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(71) **Applicant**: **VHIT S.P.A.** [IT/IT]; Strada Vicinale Delle Sabbione, 5, I-26010 Offanengo (CR) (IT).

(72) **Inventors**: **CADEDDU, Leonardo**; c/o VHIT S.P.A., Strada Vicinale Delle Sabbione, 5, I-26010 Offanengo (CR) (IT). **CALDERONI, Matteo**; c/o VHIT SPA, Strada Vicinale Delle Sabbione, 5, I-26010 Offanengo (CR) (IT). **VIVIURKA, Joao Paulo**; c/o VHIT SPA, Strada Vicinale Delle Sabbione, 5, I-26010 Offanengo (CR) (IT).

(74) **Agents**: **ROBBA, Pierpaolo** et al.; Interpatent Srl, Via Caboto, 35, I-10129 Torino (IT).

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(54) **Title**: VARIABLE DISPLACEMENT PUMP FOR FLUIDS WITH MODULATED REGULATION, AND METHOD FOR REGULATING ITS DISPLACEMENT

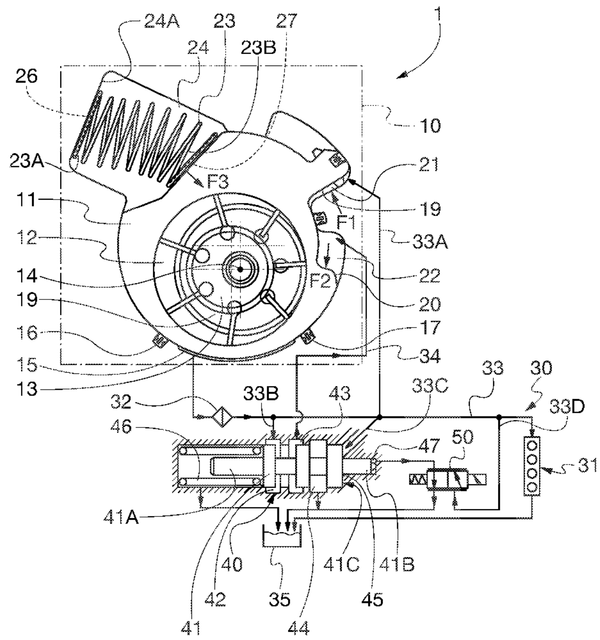

Fig. 1

(57) Abstract: A variable displacement pump (1) comprises a regulation ring (11) having at least a pair of actuation stages (19, 20), of which a first stage is permanently exposed to pressure conditions of the pumped fluid and is arranged to make the regulation ring (11) move against the action of a spring (23), and a second stage is arranged to act concordantly with the spring (23) in a manner controlled by an electrically-controlled valve (50). A spool valve (40), controlled by the electrically-controlled valve (50) and the pressure conditions of the pumped fluid, is connected between the second stage (20) and the electrically- controlled valve (50) and is arranged to modulate a regulation pressure acting on the second stage (20) depending on a control signal supplied by the electrically-controlled valve (50) and on such pressure conditions. A method for regulating the displacement of such a pump is also provided.

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VARIABLE DISPLACEMENT PUMP FOR FLUIDS WITH MODULATED REGULATION, AND METHOD FOR REGULATING ITS DISPLACEMENT

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Technical field

The present invention relates to variable displacement pumps, and more particularly it concerns a pump of this kind with modulated regulation and a method of regulating its displacement.

Preferably, but not exclusively, the invention is applied in a pump for the lubrication oil of the engine and/or the drive system of a motor vehicle, and particular reference will be made to such a preferred application in the description below.

Prior art

It is known that, in pumps for making lubricating oil under pressure circulate in engines and/or drive systems in motor vehicles, the capacity, and hence the oil delivery rate, depends on the rotation speed of the engine. Hence, the pumps are designed so as to provide a sufficient delivery rate at low speeds, in order to ensure lubrication also under such conditions. If the pump has fixed geometry, at high rotation speed the delivery rate exceeds the necessary rate, whereby high power absorption, with a consequently higher fuel consumption, and a higher stress of the components occur due to the high pressures generated in the circuit.

In order to obviate this drawback, it is known to provide the pumps with systems allowing a delivery rate regulation at the different operating conditions of the vehicle, in particular through a displacement regulation.

The solutions for displacement regulation are specific for the particular type of pumping elements (vanes, external or internal gears, pistons...), but an element common to all solutions is the provision of movable regulation members driven by the pressure of the pumped fluid and of members, generally springs, opposing the movement of the regulation members and having the function of:

- ensuring that the pump is kept in the maximum displacement condition when starting and under low speed conditions;
- enabling a quick return of the pump to the maximum displacement during vehicle deceleration and/or when the operating conditions of the engine change.

Generally, in such pumps, the problem exists of keeping the radial thrusts generated by the spring force and by the actuation pressures limited, thereby consequently reducing frictions and thus pressure hysteresis between the phases of increase and the phases of decrease of the same pressure (e.g., between the pressure values during engine acceleration and the values during engine deceleration), and of making actuation of the regulating members simple and stable.

WO 2013/140304 discloses a positive displacement rotary pump with variable displacement in which the regulation exploits the variation of the relative position between an external regulation ring and the rotor eccentrically rotating within the same ring. The variation is obtained through a rotation of the ring. The latter is configured as a multistage rotary piston directly driven by the pressure of the pumped fluid, where at least one stage is permanently exposed to the action of the fluid and at least another stage intervenes, in addition to the first stage, upon command of an electrically controlled valve with on-off operation. The spring rotation is opposed by a spring guided on a tappet coupled with the ring by means of a spherical joint. The on-off actuation of the second stage does not ensure regulation stability, and the provision of the guide tappet and of its articulation on the ring gives rise to frictions causing hysteresis in the pump reaction.

Description of the invention

It is an object of the present invention to provide a pump obviating the drawbacks of the prior art.

According to the invention, in a pump of the above kind, modulation members are connected between the second stage and the driving members and are arranged to modulate a regulation pressure acting on the second stage depending on a control signal supplied by the driving members and on the pressure conditions.

Advantageously, the modulating members include a distributor arranged to: take, depending on the control signal, at least a first and a second extreme configuration in correspondence of the maximum displacement and the minimum displacement of the pump, respectively; expose the second stage to the same pressure conditions as those acting on the first stage in the first extreme configuration, and to atmospheric pressure conditions in the second extreme configuration; and modulate the pressure acting on the second stage when the pressure of the pumped fluid reaches, while increasing or decreasing, respectively, a threshold pressure set for the intervention of members opposing a movement of a movable element of the distributor.

The invention also concerns a method of regulating the displacement of a variable displacement pump for fluids, wherein movable regulation members are provided, which include at least a pair of actuation stages, of which a first stage is permanently exposed to the pressure conditions of the pumped fluid and is arranged to make the regulation members move against the action of opposing members, and a second stage is arranged to act concordantly with the opposing members in a manner controlled by external control members, and wherein a step of making the regulation members move comprises the step of modulating the driving pressure to which the second stage is exposed depending on the control signal and the pressure conditions of the pumped fluid.

Brief description of the Figures

The above and other features and advantages of the invention will become apparent from the following description of preferred embodiments, made by way of non limiting example with reference to the accompanying drawings, in which:

- Fig. 1 is a front view of a pump according to the invention, without the cover, in the maximum displacement position;
- Fig. 2 is a view similar to Fig. 1, showing the pump in the minimum displacement position; and
- Figs. 3 and 4 are simplified diagrams showing the opposing force and its arm in the maximum and minimum displacement conditions;

Description of preferred embodiments

The Figures show, by way of example only, a variable displacement rotary pump with vanes, the general structure of which is as disclosed in WO 2013/140304. Thus, that structure will be described here only to the extent necessary for the understanding of the invention and, for further details, reference is to be made to that document.

Referring to Figs. 1 and 2, a pump 1 of the above kind comprises a body (schematised by dotted-and-dashed line 10), having a cavity within which regulation ring 11 (hereinafter also referred to simply as stator) is mounted so as to be freely rotatable along an arc of circumference about an axis 18 internal to the stator itself. Stator 11 has a chamber 12 accommodating rotor 13, keyed on a shaft 14 parallel to the rotation axis of stator 11. In the Figures, it is assumed that the rotor rotates in counterclockwise direction. As known to the skilled in the art, the rotation of stator 11 causes a variation of the relative eccentricity between stator 11 and rotor 13, and hence a variation of the displacement, between a condition of maximum eccentricity and displacement (Fig. 1), which is taken also in rest conditions of the pump, and a condition of minimum eccentricity and displacement (Fig. 2). Between stator 11 and body 10 there is formed a chamber 15 balancing the radial thrusts exerted on stator 11 because of the hydraulic pressure acting on the arc of the wall of chamber 12 corresponding to the balancing chamber. Balancing chamber 15 is defined by gaskets 16, 17 and it communicates with the devices utilising the pumped fluid, in particular with the lubrication circuit of the engine or the drive system of a motor vehicle.

Stator 11 is configured as a multistage rotary piston for displacement regulation, directly driven by pressurised fluid coming for instance from the devices utilising the pumped fluid (for instance, from a point of the lubrication circuit located downstream the oil filter). In the illustrated embodiment, the rotary piston has a pair of actuation stages (or surfaces) formed by portions 19, 20 of the external surface of stator 11. Said stages are exposed to the action of the pressurised fluid introduced into chambers 21, 22, where portions of the stator surface adjacent to actuation surfaces 19, 20 move in fluid-tight manner. Reference numerals 33, 34 denote ducts through which the regulation pressures act on stages 19, 20. Possible further stages can be formed in lightening chambers formed in stator 11, as disclosed in WO 2013/140304.

In the illustrated example, stages 19, 20 are formed so that the pressure applied to stage 19 generates a force F1 in turn arranged to generate a torque causing stator rotation towards the minimum displacement position against the action of an opposing member 23 (in particular a helical spring), and so that the pressure applied to stage 20 generates a force F2 generating an antagonistic torque concordant with the torque generated by a force F3 due to the reaction of spring 23. For the sake of easiness of description, the torques generated by F1, F2, F3 will also be referred to hereinafter as torque 1, torque 2 and torque 3.

Spring 23 is preloaded so as to prevent the rotation of stator 11 - and hence to keep it in the position shown in Fig. 1 - as long as the resultant of the pressures applied to stages 19, 20 is lower than a predetermined threshold, and to subsequently keep the pump displacement at the value corresponding to the pressure threshold. Such a condition is attained when an equilibrium is established between torques 1, 2 and 3.

Spring 23 has a longitudinal axis 28 (Figs. 3, 4) which does not cross rotation axis 18 of stator 11, and is located in a seat 24 formed in body 10. Its end loops 23A, 23B, suitably arranged close to one another and preferably tapered, abut against flat end surface 24A of seat 24 and on a flat portion 25 of the external surface of stator 11, respectively.

Planes 24A, 25 have formed thereon centring projections 26, 27 engaging end loops 23A, 23B of spring 23. Such projections are aimed at maintaining end loops 23A, 23B univocally positioned and at preventing the spring from "sliding" over planes 24A, 25 because of the radial and/or axial components of the applied forces, should the friction coefficients of the materials of spring 23, body 10 and stator 11 allow such a sliding. In place of the projections, also recesses surrounding loops 23A, 23B might be provided, or a projection might be provided on one side and a recess on the other side. The projections or the recesses may even have non-circular shape.

In the configuration shown by way of example, planes 24A, 25 are formed so that they are mutually parallel when the displacement is minimum, and so that they define a certain angle under all other conditions, said angle being maximum in the maximum displacement condition. Spring 23 will have therefore a minimum (substantially zero) deformation and a substantially rectilinear axis in the minimum displacement condition, and will attain the maximum deformation in the maximum displacement condition. Advantageously, in the deformed condition, the behaviour of the spring axis can be defined by a polynomial of third degree.

It will be appreciated that centring elements 26, 27 are the only elements retaining spring 23 and that, since they cooperate only with the end loops, they have no guiding function. The remaining portion of the spring therefore can freely deform itself during the rotation of stator 11. In this way, force vector F3 applied to plane 25 at the centre of element 27 creates a non-linear counter-motive torque since, as clearly shown in Figs. 3 and 4, the force and its application arm b3 (distance from rotation axis 18 of stator 11) change as stator 11 is rotates. In particular, in the maximum displacement condition (Fig. 3), force F3 is the resultant of the components of the whole of the radial and tangential forces acting on plane 25 and has smaller intensity and arm than in the minimum displacement condition (Fig. 4), where the vector is perpendicular to plane 25.

Such conditions are gradually attained, without any friction due to the spring.

The counter-reaction to the forces generated by spring 23 in turn is discharged at the centre of centring element 26 (Figs. 1, 2), orthogonally to plane 24A.

It is to be taken into account that, in order spring 23 correctly operates, it is necessary to prevent unwanted side "drifts" making the spring strike against the axial sides of seat 24. In other words, the deformation must be such that, in the deformed condition, the curve described by the axis remains in a plane transversal to axis 28. This is obtained through a suitable choice of the ratio between the diameter and the free length of spring 23 and of the angle between planes 24A, 25 in the maximum deformation condition. More particularly, the tests carried out have shown that the diameter-to-length ratio of spring 23 must be in the range 1 to 5, and preferably in the range 1 to 3.8, and that the angle between the planes must be in the range from about 10° to about 30°, and preferably of the order of 20°. Also the diameter of the wire cooperates to the definition of such a ratio.

Provided that such general indications are to be met, for a given application the characteristics of spring 23 will depend on the pump displacement, on the difference between the maximum and the minimum displacement, on the regulating pressure, and, in case of a rotary pump, on the driving geometry of rotor 13.

Turning back to displacement regulation stages 19, 20, chamber 21 is directly supplied with pressurised oil through a branch 33A of outlet duct 33 of oil filter 32, whereas chamber 22 is supplied through a spool valve 40 modulating the displacement regulation pressure, said valve communicating with chamber 22 through a duct 34.

In spool valve 40, spool 41, movable against the action of an opposing spring 46, defines a first annular chamber 42, it too connected to duct 33 (branch 33B), and a second annular chamber 43, where duct 33 ends and which communicates, depending on the position of spool 41, either with the first annular chamber 42 or a third annular chamber 44. The latter in turn may communicate with a non-pressurised portion of circuit 30, in particular with oil sump 35. A fourth annular chamber 45 is also supplied with pressurised oil from duct 33 (branch 33C). Spool 41 further has a first end portion 41A onto which spring 46 is guided, whereas the opposite end portion 41B slides in fluid-tight manner within a further chamber 47. Depending on the command provided by an electrically-controlled valve 50 (which, in this example, is an on-off valve), spool 41 may be positioned so as to let pressurised oil from branch 33D of duct 33 (Fig. 2) pass into chamber 47, or to intercept such oil, making chamber 47 discharge towards oil sump 35 (Fig. 1).

The operation of the described pump is as follows.

Under rest conditions, the pump is in the condition shown in Fig. 1. Rotor 15 is off axis relative to cavity 12 of stator 11 and is located close to the wall of cavity 12. Electrically-controlled valve 50 is not actuated, so that no pressure exists in chamber 47 and spring 46 of spool valve 40 pushes spool 41 completely to the right. Thus, chambers 42 and 43 communicate with each other and with chamber 22 of pump 1. Chamber 44 is isolated and permanently communicates with the drain (oil sump 35).

When pump 1 is started, the rotation of rotor 13 will give rise, in wholly conventional manner, to a flow of pressurised oil towards balancing chamber 15 and lubrication system 30 of engine 31. As the rotation speed and the flow rate increase, lubrication system 30 of the engine, by opposing an increasing resistance to the flow, will make the pressure in duct 33 increase.

Such a pressure, brought to chamber 21 through branch 33A, acts on the first stage

19, thereby creating a hydraulic thrust on stator ring 11 and generating, by means of force F1, torque 1 opposed by torque 3 generated by reaction force F3 of spring 23. The pressurised oil arrives also to chamber 22 in the pump through branch 33B of duct 33, chambers 42, 43 of valve 30 communicating with each other and duct 34, and, by acting on surface 20, generates, due to force F2, the antagonistic torque (torque 2) concordant with torque 3. Under these conditions, the pressures in both chambers 21, 22 are equivalent and the direction of action of resultant F1 - F2 will depend on the difference between the areas of surfaces 19, 20. In the illustrated example, taking into account that surface 19 has a greater area than surface 20, F1 > F2 and resultant F1 - F2 will act in counterclockwise direction.

Moreover, through branch 33C, pressurised oil is supplied to chamber 45 of valve 40 thereby applying, onto an annular surface 41C of spool 41 defining such a chamber, a force opposing the force generated by spring 46. When this opposing force exceeds the preload of spring 46, spool 41 begins moving to the left, thereby progressively shutting communication between chambers 42, 43 and progressively establishing communication between chambers 43, 44, and hence with oil sump 35, until a condition of equilibrium between the forces acting on the spool itself and the reaction of spring 46 is attained. Thus, a certain reduction in the pressure applied to stage 20, and hence of torque 2, takes place.

When the oil pressure is such that torque 1 - torque 2 > torque 3, stator 11 will rotate counterclockwise thereby reducing its eccentricity relative to rotor 13, and consequently the pump displacement. Such a pressure value, referred to as "maximum regulated pressure value", will be substantially maintained even as the rotation speed of the pump and the permeability of the engine (intended as the amount of oil used by the engine) vary.

When a suitable command arrives from the electronic control unit (not shown) of the vehicle, electrically-controlled valve 50 passes to the position shown in Fig. 2, where it supplies chamber 47 with pressurised oil. When the force due to the joint pressure of the oil introduced into chambers 45 and 47 exceeds the force exerted by spring 46, it causes spool 41 to move completely to the left, whereby pump chamber 22 discharges oil to sump 35 through chambers 43, 44 of valve 40 and thus passes to atmospheric pressure. Torque 2 becomes therefore 0 and the only torque opposing torque 3 is torque 1. Such a condition is referred to as "minimum regulated pressure value". Also in this case spool 41 will take an equilibrium position depending on the oil pressure conditions in duct 33 and on the reaction force of spring 46.

The invention actually attains the desired aims. Thanks to the provision of the torque generated by F2, that adds to the torque generated by force F3 due to opposing spring 23, the force exerted by the latter to keep the equilibrium pressure can actually be reduced and, in the minimum pressure condition, actuation will be due only to the pressure applied to the first stage 19. Moreover, modulating the pressure applied to the second stage 20 by means of spool valve 40 makes actuation simple and stable. Lastly, the provision of non-guided opposing spring 23 reduces friction and hysteresis between the two directions of displacement regulation.

It is clear that the above description is given only by way of non-limiting example and that changes and modifications are possible without departing from the scope of the invention.

For instance, even if it has been assumed that electrically-controlled valve 50 is an on-off valve, a proportional electrically-controlled valve could however be used for modulating the decrease and/or the increase of the driving pressure supplied by spool valve 40 (an hence the decrease or the increase of the pressure in chamber 22), thereby allowing a possible electronic management resulting from the engine "mapping".

Moreover, even if there has been disclosed in detail a pump where displacement regulation is performed through a rotation of the stator about an axis internal to the stator itself and said rotation is directly driven by the pressure of the pumped fluid, the invention can be applied also to pumps where the rotation of the stator is indirectly driven by said pressure, or to pumps where the displacement regulation movement is different from the stator rotation illustrated here (so-called "pendulum" pumps, pumps with a rocking or oscillating stator, pumps with a stator translation, and so on). Moreover, even if a vane pump has been illustrated, the invention can be applied also to pumps with a rotor of different kind, e.g. a gear rotor (for instance G-rotor or split G-rotor) or to non-rotary pumps, for instance pumps with pistons operated by a rotating plate with variable inclination.

Patent claims

1. A variable displacement pump for fluids, comprising:

- a regulation ring or stator (11) arranged to move, in response to operating conditions of the pump (1), between two extreme positions corresponding to a maximum displacement and a minimum displacement, respectively, of the pump; and
- a spring (23) opposing the movement of the regulation ring (11);

wherein the regulation ring (11) has at least a pair of actuation stages (19, 20) having mutually differing surfaces, a first of said actuation stages (19) being permanently exposed to pressure conditions of the pumped fluid and being arranged to make the regulation ring (11) move against the action of the spring (23), and a second of said actuation stages (20) being arranged to act concordantly with the spring (23) in a manner controlled by an electrically-controlled valve (50);

characterised in that:

- a spool valve (40) is connected between the second stage (20) and the electrically-controlled valve (50) and is arranged to modulate a regulation pressure acting on the second stage (20) depending on a control signal supplied by the electrically-controlled valve (50) and on the pressure conditions of the pumped fluid.

2. The pump as claimed in claim 1, characterised in that the spool valve (40) includes a distributor arranged to:

- take, depending on the control signal, at least a first and a second extreme configuration in correspondence of the maximum displacement and the minimum displacement of the pump, respectively;
- expose the second stage (20) to the same pressure conditions as those acting on the first stage (19) in the first extreme configuration, and to atmospheric pressure conditions in the second extreme configuration, and to modulate the pressure acting on the second stage when the pressure of the pumped fluid reaches, while increasing or decreasing, respectively, a threshold pressure set for the intervention of members (46) opposing a movement of a movable element (41) of the distributor.

3. The pump as claimed in claim 2, characterised in that the electrically-controlled valve (50) is an electrically-controlled valve with on-off operation.

4. The pump as claimed in claim 2, characterised in that the electrically-controlled valve (50) is an electrically-controlled valve with proportional operation and the distributor is arranged to take, depending on the control signal, also a plurality of intermediate configurations in each of which it is arranged to modulate the pressure acting

on the second stage when the pumped fluid reaches the threshold pressure.

5. The pump as claimed in any one of claims 2 to 4, characterised in that the spool valve (40) is configured so that the spool (41) is arranged to define:

- a first chamber (42) permanently communicating with a duct (33) in which the pumped fluid is present;
- a second chamber (43) permanently communicating with a chamber (22) of the pump (1) in which the second actuation stage (20) moves, and also communicating with the first chamber (42) in the first extreme configuration;
- a third chamber (44) arranged to communicate only with a region at atmospheric pressure (35) in the second extreme configuration, and to simultaneously communicate with the second chamber (43) and the region at atmospheric pressure (35), in a manner depending on the position of the spool (41), in valve configurations other than the extreme configurations;
- a fourth chamber (45), also permanently communicating with said duct (33); and
- a fifth chamber (47), arranged to be put in communication by the electrically-controlled valve (50) either with said duct (33), in the first extreme configuration, or with the region at atmospheric pressure (35), in the second extreme configuration.

6. The pump as claimed in any one of preceding claims, characterised in that the spring (23) is a helical spring having end loops arranged to cooperate with centring and transversally retaining members (26, 27) associated with the regulation ring (11) and with a pump body (10), and having an intermediate portion freely deformable during the movement of the regulation ring.

7. The pump as claimed in any one of preceding claims, characterised in that the pump (1) is a pump for a lubrication circuit (30) of an engine (31) and/or a drive system of a motor vehicle.

8. A method of regulating the displacement of a variable displacement pump for fluids (1), comprising the steps of:

- providing a regulation ring or stator (11) arranged to move, in response to pressure conditions of a pumped fluid (1) and against the action of a spring (23), between two extreme positions corresponding to a maximum displacement and a minimum displacement of the pump, respectively;
- providing in the regulation ring (11) at least a pair of actuation stages (19, 20) having mutually differing surfaces, a first of said actuation stages (19) being arranged to act oppositely to the spring (23), and a second of said actuation stages (20) being arranged

to act concordantly with the spring (23); and

- making said regulation ring (11) move by permanently exposing the first stage (19) to said pressure conditions and by applying a control pressure to the second stage (20) in a manner depending on a control signal;

the method being characterised in that the step of making said regulation ring (11) move further comprises the step of modulating the control pressure to which the second stage (20) is exposed depending on the control signal and the pressure conditions of the pumped fluid.

9. The method as claimed in claim 8, characterised in that the step of modulating the control pressure comprises the steps of:

- interposing, between the second stage (20) and an electrically-controlled valve (50) supplying the control signal, a spool valve (40) responsive to the control signal and the pressure conditions of the pumped fluid;
- making, by means of the control signal, the spool valve (40) take at least a first and a second extreme configuration in correspondence of the maximum displacement and the minimum displacement of the pump, respectively;
- exposing the second stage (20) to the same pressure conditions as those acting on the first stage (19) in the first extreme configuration, and to atmospheric pressure conditions in the second extreme configuration, and modulating the pressure acting on the second stage when the pressure of the pumped fluid reaches a threshold pressure while increasing or decreasing, respectively.

10. The method as claimed in claim 8, characterised in that the step of modulating the control pressure further comprises the steps of making the spool valve (40) take, depending on the control signal, also a plurality of intermediate positions between the extreme positions, and of modulating the pressure applied to the second stage also in each intermediate position, when the threshold pressure is reached.

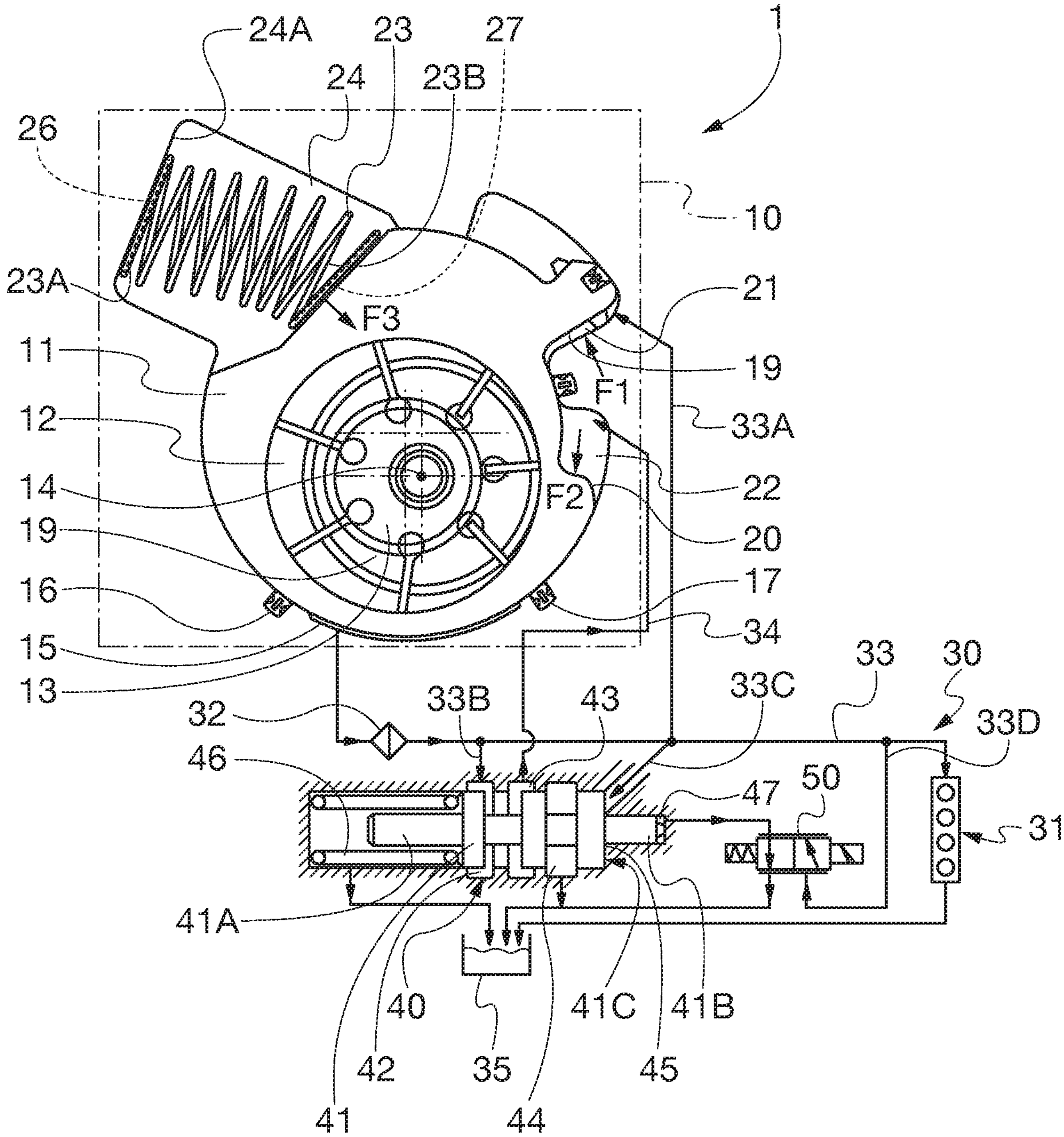
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Fig. 1

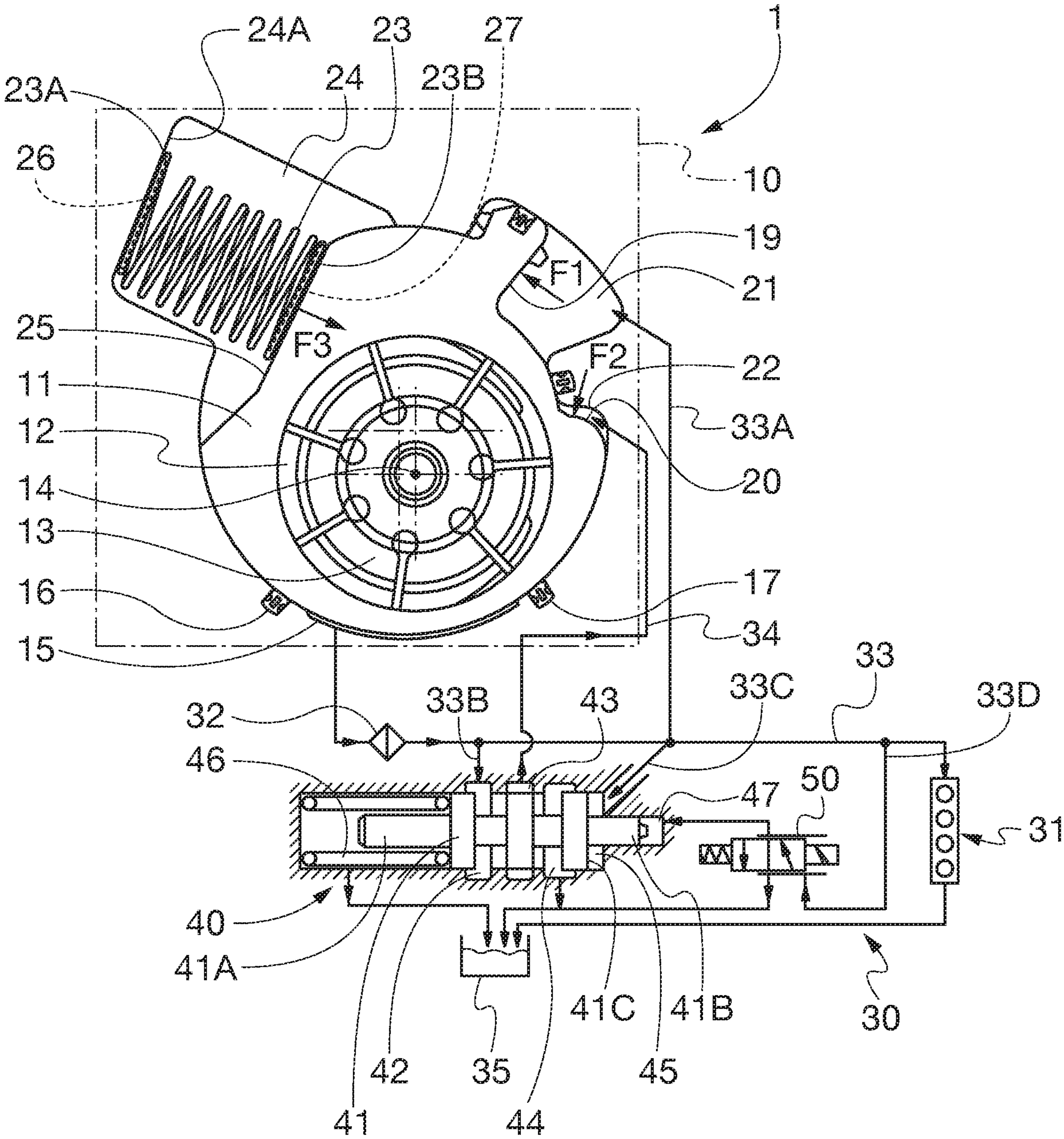
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Fig. 2

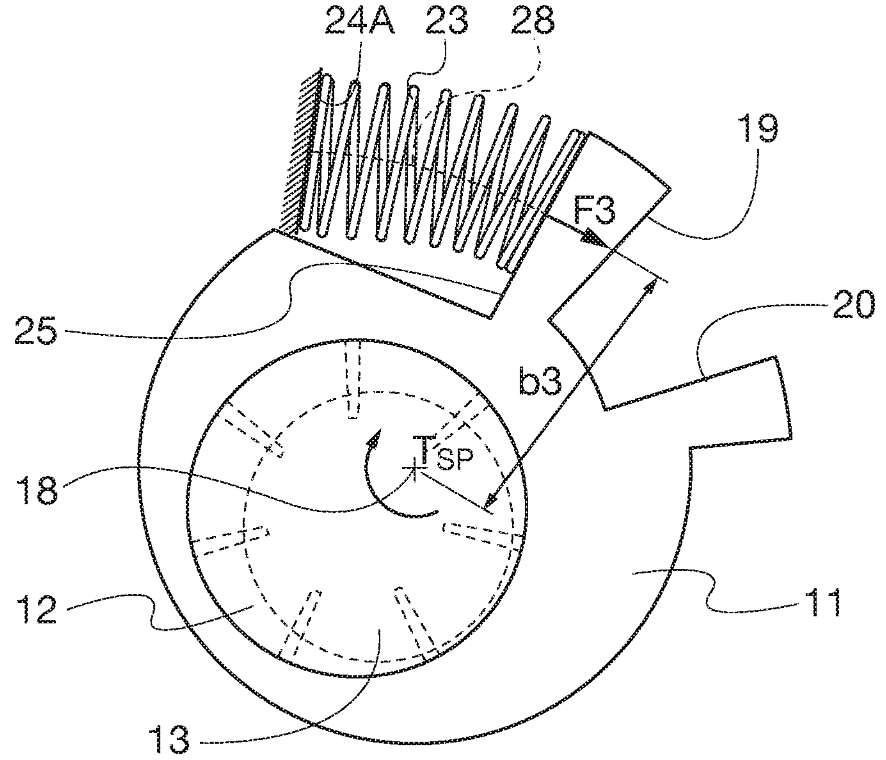
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Fig. 3

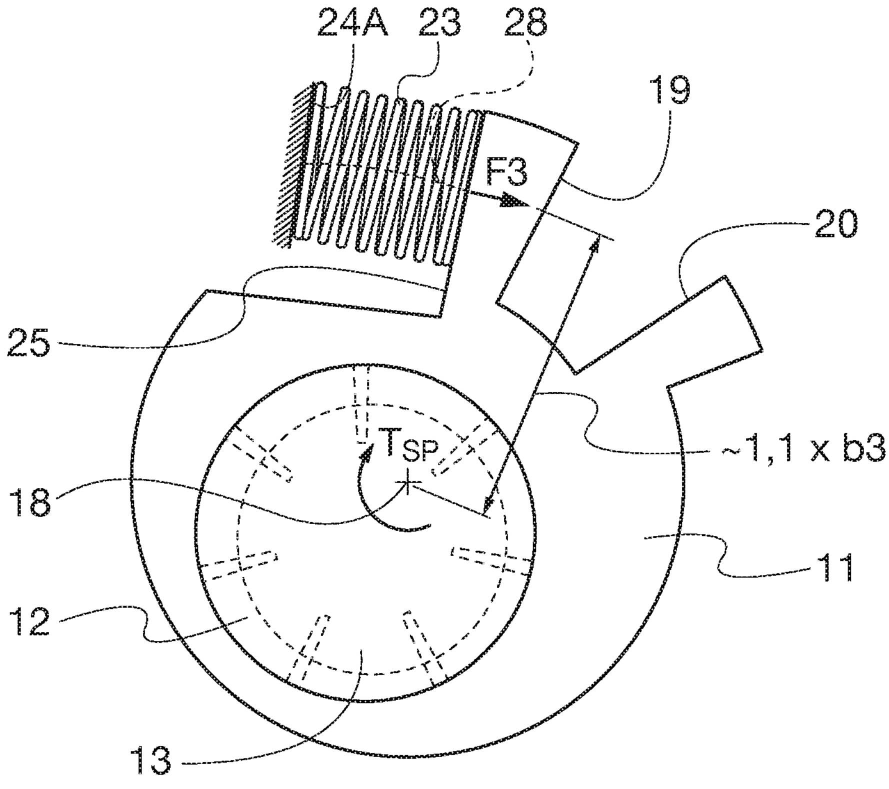
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Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/067211

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04C15/00 F04C2/344 F04C14/22
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04C F01C

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2012/149929 A2 (IXETIC BAD HOMBURG GMBH [DE]; HOLTMANN LUDGER [DE]; VAN NGUYEN DOAN [D) 8 November 2012 (2012-11-08) the whole document figures 2,4 page 7, paragraph 4 - page 8, paragraph 2 -----	1-10

☐ Further documents are listed in the continuation of Box C.

☒ 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
12 March 2015	24/03/2015

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2014/067211

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2012149929 A2	08-11-2012	DE 112012001982 A5	30-01-2014
		WO 2012149929 A2	08-11-2012