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DESCRIPTION

Title

METHOD AND SYSTEM FOR RESTORING CORRECT OPERATION OF A  
PREFEED PUMP OF A PUMP UNIT USED TO FEED FUEL TO AN INTERNAL-  
COMBUSTION ENGINE

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The present invention relates to a method and a corresponding system for restoring correct operation and preventing irreversible seizing in a prefeed pump of a pump unit used to feed fuel, preferably diesel, to an internal-combustion engine.

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In particular, the present invention relates to a pump unit including a high-pressure pump, for example a piston pump, that is able to feed fuel to an internal-combustion engine, and to a prefeed pump, for example a gear pump, that is able to draw the fuel from a tank and to feed the fuel to the high-pressure pump.

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The pump unit is normally provided with a hydraulic circuit with a first branch for connecting the tank to the prefeed pump, a second branch for connecting the prefeed pump to the high-pressure pump, and a third branch for connecting the high-pressure pump to the internal-combustion engine. The hydraulic circuit is also provided with a first filtering device arranged in the first branch to filter the fuel that the prefeed pump draws from the tank and a second filtering device mounted in the second branch to filter the fuel that the prefeed pump feeds to the high-pressure pump.

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Despite the presence of the filtering device upstream of the prefeed pump, a certain quantity of dust and/or waste present in the fuel inside the tank always reaches the prefeed pump, compromising the correct operation of the pump, with harmful consequences on same in terms of wear or even irreversible seizing. Furthermore, the abrasive wear caused by friction of the internal components of

the prefeed pump produces hard particles that could also cause the irreversible seizing of the pump.

5 The purpose of the present invention is to provide a pump unit to feed fuel to an internal-combustion engine that is robust against contamination from dust and/or waste present in the fuel and/or from hard particles generated by abrasive wear inside the pump unit, while also being simple and cheap.

10 The present invention provides a method and a system for restoring correct operation of a prefeed pump of a pump unit used to feed fuel, preferably diesel, to an internal-combustion engine, as defined in the attached claims.

The present invention is described below with reference to the attached drawings, which show a non-limiting example embodiment of same, in which:

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- Figure 1 is a schematic representation of a pump unit and the system for restoring correct operation of the prefeed pump of the pump unit, implemented according to the present invention,

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- Figure 2 is an exploded view of a detail of the pump unit in Figure 1,

- Figure 3 is a schematic representation of the operating principle of the detail in Figure 2, and

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- Figures 4 and 5 use a more detailed block diagram to show the restoration system in Figure 1 according to two respective embodiments of the invention.

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In Figure 1, reference sign 1 is used to indicate a pump unit as a whole used to feed fuel, preferably diesel, from a tank 2 to an internal-combustion engine 3, in this case a diesel-cycle internal combustion engine for an on- or off-road medium or heavy commercial vehicle. The engine 3 has a manifold 4 for distributing the fuel, commonly referred to using the term "common rail", and a plurality of injectors 5 linked to the manifold 4 and able to spray the fuel into the related combustion chambers (not shown) of the engine 3.

5 The pump unit 1 includes a high-pressure pump 6, in this case a piston pump, that is able to feed the fuel to the engine 3, and a low-pressure prefeed pump 7, in this case a gear pump, that is able to feed the fuel from the tank 2 to the pump 6.

10 The pump 6 includes a plurality of cylinders 8, in this case two cylinders 8, that are formed in a pump body 9 and each engaged slidingly by a respective piston 10. The pistons 10 are moved along the related cylinders 8 by an actuation device 11 of a known type seated inside the pump body 9 with a reciprocating rectilinear motion including an outward stroke, during which the fuel is aspirated into the related cylinders 8, and a return stroke, during which the fuel is compressed inside the related cylinders 8.

15 The pump unit 1 also includes a hydraulic circuit 12 for feeding the fuel, comprising a first branch 13 for connecting the tank 2 to the pump 7, a second branch 14 that connects the pumps 6 and 7 together and extends through the pump body 9 to lubricate the actuation device 11 and that is connected to each cylinder 8 via a related aspiration valve 15, and a third branch 16 that extends  
20 between the pump 6 and the manifold 4 and is connected to each cylinder 8 via a related delivery valve 17.

25 The branch 13 has a filtering device 2a to filter the fuel that the pump 7 draws from the tank 2. The branch 14 has another filtering device 18 for filtering the fuel that the pump 7 feeds to the pump 6, and a dosing solenoid valve 19 that is mounted upstream of the valve 15, in relation to the flow direction 20 of the fuel along the branches 13, 14 and 16, and is movable between a closed position and an open position to selectively control the instantaneous flow rate of the fuel fed to the pump 6 as a function of the values of a plurality of operating parameters of  
30 the engine 3. The filtering device 18 is the main filter of the pump unit 1.

The circuit 12 also has a fourth branch 21 that extends between the manifold 4 and the tank 2 and has a pressure-regulating solenoid valve 22 that cooperates

with the dosing solenoid valve 19 to keep the pressure in the manifold 4 at a desired level.

5 The pump 7 is an electrical gear pump formed by combining a hydraulic unit known as a "gerotor" with a permanent-magnet brushless three-phase electric motor.

10 With specific reference to Figures 2 and 3, the pump 7 includes a pump body 23 divided into two clamshelled parts and a permanent-magnet brushless three-phase electric motor 24 seated inside the pump body 23. The electric motor 24 has an annular stator 25 that is coaxial with an axis 26 and engaged rotatably by an annular rotor 27 to rotate about the axis 26.

15 The aforementioned hydraulic unit of the pump 7 has an external gear, formed by a set of internal teeth 28 of the rotor 27, and an internal gear 29, which is annular and mounted inside the rotor 27 to rotate about an axis 30 (Figure 3) that is parallel to and separate from the aforementioned axis 26 and has a set of external teeth 31 meshed with the set of internal teeth 28 such that the internal gear 29 is driven by the rotation of the rotor 27 in the same direction of rotation 20 35 (Figure 3).

25 The two sets of teeth 28 and 31 are formed to define a plurality of chambers 32 of variable volume that are distributed about the axis 26, meshed fluidtightly together, and linked hydraulically in part by a fuel inlet 33 into the pump 7 and in part by a fuel outlet 34 from the pump 7. The volume of the chambers 32 associated with the inlet 33 increases in the direction of rotation 35 such as to aspirate the fuel into the pump 7 and the volume of the chambers 32 associated with the outlet 34 reduces in the direction of rotation 35 such as to compress and expel the fuel from the pump 7.

30 Again with reference to Figure 1, the pump unit 1 has an electronic pump control unit 36 that is able to control the electric motor 24 of the pump 7 and to communicate, via a one- or two-wire communication bus 37, with an electronic engine control unit 38 that is able to control operation of the internal-combustion

5 engine 3. In particular, the engine control unit 38 provides the pump control unit 36 with a reference value VR for the speed of the electric motor 24 and the pump control unit 36 controls the supply current of the electric motor 24, i.e. the phase current IS, such that the actual speed of the electric motor 24 depends on the reference value VR.

10 The pump control unit 36 and the engine control unit 38 are also configured to define, together, the system according to the present invention for restoring correct operation of the pump 7 in response to an unexpected increased in the mechanical torque required by the pump 7 caused by dust and/or waste from fuel imperfectly filtered by the filtering device 2a and/or particles caused by abrasive wear due to friction between components of the pump 7 which are deposited on the teeth 28 and 31 of the pump 7 and/or in the axial space between the gears 28 and 29 and the pump body 23.

15 In particular, the pump control unit 36 is able to measure the phase current IS and to provide the engine control unit 38 with a signal IM indicating the measured values of the phase current IS. The engine control unit 38 compares the measured current with the threshold current value IST, which represents the maximum phase current in full operation, and commands a temporary inversion of the direction of rotation of the pump 7 if the measured current exceeds the threshold current value IST.

20 With reference to Figure 4, the pump control unit 36 has a three-phase inverter 39, i.e. one including three half-H bridges and three output phases 39c, to control the electric motor 24 in a known manner, a microcontroller 40 configured to control the inverter 39 using a PWM signal that is a function of the reference value VR and that produces a block switching of the phases, and a shunt resistor 41 connected between the low common terminal 39a of the three half-H bridges and the reference terminal 39b of the power supply voltage of the inverter 39, indicated with VDC, to produce a signal IS' indicating the phase current IS. The shunt resistor 41 is coupled directly to the input 40a of an analogue-to-digital converter (not shown) of the microcontroller 40 to enable this latter to acquire values for the signal IS', which represents the phase current IS, less a coefficient

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of scale that depends on the value of the shunt resistor 41. The microcontroller 40 is designed to convert the values of the signal IS' into the signal IM, which can be transmitted over the communication bus 37. Consequently, the shunt resistor 41 enables the stator current IS to be measured.

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The microcontroller 40 controls the inverter 39 to adjust the phase current IS such that the actual speed of the rotor 27 depends on the reference value VR. To perform this control, the microcontroller 40 calculates the actual speed of the rotor 27 as a function of the angular position of the rotor 27 and determines this angular position from the counter electromotive force induced in the windings of the stator, the counter electromotive force being measured using known techniques.

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In use, the engine control unit 38 obtains measured phase current values from the signal IM and compares them with the threshold current value IST. If the threshold value IST is exceeded, the engine control unit 38 generates a warning signal WS that commands the temporary inversion of the direction of rotation of the electric motor 24 using the following sequence of sub-steps: stopping rotation of the electric motor 24, inverting the direction of rotation of the electric motor 24 for a given number of revolutions REV and gradually returning rotation of the electric motor 24 to the previous direction and speed.

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The temporary inversion of the direction of rotation is controlled by adjusting the reference value VR for the speed of the electric motor 24.

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The reference value VR during normal operation of the pump 7 is equal to the positive first value VR1, which is substantially between 1000 and 8500 rpm. Stopping rotation is commanded by adjusting the reference speed VR to zero. Inversion of the direction of rotation is commanded by adjusting the reference speed VR to a negative second value VR2, the absolute value of which is substantially between 1000 and 8500 rpm. The value VR2 is maintained for a number of revolutions equal to the number REV, which is relatively low to prevent commencement of a fuel flow from the pump 6 to the tank 2, and is between 5 and 10. The number of revolutions REV depends on the degree of precision of

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the microcontroller 40. For example, the number of revolutions REV is determined as a function of the lower pressure limit in the delivery branches 16.

5 In particular, the microcontroller 40 counts the number of revolutions of the electric motor 24 during inversion of the direction of rotation by monitoring the angular position of the rotor 27. As mentioned above, the angular position of the motor is determined by the counter electromotive force induced in the windings of the stator. When the number of revolutions in the inverse direction (speed VR2) reaches the number REV, the microcontroller 40 communicates the event to the  
10 engine control unit 38 using a signal REVOK. At this point, the engine control unit 38 adjusts the reference speed VR using a linear time slope that runs from the second value VR2 to the first value VR1.

15 The threshold current value IST is predetermined and saved in an internal memory of the engine control unit 38. According to a variant of the invention, the threshold current value IST is determined using a self-learning algorithm implemented by the engine control unit 38.

20 Experimentation has confirmed the following analytical assumptions: at constant temperature, it is known that the mechanical torque required by the hydraulic unit of the pump 7 is a linear function of the pressure difference  $\Delta P$  between the inlet and outlet of the pump 7, of the drag torque caused by mechanical friction between the cogs 28 and 31, and of the speed of the rotor 27. In other words, the mechanical torque required comprises a torque component attributable to the  
25 pressure difference  $\Delta P$  and a torque component attributable to mechanical friction and other viscous friction. Furthermore, it is known that the average mechanical torque supplied by the electric motor 24 is proportional to the root-mean-square value of the phase current IS. It follows that, in full operation, i.e. when the speed of the rotor 27 is constant at the reference value VR, the root-mean-square value of the phase current IS is a linear function of the pressure  
30 difference  $\Delta P$  and of the drag torque.

Consequently, the increase in the phase current IS beyond the threshold value IST may have substantially two causes: an increase in the pressure difference  $\Delta P$

and an increase in mechanical friction. A high pressure difference  $\Delta P$  indicates a degree of clogging of the filtering device 18. An increase in mechanical friction indicates the presence of dust and/or waste from the fuel and/or hard particles caused by abrasive wear that have been deposited on the teeth 28 and 31 of the pump 7 and/or in the axial space between the gears 28 and 29 and the pump body 23.

The temporary inversion of the direction of rotation of the electric motor 24 makes it possible to purge the pump 7 of any dust and/or waste that has been deposited on the teeth 28 and 31. If, immediately after temporary inversion of the direction of rotation, the measured phase current  $I_S$  is still greater than the threshold value  $I_{ST}$ , it means that the increase in the mechanical torque required by the pump 7 is very probably due to clogging of the filtering device 18, and as a result a further inversion of the direction of rotation is not required. At this point, the warning signal WS activates an emergency operating mode of the motor 3 or, more simply, commands the transmission of a message to the dashboard of the vehicle to replace the filtering device 18.

To avoid unnecessary inversions of the direction of rotation of the electric motor 24, a subsequent inversion is only performed after a given time interval  $T_R$  since the last inversion performed.

According to a variant of the present invention, if, after temporary inversion of the direction of rotation, the measured phase current  $I_S$  is still greater than the threshold value  $I_{ST}$ , then the engine control unit 38 uses the measured current values to determine corresponding pressure difference values on the basis of empirical data previously stored in a memory in the engine control unit 38, and compares these pressure difference values with a predetermined pressure threshold value. If the pressure threshold value is exceeded, then the engine control unit 38 generates the warning signal WS, which is then used to activate the aforementioned emergency operating mode of the motor 3 or to send the message to replace the filtering device 18.



According to another embodiment of the present invention illustrated in Figure 5, in which the corresponding elements are indicated using the same reference signs and abbreviations as in Figure 4, the pump control unit 36 differs from the one illustrated in Figure 4 in that the microcontroller 40 is designed to control the inverter 39 through sinusoidal switching of the phase and in that it includes, instead of the shunt resistor 41, three shunt resistors 43, each of which is connected in series between a respective output phase 39c of the inverter 39 and a respective stator input 24a of the electric motor 24 to produce the respective signal IS", which represents the phase current IS less a coefficient of scale depending on the value of the shunt resistors 43. The shunt resistors 43 are coupled directly to respective inputs 40b of the analogue-to-digital converters (not illustrated) of the microcontroller 40 to enable this latter to acquire values for the signal IS".

The main advantage of the pump unit described above is to ensure the correct operation of the prefeed pump 7 in the presence of contamination from dust and/or waste that is deposited on the mechanical moving components using the temporary inversion of the direction of rotation of the pump 7, at least partially compensating for the limited filtering capacity of the filtering device 2a arranged upstream of the pump 7. Indeed, the filtering capacity of the filtering device 2a must not be too high, i.e. the filtering mesh must not be too fine (typically less than 100  $\mu\text{m}$ ), otherwise it would cause high pressure drops in the connection branch 13 with the tank 2, resulting in cavitation and subsequent erosion of the components of the pump 7.

Another advantage of the pump unit described above is to provide self protection of the prefeed pump 7 from hard particles produced by abrasive wear caused by friction between the components of the pump 7.

CLAIMS

- 5 1. Method for restoring the correct operation of a prefeed pump of a pump unit (1) used to feed fuel, preferably diesel, to an internal-combustion engine (3), the pump unit (1) having a high-pressure pump (6) used to feed the fuel to the internal-combustion engine (3) and said prefeed pump (7) being able to draw the fuel from a tank (2) before feeding same to the high-pressure pump (6) and comprising an electrical gear pump, which has a pair of meshed gears (28, 29), a  
10 permanent-magnet brushless three-phase electric motor (24) used to drive the two gears (28, 29) and an electronic pump control unit (36) that can control said electric motor (24) and to communicate with an engine control unit (38) of the internal-combustion engine (3), the method comprising:
- 15 - measuring the phase current (IS) of the electric motor (24) using current measurement means (41, 43) related to the electronic pump control unit (36), and
- using the engine control unit (38) to temporarily invert the direction of rotation of the electric motor (24) if the measured phase current (IS) exceeds a  
20 predetermined threshold current value (IST), in order to purge the prefeed pump (7) of any dust and/or waste in the fuel and/or of any particles caused by abrasive wear that have been deposited in the pair of gears (28, 29) or in the axial space between said gears (28, 29).
- 25 2. Method according to Claim 1, characterized in that the direction of rotation of said electric motor (24) is inverted for a predetermined number of revolutions (REV) to prevent commencement of a fuel flow from said high-pressure pump (6) to said tank (2).
- 30 3. Method according to Claim 1 or 2, characterized in that the temporary inversion of the direction of rotation of the electric motor (24) entails, in the following order:

- when the measured phase current (IS) exceeds said threshold current value, stopping the rotation of the electric motor (24),

5 - inverting the direction of rotation of the electric motor (24) for a certain number of revolutions (REV), and

- gradually returning the electric motor (24) to the previous direction of rotation.

10 4. Method according to one of Claims 1 to 3, characterized in that said engine control unit (38) provides said pump control unit (36) with a reference speed (VR) for the electric motor (24), the temporary inversion of the direction of rotation of the electric motor (24) being controlled by adjusting said reference speed (VR) if the measured phase current (IS) exceeds said threshold current value (IST).

15 5. Method according to Claim 3, characterized in that said engine control unit (38) provides said pump control unit (36) with a reference speed (VR) for the electric motor (24), said reference speed (VR) usually being equal to a first speed value (VR1), rotation of the electric motor (24) is stopped by adjusting the reference speed (VR) to zero, and the direction of rotation of the electric motor (24) is  
20 inverted by adjusting the reference speed (VR) to a second speed value (VR2) having the opposite sign to the first speed value (VR1).

25 6. Method according to Claim 5, characterized in that said electric motor (24) is returned to the previous direction of rotation by adjusting the reference value (VR) according to a linear time slope running from said second speed value (VR2) to the first speed value (VR1).

30 7. Method according to one of Claims 1 to 6, characterized in that said electronic pump control unit (36) has a three-phase inverter (39) with three half-H bridges to control the electric motor (24), said current measurement means including a shunt resistor (41) connected between the low common terminal (39a) of the half-H bridges and the reference terminal (39b) of the power supply voltage (VDC) of the inverter (39) to produce a signal (IS") indicating said phase current (IS).

8. Method according to one of Claims 1 to 6, characterized in that said electronic pump control unit (36) includes a three-phase inverter (39) to control the electric motor (24), said current measurement means having a plurality of shunt resistors (43), each of which is connected between a respective output phase (39c) of the inverter (39) and a respective stator input (24a) of said electric motor (24) to produce a signal (IS") indicating said phase current (IS).

9. System for restoring the correct operation of a prefeed pump of a pump unit (1) used to feed fuel, preferably diesel, to an internal-combustion engine (3), the pump unit (1) having a high-pressure pump (6) used to feed the fuel to the internal-combustion engine (3) and said prefeed pump (7) being able to draw the fuel from a tank (2) before feeding same to the high-pressure pump (6) and comprising an electrical gear pump, having a pair of meshed gears (28, 29), a permanent-magnet brushless three-phase electric motor (24) used to drive the two gears (28, 29), the system comprising an electronic pump control unit (36) that can control said electric motor (24) and includes current measurement means (41, 43) to measure the phase current (IS) of said electric motor (24), and an electronic engine control unit (38) that is able to control the internal-combustion engine (3) and is connected to the pump control unit (36) by a communication bus (37), the engine control unit (38) being configured to implement the method according to one of Claims 1 to 8.

10. System according to Claim 9, characterized in that said electronic pump control unit (36) has a three-phase inverter (39) with three half-H bridges to control the electric motor (24) and a microcontroller (40) to control the inverter (39), said current measurement means including a shunt resistor (41) connected between the low common terminal (39a) of the half-H bridges and the reference terminal (39b) of the power supply voltage (VDC) of the inverter (39) to produce a signal (IS') indicating the phase current (IS), and is coupled directly to an input (40a) of an analogue-to-digital converter of the microcontroller (40) to enable this latter to acquire values for said signal (IS').

11. System according to Claim 9, characterized in that said electronic pump control unit (36) includes a three-phase inverter (39) to control the electric motor

(24) and a microcontroller (40) to control the inverter (39), said current measurement means having a plurality of shunt resistors (43), each of which is connected to a respective output phase (39c) of the inverter (39) and a respective stator input (24a) of said electric motor (24) to produce a signal (IS") indicating said phase current (IS), and coupled directly to a respective input (40b) of an analogue-to-digital converter of the microcontroller (40) to enable this latter to acquire values for said signal (IS").

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ABSTRACT

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Method for restoring correct operation and avoiding irreversible seizing of a prefeed pump of a pump unit for fuel (1) for an internal-combustion engine (3), in which an electronic pump control unit (36) associated with the prefeed pump (7) measures the power supply current (IS) of the related electric motor (24) and the engine control unit (38) temporarily inverts the direction of rotation of the electric motor (24) if the measured phase current (IS) exceeds a predetermined threshold current value (IST) in order to purge the prefeed pump (7) of any dust and/or waste and/or hard particles.

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Main figure: 1



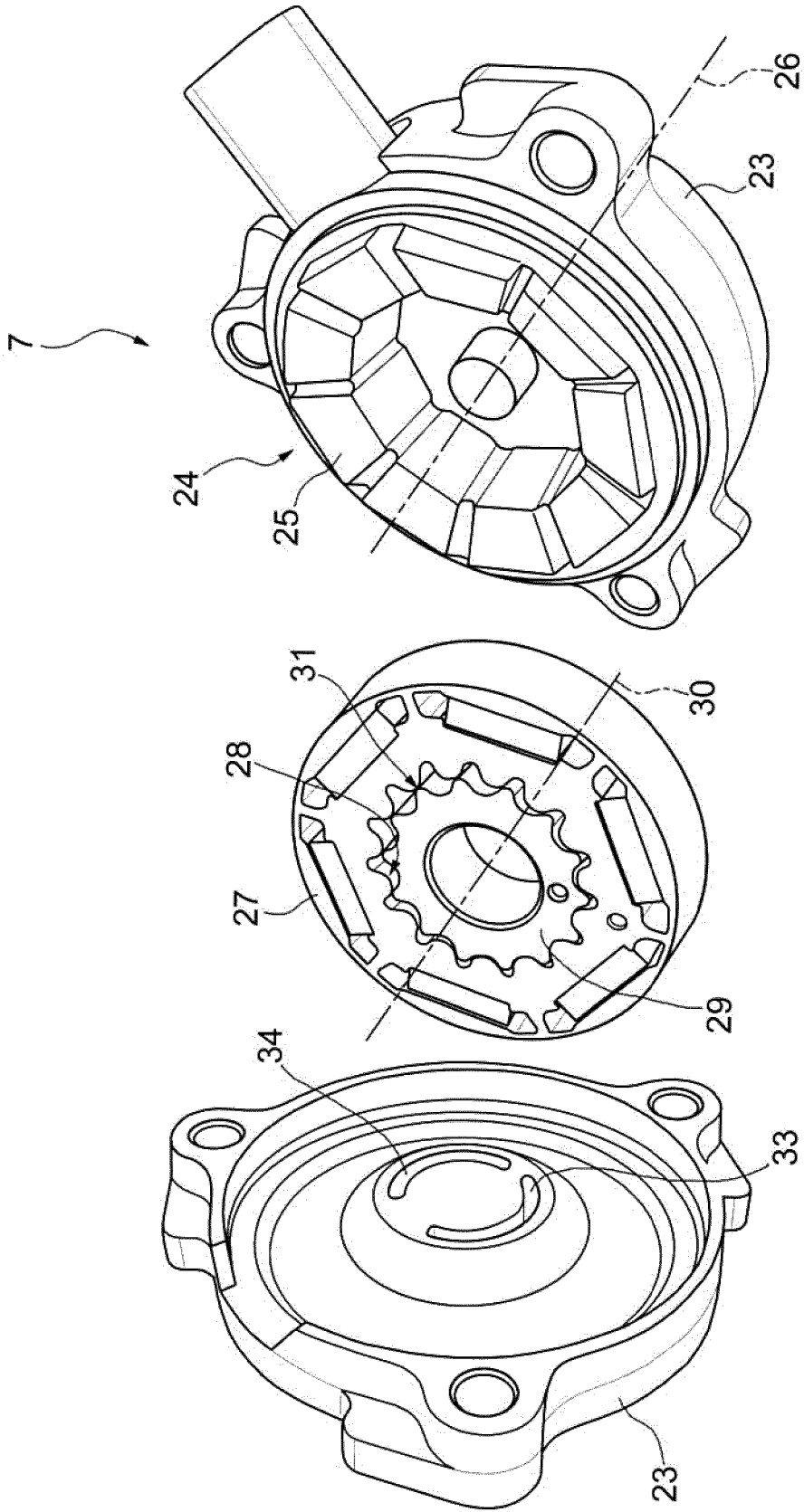


FIG.2



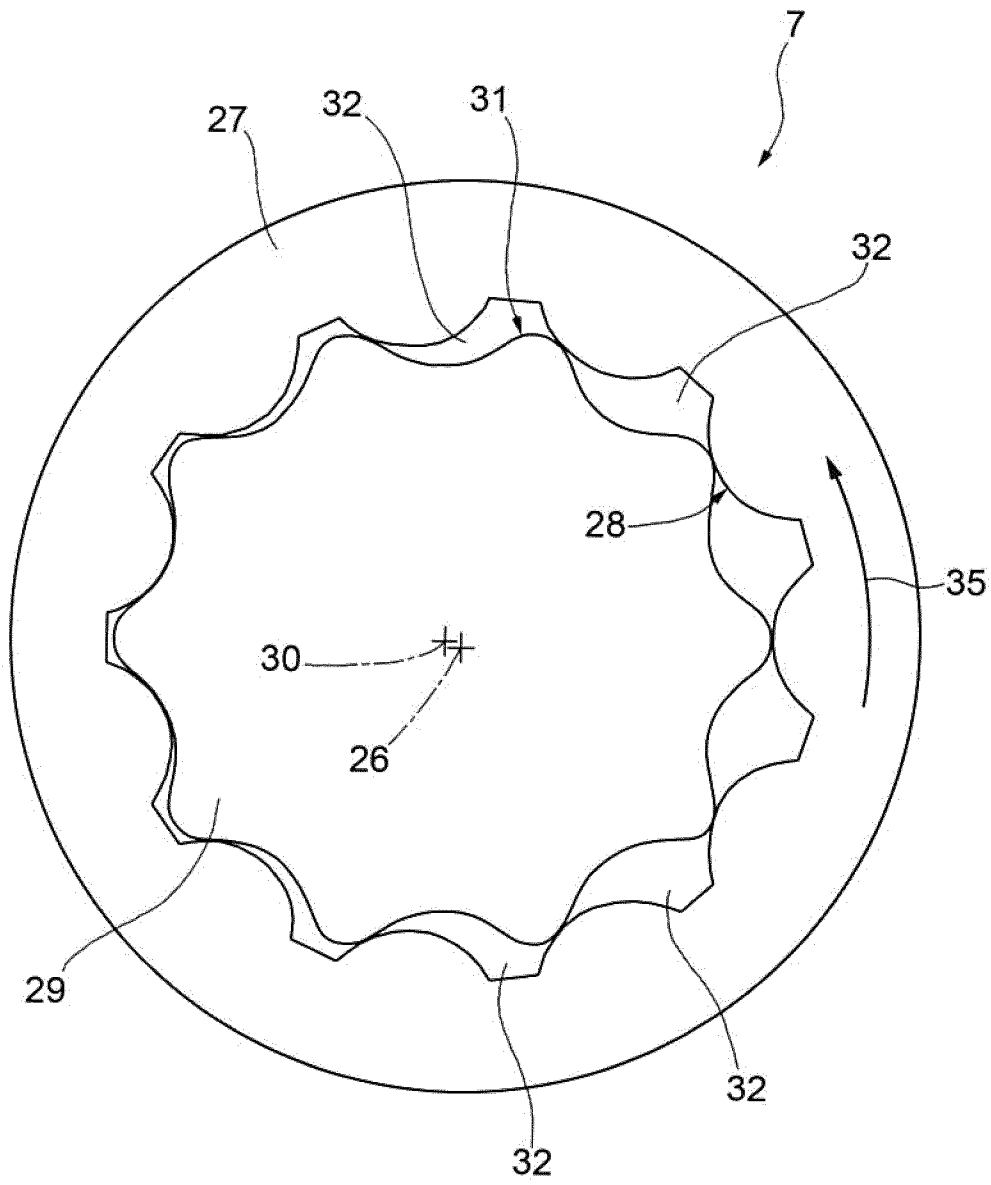


FIG.3

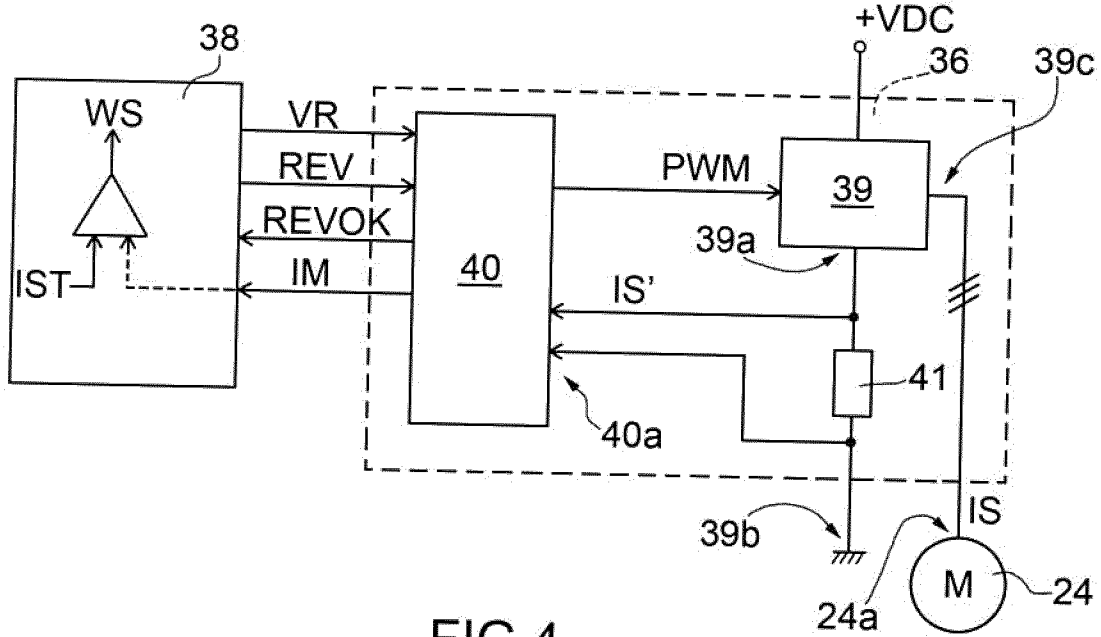


FIG. 4

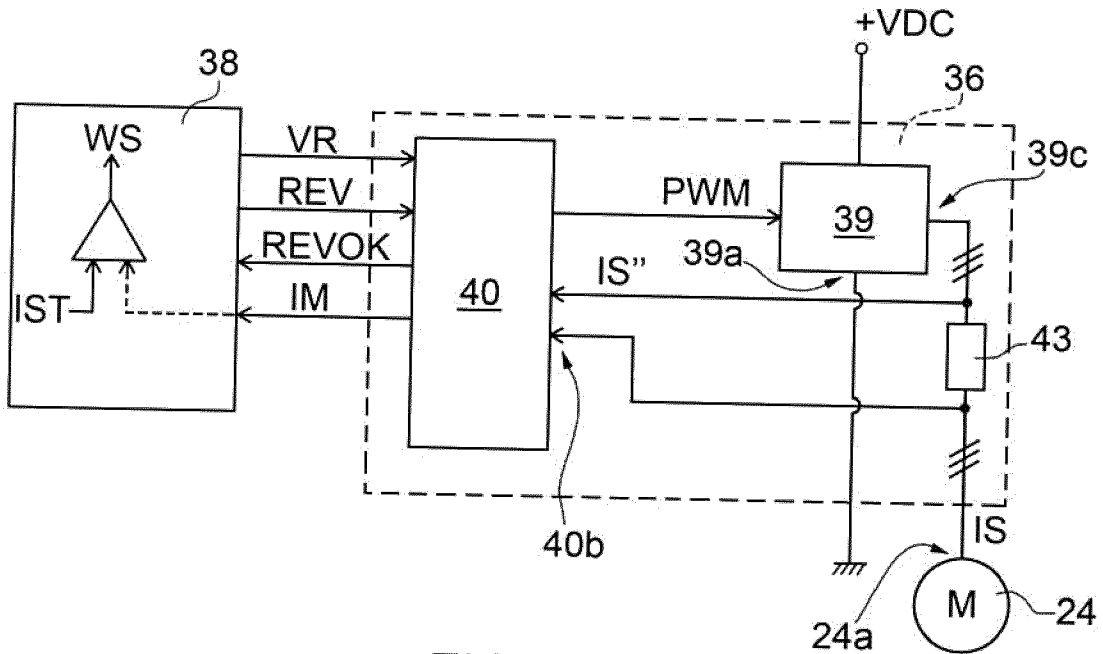


FIG. 5