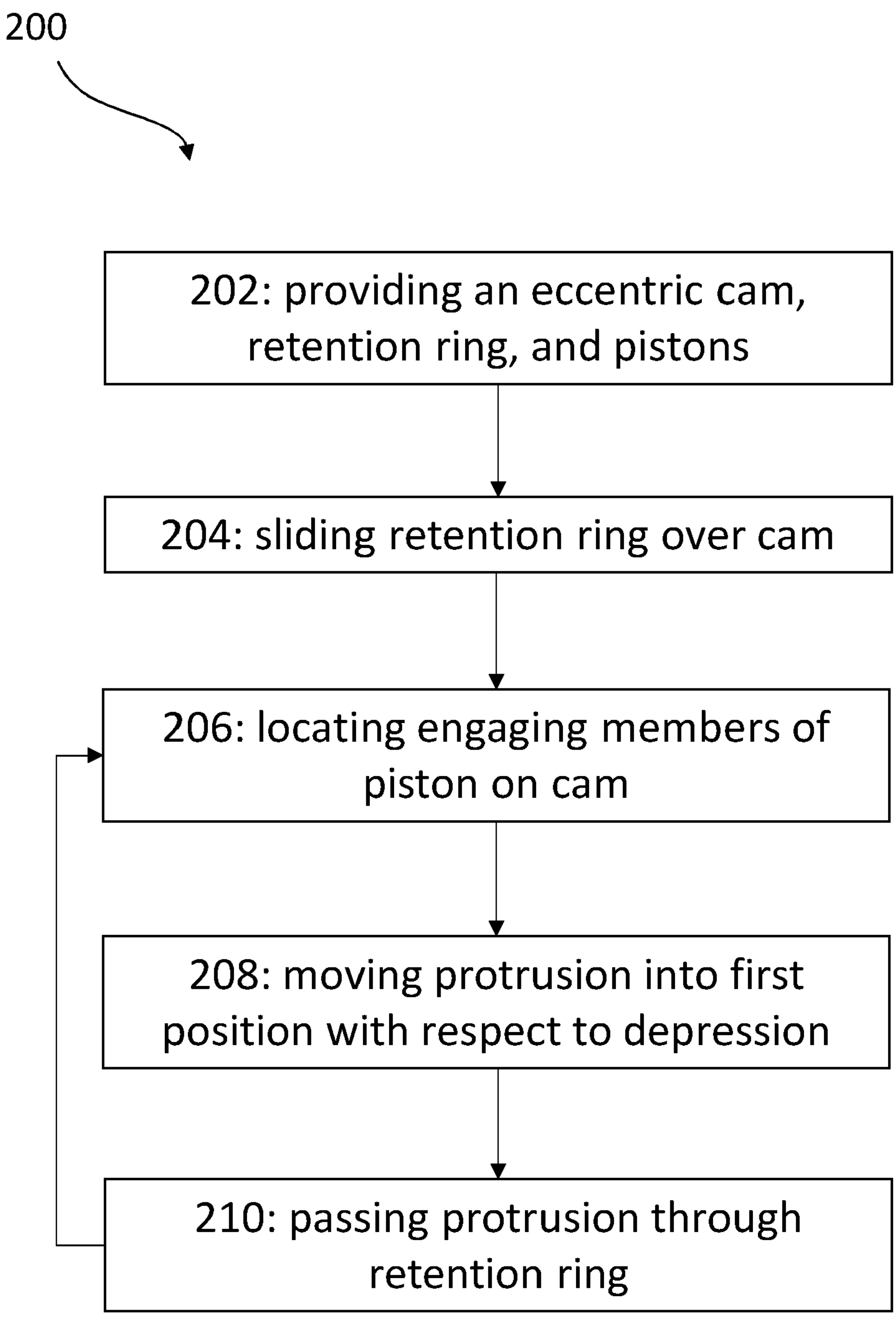
200
202: providing an eccentric cam, retention ring, and pistons
204: sliding retention ring over cam
206: locating engaging members of piston on cam
208: moving protrusion into first position with respect to depression
210: passing protrusion through retention ring

Fig. 8

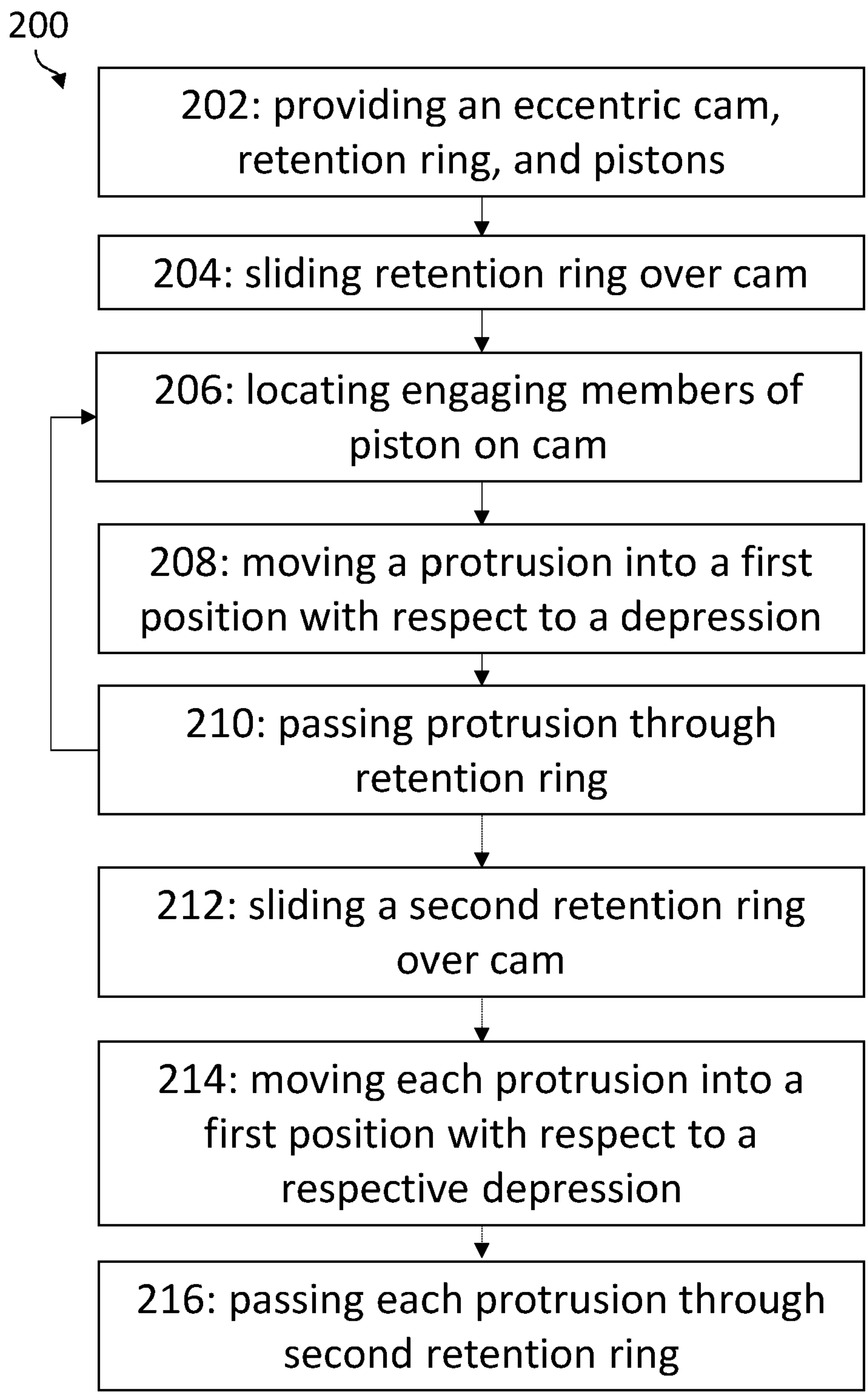
200
202: providing an eccentric cam, retention ring, and pistons
204: sliding retention ring over cam
206: locating engaging members of piston on cam
208: moving a protrusion into a first position with respect to a depression
210: passing protrusion through retention ring
212: sliding a second retention ring over cam
214: moving each protrusion into a first position with respect to a respective depression
216: passing each protrusion through second retention ring

Fig. 9

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EUROPEAN SEARCH REPORT

Application Number
EP 21 18 8082

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F04B
F03C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	25 November 2021	Olona Laglera, C

CATEGORY OF CITED DOCUMENTS

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