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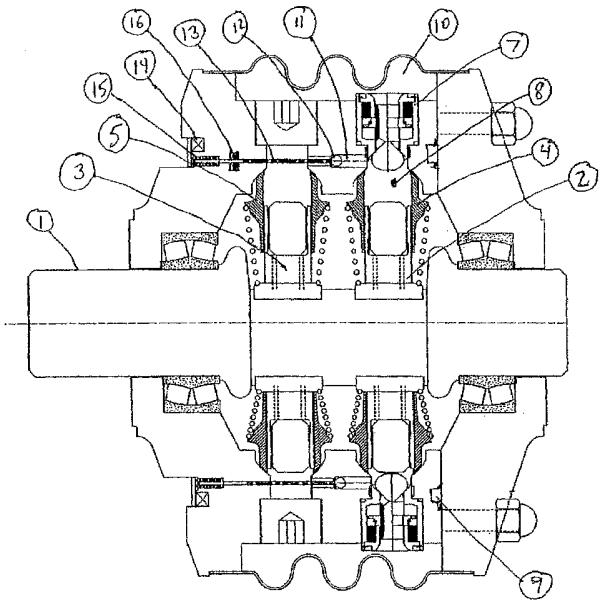
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** FLUID-WORKING MACHINES



(57) **Abstract:** A fluid-working machine comprises at least one primary working chamber such as a cylinder (4) of cyclically changing volume and primary valves (7) to control the connection of the at least one chamber to low (10)- and high (9)-pressure manifolds. The machine has at least one secondary working chamber (5) of cyclically changing volume and a secondary valve (12, 21) for placing the secondary chamber in communication with the primary chamber (4) in an active state of the secondary chamber (5) and for isolating it therefrom in an idling state of the secondary chamber.

WO 2006/109079 A1

FLUID-WORKING MACHINES

[0001] This invention relates to a fluid driven motor and/or a fluid-driving pump (the motor or pump is called a "fluid-working machine" in this specification) having working chambers of cyclically changing volume and valve means to control the connection of each chamber to low- and high-pressure manifolds. The invention also relates to a method of operating the machine.

[0002] The invention has particular reference to non-compressible fluids, but its use with gases is not ruled out. It has particular reference to machines where the at least one working chamber comprises a cylinder in which a piston is arranged to reciprocate, but its use with at least one chamber delimited by a flexible diaphragm or a rotary piston is not ruled out.

[0003] WO 91/05163 describes a fluid-working machine having a plurality of cylinders. Electromagnetically actuatable face-seating poppet valves are used to select a different number of cylinders in order to vary the output power.

[0004] When fluid-working machines are used in combination to form a variable-speed drive for an application that requires a wide operating speed range, it is difficult to provide sufficient fluid-powered motor displacement volume for low-speed, maximum-torque operation. Previously this problem has been addressed in one of three ways: a very large variable capacity motor has been used, a two-speed gearbox has been inserted into the drive train between the motor and the output, or additional fluid-power machines have been ganged, or brought into service, to increase the effective displacement.

[0005] Each of these approaches has its disadvantages and limitations. The very large variable capacity motor spends much of its working life at a small fraction of its maximum capacity, where it runs inefficiently. The gearbox adds a major extra component and thus adds significant weight, with the problem of backlash also being introduced. The gearbox also needs to be taken off-load in order to

shift between ratios. Adding additional hydraulic units requires a significantly more complex fluid circuit, with additional switching valves. The additional units may also suffer from the complexity of clutches used to disconnect the additional motors when they are not in use, so as to eliminate parasitic idle loss.

[0006] It is therefore an aim of the invention to provide a machine that addresses the disadvantages of these known approaches.

[0007] The present invention provides a fluid-working machine comprising at least one primary working chamber of cyclically changing volume and primary valves to control the connection of the at least one chamber to low- and high-pressure manifolds, characterised by at least one secondary working chamber of cyclically changing volume and a secondary valve for placing the secondary chamber in communication with the primary chamber in an active state of the secondary chamber and for isolating it therefrom in an idling state of the secondary chamber.

[0008] The at least one secondary working chamber is preferably connected only to the said at least one primary chamber. When the primary and secondary chambers are in communication the working volume of the working chambers is increased, the displacement and torque being increased at lower shaft speeds. There may be one secondary working chamber for each primary chamber. Alternatively, there may be fewer than one secondary chamber for each primary chamber, or there may be tertiary and possibly quaternary etc. chambers, connected with the secondary chambers via valves in series or parallel to the primary chambers.

[0009] The primary and secondary chambers may comprise cylinders arranged radially around a crankshaft, and having pistons connected to the crankshaft for rotation thereof.

[0010] The secondary valve can be controlled by an electromagnetic, hydraulic, pneumatic or electromechanical actuator.

[0011] Secondary valve biasing means such as a spring may be provided for biasing the secondary valve to the closed condition in which the primary and secondary chambers are isolated from each other. The secondary valve may be controlled via a rod which may extend through the secondary chamber. A force-transmitting member may be arranged to move a valve member (of which member the rod may form part) of the secondary valve via an energy storage device, for example a spring. This is useful if the force-transmitting member happens to be actuated at a point in the cycle when the pressure in the primary chamber is high. In an embodiment of the machine, one force-transmitting member is arranged to actuate a valve member of a plurality of secondary valves. The force-transmitting member may comprise a ring extending around the machine.

[0012] In a particular embodiment of the inventive machine, the primary valves comprise face-seating valves such as the poppet valves described in WO 91/05163. Alternatively, commutating port valves could be used.

[0013] In addition to the connection and disconnection between the primary and secondary chambers, the primary valves may be operable to select or deselect each primary chamber depending the required output of the machine, as described in WO 91/05163.

[0014] In order that the invention may be more readily understood, reference will now be made, by way of example only, to the accompanying drawings in which:

[0015] Figure 1 is a schematic sectional view of a hydraulic motor according to the invention; and

[0016] Figure 2 is an enlarged schematic sectional view of a secondary valve and associated components of the machine of Figure 1.

[0017] Figure 1 shows a machine comprising a plurality of cylinders, four of which are shown. In this type of machine, the cylinders are arranged radially around an eccentric of a crankshaft 1, but the invention is not restricted to such machines.

[0018] Primary cylinders 4 are arranged as follows. In the side wall of each cylinder 4 is a primary poppet valve (not shown, since it is not in the section plane) communicating with a high-pressure manifold 9 and in the end wall of each cylinder 4 is a further primary poppet valve 7 communicating with a low-pressure manifold 10. The poppet valves are active electromagnetic valves controlled electrically by a microprocessor controller.

[0019] Pistons 2 act on the crankshaft 1. The controller receives inputs from a shaft encoder, a pressure transducer, and a desired output speed demand signal.

[0020] The primary poppet valves seal the respective primary cylinders 4 from the respective manifolds 9, 10 by engagement of an annular valve part with an annular valve seat, a solenoid being provided to magnetically move each said valve part relative to its seat by reacting with ferromagnetic material on the said poppet valve, each said poppet valve having a stem and an enlarged head, the annular valve part being provided on the head and the ferromagnetic material being provided on the stem.

[0021] Secondary cylinders 5 are arranged substantially in a plane with each secondary cylinder adjacent its associated primary cylinder 4. The working volume of each secondary cylinder 5 is connected to that of the adjacent primary cylinder via a passageway 11.

[0022] As shown more clearly in Figure 2, a secondary valve comprising a valve member in the form of a ball 12 is located in the passageway 11. A secondary

valve spring 20 urges the ball 12 towards a taper 21 in the passageway. The ball 12 is connected to a rod 13 which extends along the passageway 11 as far as a recess 22 into which recess the passageway opens out. A seal 16, provided around the rod between the secondary cylinder 5 and the recess 22, isolates the pressurised secondary chamber 5. The end of the rod 13 is connected to one end of an actuating spring 15 located in the recess. The actuating spring 15 is stiffer than the secondary valve spring 20. The other end of the actuating spring 15 abuts an actuating ring 23 which extends around the machine and comprises ferromagnetic material. A coil 14 also extends around the machine at a different axial position from that of the ring 23.

[0023] The machine has one passageway 11 containing a secondary valve for each pair of cylinders 4, 5, each actuating spring 15 being connected to the actuating ring 23.

[0024] When the secondary valves are closed only the primary cylinders 4 operate. At low speed, in order to generate higher torque in the crankshaft 1, a current is applied to the coil 14. This moves the ring 23 towards the coil 14, which forces the actuating springs 15 towards the secondary valves. If the pressure in a given primary cylinder 4 is sufficiently low, the secondary valve opens against the action of the secondary valve spring 20, connecting the primary and secondary cylinders so that both are now driven by the pressurised fluid. On the other hand, if the primary cylinder 4 is at a point in its cycle where the pressure is high, the secondary valve cannot open, ball 12 and rod 13 remaining in a position to the right of that shown in Figure 2, and the actuating spring 15 is compressed. As soon as a point of sufficiently low pressure is reached, the actuating spring 15 opens the secondary valve to the position shown in Figure 2.

[0025] In the position of Figure 2, the force of the secondary valve spring 20 combined with fluid flow forces on the ball 12 is insufficient to compress the

actuating spring 15. Thus the secondary valves remain open until the current to the coil 14 is stopped, whereupon the secondary valve springs 20 close the secondary valves. This allows the machine to operate with less fluid displacement at a higher speed.

[0026] The secondary valves could be actuated by a pneumatic or hydraulic actuator instead of the solenoid comprising coil 14 and ring 23. In this regard, a single gallery could communicate with all of the recesses 22 and could be pressurised to open and close the valves when required.

[0027] All forms of the verb "to comprise" used in this specification should be understood as forms of the verbs "to consist of" and/or "to include".

CLAIMS

1. A fluid-working machine comprising at least one primary working chamber of cyclically changing volume and primary valves to control the connection of the at least one chamber to low- and high-pressure manifolds, characterised by at least one secondary working chamber of cyclically changing volume and a secondary valve for placing the secondary chamber in communication with the primary chamber in an active state of the secondary chamber and for isolating it therefrom in an idling state of the secondary chamber.

2. A machine according to claim 1, comprising one secondary working chamber for each primary chamber.

3. A machine according to claim 1 or 2, comprising tertiary and possibly quaternary etc. chambers, connected to the primary chambers via valves in series with or in parallel with the secondary chambers.

4. A machine according to claim 1, 2 or 3, wherein the primary and secondary chambers comprise cylinders arranged radially around a crankshaft, and having pistons connected to the crankshaft for rotation thereof.

5. A machine according to any preceding claim, including secondary valve biasing means for biasing the at least one secondary valve to the closed condition in which the primary and secondary chambers are isolated from each other.

6. A machine according to any preceding claim, wherein the at least one secondary valve is controlled via a rod extending through the secondary chamber.

7. A machine according to any preceding claim, wherein a force-transmitting member is arranged to move a valve member of the at least one secondary valve via an energy storage device.

8. A machine according to claim 7, wherein the energy storage device comprises a spring.

9. A machine according to any preceding claim, wherein one force-transmitting member is arranged to actuate a valve member of each of a plurality of secondary valves.

10. A machine according to claim 9, wherein the force-transmitting member comprises a ring extending around the machine.

11. A machine according to any preceding claim, including an electromagnetic actuator for actuating the at least one secondary valve.

12. A machine according to claims 10 and 11, wherein the actuator comprises the force-transmitting member of ferromagnetic material, and a coil extending around the machine.

13. A machine according to any one of claims 1 to 10, including a fluidic actuator for actuating the at least one secondary valve.

14. A machine according to any preceding claim, wherein the primary valves comprise face-seating valves.

15. A machine according to any preceding claim, wherein the primary valves are operable to select or deselect each primary chamber depending the required output of the machine.

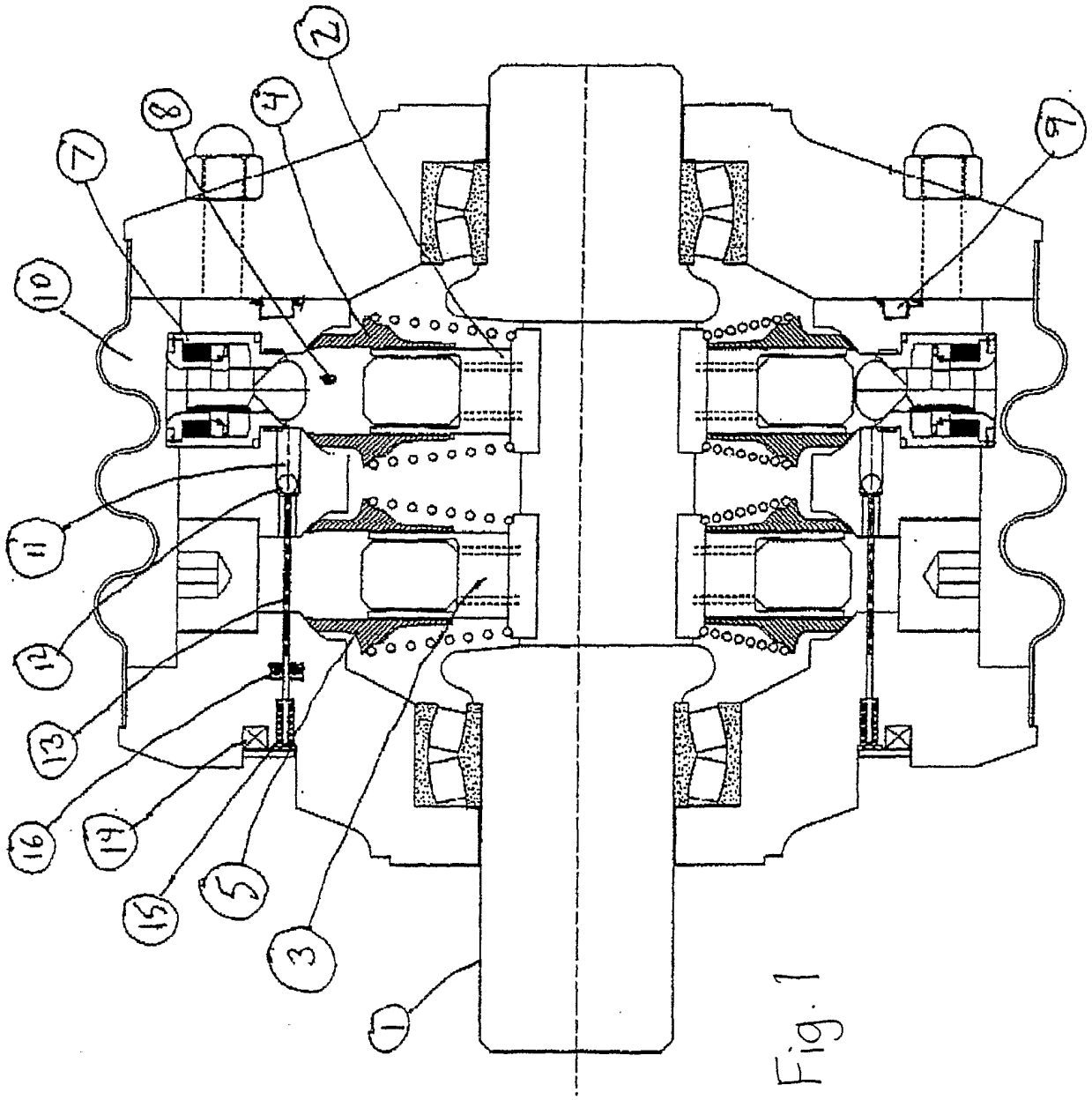


Fig. 1

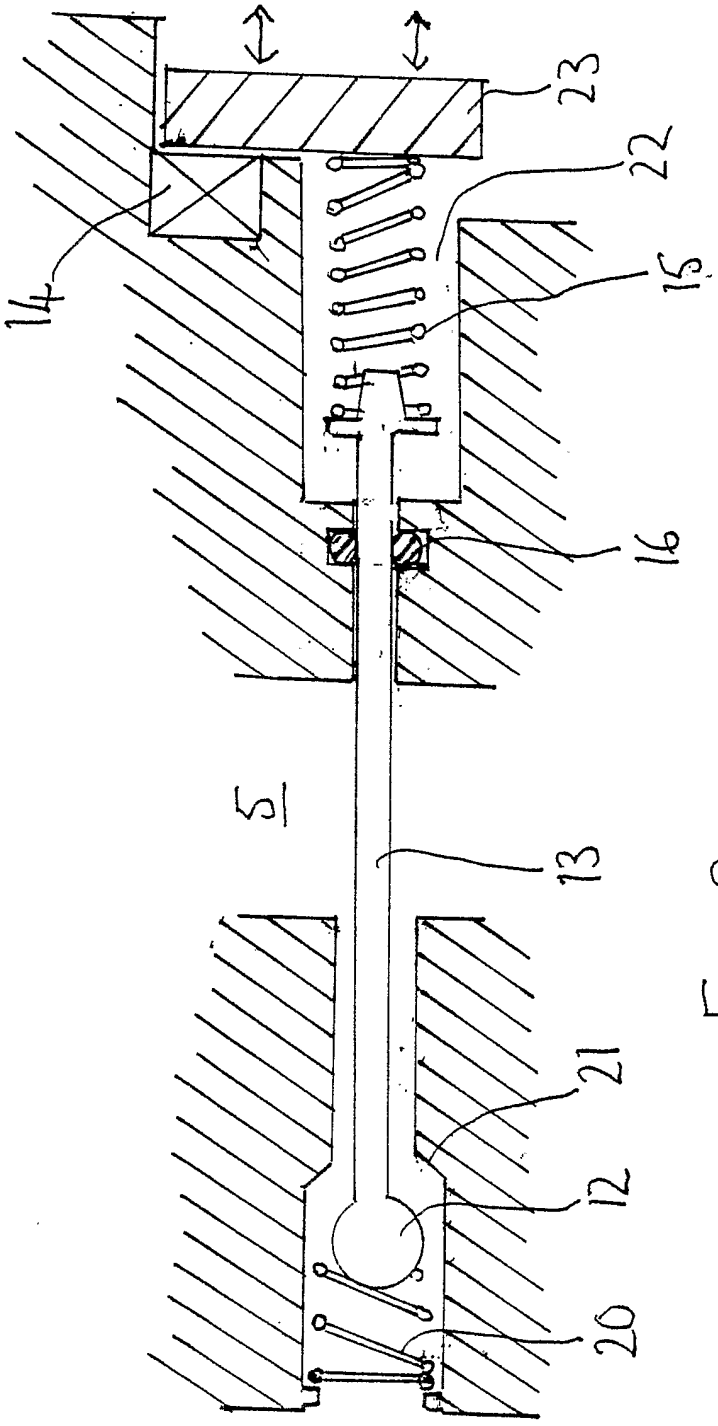


Fig. 2

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	FOR FURTHER ACTION	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
WBH.EXTENSIB		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/GB2006/001366	13/04/2006	15/04/2005
Applicant		
ARTEMIS INTELLIGENT POWER LIMITED		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 4 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language,** the international search was carried out on the basis of:
      [X] the international application in the language in which it was filed
      [ ] a translation of the international application into _____, which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b))
   b. [ ] With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. [ ] **Certain claims were found unsearchable** (See Box No. II)

3. [ ] **Unity of invention is lacking** (see Box No III)

4. With regard to the **title,**
   [X] *the text is approved as submitted by the applicant*
   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**
   [X] the text is approved as submitted by the applicant
   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority

6. With regard to the **drawings,**
   a. the figure of the **drawings** to be published with the abstract is Figure No. 1
      [X] as suggested by the applicant
      [ ] as selected by this Authority, because the applicant failed to suggest a figure
      [ ] as selected by this Authority, because this figure better characterizes the invention
   b. [ ] none of the figures is to be published with the abstract

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2006/001366

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04B49/06 F04B1/06 F01B1/06

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04B F01B

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	GB 1 299 442 A (JOSEPH LATHAM MONKS) 13 December 1972 (1972-12-13) page 3, lines 88-104; figures 2,3	1,2,4,5, 13,14 6,10-12, 15
X	GB 1 125 562 A (BRITISH AIRCRAFT CORPORATION LIMITED) 28 August 1968 (1968-08-28) page 2, lines 107-117 page 3, lines 52,53	1-5,7,8
Y	WO 91/05163 A (THE UNIVERSITY OF EDINBURGH) 18 April 1991 (1991-04-18) cited in the application abstract	10-12,15

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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
11 July 2006	25/07/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Olona Laglera, C

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2006/001366

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6 293 253 B1 (ARNOLD BERNHARD ET AL) 25 September 2001 (2001-09-25) column 7, lines 15-46; figure 4	6
A	FR 2 292 854 A (REXROTH SIGMA) 25 June 1976 (1976-06-25) the whole document	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2006/001366

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