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(54) METHOD FOR CONTROLLING THE FEED RATE OF A FEED PUMP

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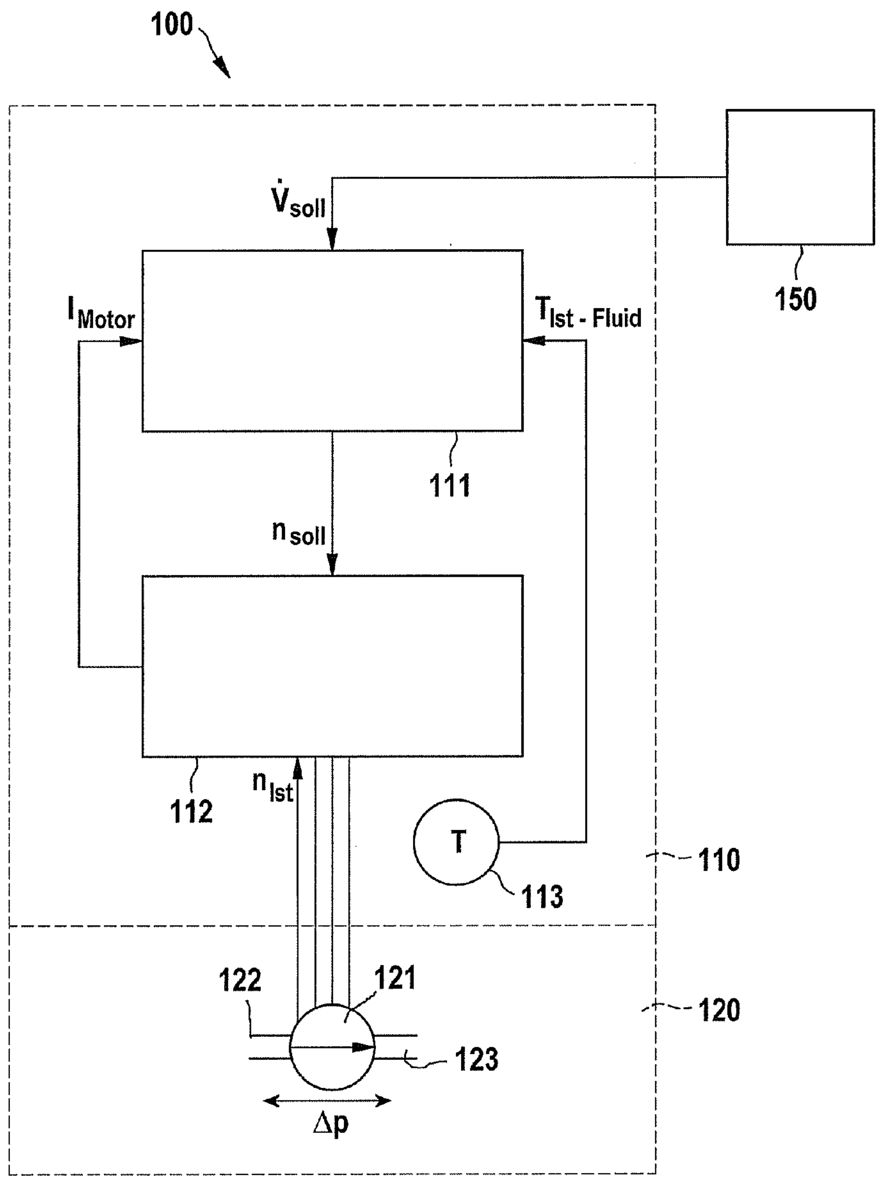
(57) **ABSTRACT**

A method for controlling the feed rate of a feed pump, including a drive part having a drive motor and a hydraulic part having an intake opening, a discharge opening and a feed mechanism situated in between, a setpoint feed rate being predefined and the feed pump being triggered based on the setpoint feed rate, the temperature of the fluid and a pressure difference between the intake opening and the discharge opening of the hydraulic part of the feed pump.



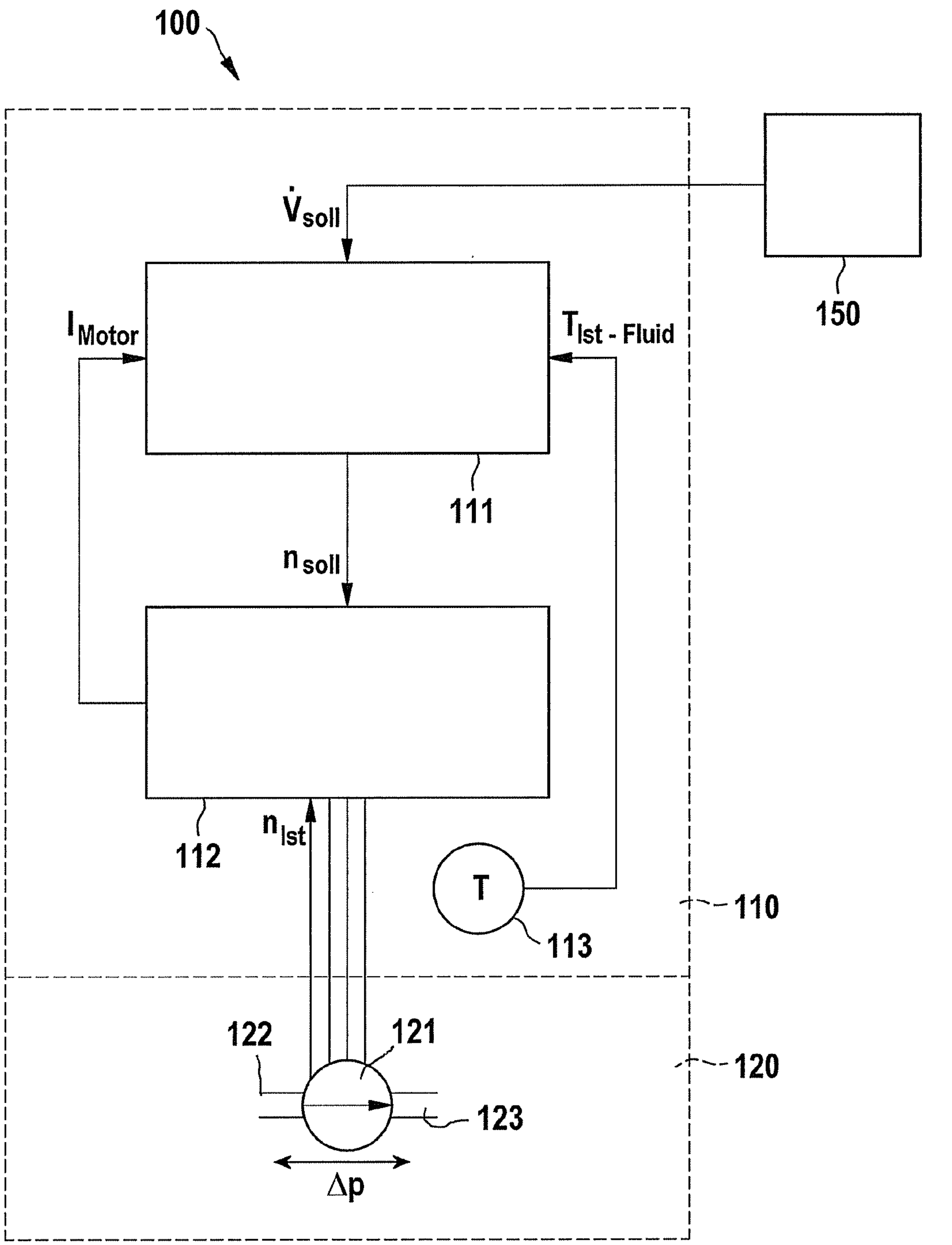

100
150
$\dot{V}_{soll}$
I_{Motor}
$T_{Ist - Fluid}$
111
n_{soll}
112
n_{Ist}
T
113
110
122
121
120
123
Δp

Fig. 1

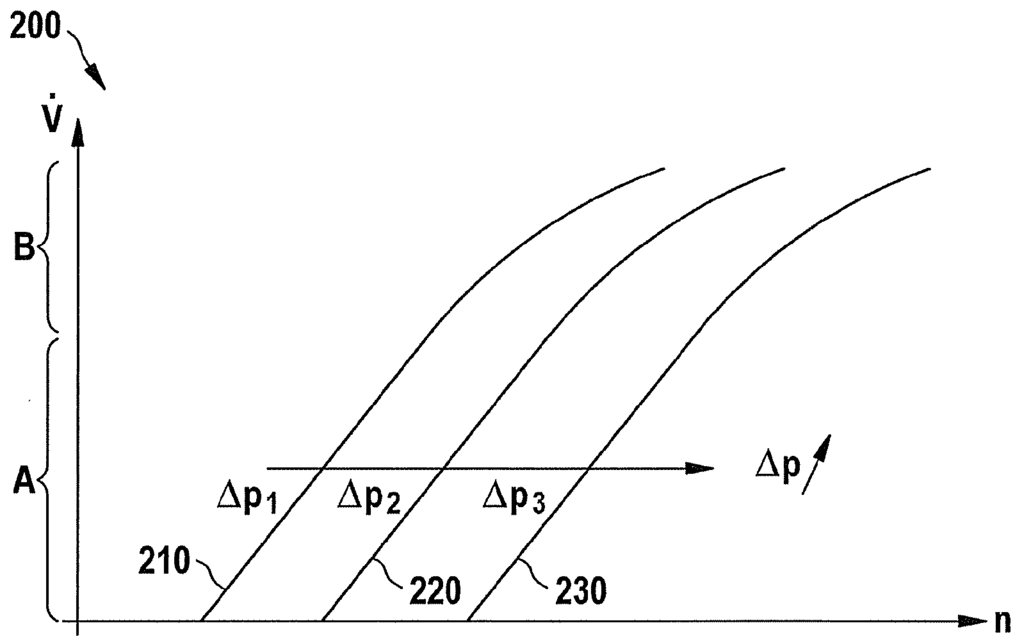

200
V̇
B
A
Δp
Δp1
Δp2
Δp3
210
220
230
n

Fig. 2

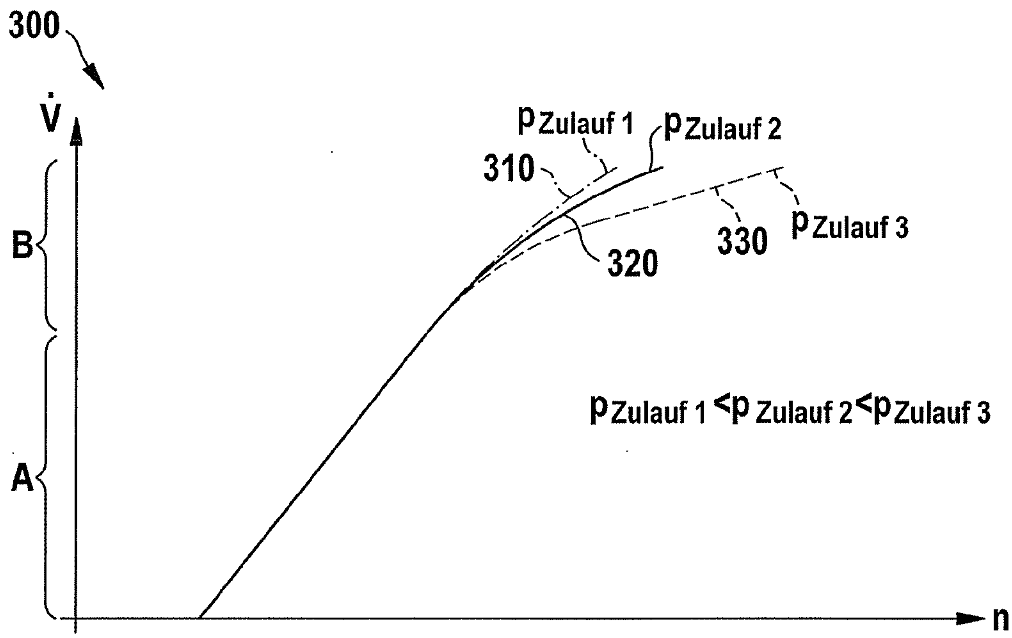

300
V̇
B
A
pZulauf 1
pZulauf 2
pZulauf 3
310
320
330
pZulauf 1<p Zulauf 2<pZulauf 3
n

Fig. 3

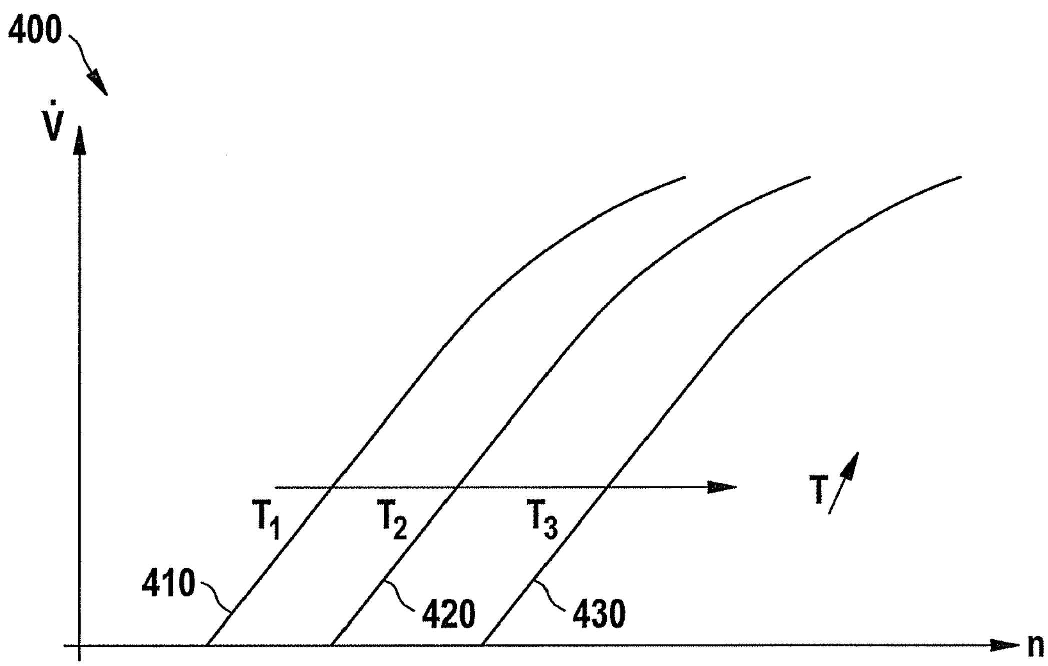


Fig. 4

METHOD FOR CONTROLLING THE FEED RATE OF A FEED PUMP

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to Application No. 10 2010 001 150.9, filed in the Federal Republic of Germany on Jan. 22, 2010, which is expressly incorporated herein in its entirety by reference thereto.

FIELD OF THE INVENTION

[0002] The present invention relates to a method for controlling the feed rate, i.e., the feed volume per unit of time, of a feed pump.

BACKGROUND INFORMATION

[0003] Feed pumps for fluids are widely used. In the automotive field, for example, feed pumps are used for feeding fuel to the engine. These feed pumps are usually designed as vane pumps or rotary vane pumps. In internal combustion engines in particular, it is important to accurately preselect the feed rate in order to obtain the desired injection pressure, the desired combustion performance and also low-emissions combustion. It is therefore conventional to regulate the feed rate, i.e., the setpoint feed rate is to be compared with the actual feed rate, and the feed pump is to be controlled according to a control deviation. This requires actual feed rate sensors, which makes regulation of feed rate relatively complex.

[0004] German Published Patent Application No. 10 2008 043 127 describes the regulation of the pump pressure. It is unnecessary to provide a pressure sensor if the actual pressure is ascertained by a so-called control observer. The feed pressure is determined on the basis of the motor current and the motor speed. No feed rate is determined.

[0005] It is therefore desirable to regulate the feed rate of a feed pump without measuring the actual feed rate.

SUMMARY

[0006] Example embodiments of the present invention include the provision of not measuring the actual feed rate of a feed pump but instead determining it based on the temperature of the fluid and the pressure difference of the intake opening and the discharge opening of the pump part or hydraulic part of the feed pump. Complex additional cost-intensive sensors may be omitted in this manner. The determination may be performed in practice on the basis of a characteristic map, for example, which extends over the temperature and pressure difference. The pressure difference to be taken into account includes the counter-pressure minus the inlet pressure.

[0007] For ascertaining the pressure difference, a drive torque of the drive motor, which is proportional to the pressure difference, may be used. A viscosity and temperature of the fluid are expediently also taken into account as these also have an influence on the pressure difference.

[0008] A relationship between drive torque M_{ZP} and pressure difference Δ_p may be written, for example, as:

$$M_{ZP} = \frac{V_{theo} \cdot \Delta p}{2 \cdot \pi \eta_{ZP}}$$

[0009] where:

[0010] V_{theo} represents the theoretical feed volume per revolution;

[0011] η_{ZP} represents the overall efficiency of the pump.

[0012] The drive torque may in turn be determined relatively easily based on known or easily determinable variables. The drive torque may be derived from the motor current, for example, if an engine characteristic map is known. This current measurement may be implemented inexpensively in the power electronics equipment.

[0013] A highly accurate quantitative regulation may be achieved even without performing a flow measurement by taking into account the pump geometry, for example, by performing a single measurement and storing additional measured values to correct the characteristic map.

[0014] Conventional feed pumps include a hydraulic part and a drive part flange-connected to the former. In addition, there are certain variants in which an internally or externally geared pump axially flange-connected to a motor shaft. The drive motors are arranged as DC variants as well as brushless DC variants. All these electric feed pumps are always arranged such that the feed part and the drive part are separate units. However, example embodiments of the present invention provide for the use of a pump of an integrated configuration, i.e., when the drive part and the hydraulic part form an inseparable unit. Examples of such a pump are described in U.S. Pat. No. 2,761,078 and European Published Patent Application No. 1 803 938. The use of such integrated pumps offers the advantage of a close spatial contact between the fluid and the electronics, so that a temperature sensor may be installed easily and without complex cabling, for example. If the control electronics or power electronics are connected directly to the feed medium, a temperature measurement cell may be accommodated here inexpensively and used for the regulation described herein.

[0015] In determining the pressure difference, a temperature-dependent leakage is expediently taken into account. This may be accomplished in particular from the following standpoints:

[0016] Based on a leakage cross section, such that positions **1** and **2** having pressures p_1 and p_2 are adjacent in the direction of the backpressure, and positions **3** and **4** having pressures p_3 and p_4 are adjacent in the intake pressure direction, it holds that:

[0017] $p_1 \approx p_2$ pump backpressure

[0018] $p_4 \approx p_3$ pump intake pressure

[0019] Since fluids are usually incompressible media, density ρ_1 is the same in positions i=1 through 4: $\rho_1=\rho_2=\rho_3=\rho_4=\rho$

[0020] Using a Bernoulli equation with a loss term, the influence of β_p on the leakage flow is estimated as follows:

$$\frac{v_2^2}{2} + \frac{p_1}{\rho} = \frac{v_3^2}{2} + \frac{p_4}{\rho} + \frac{\Delta p_v}{\rho} + \rho \int_{s1}^{s2} \frac{\partial v}{\partial t} ds \tag{1}$$

assuming $\frac{\partial v}{\partial t} = 0$ and $v_2 = v_3$, it follows that

$$\frac{p_1}{\rho} = \frac{p_4}{\rho} + \frac{\Delta p_v}{\rho} \tag{2}$$

or

$$\frac{\Delta p_v}{\rho} = \frac{p_1}{\rho} - \frac{p_4}{\rho} \text{ or } \Delta p_v = p_1 - p_4 \tag{3}$$

[0021] The loss term for a constant cross section is

$$\Delta p_v = \frac{\lambda \cdot l}{d} \cdot \rho \cdot \frac{v^2}{2} \quad (4)$$

[0022] It thus follows that:

$$v = \sqrt{\frac{2}{\rho} \cdot \Delta p \cdot \frac{d}{\lambda \cdot l}} \quad (5)$$

where

$$\lambda = \frac{\rho \cdot 64}{\mathrm{Re}} = \frac{\rho \cdot 64}{\frac{v \cdot d}{\gamma}} \quad (6)$$

[0023] A friction moment estimate M_{Reib} of a radial friction bearing is given, for example, as:

$$M_{Reib} = \mu \cdot F_{Lager}$$

where

$$\mu = \mu_0 \cdot e^{\left(-\frac{a \cdot h_{min}}{Rq}\right)}$$

where

[0024] a represents a constant; and

[0025] Rq represents a standard deviation of roughness Rq for contact pairing;

where:

$$h_{min} \approx \frac{B}{F_{Lager}} \cdot \frac{\eta \cdot D^3}{C} \cdot \frac{\pi \cdot n}{60} \left(1 + \frac{\sqrt{2} \cdot (1-\gamma^2) F}{B \cdot E \cdot h_{min}}\right)^{2/3}$$

where

[0026] B represents a supporting width;

[0027] η represents a dynamic viscosity;

[0028] E represents a modulus of elasticity;

[0029] γ represents a transverse contraction number;

[0030] D represents a diameter;

[0031] n represents a rotational speed [1/min]

[0032] Thus a loss term which depends on rotational speed may be given.

[0033] Frictional resistance M of the rotor is formulated in a manner similar to that of a rotating disk:

$$\begin{aligned} M &= 2 \int r dF_r \\ &= 2 \int r c_F \frac{\rho v^2}{2} dA \\ &= \int_0^{d/2} r c_F \cdot \rho \cdot \omega^2 r^2 \cdot 2\pi r\, dr \\ &= \underbrace{\frac{4 \cdot \pi \cdot c_F}{5}}_{c_M} \cdot \frac{\rho \cdot \omega^2}{2} \cdot \left(\frac{d}{2}\right)^5 \end{aligned}$$

where for laminar flow and $\mathrm{Re} < 3 \cdot 10^4$ it holds that:

$$C_M = \frac{2 \cdot \pi \cdot d}{s \cdot \mathrm{Re}}$$

where s represents an axial distance between the rotor and the housing;

[0034] A loss term as a function of rotational speed may in turn be given using $\omega = 2\pi n$.

[0035] The frictional resistance on the outer cylindrical surface is already taken into account in the bearing calculation.

[0036] Thus to determine the feed rate, a characteristic map as a function of temperature and motor current may be used. This is particularly simple because these parameters may be determined relatively accurately but nevertheless inexpensively and with little effort. A preferred relationship is obtained as follows:

$$\dot{V} = n \cdot (V_{theo} \cdot K_1) - \dot{V}_{Temp} - \dot{V}_{\Delta\rho} + \underbrace{n^2 \cdot K_{10} + n^{1/2} \cdot K_{11} + K_{12}}_{drehzahlabh\ddot{a}ngige\ Verluste}$$

[0037] where drehzahlabhängige Verluste refers to rpm-dependent losses;

where

$$\dot{V}_{Temp} = T^2 - K_2 + T \cdot K_3 + T^{1/2} \cdot K_4 + K_5$$

and

$$\dot{V}_{\Delta\rho} = I_{Motor}^{\ 2} \cdot K_6 + I_{Motor} \cdot K_7 + I_{Motor}^{\ 1/2} \cdot K_8 + K_9$$

where V_{theo} denotes the theoretical feed volume per revolution of the pump.

[0038] A computation unit, for example, a control unit of a motor vehicle, is equipped, in particular as far as programming is concerned, to perform a method described herein.

[0039] It should be understood that the features mentioned above and those yet to be explained below may be used not only in the particular combination given but also in other combinations or alone.

[0040] Example embodiments of the present invention are illustrated schematically in the Figures and are described below in more detail with reference to the Figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0041] FIG. **1** schematically shows a feed pump, which is suitable in particular for performing a method according to an example embodiment of the present invention.

[0042] FIG. **2** shows in a diagram the relationship between feed rate and rotational speed as a function of the pressure difference at a constant fluid temperature.

[0043] FIG. **3** shows in a diagram the relationship between feed rate and rotational speed as a function of the inlet pressure at a constant pressure difference and a constant fluid temperature.

[0044] FIG. **4** shows in a diagram the relationship between feed rate and rotational speed as a function of the fluid temperature at a constant pressure difference.

DETAILED DESCRIPTION

[0045] FIG. **1** shows an electric feed pump of an integrated configuration, in which the drive part and the hydraulic part or feed part form an inseparable unit **120**, which is diagramed schematically and labeled as **100** as a whole. In the present example, the integrated configuration is achievable by the fact that the rotor of the drive motor at the same time also forms the moving pump element of the hydraulic part, as described in European Published Patent Application No. 1 803 938, for example, which is expressly incorporated herein in its entirety by reference thereto. Hydraulic part **120** thus includes drive motor **121**, which also acts as feed mechanism **121**, drawing in a fluid, fuel in particular, through an intake opening **122** and discharging it through a discharge opening **123**. There is therefore a pressure difference Δ_p between intake opening **122** and discharge opening **123**.

[0046] The pump also includes an electronic part **110**. A regulating module **111** and a power module **112** are provided in electronic part **110**. Regulating module **111** receives a setpoint feed rate $\dot{V}_{setpoint}$ from a motor control unit **150** and determines therefrom a setpoint rotational speed $n_{setpoint}$ for the drive motor, which is transmitted to power module **112**. Power module **112** may have, for example, an inverter for operation of the drive motor. Motor current I_{motor} is determined in power module **112** and transmitted to regulating module **111**.

[0047] Based on the integrated configuration of pump **100**, there is a close spatial contact between electronic part **110** and drive and hydraulic part **120**, so that fluid temperature $T_{actual\text{-}fluid}$ is easily measurable by a measurement performed by a sensor **113** provided within electronic part **110**.

[0048] The feed rate of feed pump **110** may be controlled on the basis of measured motor current I_{motor} and measured fluid temperature $T_{actual\text{-}fluid}$. A characteristic map as a function of temperature $T_{actual\text{-}fluid}$ and motor current I_{motor} is used in regulating module **111** according to the equation:

$$\dot{V}_{Soll} = n_{Soll}\cdot(V_{theo}\cdot K_1)-- \left(T_{1st-Fluid}^2\cdot K_2 + T_{1st-Fluid}\cdot K_3 + T_{1st-Fluid}^{\frac{1}{2}}\cdot K_4 + K_5\right)-- \left(I_{Motor}^2\cdot K_6 + I_{Motor}\cdot K_7 + I_{Motor}^{\frac{1}{2}}\cdot K_8 + K_9\right)++ n_{Soll}^2\cdot K_{10} + n_{Soll}^{\frac{1}{2}}\cdot K_{11} + K_{12}$$

where

[0049] Soll denotes a setpoint, Ist denotes actual; and

[0050] V_{theo} denotes the theoretical feed volume per revolution of the pump and is usually given on the data sheet. Characteristic map constants K_1-K_{12} are ascertained empirically. To do so, a sufficient number of measured points [$\dot{V}$, n, T, I] is preferably measured and evaluated using known fitting methods (e.g., least squares fitting).

[0051] Based on the characteristic map, setpoint rotational speed $n_{setpoint}$ is determined and transmitted to power module **112**. To regulate the feed rate, actual rotational speed n_{actual} of drive motor **121** is regulated at setpoint rotational speed $n_{setpoint}$. A known rotational speed regulation may be used to do so.

[0052] Alternatively it is possible to use actual rotational speed n_{actual} together with measured motor current I_{motor} and measured fluid temperature $T_{actual\text{-}fluid}$ to determine the actual feed rate via the characteristic map and to regulate the actual feed rate at the setpoint feed rate, again with the setpoint rotational speed being regulated.

[0053] Various relationships are explained purely qualitatively below with reference to FIGS. **2** to **4** merely for the purpose of illustration.

[0054] FIG. **2** shows a diagram **200**, illustrating the relationship between feed rate $\dot{V}$ on the ordinate as a function of rotational speed n on the abscissa at a constant temperature. Three feed rate curves **210**, **220** and **230** are shown in diagram **200**, each curve being characterized by a different pressure difference Δp between the intake opening and the discharge opening. Thus a first pressure difference Δp_1 is assigned to feed rate curve **210**, a second pressure difference Δp_2 is assigned to feed rate curve **200**, and a third pressure difference Δp_3 is assigned to feed rate curve **230**, the pressure difference increasing, so that it holds that: $\Delta p_1<\Delta p_2<\Delta p_3$. The feed volume/rotational speed characteristic curve is shifted to the right with an increase in pressure difference Δp because internal leakage increases. In other words, a higher rotational speed is also necessary to supply a certain feed rate at a higher pressure difference.

[0055] Each of the three feed rate curves includes a first essentially linearly increasing range A and a following curved range B. The slope in range A is constant and depends essentially only on the geometric displacement volume of the pump. The feed volume curve flattens out in range B due in particular to partial cavitation phenomena on the intake end, caused in particular by high local flow velocities.

[0056] FIG. **3** shows in a diagram **300** the influence of pressure at the intake opening, i.e., inlet pressure p_{inlet} on the feed volume/rotational speed characteristic curve. Diagram **300** shows three characteristic curves **310**, **320** and **330** at a constant pressure difference Δp, these characteristics differing in their inlet pressure. Characteristic curve **310** is defined by inlet pressure p_{inlet1} characteristic curve **320** is defined by inlet pressure p_{inlet2} and characteristic curve **330** is defined by p_{inlet3} where the following holds: $p_{inlet1}>p_{inlet2}>p_{inlet3}$.

[0057] A variation in the inlet pressure produces a shift in ranges A and B such that the stable, i.e., linear operating range A becomes smaller with a drop in inlet pressure. In other words, the stable range is smaller the higher the inlet pressure p_{inlet}. It is thus advisable to provide a limit in the pump specification to avoid operating in range B.

[0058] FIG. **4** shows the influence of the fluid temperature on the feed volume/rotational speed characteristic curve in a diagram **400**. Three characteristic curves **410**, **420** and **430** are shown in diagram **400**, a different fluid temperature T_1, T_2 and T_3 being assigned to each diagram, where it holds that $T_1<T_2<T_3$. The characteristic curves are shifted to the right with an increase in fluid temperature because the temperature influences the viscosity of the fluid and thus affects the leakage. Furthermore, the pump components expand, so that different materials are usually used for different components and thus there is different thermal expansion. For example, the housing is often made of aluminum, whereas the feed mechanism often has steel elements, which thus have a lower thermal expansion than the housing. As a result, the leakage increases with an increase in temperature. On the whole, it is apparent that a higher rotational speed is also needed at a higher fluid temperature to supply a certain feed rate.

What is claimed is:

1. A method for controlling a feed rate of a feed pump, including a drive part having a drive motor and a hydraulic part having an intake opening, a discharge opening and a feed mechanism situated in between, comprising:

specifying a setpoint feed rate; and

triggering the feed pump based on the setpoint feed rate, a temperature of the fluid, and a pressure difference between the intake opening and the discharge opening of the hydraulic part of the feed pump.

2. The method according to claim **1**, further comprising determining the pressure difference based on a drive torque of the drive motor.

3. The method according to claim **2**, further comprising determining the drive torque based on a motor current flowing through the drive motor.

4. The method according to claim **3**, further comprising determining at least one of (a) an actual feed rate and (b) a setpoint rotational speed using characteristic map based on the temperature and the motor current.

5. The method according to claim **1**, further comprising determining the pressure difference based on a viscosity and the temperature of the fluid.

6. The method according to claim **1**, further comprising determining the pressure difference taking into account a temperature-dependent leakage.

7. The method according to claim **1**, further comprising triggering a setpoint rotational speed of the drive motor.

8. The method according to claim **1**, wherein the feed pump is arranged as a pump of an integrated configuration, in which the drive part and the hydraulic part form an inseparable unit.

9. The method according to claim **8**, further comprising determining the temperature by measuring in an electronic part of the feed pump.

10. The method according to claim **9**, further comprising determining a motor current in a power module of the electronic part.

11. A computation unit configured to perform a method for controlling a feed rate of a feed pump, including a drive part having a drive motor and a hydraulic part having an intake opening, a discharge opening and a feed mechanism situated in between, the method including:

specifying a setpoint feed rate; and

triggering the feed pump based on the setpoint feed rate, a temperature of the fluid, and a pressure difference between the intake opening and the discharge opening of the hydraulic part of the feed pump.

* * * * *