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(71) Applicant (for all designated States except US):
ARTEMIS INTELLIGENT POWER LIMITED [GB/GB]; Unit 3, Edgefield Industrial Estate, Edgefield Road, Loanhead, Midlothian EH20 9TB (GB).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **SALTER, Stephen, Hugh** [GB/GB]; 27 Blackford Road, Edinburgh EH9 2DT (GB). **RAMPEN, William, Hugh, Salvin** [GB/GB]; 1 Merchiston Crescent, Edinburgh EH10 5AN (GB). **STEIN, Uwe, Bernhard, Pascal** [DE/GB]; 19 Hope Lane North, Edinburgh EH15 2PT (GB). **FOX, Robert, George** [GB/GB]; 29 Edderston Ridge, Peebles EH45 9NA (GB).

(74) Agent: **HINDLE, Alistair, Andrew**; Hindle Lowther, 66 Hanover Street, Edinburgh EH2 1EL (GB).

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(54) Title: VARIABLE DISPLACEMENT RADIAL PISTON FLUID WORKING MACHINE

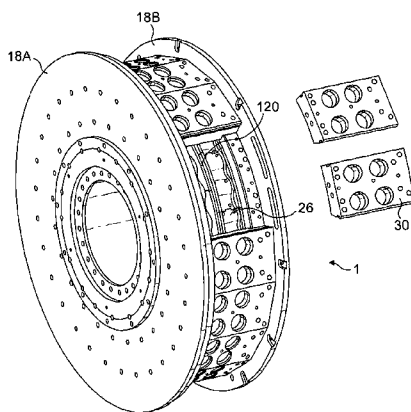


FIG. 3

(57) Abstract: A variable displacement fluid working machine for use in applications where a large fluid working machine is required at an inaccessible location, for example, in the nacelle of a wind turbine tower. The machine includes an inward ring and an outward ring, one of the inward ring and the outward ring comprising a rotatable ring cam coupled to a drive shaft, the other comprising a plurality of radially extending piston cylinders circumferentially spaced around the respective ring. The outward ring comprising first and second axially spaced structural members and a plurality of demountable blocks demountably retainable therebetween, the demountable blocks comprising either piston cylinders or ring cam segments. The demountable blocks are removable radially to facilitate maintenance and repair and to facilitate radial access to the inward ring. Components of the inward ring may also be removed radially through the resulting gap. The demountable blocks also have a structural function, enabling the mass of the machine to be less than would otherwise be required.



1 Variable displacement radial piston fluid working machine

2

3 Field of the invention

4

5 The invention relates to variable displacement radial piston fluid working machines
6 having a rotating ring cam. The invention is of especial relevance to large fluid
7 working machines for use in environments where maintenance is difficult, for
8 example, in the nacelle of a wind turbine tower.

9

10 Background to the Invention

11

12 Fluid working machines include fluid-driven and/or fluid-driving machines, such as
13 pumps, motors, and machines which can function as either a pump or as a motor in
14 different operating modes.

15

16 When a fluid working machine operates as a pump, a low pressure manifold typically
17 acts as a net source of fluid and a high pressure manifold typically acts as a net sink
18 for fluid. When a fluid working machine operates as a motor, a high pressure
19 manifold typically acts as a net source of fluid and a low pressure manifold typically
20 acts as a net sink for fluid. Within this description and the appended claims, the
21 terms "high pressure manifold" and "low pressure manifold" are relative, with the
22 relative pressures being determined by the application. In some embodiments of the
23 present invention the pressure within the low pressure manifold is significantly higher
24 than atmospheric pressure, for example, several atmospheres, however, it will be
25 less than the pressure in the high pressure manifold during normal operation. A fluid

1 working machine may have more than one low pressure manifold and more than one
2 high pressure manifold.

3

4 Large displacement ring cam fluid working machines (i.e. those having a large
5 rotating annular cam driving a multitude of pistons arranged around the cam, with
6 each piston cycling multiple times per cam revolution) are known and are proposed
7 for use in renewable energy applications in which there is a low speed rotating input
8 but a relatively high speed electrical generator (Rampen, Taylor & Riddoch, *Gearless*
9 *transmissions for wind turbines*, DEWEK, Bremen, Dec. 2006). Ring cam fluid
10 working machines typically have a plurality of rollers rolling on a wave shaped cam
11 and driving pistons within cylinders. Either the pistons and cylinders may rotate inside
12 the cam or the cam may rotate inside the pistons and cylinders. Such pumps driving
13 relatively small hydraulic motors have been proposed as robust variable speed
14 transmissions not just for wind turbine generators, but also for tidal stream and
15 gravity-fed hydroelectric generators. Variable displacement could be added to the
16 pumps or the motors, or both, using the operating principle above, for example.

17

18 However, large ring cam machines are difficult and expensive to repair, requiring
19 disassembly of the whole body to repair even one working chamber. This is
20 particularly expensive in renewable energy applications because the heavy pump
21 must be brought to the surface, requiring a large and costly crane at typically a
22 remote location.

23

24 Accordingly, the invention aims to provide a fluid working machine which is readily
25 repairable in situ, even if the machine is massive (e.g. greater than 500kg) and in a
26 location which is difficult to access.

27

28 EP 0 692 071 proposed a modular construction in which the ring cam is made up of
29 segments having confronting ends joined at a tongue and groove formation across
30 which the rollers roll, and bolted via flanges to a rotating shaft. It was also proposed
31 to provide removable piston and cylinder carrying units, bolted to each other around
32 or within the ring cam. This machine suffers from difficulty of repair in situ in a working
33 application because the supporting structure of the machine is broken when the
34 pumping modules are bolted to a surrounding frame which prevents their removal
35 without dismantling the frame.

36

1 EP 1 985 853 (Golle) discloses a pump from which piston cylinders can be
2 demounted, but only partially exposing an internal ring cam surface. This makes it
3 impossible to maintain the ring cam without removal of the shaft from the pump. Also,
4 the pump of Golle includes a single metal body with bores within which the piston
5 cylinders are received and, accordingly, it is relatively heavy for a given fluid
6 displacement and it would be difficult to access and maintain components of the
7 pump if it were built to a large scale suitable for, e.g. a wind turbine generator nacelle.

8

9 Accordingly, the invention aims to provide a fluid working machine which can retain
10 its structural integrity during maintenance. Related to this, large fluid working
11 machines for high torque applications require a structure which retains its structural
12 integrity despite that substantial forces arising from the weight of the machine and the
13 torque of the load (in the case of a motor) or input (in the case of a pump). This can
14 be most simply obtain by providing large structural elements, for example, a large
15 chassis or housing. However, the mass of the resulting components can be
16 substantial and the invention aims to provide a structure which has sufficient
17 mechanical strength while minimising the mass of the structural elements which are
18 required to maintain integrity in use.

19

20 Summary of the Invention

21

22 According to a first aspect of the present invention there is provided a variable
23 displacement radial piston fluid working machine, the fluid working machine
24 comprising:

25

26 an inward ring and an outward ring around (typically, concentric with) the
27 inward ring;

28

29 one of the inward ring and the outward ring comprising a rotatable ring cam,
30 the other comprising a plurality of radially extending cylinders circumferentially
31 spaced around the respective ring, each cylinder having a piston reciprocally
32 mounted therein;

33

34 a drive shaft coupled to the ring cam;

35

36 the outward ring comprising first and second axially spaced structural
37 members and a plurality of demountable blocks demountably retainable

1 therebetween, each of the plurality of demountable blocks comprising either at
2 least some of the said plurality of cylinders (where the outward ring comprises
3 the plurality of radially extending cylinder) or a segment of the ring cam
4 (where the outward ring comprises the ring cam) respectively, each said block
5 being mountable to locate one or more said cylinders in opposing relation to a
6 portion of the ring cam to enable the pistons to be driven by the ring cam
7 (optionally through one or more other components, such as a cam roller) and
8 demountable to expose the inward ring for access.

9

10 Thus, the demountable blocks, which must be present in operation to enable the ring
11 cam to drive the pistons, are individually removable to facilitate repair and
12 maintenance, not only of the demountable blocks, but of whichever of the ring cam
13 and the plurality of cylinders are part of the inward ring. As the pumps typically have
14 a mass in excess of 500kg, and may be mounted in inaccessible locations (e.g. in a
15 nacelle on the tower of a wind turbine installation), the facility to readily access the
16 inward ring for the purpose of maintenance (including inspection) and repair
17 (including replacement) is of considerable practical benefit. Only one, or a small
18 number of, demountable blocks need to be removed to access part of the radially
19 inwards ring. Furthermore, the demountable blocks can fulfil a structural role in
20 maintaining the integrity of the outward ring, enabling the overall mass of the outward
21 ring to be lower than would otherwise be the case.

22

23 Typically, when the device is fully assembled, the pistons are driven by the ring cam
24 through rollers mounted to the pistons. Each cylinder, and its respective piston,
25 together defines a working chamber having a volume which varies cyclically with
26 rotation of the ring cam. One end of each cylinder is typically directed towards the
27 ring cam in the assembled machine and the cylinders may extend radially away or
28 towards an axis of the inner ring or, more typically, at a slight angle to radially away or
29 towards an axis of the inner ring to counteract tangential forces arising from friction.

30

31 Typically, the demountable blocks are demountable by radially outward movement,
32 facilitating access for maintenance from the periphery of the outward ring.
33 Preferably, the demountable blocks are individually demountable. Thus, while one, or
34 a small proportion of the demountable blocks are removed, the remaining mounted
35 blocks can still fulfil their structural role in supporting and maintaining the integrity of
36 the outward ring.

37

1 Demountable blocks demountably retained between the first and second axially
2 spaced structural elements may act to resist forces between the first and second
3 axially spaced structural members.

4

5 In practice, there will typically be significant forces acting between the structural
6 elements, and the demountable blocks can be employed to resist these forces.
7 These forces may be vertical, axial and/or torsional forces. The forces between
8 structural elements include forces arising from the weight of components of the
9 machine bearing on the drive shaft, radial forces acting to separate the pistons and
10 ring cam, and tangential forces from the action of the pistons on the ring cam in use.
11 There may also be shear forces acting between the first and second axially spaced
12 structural elements arising from the torque exerted on the drive shaft.

13

14 One of the first and second axially spaced structural elements may comprise or be
15 attached to a coupling for coupling the fluid working machine to a support through the
16 said one of the first and second axially spaced structural elements.

17

18 In this case, the weight of the fluid working machine can therefore be supported
19 through a single one of the first and second axially spaced structural elements (in
20 addition to weight bearing on the drive shaft, typically through bearings). This is a
21 convenient mechanism for attaching a fluid working machine, particularly one of
22 generally toroidal shape, to a support. However, the weight of the second axially
23 spaced structural element will be borne at least in part by the coupling between the
24 first and second axially spaced structural elements and this is a further force which
25 can be borne by the demountable blocks.

26

27 The ability of the demountable blocks to resist forces between the first and second
28 axially spaced structural elements is of further benefit in embodiments in which the
29 demountable blocks comprise the cylinders and define a volume which receives
30 working fluid having a preloaded pressure in use, for example, working fluid with a
31 pressure of at least two atmospheres. It can be advantageous for the demountable
32 blocks to define a volume, which may be outwards of the cylinders, which receives
33 working fluid having a preloaded pressure which is supplied into the working
34 chambers in use. The resulting pressure in the working chambers assists in
35 providing a pressure holding the pistons (typically through cam rollers) against the
36 ring cam. In this case, the pressurised working fluid may exert additional forces
37 acting to urge the first and second axially spaced structural elements apart or to urge

1 the demountable blocks radially outwards. In this case, the provision of demountable
2 blocks which can act to resist forces acting between the first and second axially
3 spaced structural elements is of additional benefit.

4
5 Therefore, by providing blocks which resist forces acting between the first and
6 second structural elements and comprise either one or some of the cylinders, or a
7 segment of the ring cam, and which are demountable, the requirement for additional
8 strengthening elements to resist some or all of the forces described above, in addition
9 to the said one or some cylinders, or ring cam segment, is reduced or removed. This
10 can enable the mass of the machine to be less than would otherwise be the case.

11
12 One or both of the first and second axially spaced structural elements may extend
13 radially inwards at least as far as, or inward of whichever of the ring cam and the
14 plurality of cylinders are part of the inward ring. One or both of the first and second
15 axially spaced structural elements may take the form of disks. The first and second
16 axially spaced structural elements may be parallel disks.

17
18 The first and second axially spaced structural elements may be independently
19 mounted on bearings. The drive shaft may extend through at least one of the axially
20 spaced structural elements.

21
22 The drive shaft may extend through or terminate within or before the other of the
23 axially spaced structural elements. The first and second axially spaced structural
24 elements typically extend to either side of the inner ring. For example, wherein the
25 inner ring comprises a ring cam, the first and second axially spaced structural
26 elements are typically spaced apart, on either side of the ring cam, to retain the
27 demountable blocks around the ring cam. Whichever of the ring cam and the plurality
28 of cylinders are part of the inward ring is typically located between the first and
29 second axially spaced structural members. Indeed, both the ring cam and the plurality
30 of cylinders may be located between the first and second axially spaced structural
31 members.

32
33 The first and second axially spaced structural elements and the demountable blocks
34 may comprise cooperating formations for bolting the demountable blocks to each of
35 the first and second axially spaced structural elements both axially and radially.

36

1 This provides additional mechanical strength in the assembled structure. Axial bolts
2 tie the axially spaced structural elements together and resist forces arising from, for
3 example, the weight of one of the structural elements or a preloaded pressure within
4 the demountable blocks. Radial bolts resist shear and forces arising from preloaded
5 pressure. The radial bolts are typically applied under sufficient tension to together
6 provide a force in a radial inwards direction which exceeds the outward force acting
7 on the demountable blocks which is anticipated from the preloaded pressure of the
8 working fluid (where present) and the radial force exerted on the pistons during
9 rotation of the cam track in use, so that the radial bolts remain in tension in use.

10
11 Preferably, each demountable block comprises cooperating formations for bolting the
12 demountable block both axially and radially at least two circumferentially spaced
13 locations (typically close to opposite ends) to each of the first and second axially
14 spaced structural elements.

15
16 The first and second axially spaced structural elements may each comprise one or
17 more shoulders having a radially outward surface for engaging with the demountable
18 blocks, the demountable blocks having cooperating radially inward surfaces.

19
20 Preferably, at least some cylinders of the segment of the ring cam of a demountable
21 block are mounted to the body of the demountable block (which is in turn
22 demountably mountable to the first and second axially spaced elements) and not
23 directly mounted to the first or second axially spaced structural elements. This
24 facilitates removal of the demountable blocks.

25
26 The shoulders typically extend in a ring around the respective axially spaced
27 structural elements. The shoulders are typically located at, or close to, the
28 circumference of the axially spaced structural elements. The shoulders may serve to
29 locate the demountable blocks and, in particular, to define the distance between a
30 mounted block and the ring cam. The shoulders may comprise fixtures (such as bolt
31 holes) for radially bolting demountable blocks to the structural elements. The first
32 and/or second axially spaced structural elements may be circular and the
33 circumferential shoulders may be at a radius less than the outer radius of the first or
34 second axially spaced structural elements.

35
36 It may be that the demountable blocks are cylinder blocks, comprising one or more
37 said cylinders, and the inward ring comprises a ring cam. In this case, the ring cam

1 may comprises a plurality of ring cam segments (each of which comprises a part of
2 the cam surface of the ring cam) which are individually removable in a radially
3 outward direction between the first and second axially spaced structural elements
4 when the or each cylinder block which would otherwise overlay the respective ring
5 cam segment is demounted. Thus, not only may the cylinder blocks be removed in a
6 radially outwards direction, the ring cam segments can be individually removed in a
7 radially outwards direction. Thus, the ring cam can be maintained or replaced by the
8 removal of individual ring cam segments in turn, without requiring the entire ring cam
9 to be exposed, which would be difficult and time consuming for a large pump in an
10 inaccessible location.

11

12 It may be that the demountable blocks comprise ring cam segments. In this case, the
13 inner ring may contain a plurality of cylinder blocks, each of which comprises one or
14 more cylinders, which are accessible for maintenance (typically in a radially inwards
15 direction) through the space left by a removed ring cam segment.

16

17 Typically, the outward ring is continuous. Typically, the first and second axially
18 spaced structural elements are continuous (and typically each has a unitary
19 construction). The first and second axially spaced structural elements may have
20 continuous substantially circular perimeters.

21

22 In some embodiments, the ring cam further comprises a side plate, on one or both
23 sides thereof. The side plates extend around the circumference of the ring cam and
24 prevent the rollers (or other means of operative engagement between the said
25 pistons and the ring cam) from sliding off (i.e. in an axial direction) the wave-like
26 surface of the ring cam.

27

28 Typically, the or each side plate abuts an edge of the cam surface, around the
29 circumference of the ring cam. Thus, in use, a cam roller (or other cam following
30 element) is biased against the cam surface of the ring cam, and in at least some
31 operating conditions the roller abuts the inner faces of the respective side plates, the
32 side plates defining a track or trench within which the cam roller runs when the ring
33 cam rotates with respect to the cam roller.

34

35 Accordingly, the invention extends in a further aspect to a ring cam for a fluid-working
36 machine, having a cam surface and a side plates extending around one or both sides

1 thereof, the or each side plate abutting the edge of the cam surface around the
2 circumference of the ring cam.

3

4 Each said side plate may, in some embodiments, extend a fixed distance from the
5 cam surface. Thus, a side plate of a ring cam having a wave-like cam surface will
6 also have a wave-like circumference. In some embodiments, each said side plate
7 extends from the cam surface a distance that is less, and preferably much less, than
8 the radius of the or each roller (for example, less than 50%, or 25% or 10% of the
9 radius of the each said roller).

10

11 In use, when the ring cam is rotating in relation to each said roller, the relative
12 velocity of the cam surface and the surface of the roller (around the circumference of
13 the cam surface) is zero (or negligible). The velocity of the external surfaces of the
14 roller in relation to the cam surface, and thus also in relation to each said side plate
15 (or any object or feature fixed in relation to the ring cam) increases with distance from
16 the cam surface.

17

18 Thus, when the roller abuts the side plate it does so where the relative velocity of the
19 roller and the side plate is low. Thus, the roller is prevented from moving laterally (i.e.
20 in an axial direction) on the cam surface, whilst friction between the roller and the
21 side plates is minimised.

22

23 In some embodiments, the external circumference of each said side plate is
24 substantially circular.

25

26 The opposing inner faces of the side plates (of a ring cam having two side plates)
27 may be parallel, or may diverge with distance from the axis of rotation of the ring cam.
28 Preferably each said side plate meets the cam surface at the same angle as the
29 angle at which the side of each said roller meets the cam surface (which is typically a
30 right angle). Each said side plate may diverge from said roller (such that, in use, the
31 side of roller contacts the side plate only close to the junction between the side plate
32 and the cam surface).

33

34 The ring cam (and typically each said side plate) may comprise an abutment
35 extending across a part of the inner surface of each said side plate, along the junction
36 between the cam surface and each said side plate.

37

1 The abutment may extend a fixed distance from the cam surface. Thus, side plate of
2 a cam having a wave-like cam surface will be provided with a wave like abutment.

3

4 The distance between the opposing inner surfaces of the side plates of a cam ring is
5 larger than the distance between abutments along the respective junctions between
6 the side plates and the cam surface.

7

8 Each said abutment typically extends from the cam surface a distance that is less,
9 and preferably much less, than the radius of the or each roller (for example, less than
10 50%, or 25% or 10% of the radius of the each said roller).

11

12 An abutment extending across a part of the inner surface of a said side plate (a
13 distance that is less, and preferably much less, than the radius of the or each roller),
14 along the junction between the side plate and the cam surface, may abut in at least
15 some operating conditions each said roller in the region (and typically a small region)
16 where the roller contacts the cam surface and the roller is prevented from contacting
17 the side plate directly, in normal use.

18

19 In use, when the ring cam is rotating in relation to each said roller, the relative
20 velocity of the cam surface and the surface of the roller (around the circumference of
21 the cam surface) is zero (or negligible). The velocity of the external surfaces of the
22 roller in relation to the cam surface, and thus also in relation to each said side plate
23 (or any object or feature fixed in relation to the ring cam) increases with distance from
24 the cam surface.

25

26 Thus, the roller abuts the abutment at a region where the relative velocity of the roller
27 and the abutment is low. Thus, the roller is prevented from moving laterally (i.e. in an
28 axial direction) on the cam surface by the abutments, whilst friction between the roller
29 and the side plates is minimised.

30

31

32 The surface material of the abutment, or the entire abutment, may be a different
33 material to the material of the side plate. The abutment may comprise or consist of a
34 resilient material, or a low friction material. The abutment may be a hard wearing
35 and/or low friction coating on the surface of the side plate along the junction between
36 the cam surface and each said side plate. The abutment may be formed from the

1 material of the side plate and the side plate (or side plate segment and abutment may
2 be unitary.

3

4 In embodiments with two or more ring cams, there may be one side plate positioned
5 intermediate two cam rings, the said side plate functioning to prevent rollers from
6 sliding off both cam rings. Alternatively, each said cam ring may have two (separate,
7 and not shared) side plates.

8

9 The side plates may be unitary, or may comprise a plurality of side plate segments.
10 Thus, each ring cam segment may be secured to a side plate segment (or to two side
11 place segments, to either side of the wave like surface of the ring cam segment). The
12 ring cam may comprise the same number, fewer, or more, side plate segments
13 disposed around each side of the circumference of the or each ring cam than the
14 number of ring cam segments.

15

16 The side plates (or side plate segments, as the case may be) may be secured to the
17 said segments by bolts (or other suitable fixings) extending through the side plate (or
18 side plate segments) into or through the ring cam segments. In some embodiments,
19 each said bolt may extend through more than one side plate (or segment thereof) and
20 into or through more than one segment of more than one ring cam.

21

22 The side plate segments may be angularly offset from the cam segments so that
23 each side plate overlaps two (or more) segments of the assembled ring cam, and in
24 the assembled ring cam, the joint between side plate segments does not align or
25 overlap with the joint between segments. The overlap may be used to axially (i.e. with
26 respect to the shaft) align the cam segments. In some embodiments the side plates
27 may be fixed to the shaft, or fixed relative to the valves and working chambers such
28 that the cam segments move between the side plates.

29

30 In some embodiments, the side plate segments may be removable in a radially
31 outward direction. Typically, each said ring cam segment is secured to one or more
32 side plate segment (on one or both sides of the said ring cam segment) is be
33 removable as a ring cam segment assembly (comprising a ring cam segment and
34 one or more side plate segments secured thereto)in a radially outward direction.

35

36 The invention extends to ring cam segment assembly comprising a ring cam segment
37 and one or more side plate segments secured thereto. Preferred and optional

1 features of each said side plate segment correspond to preferred and optional
2 features of the side plates herein disclosed.

3

4 Typically, one or more fluid manifolds (for example, a high pressure manifold for
5 conveying pumped fluid to a load) extend through at least one of the axially spaced
6 structural elements. Thus, at least one of the axially spaced structural elements
7 typically comprises a plurality of ports for receiving working fluid from the said
8 working chambers. For each said port, a seal is typically provided to resist leakage of
9 fluid passing through the port from the cylinder blocks. Either or both ports typically
10 comprise a non-return valve.

11

12 At least one of the axially spaced structural elements (typically a said shoulder
13 thereof) may comprise one or more ports for receiving working fluid, and wherein
14 each said cylinder block includes at least one cooperating port for expelling working
15 fluid, either or both said ports including a seal, wherein the said ports and the or each
16 seal are located on radially inward or outward facing surfaces.

17

18 The risk of damage to the seals is lower than would be the case if the ports and the or
19 each seal were located on axially facing surfaces, as the demountable blocks can be
20 slid radially inwards or radially outwards, against axially facing surfaces during the
21 mounting and demounting process, without substantial friction being exerted on the
22 or each seal. This is especially relevant if the or each seal stands proud of the
23 surface including the port with which it is associated.

24

25 The fluid working machine may further comprise a plurality of manifolds and a
26 plurality of valves, each of which is operable to regulate the flow of fluid between a
27 working chamber and a manifold.

28

29 It is especially advantageous for the cylinders to be stationery and the ring cam to
30 rotate in such machines, which employ valves to regulate the flow of fluid between a
31 working chamber and a manifold in contrast to, for example, machines employing
32 only port plates to regulate the flow of fluid between working chambers and
33 manifolds.

34

35 The fluid working machine may, for example, be a fluid working pump having either or
36 both a check valve for regulating the flow of fluid between a respective working

1 chamber and a low pressure manifold and a check valve for regulating the flow of
2 fluid between a respective working chamber and a high pressure manifold.

3

4 At least one valve associated with each working chamber may be an actively
5 controllable valve. Typically, at least one valve associated with each working
6 chamber is an electronically controllable valve. By an electronically controllable valve
7 we refer to valves which may be one or more of actively opened, actively closed,
8 actively held open against a pressure differential and actively closed against a
9 pressure differential. Electronically controllable valves may be actively controlled in
10 only some circumstances and may open or closed passively in other circumstances.

11

12 The fluid working machine may comprise a controller and at least one valve
13 associated with each working chamber may be an actively controllable valve,
14 controllable by the controller in phased relationship with cycles of working chamber
15 volume to select the net displacement of working fluid by each working chamber on a
16 cycle by cycle basis. Fluid working machines are known, for example, from
17 EP 0 361 927 which disclosed a method of controlling the net throughput of fluid
18 through a multi-chamber pump by opening and/or closing electronically controllable
19 'low pressure' poppet valves, in phased relationship to cycles of working chamber
20 volume, to regulate fluid communication between individual working chambers of the
21 pump and a low pressure manifold. As a result, individual chambers are selectable
22 by a controller, on a cycle by cycle basis, to either displace a predetermined fixed
23 volume of fluid or to undergo an idle cycle with no net displacement of fluid, thereby
24 enabling the net throughput of the pump to be matched dynamically to demand.

25

26 EP 0 494 236 developed this principle and included electronically controllable 'high
27 pressure' poppet valves which regulate fluid communication between individual
28 working chambers and a high pressure manifold, thereby facilitating the provision of a
29 fluid working machine functioning as either a pump or a motor in alternative operating
30 modes. EP 1 537 333 introduced the possibility of part cycles, allowing individual
31 cycles of individual working chambers to displace any of a plurality of different
32 volumes of fluid to better match demand. Due to the complexity of fluid working
33 machines of this type, it is especially advantageous that the invention provides a
34 system with a rotating ring cam, enabling the actively controlled valves to remain
35 substantially stationary in use.

36

1 By inward ring and outward ring we refer to the relative radial position of the said
2 rings. Further rings having ring cams or cylinders may be provided. For example, a
3 pump may comprise two ring cams, one facing outwards and one facing inwards,
4 each of which drives a plurality of radially extending cylinders. Either ring may
5 comprise a plurality of ring cams and the plurality of cylinders may be arranged in a
6 plurality of axially spaced rings. Still further demountable blocks may be provided
7 radially outward of the said demountable blocks, enabling three or more concentric
8 rings of components to be removed in a radially outwards direction.

9

10 The invention also extends in a second aspect to a kit of parts which can be
11 assembled to form a variable displacement radial piston fluid working machine
12 according to the first aspect of the invention.

13

14 In a third aspect, the present invention extends to a variable displacement radial
15 piston fluid working machine chassis, the chassis comprising:

16

17 an inward ring and an outward ring around (typically, concentric with) the
18 inward ring;

19

20 one of the inward ring and the outward ring comprising a rotatable ring cam
21 retaining formation (which may, for example, comprise the outward or inward
22 periphery respectively of the ring and which, in the case of the inward ring,
23 may in some embodiments have the rotatable ring cam coupled temporarily or
24 permanently thereto), the other comprising a plurality of mountings for
25 retaining radially extending cylinders circumferentially spaced around the
26 respective ring (which may, in the case of the inward ring, have cylinders
27 retained permanently or temporarily therein);

28

29 a coupling to couple the ring cam retaining formation to a drive shaft (which
30 may be a permanent coupling in the case where the drive shaft and ring cam
31 retaining formation are integral);

32

33 the outward ring comprising first and second axially spaced structural
34 members for demountably retaining a plurality of demountable blocks
35 comprising either at least some of the said plurality of cylinders or a segment
36 of the ring cam respectively to locate one or more said cylinders in opposing
37 relation to a portion of the ring cam to enable pistons slidably mounted within

1 the cylinder to be driven by the ring cam (optionally through one or more other
2 components, such as a cam roller).

3

4 Further optional and preferred features of the second and third aspects of the
5 invention correspond to the optional and preferred features set out in respect of the
6 first aspect of the invention.

7

8 The invention also extends in a fourth aspect to a turbine assembly comprising a
9 variable displacement radial fluid working machine according to the first aspect of the
10 invention and a turbine comprising a plurality of blades mounted to the drive shaft to
11 transmit torque to the ring cam as the blades rotate.

12

13 The turbine assembly may be a wind turbine assembly. Typically, the wind turbine
14 assembly includes a tower, with the radial fluid working machine mounted within the
15 tower. The tower may be mounted on the sea bed, or the tower may float and be
16 moored to the sea bed. The invention is especially applicable in such a location as
17 access to the pump for maintenance would otherwise be difficult. However, the
18 turbine assembly may comprise a turbine for receiving energy from a flowing fluid, for
19 example, from tidal flows, or water flowing in a river or through a conduit in a
20 hydroelectric power installation. The invention extends to a wind turbine nacelle
21 comprising a fluid working machine according to the first aspect of the invention,
22 operable as a pump for driving by a turbine (by way of the drive shaft).

23

24 It may be that the drive shaft of the fluid working machine and the rotating shaft of the
25 turbine are each hollow and in communication with each other so that a human may
26 access the interior of the turbine blades through the draft shaft.

27

28 According to a third aspect of the invention there is provided a method of maintaining
29 a variable displacement machine according to the first aspect of the invention, or a
30 turbine assembly according to the second aspect of the invention, comprising
31 removing a demountable block and carrying out one or more of (a) maintaining the
32 demountable block and remounting the maintained demountable block, (b) mounting
33 a replacement demountable block in place of the demounted block, and (c)
34 maintaining a portion of the inner ring through the space left by the demounted block.

35

36 By maintaining we include testing, repairing and replacing component parts. The
37 demountable block is typically removed radially from the axially spaced structural

1 members. Maintaining a portion of the inner ring through the space left by the
2 demounted block may comprise removing a portion of the inner ring (for example, a
3 ring cam portion, where the inner ring comprises the ring cam).

4

5 The portion of the inner ring which is removed may be removed radially. The
6 removed portion may then be tested, repaired or replaced. The demounted block, or
7 a replacement demounted block is then mounted back in position.

8

9 Description of the Drawings

10

11 Figure 1 is an isometric projection of the components of the nacelle of a wind turbine
12 including a fluid working machine according to the present invention;

13

14 Figure 2 is an isometric projection of an assembled fluid working machine, and (to a
15 different scale) the fluid working machine with the housing removed to show the
16 internal components;

17

18 Figure 3 is an isometric projection of the fluid working machine, without the housing,
19 with two cylinder blocks removed;

20

21 Figure 4 is an isometric projection of the fluid working machine, without the housing,
22 with two cylinder blocks removed and a ring cam segment removed;

23

24 Figure 5 is an exploded isometric view of components of the fluid working machine;

25

26 Figure 6 is a part cut away side view of components of the fluid working machine with
27 the back end plate removed;

28

29 Figure 7 is a schematic diagram of a radial cross section through a fluid working
30 machine according to the invention;

31

32 Figure 8 corresponds to Figure 7 with addition of the coupling to the turbine shaft;

33

34 Figure 9 is a schematic diagram of a working chamber of the fluid working machine
35 and the valves regulating fluid flow;

36

1 Figure 10 is a cross sectional view of a ring cam segment assembly, perpendicular to
2 the axis of rotation of the ring cam in use; and

3

4 Figure 11 is a cross sectional view of a ring cam segment assembly, parallel to the
5 axis of rotation of the ring cam in use.

6

7 Detailed Description of an Example Embodiment

8

9 An example embodiment of the invention will now be described with reference to a
10 pump for a wind turbine. However, fluid working machines according to the invention
11 may be used for numerous alternative applications.

12

13 With reference to Figures 1 through 7, a variable displacement radial piston pump 1
14 (being an example of a variable displacement radial fluid working machine) has a size
15 and construction suitable for application in the nacelle 2 of a wind turbine, where it is
16 driven by a turbine 4. The turbine is connected through turbine shaft 6 to the hollow
17 drive shaft 8 of the pump. Output pressurised fluid is used to drive motors 10 and
18 electrical generators 12. The pump is connected to a chassis 14 through a mounting
19 plate 16. As the drive shaft of the pump is hollow, it provides a convenient passage
20 through which a person may pass to conduct maintenance and repair of other
21 components, for example to gain access to the wind turbine blades.

22

23 The pump comprises first and second end plates 18A and 18B and a housing 20
24 which can be slid axially to reveal internal components for maintenance and repair.
25 The pump is generally rotationally symmetric about an axis extending through the
26 drive shaft. In this example, the pump is generally drum-like to minimise mass and
27 size. Although the arrangement of cylinders (discussed below) should be generally
28 circular, the shape of the outer periphery of the pump is less critical to its function.

29

30 The pump comprises an inward ring shown generally as 21, comprising a toroidal ring
31 cam support 22 having a plurality of wave-like ring cam segments 23 demountably
32 secured thereto in use and which together form a ring cam. The ring cam is
33 multilobal and in this example, two ring cams are mounted to the ring cam support
34 adjacent to each other and axially spaced.

35

36 The pump further comprises an outward ring shown generally as 24, comprising the
37 first and second end plates 18A and 18B, which are independently mounted on the

1 drive shaft 26 through bearings 28, and a plurality of demountable cylinder blocks 30.
2 The drive shaft extends through both the first and second end plates and the end
3 plates function as the first and second axially spaced structural members. The
4 outward ring is continuous.

5

6 The cylinder blocks are shown in cross-section in Figure 7. Each comprises a
7 plurality of cylinders 32 having a piston slidably mounted therein 34. Within each
8 cylinder a working chamber of cyclically varying volume 36 is defined by the piston
9 and the interior of the cylinder. Each piston is mounted on a roller 38 in driving
10 engagement with the ring cam.

11

12 The first and second end plates each comprise a circular shoulder 40A and 40B,
13 extending around the respective end plate, close to but within the outer perimeter of
14 the first and second end plates. Each cylinder block is demountably retained on the
15 circular shoulder. This defines the distance between each cylinder and the ring cam
16 and provides structural strength. Each cylinder block is mounted in place by axial
17 bolts 42 extending through apertures in the end plates and through the cylinder block,
18 between cylinders, and also by radial bolts 44 extending through apertures in the
19 cylinder blocks and into the circular shoulders. Typically, an axial bolt is provided
20 towards each circumferentially spaced end of each cylinder block and a pair of radial
21 bolts (one for each end plate) is provided towards each circumferentially spaced end
22 of the each cylinder block.

23

24 The volume between the outer housing and the cylinder blocks functions as a low
25 pressure manifold 46, receiving hydraulic fluid to be supplied to the pump. The fluid
26 in the low pressure manifold has a preload pressure of a few atmospheres. This
27 helps to force the pistons against the ring cam. Working fluid is supplied from this
28 cavity into each working chamber through a conduit 48 and electronically controlled
29 valve 50. A further conduit 52, functions as part of a high pressure manifold,
30 receiving fluid via a check valve 54. The conduit extends through the cylinder block
31 and radially inwards through ports in the cylinder block and the shoulder of the
32 second end plate, to further conduits for output high pressure fluid 56. At least one of
33 each pair of cooperating ports has a seal. The second end plate includes outflow
34 ports (not shown) for delivering high pressure fluid to a load, such as a hydraulic
35 motor which in turn drives an electricity generator.

36

1 In the assembled machine, the cylinder blocks not only function as housings for the
2 piston cylinders, but also provide structural integrity. They are flush to both the first
3 and second end plates and are axially and radially bolted into position in use, at each
4 circumferentially spaced end. They can therefore resist forces acting between the
5 end plates in use, for example forces arising from the weight of the pump which is
6 supported predominantly through the mounting plate which is attached to only the
7 first end plate, and torsional forces arising from the forces acting through the drive
8 shaft and on the pistons, which do not extend directly radially but at a slight angle.
9 The radial bolts also act to resist outwards forces on the cylinder blocks arising from
10 the outwards forces of the ring cam acting on the pistons and the preload pressure in
11 the low pressure manifold.

12

13 For maintenance (including inspection) and repair, the housing is removed axially as
14 shown in Figure 2, exposing the cylinder blocks. One, or a small number, of cylinder
15 blocks may be removed radially as illustrated in Figure 3, revealing the inner ring
16 including the surface of the ring cam, which can be accessed radially. Typically, only
17 one or a small number of cylinder blocks will be demounted at once. Indeed, due to
18 their structural role, it may not be possible to remove more than a predetermined
19 number of the cylinder blocks simultaneously while the pump is mounted in position.
20 The cylinder blocks, and their components such as valves, pistons and so forth, may
21 then be maintained and repaired, and then replaced with the same, or a replacement
22 cylinder block.

23

24 While one or more cylinder blocks are removed, the inner ring can be maintained.
25 Segments of the ring cam may be maintained or repaired in situ or removed radially
26 as illustrated in Figure 4, and then maintained, repaired or replaced as need be.

27

28 The ring cam further comprises side plates 120 (on one or more preferably both sides
29 of the ring cam) extending around the circumference of the ring cam, which prevent
30 the rollers 38 from sliding off the wave-like surface of the ring cam. In embodiments
31 with two or more ring cams, there may be one side plate positioned intermediate two
32 cam rings and which function to prevent rollers from sliding off both cam rings.
33 Alternatively, each of the two or more cam rings may have separate side plates, as
34 shown in the fluid-working machine of Figures 1-10.

35

36 The side plates may be unitary, or may be segmented as shown most clearly in
37 Figures 4 and 10. In the embodiment shown in Figures 1-10, each ring cam segment

1 is secured to a side plate segment 124 (and typically to two side plate segments, to
2 either side of the wave like surface of the segment). In alternative embodiments there
3 may be fewer, or more, side plate segments disposed around each side of the
4 circumference of the or each ring cam than there are ring cam segments.

5

6 The side plates are held to the segment 23 by bolts 122 extending through cross bolt
7 holes. The bolts may each extend through more than one ring cam.

8

9 The side plate segments may be angularly offset from the cam segments so that
10 each side plate overlaps two (or more) segments of the assembled ring cam. Thus,
11 and in the assembled ring cam, the joint between side plate segments does not align
12 or overlap with the joint between segments and the overlap may be used to axially
13 (i.e. with respect to the shaft) align the cam segments (for example during assembly
14 and maintenance, or to reduce wear caused by motion of adjacent ring cam
15 segments in relation to one another, when forces are applied to the wave like surface,
16 in use). In some embodiments the side plates may be fixed to the shaft, or fixed
17 relative to the valves and working chambers such that the cam segments move
18 between the side plates.

19

20 As can be best seen in Figures 10 and 11, the side plates further comprise abutting
21 strips 126, at least the surface thereof being composed of a resilient and low friction
22 material extending along the junction between the side plates and the cam surface,
23 such as dry sliding bearing materials typically comprising a PTFE and/or bronze
24 surface. The strips extend away from the cam surface only a small distance (in
25 comparison to the radius of the roller 36). In use, the roller abuts the strips 126 near
26 the point of contact between the roller and the cam surface, where the relative
27 velocity of the roller and the side plate and is low, and is thereby prevented from
28 contacting the inner faces 128 of the side plates, where the velocity of the roller in
29 relation to the side plates is greater. Thus, the roller is prevented from moving
30 laterally (i.e. in an axial direction) on the cam surface, whilst friction between the roller
31 and the side plates is minimised.

32

33 Figure 5 is an exploded view showing the components of the pump, although it would
34 not normally be advisable, or in some embodiments possible, to remove the
35 illustrated number of cylinder blocks simultaneously when the pump is mounted, due
36 to the structural role of the cylinder blocks. However, as shown in Figure 6, it may be
37 that the second end plate is removable axially to enable the bearings to be accessed

1 and maintained, repaired or replaced as need be without a need for the entire pump
2 to be demounted. This is highly advantageous as the mass of the pump may be
3 sufficiently large as to require a crane or other heavy lifting gear, whereas the second
4 end plate and individual components such as the cylinder blocks may be removable
5 with relatively small lifting gear.

6

7 Typically, the cylinder blocks are removed radially from the outer ring using lifting
8 apparatus. When they are mounted, they are held in place by the axial and radial
9 bolts and the radial bolts are tensioned sufficiently that they exert a force which
10 exceeds the maximum outward force expected in use, so that they remain in tension
11 throughout normal operation. As the cylinder blocks are removed radially, the seals
12 for delivering high pressure fluid to the second end plate are compressed only by the
13 inwards motion of the cylinder blocks and are not subject to shear forces which would
14 occur if they were on axially facing surfaces along which the cylinder blocks slide
15 during mounting and demounting.

16

17 Accordingly, the invention has provided a fluid working machine which is readily
18 maintainable in a difficult to access location, such as in the nacelle of a wind turbine
19 tower, despite the substantial mass of machine required in applications such as large
20 scale wind power generation.

21

22 Although the example illustrated in Figures 1 through 7 includes demountable
23 cylinder blocks, it would be possible for the outward ring to comprise the ring cam and
24 for the inward ring to include the cylinders. In this case, demountable ring cam
25 blocks, including one or more parallel segments of ring cam would be demountably
26 retained between the first and second end plates. The inward ring would be
27 accessed by removal of one or several ring cam blocks, exposing the cylinders for
28 maintenance, repair and replacement by a radial access pathway. Again, the
29 cylinder may be provided in demountable blocks, removably radially through the
30 space between the first and second end plates left by the demounted ring cam
31 blocks.

32

33 A further feature is illustrated in Figure 8. The drive shaft 72 of the pump is
34 conveniently attached to the turbine shaft 74 by one or more axial bolts 70. The
35 interface 76 may comprise a face spline, key or other coupling, or may be a friction
36 drive. This is significantly more practical than typical arrangements for coupling a
37 pump drive shaft to an input shaft using, for example, a shrink disk or flange plate. In

1 particular, the pump may be detached from the turbine shaft with very low force,s
2 without requiring a significant axial withdrawal distance and without the use of
3 complicated differential thermal expansion techniques and equipment. In use, some
4 of the weight of the pump typically bears on the drive shaft and thereby onto the main
5 shaft bearing 78, however the mounting plate provides additional support, sufficient to
6 enable the axial bolts to be removed where required for maintenance.

7
8 The illustrated example is a radial piston pump, however, the fluid working machine
9 may alternatively be a radial piston motor or a device operable as a pump or a motor
10 in alternative operating modes or conceivably simultaneously (with some working
11 chambers motoring and some working chambers pumping).

12
13 A number of different types of variable displacement radial piston fluid working
14 machine are known and the invention is applicable with many of these types of
15 machine. However, the fluid working machine may be a fluid working machine which
16 is operable to select the volume to be displaced by working chambers during
17 individual volume cycles on each successive cycle of working chamber volume.

18 Figure 9 illustrates in schematic form suitable control apparatus. An individual
19 working chamber 31 has a volume defined by the interior surface of cylinder 32 and
20 piston 34 which is driven from the ring cam 26 by way of roller 32 and which
21 reciprocates within the cylinder to cyclically vary the volume of the working chamber.
22 Pressure within the working chamber, or alternatively a spring (not shown) keeps the
23 roller in contact with the ring cam. A shaft position and speed sensor 60 determines
24 the instantaneous angular position and speed of rotation of the shaft, and informs a
25 controller 62, by way of electrical connection 64, which enables the controller to
26 determine the instantaneous phase of the cycles of each individual working chamber.
27 The controller is typically a microprocessor or microcontroller which executes a
28 stored program in use.

29
30 The working chamber comprises a low pressure valve (LPV) in the form of an
31 electronically actuatable face-sealing poppet valve 44 which faces inwards toward
32 the working chamber and is operable to selectively seal off a channel extending from
33 the working chamber to a low pressure manifold 46, which functions generally (in the
34 pumping mode) as a net source of fluid in use (or sink in the case of motoring). The
35 LPV is a normally open solenoid closed valve which opens passively when the
36 pressure within the working chamber is less than the pressure within the low pressure
37 manifold, during an intake stroke, to bring the working chamber into fluid

1 communication with the first low pressure manifold, but is selectively closable under
2 the active control of the controller via a LPV control line 66 to bring the working
3 chamber out of fluid communication with the low pressure manifold. Alternative
4 electronically controllable valves may be employed, such as normally closed solenoid
5 opened valves.

6

7 The working chamber further comprises a high pressure valve (HPV) 54 in the form of
8 a pressure actuated delivery valve. The HPV faces outwards from the working
9 chamber and is operable to seal off a channel extending from the working chamber to
10 a high pressure manifold 52, 56, which functions as a net source or sink of fluid in
11 use. The HPV functions as a normally-closed pressuring-opening check valve which
12 opens passively when the pressure within the working chamber exceeds the pressure
13 within the high pressure manifold. The HPV may also function as a normally-closed
14 solenoid opened check valve which the controller may selectively hold open via a
15 HPV control line 68 once the HPV is opened by pressure within the working chamber.
16 The HPV may be openable under the control of the controller when there is pressure
17 in the high pressure manifold but not in the working chamber, or may be partially
18 openable.

19

20 Importantly, as well as determining whether or not to close or hold open the primary
21 low pressure valve on a cycle by cycle basis in the manner known from, for example,
22 EP 0 361 927, EP 0 494 236, and EP 1 537 333, the controller is operable to vary the
23 precise phasing of the closure of the LPV and HPV with respect to the varying
24 working chamber volume during cycles which it has been determined that the LPV
25 and HPV should close, and thereby to determine the time-average net displacement
26 of fluid to or from the high pressure manifold 52,56 or low pressure manifold 46.

27

28 Further variation and modifications may be made within the scope of the invention
29 herein disclosed.

1 Claims

2

3 1. A variable displacement radial piston fluid working machine, the fluid working
4 machine comprising:

5

6 an inward ring and an outward ring around the inward ring;

7

8 one of the inward ring and the outward ring comprising a rotatable ring cam,
9 the other comprising a plurality of radially extending cylinders circumferentially
10 spaced around the respective ring, each cylinder having a piston reciprocally
11 mounted therein;

12

13 a drive shaft coupled to the ring cam;

14

15 the outward ring comprising first and second axially spaced structural
16 members and a plurality of demountable blocks demountably retainable
17 therebetween, each of the plurality of demountable blocks comprising either at
18 least some of the said plurality of cylinders or a segment of the ring cam
19 respectively, each said block being mountable to locate one or more said
20 cylinders in opposing relation to a portion of the ring cam to enable the pistons
21 to be driven by the ring cam and demountable to expose the inward ring for
22 access.

23

24 2. A variable displacement radial piston fluid working machine as claimed in
25 claim 1, wherein the demountable blocks are individually demountable.

26

27 3. A variable displacement radial piston fluid working machine as claimed in
28 claim 1 or claim 2, wherein the demountable blocks are demountable by
29 radially outwards motion.

30

31 4. A variable displacement radial piston fluid working machine according to any
32 one preceding claim, wherein at least some cylinders or the segment of the
33 ring cam of a demountable block are mounted to the body of the demountable
34 block and not directly mounted to the first or second axially spaced structural
35 elements.

36

- 1 5. A variable displacement radial piston fluid working machine as claimed in
2 claim 1, wherein demountable blocks demountably retained between the first
3 and second axially spaced structural elements resist forces between the first
4 and second axially spaced structural members.
5
- 6 6. A variable displacement radial piston fluid working machine as claimed in
7 claim 1 or claim 5, wherein one of the first and second axially spaced
8 structural elements comprises or is attached to a coupling for coupling the
9 fluid working machine to a support through the said one of the first and
10 second axially spaced structural elements.
11
- 12 7. A variable displacement radial piston fluid working machine as claimed in any
13 one preceding claim, wherein the first and second axially spaced structural
14 elements are independently mounted on bearings.
15
- 16 8. A variable displacement radial piston fluid working machine according to any
17 one preceding claim, wherein the drive shaft extends through at least one of
18 the axially spaced structural elements.
19
- 20 9. A variable displacement radial piston fluid working machine according to any
21 one preceding claim, wherein the first and second axially spaced structural
22 elements and the demountable blocks comprise cooperating formations for
23 bolting the demountable blocks to each of the first and second axially spaced
24 structural elements both axially and radially.
25
- 26 10. A variable displacement radial piston fluid working machine according to any
27 one preceding claim, wherein the first and second axially spaced structural
28 elements each comprise one or more shoulders having a radially outward
29 surface for engaging with the demountable blocks, the demountable blocks
30 having cooperating radially inward surfaces.
31
- 32 11. A variable displacement radial piston fluid working machine according to any
33 one preceding claim, wherein the demountable blocks are cylinder blocks,
34 comprising one or more said cylinders, and the inward ring comprises a ring
35 cam.
36

- 1 12. A variable displacement radial piston fluid working machine according to claim
2 11, wherein the ring cam comprises a plurality of ring cam segments which
3 are individually removable in a radially outward direction between the first and
4 second axially spaced structural elements when the or each cylinder block
5 which would otherwise overlay the respective ring cam segment is
6 demounted.
7
- 8 13. A variable displacement radial piston fluid working machine according to claim
9 12, wherein the ring cam comprises a side plate on one or both sides thereof,
10 each said side plate having an inner surface adjacent the cam surface, the
11 ring cam further comprising an abutment extending across a part of the inner
12 surface of each said side plate.
13
- 14 14. A variable displacement radial piston fluid working machine according to claim
15 13, wherein each said abutment comprises or consists of resilient or low
16 friction material.
17
- 18 15. A variable displacement radial piston fluid working machine according to any
19 one of claims 12 to 14, wherein the ring cam comprises a side plate on one or
20 both sides thereof, the or each side plate comprising a plurality of side plate
21 segments.
22
- 23 16. A variable displacement radial piston fluid working machine according to claim
24 15, wherein each said side plate segment are angularly offset from the said
25 ring cam segments, and each side plate overlaps two or more segments of
26 the assembled ring cam.
27
- 28 17. A variable displacement radial piston fluid working machine according to claim
29 15 or claim 16, wherein each said ring cam segment is secured to one or
30 more side plate segments.
31
- 32 18. A variable displacement radial piston fluid working machine according to claim
33 17, wherein each said ring cam segment and one or more side plate
34 segments secured thereto, are removable as a unit in a radially outward
35 direction.
36

- 1 19. A variable displacement radial piston fluid working machine according to any
2 one or claims 11 to 16, wherein at least one of the axially spaced structural
3 elements comprises one or more ports for receiving working fluid, and
4 wherein each said cylinder block includes at least one cooperating port for
5 expelling working fluid, either or both said ports including a seal, wherein the
6 said ports and the or each seal are located on radially inward or outward
7 facing surfaces.
8
- 9 20. A variable displacement radial piston fluid working machine according to any
10 one preceding claim, further comprising a plurality of manifolds and a plurality
11 of valves, each of which is operable to regulate the flow of fluid between a
12 working chamber and a manifold.
13
- 14 21. A variable displacement radial piston fluid working machine according to claim
15 20, comprising a controller and at least one valve associated with each
16 working chamber may be an actively controllable valve, controllable by the
17 controller in phased relationship with cycles of working chamber volume to
18 select the net displacement of working fluid by each working chamber on a
19 cycle by cycle basis.
20
- 21 22. A kit of parts which can be assembled to form a variable displacement radial
22 piston fluid working machine according to any one preceding claim.
23
- 24 23. A variable displacement radial piston fluid working machine chassis, the
25 chassis comprising:
26
27 an inward ring and an outward ring around the inward ring;
28
29 one of the inward ring and the outward ring comprising a rotatable ring cam
30 retaining formation, the other comprising a plurality of mountings for retaining
31 radially extending cylinders circumferentially spaced around the respective
32 ring;
33
34 a coupling to couple the ring cam retaining formation to a drive shaft;
35
36 the outward ring comprising first and second axially spaced structural
37 members for demountably retaining a plurality of demountable blocks

1 comprising either at least some of the said plurality of cylinders or a segment
2 of the ring cam respectively to locate one or more said cylinders in opposing
3 relation to a portion of the ring cam to enable pistons slidably mounted within
4 the cylinders to be driven by the ring cam.

5
6
7 24. A turbine assembly comprising a variable displacement radial piston fluid
8 working machine according to any one of claims 1 to 21 and a turbine
9 comprising a plurality of blades mounted to the drive shaft to transmit torque
10 to the ring cam as the blades rotate.

11
12 25. A method of maintaining a variable displacement machine according to any
13 one of claims 1 to 21 or a turbine assembly according to claim 24, comprising
14 removing a demountable block and carrying out one or more of (a)
15 maintaining the demountable block and remounting the maintained
16 demountable block, (b) mounting a replacement demountable block in place
17 of the demounted block, and (c) maintaining a portion of the inner ring through
18 the space left by the demounted block.

19
20 26. A method according to claim 25, wherein maintaining a portion of the inner
21 ring through the space left by the demounted block comprises removing a
22 portion of the inner ring.
23

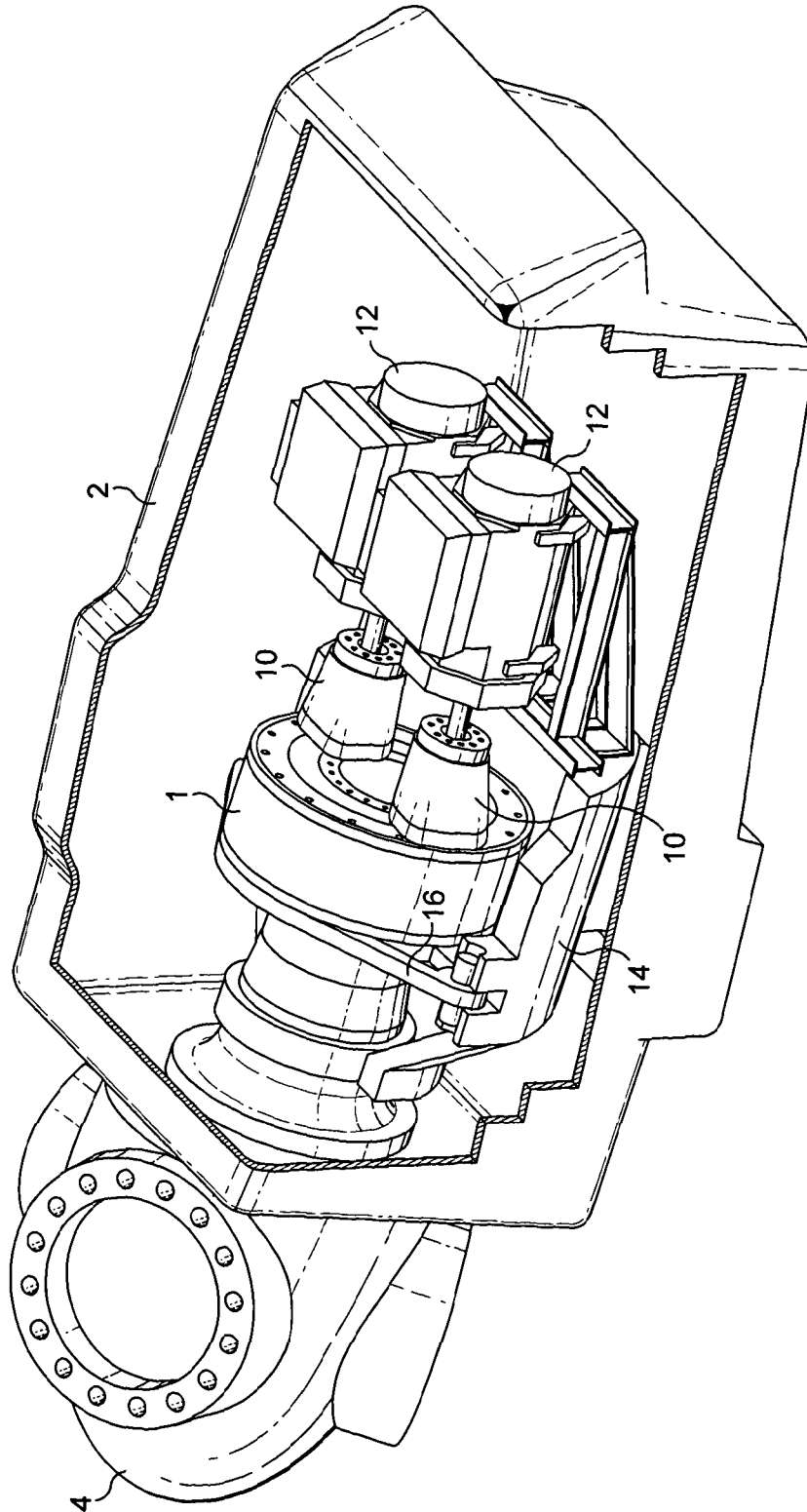


FIG. 1

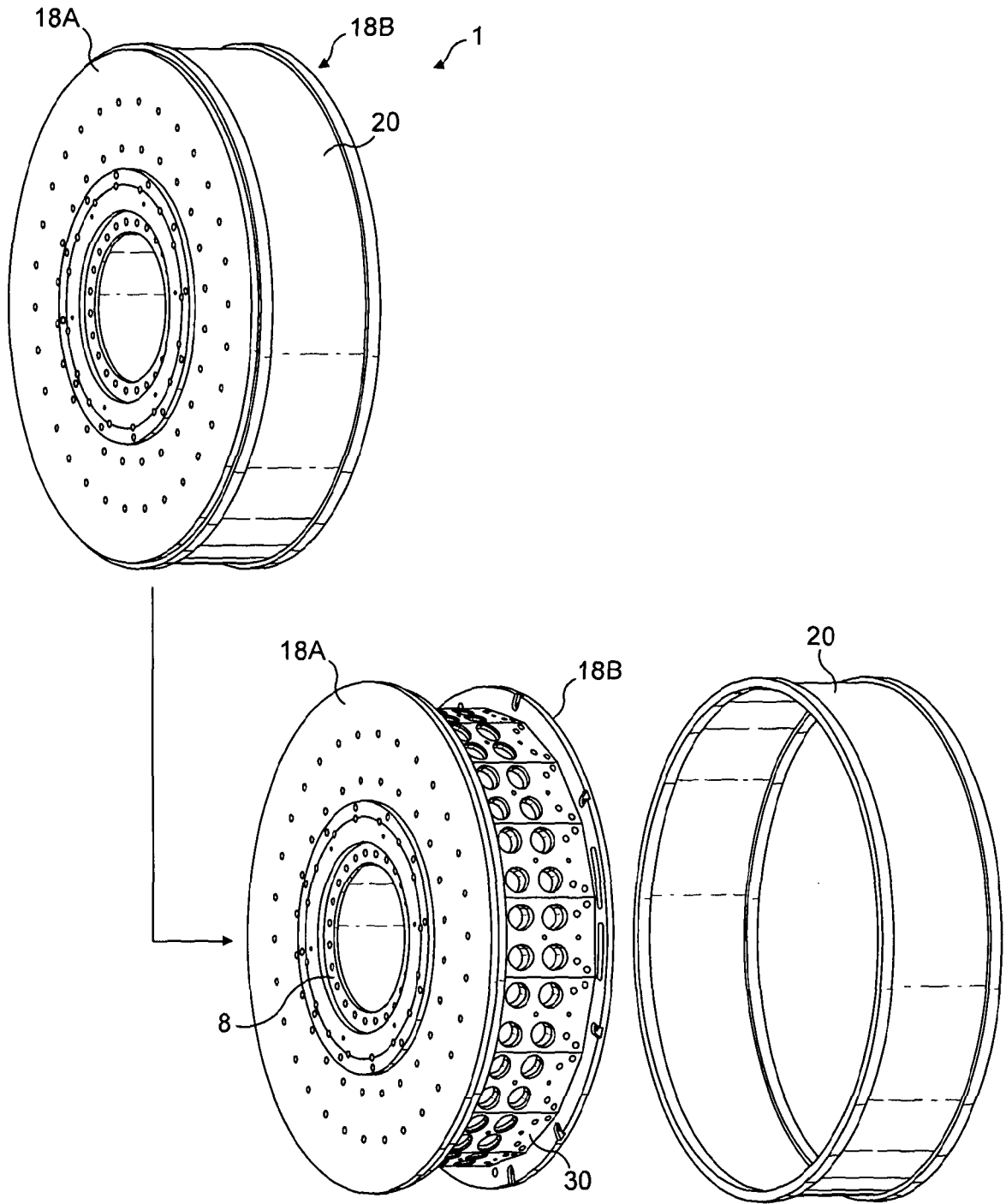


FIG. 2

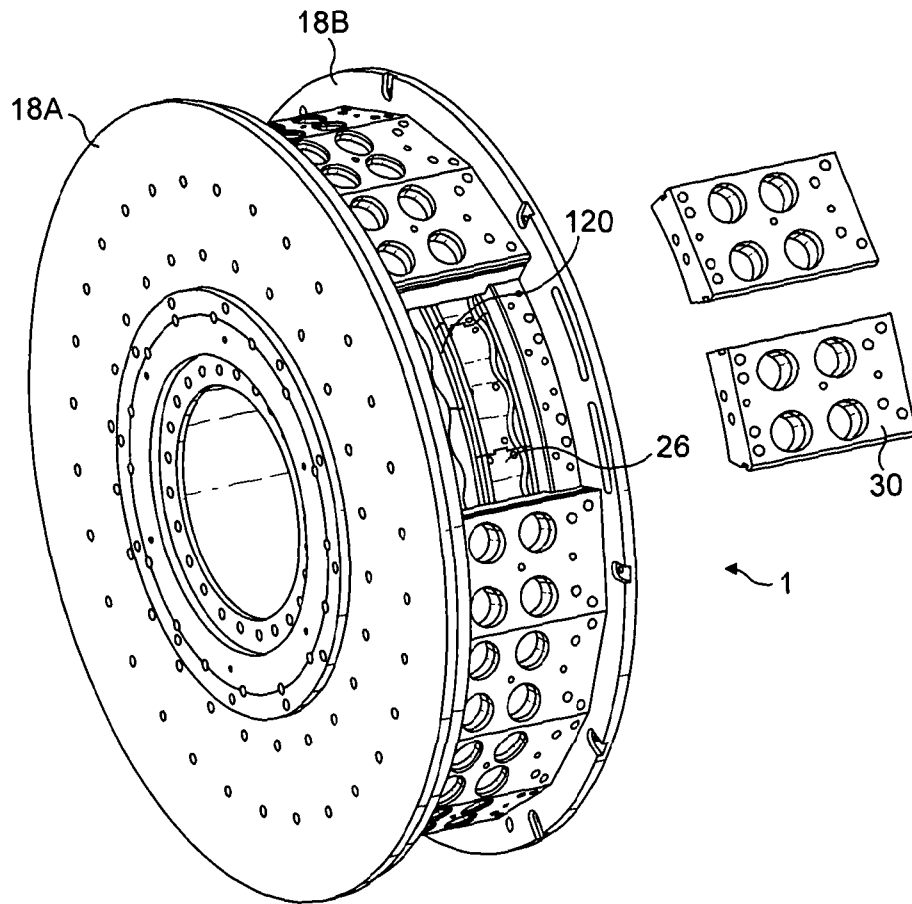


FIG. 3

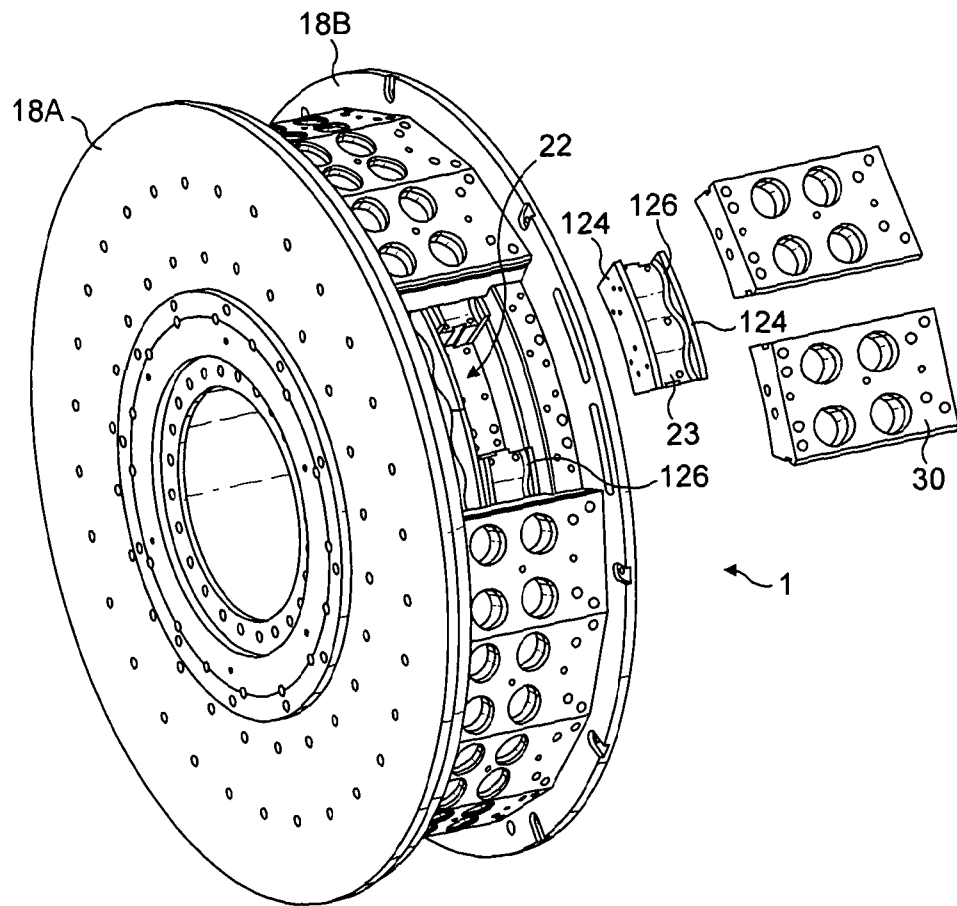


FIG. 4

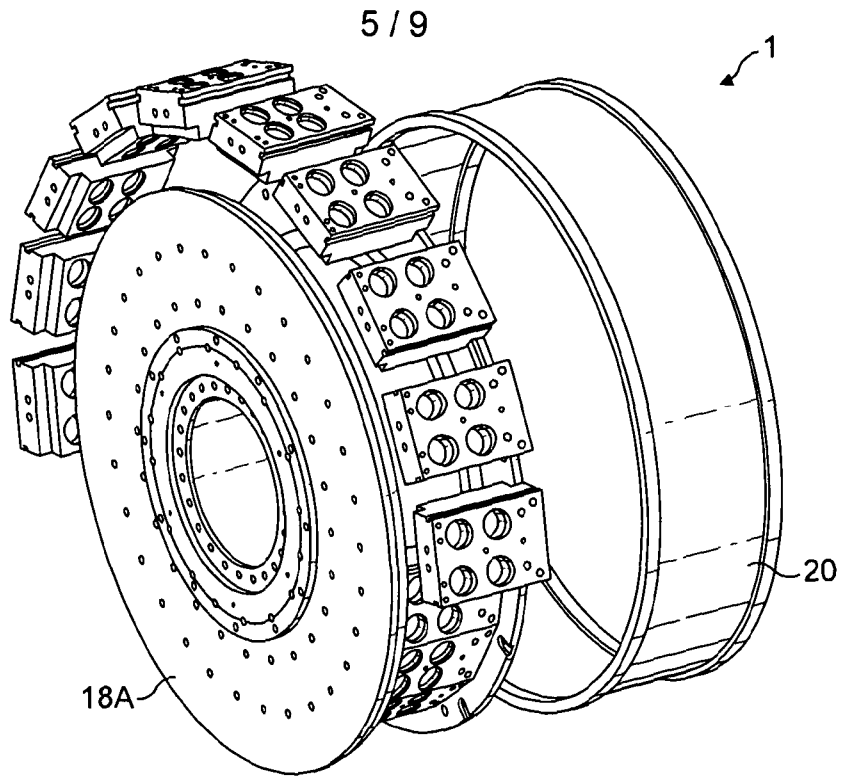


FIG. 5

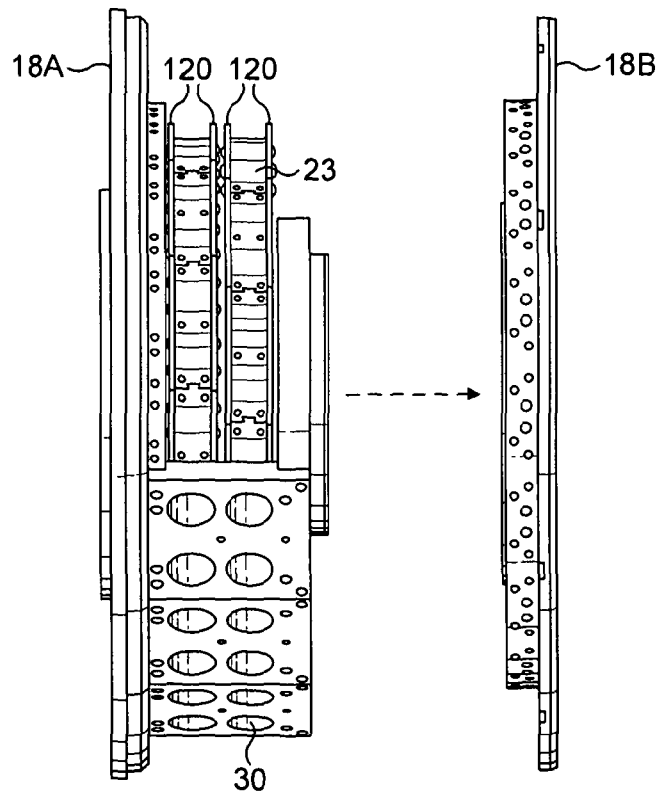


FIG. 6

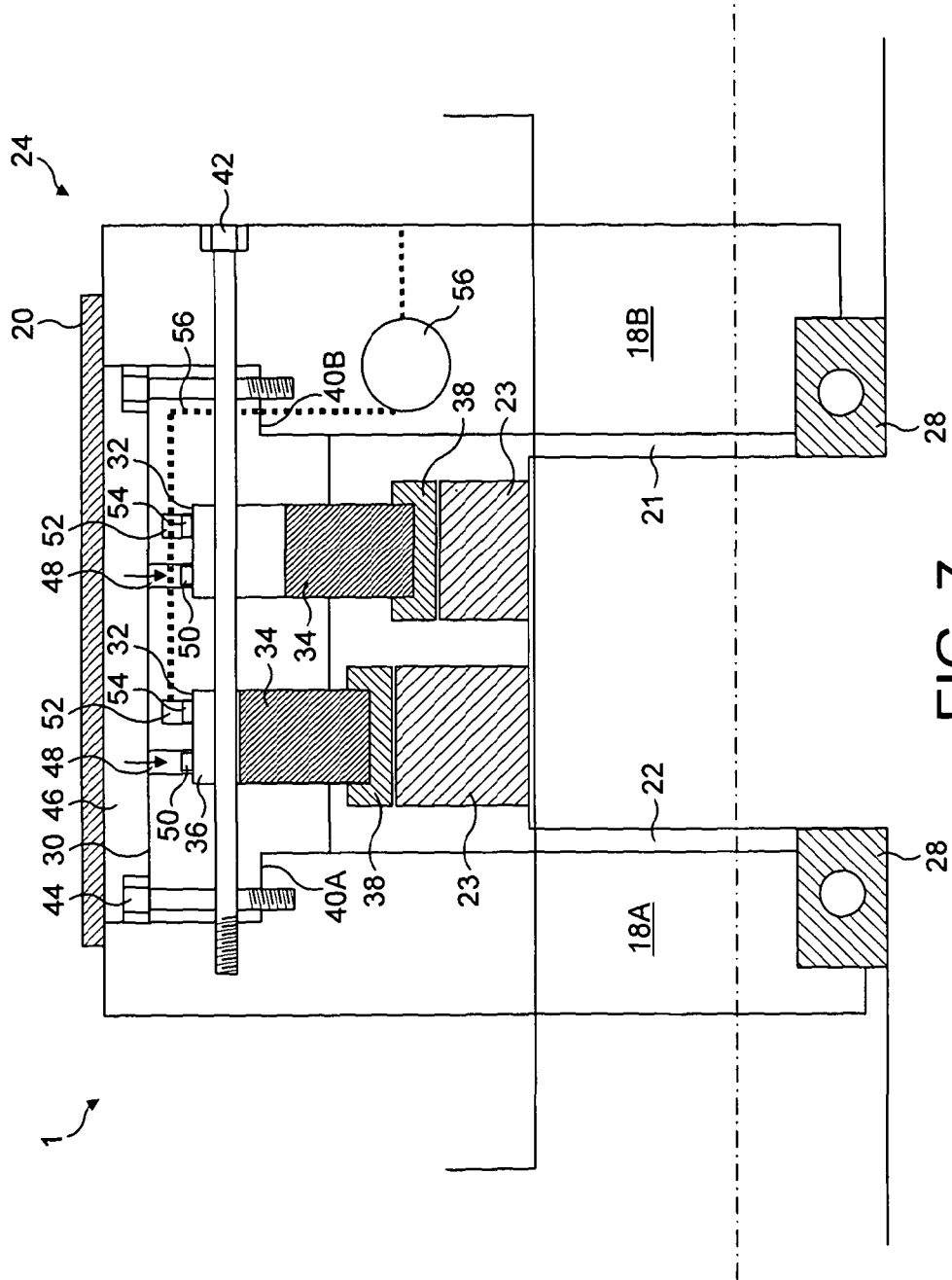


FIG. 7

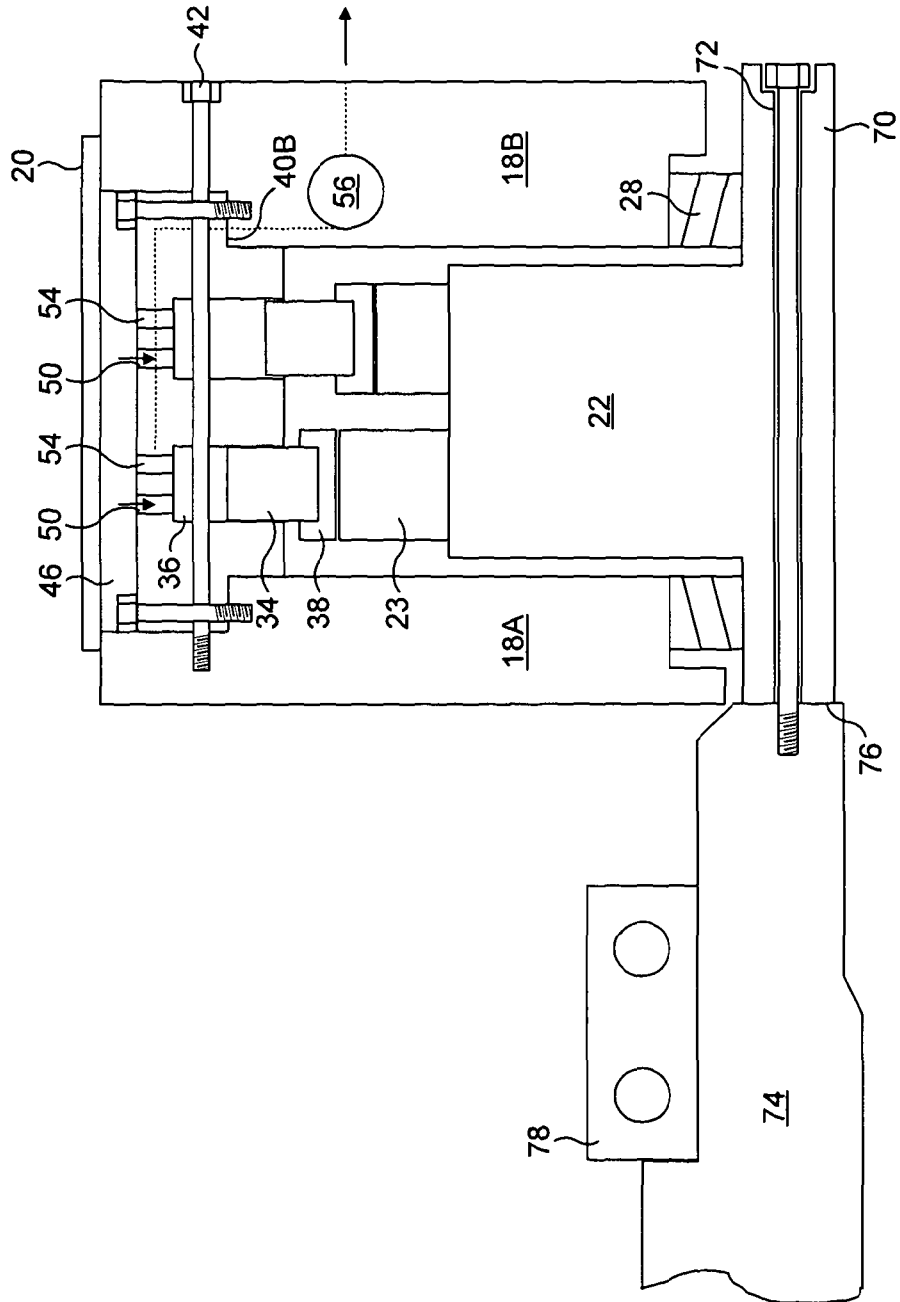


FIG. 8

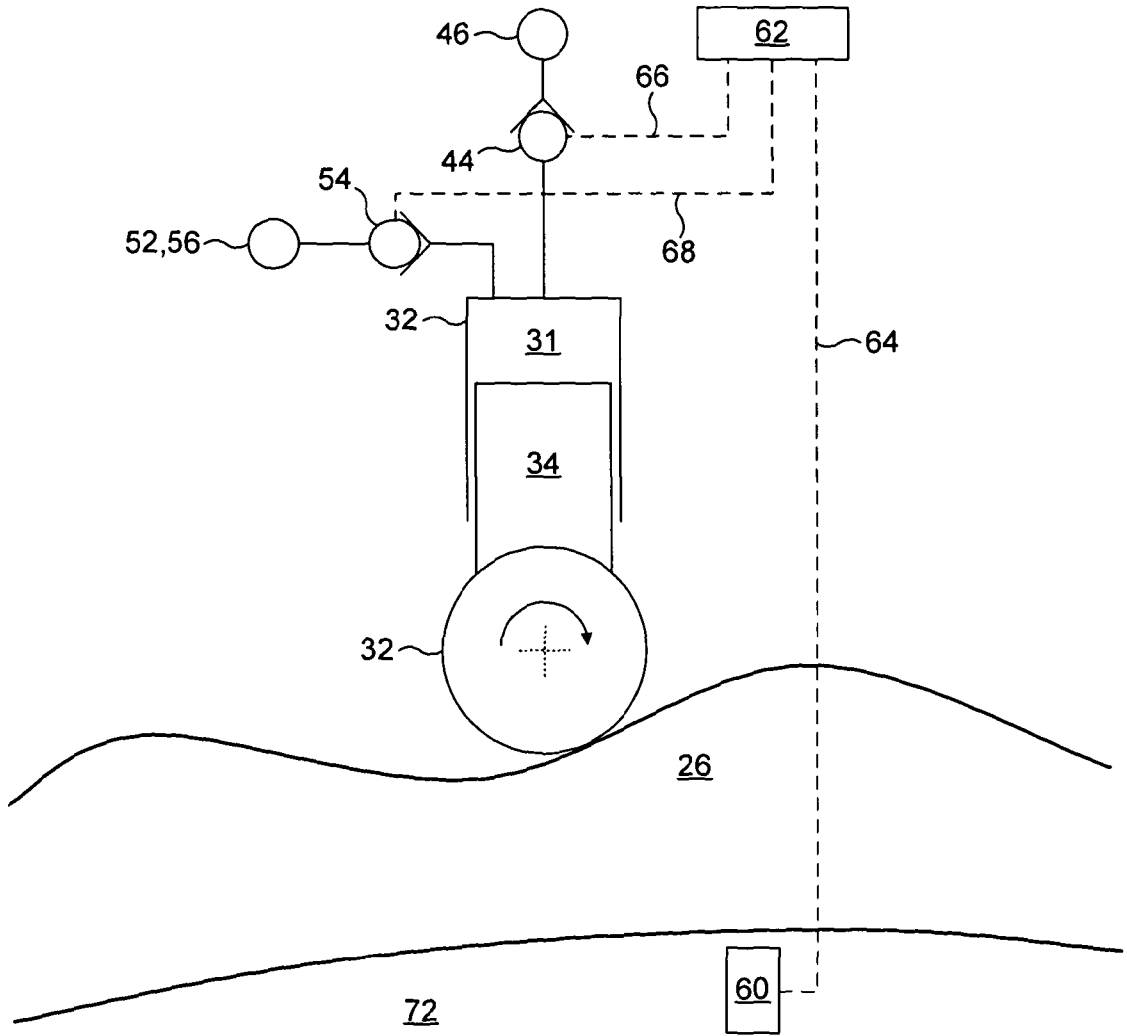


FIG. 9

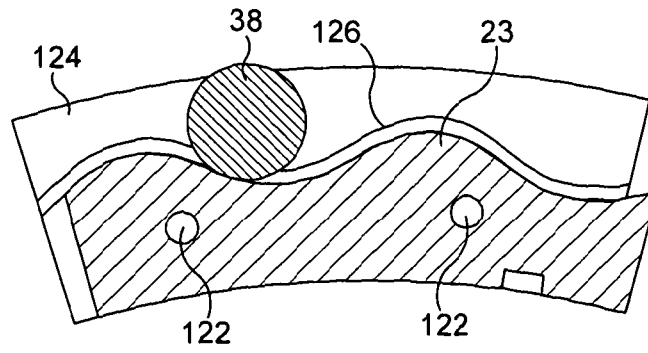


FIG. 10

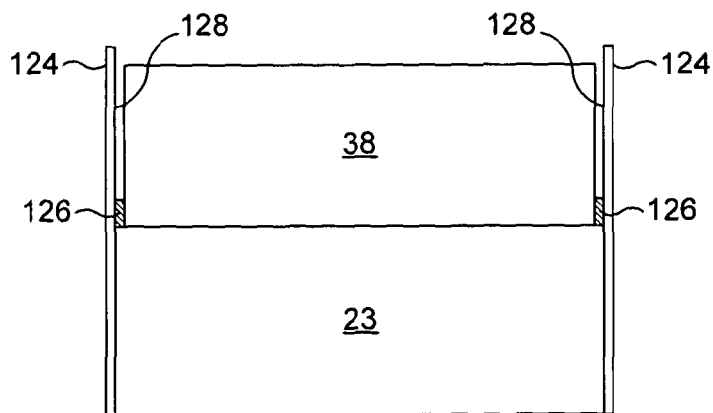


FIG. 11