(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 202 225 A1

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
**28.06.2023 Bulletin 2023/26**

(21) Application number: **22212107.1**

(22) Date of filing: **08.12.2022**

(51) International Patent Classification (IPC):
***F04D 15/00*** *(2006.01)* ***F04B 49/06*** *(2006.01)*
***F04B 49/08*** *(2006.01)* ***F04D 15/02*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
**F04D 15/0066; F04B 9/02; F04B 17/03; F04B 49/065; F04B 49/08; F04B 49/20; F04D 15/0209; F04D 15/0245; F04D 15/0254;**
F04B 2203/0404

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR**
Designated Extension States:
**BA**
Designated Validation States:
**KH MA MD TN**

(30) Priority: **23.12.2021 CN 202111588703**

(71) Applicant: **Bosch Rexroth (Changzhou) Co., Ltd.**
**Changzhou, Jiangsu 213161 (CN)**

(72) Inventors:
- **Liebler, Gerold**
  **Wujin, Juangsu, 213164 (CN)**
- **XIE, Dongdong**
  **Wujin, Juangsu, 213164 (CN)**
- **ZHANG, Yonghai**
  **Wujin, Juangsu, 213164 (CN)**

(74) Representative: **Bee, Joachim**
**Robert Bosch GmbH**
**C/IPE**
**Wernerstrasse 51**
**70469 Stuttgart (DE)**

(54) **MULTI-SETTING PUMP WITH DELAYED SETTING SWITCHING FUNCTION**

(57) A multi-setting pump, comprising a pump part (1) driven by a motor (2), the multi-setting pump having multiple settings which at least comprise a high setting and a low setting, wherein the multi-setting pump further comprises a control unit (3), comprising: a control board for controlling operation of the motor and the pump part, a frequency changer for controlling a drive current of the motor, and a setting control module integrated in the control board or frequency changer; a low-setting operating situation condition and a high-setting operating situation condition are set in the setting control module; the setting control module is configured to perform a down-switching operation after a down-switching delay when the low-setting operating situation condition is met, and/or perform an up-switching operation after an up-switching delay when the high-setting operating situation condition is met.

EP 4 202 225 A1

## Description

### Technical field

**[0001]** The present application relates to a multi-setting pump with a delayed setting switching function.

### Background art

**[0002]** Mult-setting (multi-point) pumps have multiple switchable displacement settings. During actual operation, the pump setting needs to be switched according to actual pump pressure and rotation speed, so that the pump operates at a suitable setting, thereby increasing the level of pressure control and the level of system energy conservation.

**[0003]** In the prior art, a programmable controller (PLC) is generally used to control the operation of a multi-setting pump; the PLC inputs switching signals to the multi-setting pump to control the switching of the setting of the multi-setting pump. However, many users are reluctant to perform additional control programming in the PLC, and want the manufacturer of the multi-setting pump to improve the control system of the pump itself, by adding a setting control algorithm in the control system of the multi-setting pump itself, to reduce the additional programming work of the user. Further, in the control system of the multi-setting pump itself, many factors need to be taken into account when constructing the setting control algorithm. One important factor that needs to be taken into account is that frequent switching of the setting will cause the pump output to be unstable. For example, a momentary shock or interference in a hydraulic system might cause erroneous switching of the setting. As another example, in certain operating situations which are briefly suitable for switching of the setting, the user is required to ignore this and not switch the setting. In addition, in the process of matching timing with another actuator, switching of the setting might need to be delayed.

**[0004]** Thus, it is hoped to provide a multi-setting pump with an automatic setting switching function added in its own control system, the pump being able to solve the problems associated with switching the setting as described above.

### Summary of the invention

**[0005]** An objective of the present application is to provide a multi-setting pump, which can add an automatic setting switching function in the pump's own control system.

**[0006]** To achieve this objective, in one aspect the present application provides a multi-setting pump, comprising a pump part driven by a motor, the multi-setting pump having multiple settings which at least comprise a high setting and a low setting, wherein the multi-setting pump further comprises a control unit, comprising: a control board for controlling operation of the motor and the pump part, a frequency changer for controlling a drive current of the motor, and a setting control module integrated in the control board and/or the frequency changer; setting-change conditions are set in the setting control module, the setting-change conditions comprising a low-setting operating situation condition and a high-setting operating situation condition corresponding to the low-setting operating situation condition; the setting control module is configured to collect operating situation conditions, and is able to perform setting-change operations when the operating situation conditions meet the setting-change conditions, wherein the setting control module is configured to perform a down-switching operation after a down-switching delay when the low-setting operating situation condition is met, and/or perform an up-switching operation after an up-switching delay when the high-setting operating situation condition is met.

**[0007]** In one embodiment, the low-setting operating situation condition comprises multiple parallel low-setting operating situation conditions, and the setting control module permits a down-switching operation to be performed when any one or more of the multiple low-setting operating situation conditions is met; the high-setting operating situation condition comprises multiple parallel high-setting operating situation conditions, and the setting control module permits an up-switching operation to be performed when any one or more of the multiple high-setting operating situation conditions is met.

**[0008]** In one embodiment, in the setting control module, a respective down-switching delay is set for each low-setting operating situation condition respectively, and a respective up-switching delay is set for each high-setting operating situation condition respectively.

**[0009]** In one embodiment, the setting control module is configured to: when one of the multiple high-setting operating situation conditions is met, further judge whether the low setting was switched to previously because the corresponding low-setting operating situation condition was met; if the low setting was switched to previously because the corresponding low-setting operating situation condition was met, switching to the high setting is permitted, but if the reason for switching to the low setting previously was not that the corresponding low-setting operating situation condition was met, switching to the high setting is not permitted.

**[0010]** In one embodiment, the low-setting operating situation condition comprises a low-setting operating situation condition A1, the low-setting operating situation condition A1 being defined as:

> a difference (ΔP) between a set output pressure (P_cmd) and an actual output pressure (P_real) of the pump is less than a set first pressure difference limit value (ΔP_threshold1); and
> an actual rotation speed (N_real) of the pump is lower than a set pump speed limit value; and
> the actual output pressure (P_real) of the pump is higher than a set first pressure limit value (P_lim1);

the high-setting operating situation condition comprises a high-setting operating situation condition A2 corresponding to the low-setting operating situation condition A1, the high-setting operating situation condition A2 being defined as:

the low-setting operating situation condition A1 in the previous cycle was met,
and the low-setting operating situation condition A1 in the current cycle is not met; and

the difference (ΔP) between the set output pressure and the actual output pressure of the pump is greater than a set second pressure difference limit value (ΔP_threshold2), wherein the second pressure difference limit value (ΔP_threshold2) is greater than the first pressure difference limit value (ΔP_threshold1); or the actual output pressure (P_real) of the pump is lower than a first pressure selection value (X1), wherein the first pressure selection value is lower than the first pressure limit value (P_lim1).

**[0011]** In one embodiment, the low-setting operating situation condition comprises a low-setting operating situation condition B1, the low-setting operating situation condition B1 being defined as:

an actual output pressure (P_real) of the pump is higher than a set second pressure limit value (P_lim2), and a set output pressure (P_cmd) of the pump is higher than a set third pressure limit value (P_lim3);
the high-setting operating situation condition comprises a high-setting operating situation condition B2 corresponding to the low-setting operating situation condition B1, the high-setting operating situation condition B2 being defined as:

the low-setting operating situation condition B1 in the previous cycle was met, and the low-setting operating situation condition B1 in the current cycle is not met; and
the actual output pressure (P_real) of the pump is lower than a second pressure selection value (X2), wherein the second pressure selection value is lower than the second pressure limit value (P_lim2); or the set output pressure (P_cmd) of the pump is lower than a third pressure selection value (X3), wherein the third pressure selection value is lower than the third pressure limit value (P_lim3).

**[0012]** In one embodiment, the low-setting operating situation condition comprises a low-setting operating situation condition C1, the low-setting operating situation condition C1 being defined as:

a set output flow rate (Q_cmd) of the pump is less than a set output flow rate limit value (Q_cmd_lim);
the high-setting operating situation condition comprises a high-setting operating situation condition C2 corresponding to the low-setting operating situation condition C1, the high-setting operating situation condition C2 being defined as:

the low-setting operating situation condition C1 in the previous cycle was met, and the low-setting operating situation condition C1 in the current cycle is not met; and
the set output flow rate (Q_cmd) of the pump is greater than a flow rate selection value (X4), the flow rate selection value being less than the output flow rate limit value.

**[0013]** In one embodiment, the multi-setting pump further comprises a user signal interface, and the setting control module is configured to receive a signal inputted by a user via the user signal interface, the signal inputted by the user comprising a forced setting-change signal; and the setting control module is configured to perform a setting change based on the forced setting-change signal received, regardless of whether the setting-change conditions are met.

**[0014]** In one embodiment, the signal inputted by the user further comprises a setting-change prohibition signal, the setting-change prohibition signal and the forced setting-change signal being mutually exclusive; and the setting control module is configured to prohibit a setting-change operation based on the setting-change prohibition signal received, regardless of whether the setting-change conditions are met.

**[0015]** In one embodiment, the control unit is configured to be able to:

calculate an output pressure of the multi-setting pump based on a motor torque and a pump displacement; or
calculate a displacement of the multi-setting pump based on an output pressure of the multi-setting pump and a motor torque.

**[0016]** In one embodiment, the multi-setting pump is a dual-setting pump.

**[0017]** In the present application, a setting control algorithm is added in the multi-setting pump's own control system, and is suitable for a variety of variable-speed/variable-displacement applications, with no need for the end user to perform additional programming for this purpose, thus saving time and reducing costs for the client. In addition, a delayed setting switching function is provided in the setting switching logic, so erroneous switching can be avoided, or switching can be prohibited according to a user requirement, and a delay required for matching to the timing of another actuator can be provided.

## Brief description of the drawings

**[0018]** Further understanding of the present application can be gained by reading the following detailed description with reference to the drawings, in which:

Fig. 1 is a schematic diagram of a multi-setting pump according to the present application.

Fig. 2 is a schematic diagram of the delayed setting switching function in the multi-setting pump of the present application.

Fig. 3 is a flow chart of an exemplary setting control algorithm which can be used in the multi-setting pump of the present application.

Fig. 4 is a graph showing the displacement of the multi-setting pump when a setting control algorithm is used according to the present application.

## Detailed description of embodiments

**[0019]** The present application relates generally to a multi-setting pump, for example a two-setting pump, etc. The multi-setting pump has multiple switchable settings, each setting being realizable by means of an internal setting-change structure of the multi-setting pump.

**[0020]** The multi-setting pump is essentially as shown schematically in Fig. 1, being able to deliver a liquid medium at multiple (two or more) displacement settings. The multi-setting pump comprises a pump part 1, a motor 2 and a control unit 3. The motor 2 drives the pump part 1 to run. The control unit 3 comprises a frequency changer and a control board for controlling the rotation speed of the motor 2; the control board also controls the operation of the pump part 1 (e.g. switching of the setting, etc.). The output of the multi-setting pump is mainly embodied by two indices, namely flow rate Q and pressure P, which both vary with time and therefore can be represented as Q(t) and P(t) respectively.

**[0021]** The multi-setting pump of the present application is provided with a user signal interface (in the form of hardware or software), and the user may autonomously choose to input/set a control signal directly by digital/analogue/bus communication/Bluetooth, and may also input/set a control signal by an externally connected programmable controller (PLC).

**[0022]** The control signal that is inputted/set by the user comprises a desired flow rate Q_cmd and a desired pressure P_cmd of the pump. The desired flow rate and desired pressure may also vary with time. The control unit 3 also receives or estimates an actual output pressure P_real of the pump and an actual rotation speed N_real of the motor 2. Based on the desired flow rate Q_cmd, the desired pressure P_cmd and the actual output pressure P_real of the pump, and the actual rotation speed N_real of the motor 2 (i.e. the actual rotation speed of the pump part 1), the control unit 3 can automatically control the internal setting-change structure of the pump, realizing closed-loop control of the multi-setting pump.

**[0023]** A setting control module is added in the control unit 3 of the present application; the setting control module may be embedded in the control board and/or the frequency changer, so that the end user does not need to perform the additional work of programming (e.g. in the externally connected PLC) for switching the setting of the multi-setting pump. The control board and frequency changer are hardware included in the pump drive system itself, and thus can save wiring, and might even allow the externally connected PLC to be omitted.

**[0024]** The setting control module is configured to switch the setting of the pump according to a system state variable, and can influence a control result based on an active input signal of a client at any moment, and may even select an input signal of the user as a unique criterion.

**[0025]** The setting control module of the multi-setting pump is realized by a PID circuit and an algorithm inside the drive system; once the setting of the pump has been switched, a suitable PID parameter can be adjusted according to the new setting (displacement), to achieve a better control result.

**[0026]** The system state variable on which the setting control module is based may comprise: a set value and an actual value of pump output pressure, and a real-time difference between these two values; a set value and an actual value of pump rotation speed, and a real-time difference between these two values; displacement state feedback for the pump at the present time; the speed of execution of switching of the setting; a switching instruction signal delay; and so on.

**[0027]** A simple form of the multi-setting pump is a dual-setting pump, which has two settings: high and low. Some feasible embodiments of the present application are described below, taking a dual-setting pump as an example. It will be understood that the principles and features of the present application are likewise suitable for multi-setting pumps with other numbers of settings.

**[0028]** The setting control module is configured to execute a setting control algorithm of the present application, wherein preferably, an initial setting of the dual-setting pump after startup is set as the high setting, and operating situation conditions are checked in real time; and when a low-setting operating situation condition is met, the setting is permitted to be switched from the high setting to the low setting. In addition, when a high-setting operating situation condition is met in a particular cycle in a state of low-setting running, the setting is permitted to be switched from the low setting to the high setting.

**[0029]** Of course, the setting control module may also be configured to set the initial setting of the pump after startup as the low setting.

**[0030]** Here, the "low-setting operating situation condition" means that in the current operating situation, the dual-(multi-)setting pump will have better performance if it runs at the low setting; and the "high-setting operating situation condition" means that in the current operating situation, the dual-(multi-)setting pump will have better performance if it runs at the high setting. The performance of the dual-(multi-)setting pump can be measured by the efficiency of the pump part 1 or the overall efficiency of the pump part 1 and the motor 2. Of course, other indices may also be used to measure the performance of the dual-(multi-)setting pump.

**[0031]** Different setting-change conditions can be set for job requirements in different operating cycles of the dual-setting pump, including low-setting operating situation conditions and high-setting operating situation conditions.

**[0032]** For example, low-setting operating situation conditions may comprise operating situation conditions A1, B1, C1.

**[0033]** Condition A1 is an actual output flow rate and actual output pressure condition when the rotation speed is lower than a pump speed limit value (depending on the job requirements of the dual-setting pump at the present time), and for example is suitable for a low-speed pressure-maintaining stage.

**[0034]** For example, condition A1 is defined as:

$|\Delta P| < \Delta P\_threshold1$; and
$N\_real < Nk$; and
$P\_real > P\_lim1$.

Here, ΔP is the difference between the set output pressure P_cmd of the pump and the detected actual output pressure P_real of the pump,

ΔP_threshold1 is a set first pressure difference limit value;

N_real is the detected actual rotation speed of the pump;

Nk is a pump speed limit value based on the job requirements of the dual-setting pump, and is user-adjustable;

P_lim1 is a set first pressure limit value.

**[0035]** Condition B1 is a set output pressure and actual output pressure condition.

**[0036]** For example, condition B1 is defined as:

$P\_real > P\_lim2$; and
$P\_cmd > P\_lim3$.

**[0037]** Here, P_lim2 is a set second pressure limit value, and P_lim3 is a set third pressure limit value.

**[0038]** Condition C1 is a set output flow rate condition.

**[0039]** For example, condition C1 is defined as: $Q\_cmd < Q\_cmd\_lim$.

**[0040]** Here, Q_cmd is a set output flow rate of the pump, and Q_cmd_lim is a set output flow rate limit value.

**[0041]** Conditions A1, B1, C1 are three parallel conditions; if any one of them is met, this means that the low-setting operating situation condition is met. P_lim1, P_lim2 and P_lim3 are all set values, and there is no specific relationship among the sizes thereof.

**[0042]** Other low-setting operating situation conditions may also be set according to job requirements in specific operating processes.

**[0043]** For different operating situations, for example different process steps in one operating process (with different requirements in terms of pump output pressure and displacement), each settable parameter in conditions A1, B1, C1... may be specifically set, to meet the requirements of the particular operating situation. In addition, for a specific process step, one or more of conditions A1, B1, C1... may be selected as the low-setting operating situation condition(s).

**[0044]** According to one embodiment, if any one or more of operating situation conditions A1, B1, C1... is met in a particular cycle, the setting control module can control the setting of the dual-setting pump to switch from the high setting to the low setting.

**[0045]** According to a further optional embodiment, in addition to the solution in which downward switching of the setting is determined based on the abovementioned operating situation conditions, the setting control module may also forcibly switch down the setting based on a forced low-setting signal inputted by the client (regardless of whether operating situation conditions A1, B1, C1... are met). If a user-inputted signal is received in a particular cycle, the setting control module can control the setting of the dual-setting pump to switch from the high setting to the low setting.

**[0046]** In addition, according to a further optional embodiment, the setting control module may also determine that downward switching of the setting shall be prohibited according to operating situation conditions A1, B1, C1... and a low-setting prohibition signal inputted by the user. Specifically, in a particular cycle, even if one of operating situation conditions A1, B1, C1... is met, but there is a corresponding low-setting prohibition signal inputted by the client, the setting control module will not perform a down-switching operation; the setting control module can only perform a down-switching operation when there is no low-setting prohibition signal inputted by the client.

**[0047]** The low-setting prohibition signal inputted by the user is reciprocal to the forced low-setting signal; each low-setting prohibition signal may be inputted via the same interface as the corresponding forced low-setting signal, but cannot be inputted at the same time, thus preventing erroneous operation by the user.

**[0048]** Further, the setting control module is configured to permit the setting to be switched from the low setting to the high setting in a particular cycle if the high-setting operating situation condition is met in that cycle.

**[0049]** High-setting operating situation conditions suitable for switching the setting of the dual-setting pump include operating situation conditions A2, B2, C2 as examples; these respectively correspond to the low-setting operating situation conditions A1, B1, C1 mentioned above.

**[0050]** For example, condition A2 is defined as:

Condition A1 in the previous cycle was met, and condition A1 in the current cycle is not met, and there is no corresponding forced low-setting signal DIA1; and $|\Delta P| > \Delta P\_threshold2$ or P_real < X1.

**[0051]** Here, ΔP_threshold2 is a set second pressure difference limit value, ΔP_threshold2 > ΔP_threshold1.

**[0052]** X1 may be called a first pressure selection value, let X1 = P_lim1 - P1, where P1 is a set pressure value; or let X1 = P_min1, where P_min1 is a value that can be set by the user, P_lim1 - P1 < P_min1 < P_lim1.

**[0053]** Condition B2 is defined as:

Condition B1 in the previous cycle was met, and condition B1 in the current cycle is not met, and there is no corresponding forced low-setting signal DIB1; and P_real <X2 or P_cmd < X3.

**[0054]** Here, X2 may be called a second pressure selection value, let X2 = P_lim2 - P2, where P2 is a set pressure value;

or let X2 = P_min2, where P_min2 is a value that can be set by the user, P_lim2 - P2 < P_min2 < P_lim2.

**[0055]** X3 may be called a third pressure selection value, let X3 = P_lim3 - P3, where P3 is a set pressure value; or let X3 = P_min3, where P_min3 is a value that can be set by the user, P_lim3 - P3 < P_min3 < P_lim3.

**[0056]** Condition C2 is defined as:

Condition C1 in the previous cycle was met, and condition C1 in the current cycle is not met, and there is no corresponding forced low-setting signal DIC1; and Q_cmd > X4.

**[0057]** Here, X4 may be called a flow rate selection value, let X4 = Q_cmd_lim - Q0, wherein Q0 is a set flow rate value;

or let X4 = Q_min, where Q_min is a value that can be set by the user, Q_cmd_lim - Q0 < Q_min < Q_cmd_lim.

**[0058]** Other high-setting operating situation conditions may also be set according to specific operating processes.

**[0059]** For different operating situations, for example different process steps in one operating process (with different requirements in terms of pump output pressure and displacement), each settable parameter in conditions A2, B2, C2... may be specifically set, to meet the requirements of the particular operating situation. In addition, for a specific process step, one or more of conditions A2, B2, C2... (corresponding to the selected low-setting operating situation condition(s) A1, B1, C1 ...) may be selected as the high-setting operating situation condition(s).

**[0060]** If at least one of operating situation conditions A2, B2, C2... is met in a particular cycle, the setting control module switches the pump setting from the low setting to the high setting.

**[0061]** In addition to the solution in which upward switching of the setting is determined based on the abovementioned operating situation conditions, the setting control module may also forcibly switch up the setting based on a forced high-setting signal inputted by the client (regardless of whether operating situation conditions A2, B2, C2... are met). If a forced high-setting signal inputted by a user is received in a particular cycle, the setting control module can control the setting of the dual-setting pump to switch from the low setting to the high setting.

**[0062]** In addition, the setting control module may also determine that upward switching of the setting shall be prohibited according to operating situation conditions A2, B2, C2... and a high-setting prohibition signal inputted by the user. Specifically, in a particular cycle, even if one of operating situation conditions A2, B2, C2... is met, but there is a corresponding high-setting prohibition signal inputted by the client, the setting control module will not perform an up-switching operation; the setting control module can only perform an up-switching operation when there is no corresponding high-setting prohibition signal.

**[0063]** The high-setting prohibition signal is reciprocal to the forced high-setting signal; each high-setting prohibition signal may be inputted via the same interface as the corresponding forced high-setting signal, but cannot be inputted at the same time, thus preventing erroneous operation by the user.

**[0064]** The forced low-setting signal may be used as the high-setting prohibition signal, and the forced high-setting signal may be used as the low-setting prohibition signal.

**[0065]** According to a further feasible solution, when one of the high-setting operating situation conditions A2, B2, C2... is met, it is further necessary to judge whether the low setting was switched to previously because the corresponding low-setting operating situation condition A1, B1, C1... was met. If the low setting was switched to previously because the corresponding low-setting operating situation condition A1, B1, C1... was met, switching to the high setting will be permitted, otherwise, switching to the high setting will not be permitted. For example, when high-setting operating situation condition A2 is met, it is further necessary to judge whether the low setting was switched to previously because the corresponding low-setting operating situation condition A1 was met. If the low setting was switched to previously because the corresponding low-setting operating situation condition A1 was met, switching to the high setting will be permitted; if the reason for switching to the low setting was not that the corresponding low-setting operating situation condition A1 was met (e.g. the low setting was switched to because the low-setting operating situation conditions B1, C1 were met or because of a forced signal from the user), switching to the high setting will not be permitted.

**[0066]** Furthermore, if the setting control module permits the setting to be changed, it does not immediately perform a setting-change operation, but performs a setting-change operation after a delay.

**[0067]** Fig. 2 shows such a delay schematically; in the figure, the horizontal axis is the time t experienced by the dual-setting pump after startup, and the vertical axis represents the pump displacement Vg, i.e. the displacement per revolution, typically including a high displacement Vh at the high setting and a low displacement Vl at the low setting.

**[0068]** As shown in Fig. 2, the dual-setting pump runs at the high setting after startup.

**[0069]** At time t1, the setting control module determines that one or more of the low-setting operating situation conditions is met. The setting control module maintains the high setting for a delay period, waiting until time t2 to switch the setting down to the low setting. The delay between times t1 and t2 may be called the down-switching delay.

**[0070]** The dual-setting pump runs at the low setting. At time t3, the setting control module determines that one or more of the high-setting operating situation conditions is met. The setting control module maintains the low setting for a delay period, waiting until time t4 to switch the setting up to the high setting. The delay between times t3 and t4 may be called the up-switching delay.

**[0071]** The down-switching delay and up-switching delay may be collectively called setting-change delays; they may be set for specific job requirements and are adjustable. For the abovementioned operating situation conditions A1, B1, C1... A2, B2, C2..., corresponding delay durations may be respectively set.

**[0072]** For example, each down-switching delay and up-switching delay may be respectively set to about 10 seconds (the two delays are not necessarily equal); in this way, most system shocks (generally less than 2 seconds) can be screened out.

**[0073]** The down-switching delay and up-switching delay can provide many benefits.

**[0074]** For example, momentary shocks or interference sometimes occur in hydraulic systems. By using a down-switching delay and up-switching delay for specific job requirements, momentary shocks or interference can be filtered out, thus avoiding erroneous switching of the setting.

**[0075]** As another example, in certain operating situations which are briefly suitable for switching of the setting, the user might be required to ignore this and not switch the setting. In this case, by using a down-switching delay and up-switching delay, the possibility of brief switching of the setting can be eliminated.

**[0076]** In addition, in some jobs, the dual-(multi-)setting pump needs to be matched to the timing of another actuator, and switching of the setting of the dual-(multi-)setting pump might need to be delayed. In this case, by using a down-switching delay and up-switching delay, precise matching of the dual-(multi-)setting pump to the timing of the other actuator can be achieved.

**[0077]** For a particular operating cycle, both a down-switching delay and an up-switching delay may be set simultaneously, but it is also possible to only set a down-switching delay or only set an up-switching delay.

**[0078]** An exemplary procedure of a setting control algorithm which may be executed in the setting control module of the dual-setting pump is described below with reference to Fig. 3.

**[0079]** Referring to Fig. 3, firstly, in step S1, the dual-setting pump is started up.

**[0080]** Next, in step S2, the drive system of the dual-setting pump is initialized, the user inputs a set pressure, flow rate, rotation speed, pump operating mode and pump technical data, etc., the dual-setting pump initially pumps liquid at one setting (the high setting generally being chosen), and high/low-setting operating situation conditions and optional user-inputted forced setting-change signals and setting-change prohibition signals in the current cycle are monitored.

**[0081]** Next, in step S3, the setting control module judges whether setting-change conditions (low-setting operating situation conditions and high-setting operating situation conditions) in the current cycle are met, and optionally, whether there are corresponding user-inputted forced/prohibition signals, and thereby determines whether the current setting is suitable in the current cycle.

**[0082]** If it is judged in step S3 that the current setting is not suitable in the current cycle, the method proceeds to step S4; if it is judged that the current setting is suitable in the current cycle, the method returns to step S2.

**[0083]** In step S4, the setting-change delay is implemented.

**[0084]** Next, in step S5, it is determined again whether the current setting is suitable in the current cycle (similar to step S3).

**[0085]** If it is judged in step S5 that the current setting is not suitable in the current cycle, the method proceeds to step S6; if it is judged that the current setting is suitable in the current cycle, the method returns to step S2.

**[0086]** In step S6, the setting is changed, then the method returns to step S2, to perform operating situation monitoring and the setting control loop for the next cycle.

**[0087]** It will be understood that those skilled in the art could make various modifications to the steps in the procedure in Fig. 3, e.g. add judgement conditions, etc.

**[0088]** To verify the technical effect of the setting control algorithm having a delay function according to the present application, a corresponding test platform was used to test different dual-setting pump setting control techniques; the test results can be seen in Fig. 4, in which curve S1 represents operating situation conditions, and curve S2 represents displacement (corresponding to setting).

**[0089]** Firstly, the setting control module controls the dual-setting pump to run at high displacement Vh (high setting). During this period, a low-setting operating situation condition briefly occurs on two occasions in the operating situation conditions. However, the duration of each low-setting operating situation condition is shorter than the down-switching delay, so the setting control module does not perform a down-switching operation.

**[0090]** Thereafter, a low-setting operating situation condition of duration longer than the down-switching delay occurs, and the setting control module performs a down-switching operation, such that the dual-setting pump runs at low displacement Vl (low setting). During this period, a high-setting operating situation condition briefly occurs once in the operating situation conditions. However, the duration of the high-setting operating situation condition is shorter than the up-switching delay, so the setting control module does not perform an up-switching operation.

**[0091]** Thereafter, a high-setting operating situation condition of duration longer than the up-switching delay occurs, and the setting control module performs an up-switching operation, such that the dual-setting pump runs at high displacement Vh (high setting).

**[0092]** The test results in Fig. 4 show that the setting control module in the control unit 3 of the present application can avoid brief setting-change operations, so that the pump output remains stable, and fluctuation in output pressure is avoided.

**[0093]** The setting control module of the present application is preferably configured to control the dual-setting pump to run at the high setting after startup of the dual-setting pump, and prohibit down-switching of the setting within a set period of time after startup.

**[0094]** The various ideas and features described above for the dual-setting pump are likewise applicable to other multi-setting pumps.

**[0095]** Further, in a hydraulic system, it is generally necessary to collect system pressure information in real time, as parameters for feedback control. For example, the output pressure of the multi-setting pump of the present application may be acquired by means of a pressure sensor installed in the hydraulic system. However, due to oil path switching, the pressure sensor is sometimes unable to provide a true reflection of the pressure load acting at the output end of the multi-setting pump (i.e. the output pressure of the multi-setting pump). In some cases, the hydraulic system or multi-setting pump is not equipped with a pressure sensor. In these cases, the control unit 3 of the present application is configured to be able to estimate the output pressure of the multi-setting pump.

**[0096]** Specifically, the motor torque may be measured by a torque sensor. Alternatively, the motor torque may be calculated based on a control current outputted by the frequency changer to the motor 2 and the rotation speed of the motor 2. For example, the motor torque may be obtained by multiplying the motor control current by a torque constant related to rotation speed. Based on the measured or calculated motor torque and the pump displacement determined by the control unit 3, the output pressure of the multi-setting pump can be calculated. For example, the output pressure (expressed in the form of a pressure difference between an oil outlet and an oil inlet) may be obtained by multiplying the motor torque by efficiency, then dividing by the pump displacement and then multiplying by a coefficient.

**[0097]** Although the output pressure of the multi-setting pump that is calculated in this way is an estimated value, it is sufficiently precise, and can be used for the setting control described above that is performed by the setting control module.

**[0098]** The estimated output pressure of the multi-setting pump in the present application may be used directly for setting control and other control when the hydraulic system or multi-setting pump is not equipped with a pressure sensor; and when the hydraulic system or multi-setting pump is equipped with a pressure sensor, the estimated output pressure may be used to correct a detected value of the pressure sensor or directly replace the detected value of the pressure sensor in the event of oil path switching or other situations, for use in setting control and other control.

**[0099]** Furthermore, if the hydraulic system or multi-setting pump is equipped with a pressure sensor, a formula similar to the previous formula for calculating pump displacement is used to calculate the pump displacement based on the detected value of the pressure sensor and the motor torque (or motor control current). Thus, if the multi-setting pump is not equipped with a displacement sensor, the pump displacement calculated (estimated) in this way is used to perform multi-setting pump control.

**[0100]** The setting control algorithm of the present application is suitable for various multi-setting pumps, and is not limited to the dual-setting pump described above. Generally, a multi-setting pump comprises multiple settings, which include at least one pair of settings which are high and low relative to one another (the displacement at the high setting being greater than the displacement at the low setting), e.g. setting 4 and setting 3, setting 3 and setting 2, setting 2 and setting 1, setting 4 and setting 2, setting 4 and setting 1, setting 3 and setting 1, and so on. Depending on the type of pump, the multi-setting pump may also include a zero setting, or even a negative setting. The setting control algorithm of the present application can achieve automatic control of switching of the pump setting between the high setting and the low setting. For switching between different high and low settings, all that need be done is to set corresponding control conditions.

**[0101]** In the present application, the setting control algorithm is added in the multi-setting pump's own control system, and is suitable for a variety of variable-speed/variable-displacement applications, with no need for the end user to perform additional programming for this purpose, thus saving time and reducing costs for the user. In addition, an external signal interface is reserved, and the end user can actively input control signals as he or she wishes via the external signal interface to influence the setting control result; this increases the practicality. In addition, the setting control algorithm is integrated in the drive system of the multi-setting pump, and the end user may even omit the PLC, thus reducing wiring and costs.

**[0102]** In addition, according to the setting control algorithm of the present application, the multi-setting pump can achieve automatic switching of the setting so that the displacement of the multi-setting pump is suitable for a particular operating situation; thus, the operational precision and pump discharge precision are increased.

**[0103]** Furthermore, by setting the various parameters in setting switching, e.g. the second pressure difference limit value that is set in the high-setting operating situation condition A2 being greater than the first pressure difference limit value that is set in the corresponding low-setting operating situation condition A1, the operating stability can be increased, to avoid overly frequent switching of the setting and pressure fluctuation.

**[0104]** In addition, once a condition for switching the setting has been met, a setting-change operation is performed only after a switching delay, so erroneous switching due to system shocks can be avoided, switching can be prohibited according to a user requirement, and a delay required for matching to the timing of another actuator can be provided.

**[0105]** Although the present application has been described here with reference to specific embodiments, the scope of the present application is not limited to the details shown. Various modifications can be made to these details without deviating from the basic principles of the present application.

## Claims

1. Multi-setting pump, comprising a pump part driven by a motor, the multi-setting pump having multiple settings which at least comprise a high setting and a low setting,

   wherein the multi-setting pump further comprises a control unit, comprising: a control board for controlling operation of the motor and the pump part, a frequency changer for controlling a drive current of the motor, and a setting control module integrated in the control board and/or the frequency changer;
   setting-change conditions are set in the setting control module, the setting-change conditions comprising a low-setting operating situation condition and a high-setting operating situation condition corresponding to the low-setting operating situation condition;
   the setting control module is configured to collect operating situation conditions, and is able to perform setting-change operations when the operating situation conditions meet the setting-change conditions,
   wherein the setting control module is configured to perform a down-switching operation after a down-switching delay when the low-setting operating situation condition is met, and/or perform an up-switching operation after an up-switching delay when the high-setting operating situation condition is met.

2. Multi-setting pump according to Claim 1, wherein the low-setting operating situation condition comprises multiple parallel low-setting operating situation conditions, and the setting control module permits a down-switching operation to be performed when any one or more of the multiple low-setting operating situation conditions is met;
   the high-setting operating situation condition comprises multiple parallel high-setting operating situation conditions, and the setting control module permits an up-switching operation to be performed when any one or more of the multiple high-setting operating situation conditions is met.

3. Multi-setting pump according to Claim 2, wherein in the setting control module, a respective down-switching delay is set for each low-setting operating situation condition respectively, and a respective up-switching delay is set for each high-setting operating situation condition respectively.

4. Multi-setting pump according to Claim 2 or 3, wherein the setting control module is configured to: when one of the multiple high-setting operating situation conditions is met, further judge whether the low setting was switched to previously because the corresponding low-setting operating situation condition was met; if the low setting was switched to previously because the corresponding low-setting operating situation condition was met, switching to the high setting is permitted, but if the reason for switching to the low setting previously was not that the corresponding low-setting operating situation condition was met, switching to the high setting is not permitted.

5. Multi-setting pump according to any one of Claims 1 - 4, wherein the low-setting operating situation condition comprises a low-setting operating situation condition A1, the low-setting operating situation condition A1 being defined as:

   a difference (ΔP) between a set output pressure (P_cmd) and an actual output pressure (P_real) of the pump is less than a set first pressure difference limit value (ΔP_threshold1); and
   an actual rotation speed (N_real) of the pump is lower than a set pump speed limit value; and
   the actual output pressure (P_real) of the pump is higher than a set first pressure limit value (P_lim1);
   the high-setting operating situation condition comprises a high-setting operating situation condition A2 corresponding to the low-setting operating situation condition A1, the high-setting operating situation condition A2 being defined as:
   the low-setting operating situation condition A1 in the previous cycle was met, and the low-set-

ting operating situation condition A1 in the current cycle is not met; and

the difference (ΔP) between the set output pressure and the actual output pressure of the pump is greater than a set second pressure difference limit value (ΔP_threshold2), wherein the second pressure difference limit value (ΔP_threshold2) is greater than the first pressure difference limit value (ΔP_threshold1); or the actual output pressure (P_real) of the pump is lower than a first pressure selection value (X1), wherein the first pressure selection value is lower than the first pressure limit value (P_lim1).

**6.** Multi-setting pump according to any one of Claims 1 - 5, wherein the low-setting operating situation condition comprises a low-setting operating situation condition B1, the low-setting operating situation condition B1 being defined as:

an actual output pressure (P_real) of the pump is higher than a set second pressure limit value (P_lim2), and a set output pressure (P_cmd) of the pump is higher than a set third pressure limit value (P_lim3);

the high-setting operating situation condition comprises a high-setting operating situation condition B2 corresponding to the low-setting operating situation condition B1, the high-setting operating situation condition B2 being defined as:

the low-setting operating situation condition B1 in the previous cycle was met, and the low-setting operating situation condition B1 in the current cycle is not met; and

the actual output pressure (P_real) of the pump is lower than a second pressure selection value (X2), wherein the second pressure selection value is lower than the second pressure limit value (P_lim2); or the set output pressure (P_cmd) of the pump is lower than a third pressure selection value (X3), wherein the third pressure selection value is lower than the third pressure limit value (P_lim3).

**7.** Multi-setting pump according to any one of Claims 1 - 6, wherein

the low-setting operating situation condition comprises a low-setting operating situation condition C1, the low-setting operating situation condition C1 being defined as:

a set output flow rate (Q_cmd) of the pump is less than a set output flow rate limit value (Q_cmd_lim);

the high-setting operating situation condition comprises a high-setting operating situation condition C2 corresponding to the low-setting operating situation condition C1, the high-setting operating situation condition C2 being defined as:

the low-setting operating situation condition C1 in the previous cycle was met, and the low-setting operating situation condition C1 in the current cycle is not met; and

the set output flow rate (Q_cmd) of the pump is greater than a flow rate selection value (X4), the flow rate selection value being less than the output flow rate limit value.

**8.** Multi-setting pump according to any one of Claims 1 - 7, wherein it further comprises a user signal interface, and the setting control module is configured to receive a signal inputted by a user via the user signal interface, the signal inputted by the user comprising a forced setting-change signal; and the setting control module is configured to perform a setting change based on the forced setting-change signal received, regardless of whether the setting-change conditions are met.

**9.** Multi-setting pump according to Claim 8, wherein the signal inputted by the user further comprises a setting-change prohibition signal, the setting-change prohibition signal and the forced setting-change signal being mutually exclusive; and the setting control module is configured to prohibit a setting-change operation based on the setting-change prohibition signal received, regardless of whether the setting-change conditions are met.

**10.** Multi-setting pump according to any one of Claims 1 - 9, wherein the control unit is configured to be able to:

calculate an output pressure of the multi-setting pump based on a motor torque and a pump displacement; or

calculate a displacement of the multi-setting pump based on an output pressure of the multi-setting pump and a motor torque.

**11.** Multi-setting pump according to any one of Claims 1 - 10, wherein the multi-setting pump is a dual-setting pump.

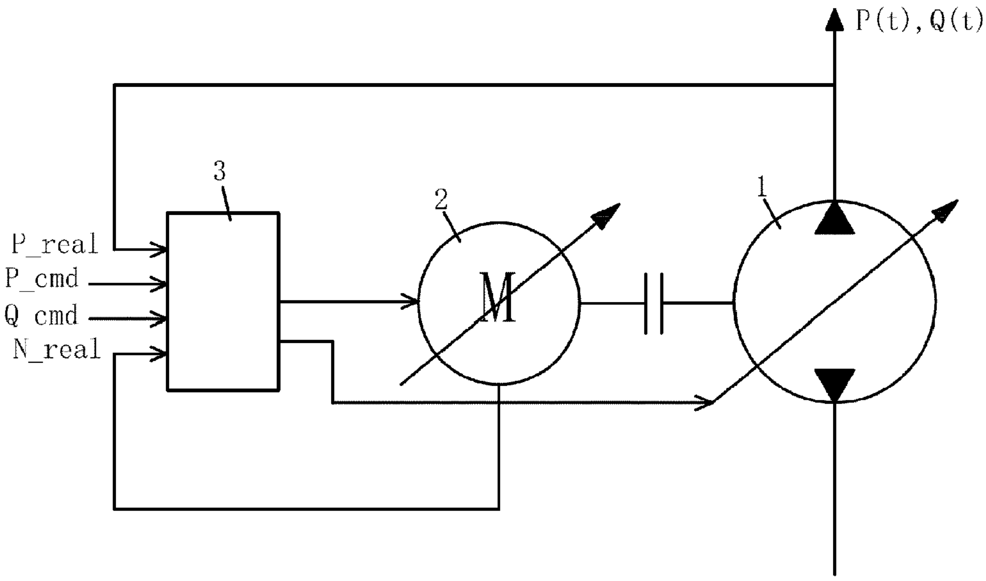


Fig. 1

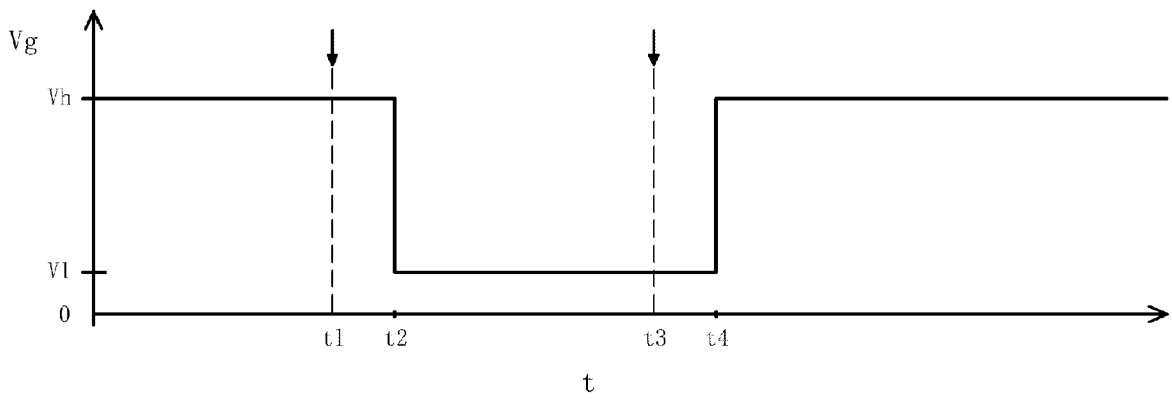


Fig. 2

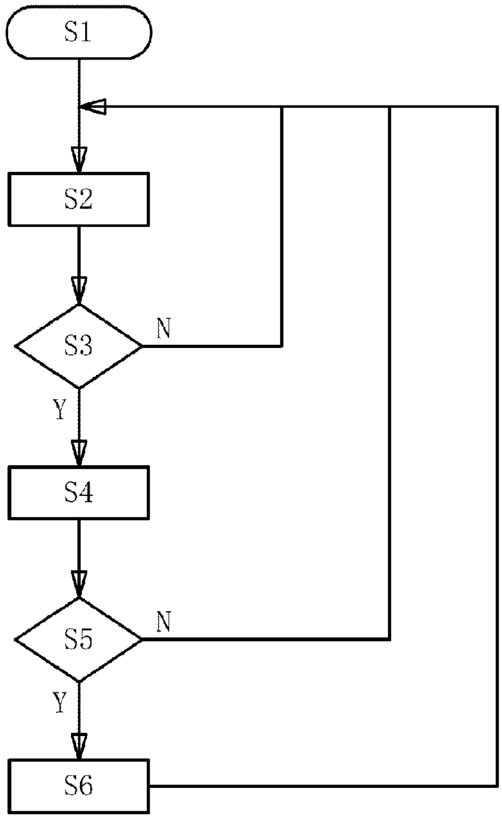


Fig. 3

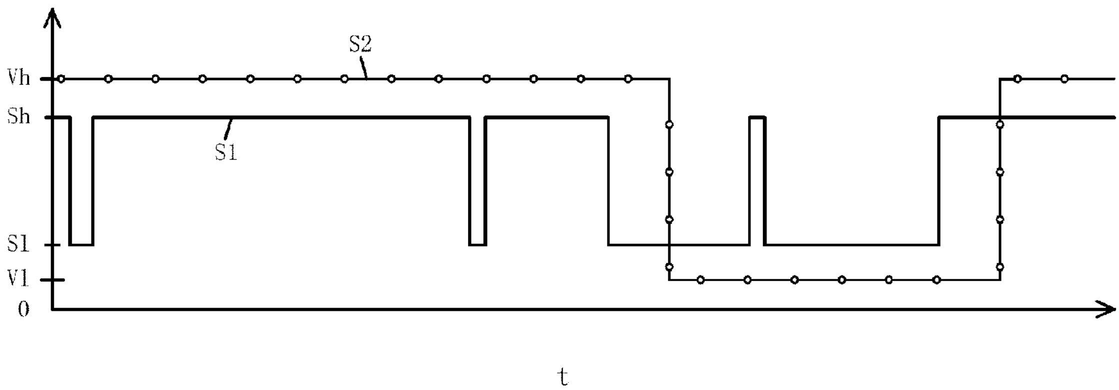


Fig. 4

Europäisches Patentamt
European Patent Office
Office européen des brevets

# EUROPEAN SEARCH REPORT

Application Number
EP 22 21 2107

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
|---|---|---|---|
| X<br>A | US 2016/346462 A1 (ADAMS GRANT [US] ET AL) 1 December 2016 (2016-12-01)<br>* paragraphs [0014], [0052]; claim 1; figures 5,10 * | 1-3,5-11<br>4 | INV.<br>F04D15/00<br>F04B49/06<br>F04B49/08<br>F04D15/02 |
| A | DE 10 2012 009136 A1 (BOSCH GMBH ROBERT [DE]) 7 November 2013 (2013-11-07)<br>* claim 1; figure 1 * | 1 | |
| A | DE 10 2014 001981 A1 (BOSCH GMBH ROBERT [DE]) 20 August 2015 (2015-08-20)<br>* claim 1; figures 1,2 * | 1 | |

TECHNICAL FIELDS SEARCHED (IPC)

F04D
F04B

The present search report has been drawn up for all claims

2

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 19 April 2023 | de Martino, Marcello |

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

# ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 22 21 2107

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

19-04-2023

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| US 2016346462 A1 | 01-12-2016 | CA 2938092 A1 | 20-08-2015 |
| | | CN 105979983 A | 28-09-2016 |
| | | EP 3104906 A1 | 21-12-2016 |
| | | US 2016346462 A1 | 01-12-2016 |
| | | US 2019240397 A1 | 08-08-2019 |
| | | US 2022080110 A1 | 17-03-2022 |
| | | WO 2015123012 A1 | 20-08-2015 |
| DE 102012009136 A1 | 07-11-2013 | DE 102012009136 A1 | 07-11-2013 |
| | | WO 2013167248 A1 | 14-11-2013 |
| DE 102014001981 A1 | 20-08-2015 | AT 515590 A1 | 15-10-2015 |
| | | DE 102014001981 A1 | 20-08-2015 |

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82