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(54) **METHOD AND CONTROL SYSTEM FOR A HYDRAULIC CIRCUIT OF A WORK VEHICLE**

(57) Method of controlling a hydraulic circuit of a work vehicle, the vehicle comprising a hydraulic circuit (HC) operatively connected to a fixed displacement hydraulic pump (P) and a prime mover (E) arranged to drive the hydraulic pump in rotation, said prime mover (E), electric, a hydraulic actuator (A1) arranged to be powered by the hydraulic circuit, and in which the hydraulic circuit comprises a supply valve of the hydraulic actuator (A1), a lever (JOYSTICK) for controlling said feed valve and said

prime mover (E), a temperature sensor (TS) and a pressure sensor (PS) operatively associated with a delivery port of the hydraulic pump (P), the method comprising an iterative process of variation of the rotation speed of the hydraulic pump which provides for the recalculation of a volumetric efficiency value based on a variation of the rotation speed, in order to force the real flow (Q_r) of oil hydraulic to converge towards the theoretical flow (Q_n) of hydraulic oil pumped by the hydraulic pump.

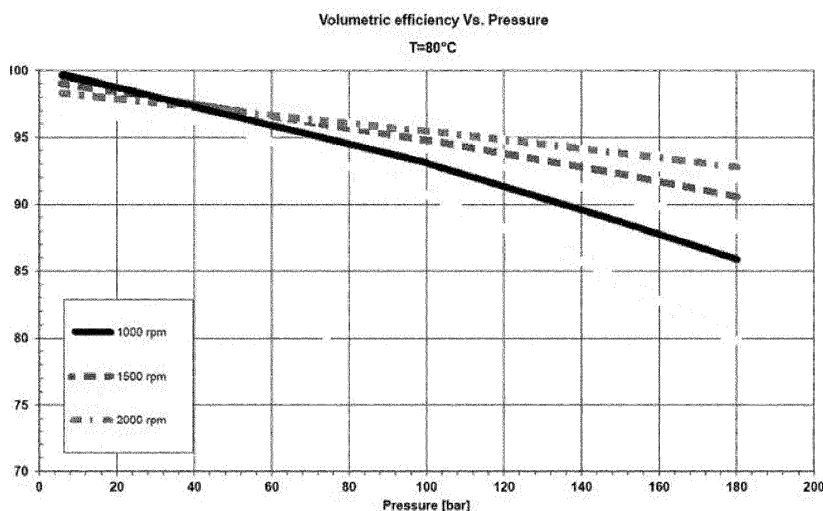


Fig. 3

Description

Field of the invention

[0001] The present invention relates to the field of hydraulic circuits and in particular of the type comprising an electro-hydraulic circuit for the actuation of at least one hydraulic member, including an arm and/or a bucket.

State of the art

[0002] In the field of work and agricultural vehicles, the operation of users, such as arms and related tools, is carried out by means of a hydraulic circuit.

[0003] The hydraulic circuit is powered by a hydraulic pump driven in rotation by a prime mover, very often an internal combustion engine. However, the progressive technological development of battery power systems makes it possible to design work vehicles with electric traction and/or with hydraulic systems operated by electric motors, such as a hydraulic circuit for the actuation of at least one hydraulic actuator enslaved to the movement of a hydraulic work member.

[0004] By "hydraulic work member" it is meant one of those components such as arms, buckets, etc .. distinct and separate from those inherent to the movement of the work vehicle, such as for example transmissions, braking systems, etc. Hereinafter, for convenience, reference is made to a "hydraulic member" meaning a "working hydraulic member".

[0005] In working machines the most known and implemented members are the arms equipped with bucket or forks or other devices.

[0006] The lifting and lowering of the arm is carried out by means of at least one double-action linear hydraulic actuator. It includes a pair of opposing chambers, which fill and empty alternately to raise or lower the arm.

[0007] The valve for controlling a hydraulic actuator is generally controlled by the operator using a joystick placed in the vehicle's cockpit.

[0008] The electrical signal generated by the joystick is acquired by a processing unit, which processes it to control the directional control valve. The directional control valve is evidently of the electro-hydraulic type.

[0009] Wear of the hydraulic pump or a malfunction in the hydraulic circuit can lead to unexpected behaviour of the actuator or the inability to lift a load.

[0010] The volumetric efficiency of a hydraulic pump essentially depends on the pressure, i.e. the load applied to the hydraulic member, and on the temperature of the hydraulic oil. Indeed, the temperature affects the viscosity of the hydraulic oil.

[0011] The theoretical or nominal flow rate Q_n of a hydraulic pump is defined as the product between the volumetric efficiency V and the rotation speed of the pump RPM_n . Under these conditions it is assumed that the volumetric efficiency is unitary. This definition can be identified, for example, in the manual "Oleodinamica e Pneu-

matica" prof. Nicola Nervegna, Edition May 2003 POLITEKO.

[0012] A change in volumetric efficiency involves a change in the flow of hydraulic oil generated by the hydraulic pump.

[0013] The manufacturers of hydraulic pumps provide tables that describe the efficiency of the pump as a function of pressure in a predetermined sub-temperature range. Therefore, considering the entire operating temperature range of a hydraulic pump, the manufacturer provides as many tables as there are sub-ranges or temperature values into which the entire temperature range is divided.

[0014] When the hydraulic pump is driven in rotation by an electric motor, the lever, generally a joystick placed in the vehicle cabin, controlling the hydraulic actuator controls both the opening of the directional valve and the rotation speed of the electric motor.

[0015] There is an approximately linear relationship between the angle of deviation of the joystick and the opening of the directional valve and between the angle of deviation of the joystick and the speed of rotation of the motor.

[0016] However, in relation to the operating conditions, the behavior of the hydraulic member may appear significantly different.

[0017] If not specifically excluded in the detailed description that follows, what is described in this chapter is to be considered as an integral part of the detailed description.

Summary of the invention

[0018] The object of the present invention is to indicate a method and system for controlling a hydraulic circuit of a work vehicle in particular to improve the response of the hydraulic circuit to the requests of an operator.

[0019] The basic idea of the present invention is to calculate the effective flow rate of the hydraulic pump on the basis of

- The position of the control lever of the directional valve,
- The temperature of the hydraulic oil,
- The pressure at the delivery port of the hydraulic pump, and to modify the rotation speed of the electric motor in order to generate a flow of hydraulic oil which is exclusively a function of the position of the control lever and independent of the volumetric efficiency of the hydraulic pump which in turn is a function of the temperature and pressure at the port of the hydraulic pump.

[0020] In other words, the idea is to compensate for the volumetric efficiency variability of the hydraulic pump by correcting the rotation speed of the prime mover.

[0021] This means that in order to obtain a preordained flow of hydraulic oil, in conditions of halving the volumetric

efficiency, the rotation speed of the prime mover approximately doubles.

[0022] This means that for the operator who controls the vehicle, the hydraulic system responds in a predictable and transparent way to the changes in terms of pressure and temperature.

[0023] The dependent claims describe preferred variants of the invention, forming an integral part of this description.

Brief description of the figures

[0024] Further objects and advantages of the present invention will become clear from the following detailed description of an example of its embodiment (and its variants) and from the attached drawings given purely for explanatory and non-limiting purposes, in which:

Figure 1 shows a preferred variant of an electro-hydraulic circuit modified according to the present invention;

Figure 2 shows an example of a work vehicle in which the present invention is implemented;

Figure 3 shows a volumetric efficiency diagram at different rotation speeds of the hydraulic pump as the pressure at the port of the hydraulic pump varies and for a given temperature value;

Figure 4 shows an exemplary flow chart of the present invention.

[0025] The same reference numbers and letters in the figures identify the same elements or components or functions.

[0026] It should be noted that the terms "first", "second", "third", "upper", "lower" and the like can be used here to distinguish various elements. These terms do not imply a spatial, sequential or hierarchical order for the modified elements unless specifically indicated or inferred from the text.

[0027] The elements and features illustrated in the various preferred embodiments, including the drawings, can be combined with each other without however departing from the scope of this application as described below.

Detailed description of exemplary embodiments

[0028] Figure 1 shows an example of an electro-hydraulic circuit for powering a hydraulic actuator A1, A2 shown in figure 2. The hydraulic circuit HC is powered by a fixed displacement hydraulic pump P, driven in rotation by an electric prime mover E, powered by battery or fuel cells.

[0029] The pump draws oil from a storage tank T and sends it to a directional valve (not shown).

[0030] In figure 1, the remaining electro-hydraulic circuit is summarized with the block "HYDRAULIC FUNCTIONS".

[0031] In relation to the chamber fed by the hydraulic

circuit, the actuator extracts or retracts its shaft allowing the relative working member to move in two opposite directions. For example, the arm B of the compact wheel loader CWL of figure 2 raises or lowers.

[0032] The lever JOYSTICK, preferably arranged in the cab of the work vehicle CWL, in relation to the deflection imposed by an operator, is capable of generating an electrical signal, detected by a control unit CONTROL UNIT.

[0033] The control unit, on the basis of this electrical signal, is configured to generate a control signal for the directional valve and to control the prime mover E. In particular, on the basis of this electrical signal, the control unit commands the opening of the directional valve and at the same time the rotation speed of the prime mover E.

[0034] A pressure sensor PS and a temperature sensor TS are associated with the delivery port of the hydraulic pump. These sensors are operationally connected with the control unit. The volumetric efficiency tables supplied by the manufacturer of the hydraulic pump or experimentally detected on the work vehicle are stored in the control unit, so that according to the volumetric efficiency the rotation speed of the prime mover is increased in order to compensate for the effects on the flow of hydraulic oil generated by the hydraulic pump.

[0035] The real flow rate $Q_r = E_r * V * \text{RPM}_n$, where E_r is the real volumetric efficiency lower than 1, V the displacement of the hydraulic pump P and RPM_n the nominal speed of rotation of the hydraulic pump as a function of the angular position of the control lever.

[0036] As mentioned above, the value of the RPM_n speed is a function of the deflection of the control lever of the hydraulic actuator according to a linear proportional factor.

[0037] It is worth noting that the efficiency is also a function of the pump rotation speed and therefore the symbol E_r shows the subscript "r" to indicate that as the pump rotation speed varies, the efficiency curve also varies. A bundle of efficiency curves is shown in the exemplary diagram of Figure 3 for a given temperature value ($T = 80^\circ \text{C}$) or temperature range.

[0038] To compensate for the fact that the volumetric efficiency E_r is a value lower than unity, according to the present invention, a correct speed value $\text{RPM}_c = \text{RPM}_n / E_r$ is required. This implies that $\text{RPM}_c > \text{RPM}_n$.

[0039] A change in the rotation speed of the hydraulic pump from RPM_n to RPM_c involves a change in the efficiency by moving to another curve of the beam in Figure 3, therefore, the real efficiency E_r is passed to the correct one E_c . Therefore, the correct real flow rate is $Q_c = E_c * V * \text{RPM}_c$.

[0040] Once Q_c has been calculated, this can be compared with Q_n and it is decided whether to stop the correction procedure of the rotation speed of the hydraulic pump or not.

[0041] For example if $Q_n - Q_c < T_h$ then the process stops. T_h is a settable threshold.

[0042] The process can iterate as long as the real flow

differs by less than a predetermined threshold T_h from the theoretical flow rate or it can be stopped after a predetermined number of iterations.

[0043] During the iterative calculation operations of the final correct rotation speed value RPM_{cn} obtained after n number of iterations, the correct rotation speed values (RPM_{c2} , RPM_{c3} , ..., RPM_{cn}) for each of the 2, 3, ..., n iterations subsequent to the first, are preferably calculated as the average of the last two values previously identified. Thanks to the present invention, regardless of the temperature conditions of the hydraulic oil and the load applied to the mechanical member, an angular position of the control lever corresponds to approximately the same flow generated by the hydraulic pump.

[0044] The method object of the present invention can be summarized by the following steps:

- (a) Acquisition of a deflection angle of the control lever and calculation of a corresponding nominal value (RPM_n) of rotation speed of the prime mover, proportional to said deflection angle,
- (b) acquisition of a temperature and pressure value at the delivery port of the hydraulic pump,
- (c) calculation of a theoretical flow (Q_n) of hydraulic oil pumped by said hydraulic pump,
- (d) calculation of a real flow (Q_r) of hydraulic oil pumped by said hydraulic pump as a function of a table expressing a first volumetric efficiency value (E_r) as a function of said temperature values, pressure and nominal rotation speed,
- (e) calculation of a first corrected rotation speed value ($RPM_c = RPM_n / E_r$) as a function of said first volumetric efficiency value,
- (f) Calculation of a first corrected flow rate value (Q_c) as a function of said first corrected rotational speed value (RPM_c) and of a corresponding first corrected volumetric efficiency value (E_c), in which the first volumetric efficiency value corrected (E_c) is obtained from said table,
- (g1) if said first corrected flow rate value (Q_{c1}) is less than a predetermined threshold (T_h) of said theoretical flow rate value (Q_n) then the process stops, otherwise
- (g2) if said first corrected flow rate value is less than said predetermined threshold (T_h) of said theoretical flow rate value (Q_n) then the process restarts from step (e), calculating in succession a second, third, ..., n -th correct rotation speed value (RPM_{c2} , RPM_{c3} , ..., RPM_{cn}) and in parallel a second, third, ..., n -th correct flow rate value (Q_{c2} , Q_{c3} , ..., Q_{cn}) as long as the corrected flow rate value ($Q_{c2,3}$, ..., n) is far less than said predetermined threshold (T_h) from said theoretical flow rate value (Q_n).

When the process converges to a calculated rotation speed value, this is set (Set) by the control unit forcing the electric motor to adapt to this calculated rotation

speed value.

[0045] The recursive portion of the flowchart is enclosed in the hh block.

[0046] The iterative process performs a gradual change in the rotation speed of the hydraulic pump. At each step the volumetric efficiency value is calculated on the basis of the variation of the rotation speed, of a temperature and pressure value measured by the sensors TS and PS, in order to force the real flow Q_r of hydraulic oil pumped by the hydraulic pump to converge towards the theoretical value Q_n .

[0047] The wording "...is far more (or less) than said predetermined threshold T_h of said theoretical flow rate value Q_n " means that a given value is outside (or inside) an interval having an width equal to the threshold T_h and centered on the flow rate theoretical value.

[0048] The present invention can be advantageously carried out by means of a computer program, which comprises coding means for carrying out one or more steps of the method, when this program is executed on a computer. Therefore, it is intended that the scope of protection extends to said computer program and further to computer readable means comprising a recorded message, said computer readable means comprising program coding means for carrying out one or more steps of the method, when said program is run on a computer.

[0049] Implementation variants of the described non-limiting example are possible, without however departing from the scope of protection of the present invention, including all the equivalent embodiments for a person skilled in the art, to the content of the claims.

[0050] From the above description, the person skilled in the art is able to realize the object of the invention without introducing further construction details.

Claims

1. Method for controlling a hydraulic circuit of a work vehicle, the vehicle including

- a hydraulic circuit (HC) operatively connected to a fixed displacement hydraulic pump (P) and a prime mover (E) arranged to drive the hydraulic pump in rotation,
- said prime mover (E), being electric type,
- a hydraulic actuator (A1) arranged to be powered by the hydraulic circuit, and in which the hydraulic circuit includes a hydraulic actuator supply valve (A1),
- a lever (JOYSTICK) for controlling said feed valve and said prime mover (E),
- a temperature sensor (TS) and a pressure sensor (PS) operatively associated with a delivery port of the hydraulic pump (P),

the method comprising

- (a) Acquisition of a deflection angle of the control lever and calculation of a corresponding nominal value (RPMn) of rotation speed of the prime mover, proportional to said deflection angle,
- (b) acquisition of a temperature and pressure value at the delivery port of the hydraulic pump,
- (c) calculation of a theoretical flow (Qn) of hydraulic oil pumped by said hydraulic pump,
- (d) calculation of a real flow (Qr) of hydraulic oil pumped by said hydraulic pump as a function of a table expressing a first volumetric efficiency value (Er) as a function of said values of temperature, pressure and nominal rotation speed,

and subsequently

- (hh) execution of an iterative process of variation of the rotation speed of the hydraulic pump which includes, at each iteration, the calculation of a volumetric efficiency value on the basis of said variation of the rotation speed, of the temperature value and of pressure measured by said sensors, so as to force the real flow (Qr) of hydraulic oil pumped by the hydraulic pump to converge towards said theoretical flow value (Qn).

2. Method according to claim 1 wherein said iterative process comprises the following steps in succession:

- (e) calculation of a first corrected rotation speed value (RPMc = RPMn/Er) as a function of said first volumetric efficiency value,
- (f) Calculation of a first corrected flow rate value (Qc) as a function of said first corrected rotational speed value (RPMc) and of a corresponding first corrected volumetric efficiency value (Ec), wherein the first volumetric efficiency value corrected (Ec) is obtained from said table,
- (g1) if said first corrected flow rate value (Qc) is less than a predetermined threshold (Th) of said theoretical flow rate value (Qn) then the process stops, otherwise (g2) if said first corrected flow rate value is lower than said predetermined threshold (Th) of said theoretical flow rate value (Qn) then the process restarts from step (e) by calculating in succession a second, third, ..., n -th correct rotation speed value (RPMc2, RPMc3, ..., RPMcn) and in parallel a second, third, ..., n-th correct flow rate value (Qc2, Qc3, ..., Qcn) as long as the value of the corrected flow rate (Qc2,3, ..., n) is far, less than said predetermined threshold (Th), from said theoretical flow rate value (Qn).

3. Control system a hydraulic circuit of a work vehicle,

including the vehicle

- a hydraulic circuit (HC) operatively connected to a fixed displacement hydraulic pump (P) and a prime mover (E) arranged to drive the hydraulic pump in rotation,
- said prime mover (E), of the electric type,
- a hydraulic actuator (A1) arranged to be powered by the hydraulic circuit, and wherein the hydraulic circuit includes a hydraulic actuator supply valve (A1),
- a lever (JOYSTICK) for controlling said feed valve and said prime mover (E),
- a temperature sensor (TS) and a pressure sensor (PS) operatively associated with a delivery port of the hydraulic pump (P),

a processing unit configured for

- (a) Acquiring a deflection angle of the control lever and calculate a corresponding nominal value (RPMn) of rotation speed of the prime mover, proportional to said deflection angle,
- (b) acquiring a temperature and pressure value at the delivery port of the hydraulic pump,
- (c) calculating a theoretical flow (Qn) of hydraulic oil pumped by said hydraulic pump,
- (d) calculating a real flow (Qr) of hydraulic oil pumped by said hydraulic pump as a function of a table, stored in a non-volatile memory of the processing unit, expressing a first volumetric efficiency value (Er) as a function of said values of temperature, pressure and nominal rotation speed, and subsequently for
- (hh) carrying out an iterative process of variation of the rotation speed of the hydraulic pump which provides for the recalculation of a volumetric efficiency value on the basis of said variation of the rotation speed, of the temperature and pressure value measured by means of said sensors in so as to force the real flow (Qr) of hydraulic oil pumped by the hydraulic pump to converge towards said theoretical flow value and
- (Set) controlling said prime mover so as to operate at said varied rotation speed value.

4. Work vehicle comprising a hydraulic member

- a hydraulic circuit (HC) operatively connected to a fixed displacement hydraulic pump (P) and a prime mover (E) arranged to drive the hydraulic pump in rotation,
- said prime mover (E), electric,
- a hydraulic actuator (A1) arranged to be powered by the hydraulic circuit, and in which the hydraulic circuit includes a hydraulic actuator supply valve (A1),

- a lever (JOYSTICK) for controlling said feed valve and said prime mover (E),
- a temperature sensor (TS) and a pressure sensor (PS) operatively associated with a delivery port of the hydraulic pump (P), 5
- a processing unit configured for
- (a) Acquiring a deflection angle of the control lever and calculate a corresponding nominal value (RPMn) of rotation speed of the prime mover, proportional to said deflection angle, 10
- (b) acquiring a temperature and pressure value at the delivery port of the hydraulic pump,
- (c) calculating a theoretical flow (Qn) of hydraulic oil pumped by said hydraulic pump, 15
- (d) calculating a real flow (Qr) of hydraulic oil pumped by said hydraulic pump as a function of a table, stored in a non-volatile memory of the processing unit, expressing a first volumetric efficiency value (Er) as a function of said values of temperature, pressure and nominal rotation speed, and subsequently for 20
- (hh) carrying out an iterative process of variation of the rotation speed of the hydraulic pump which provides for the recalculation of a volumetric efficiency value on the basis of said variation of the rotation speed, of a temperature and pressure value measured by means of said sensors in so as to force the real flow (Qr) of hydraulic oil to converge towards said theoretical flow (Qn) ed 25
- (Set) controlling said prime mover so as to operate at said varied rotational speed value. 30

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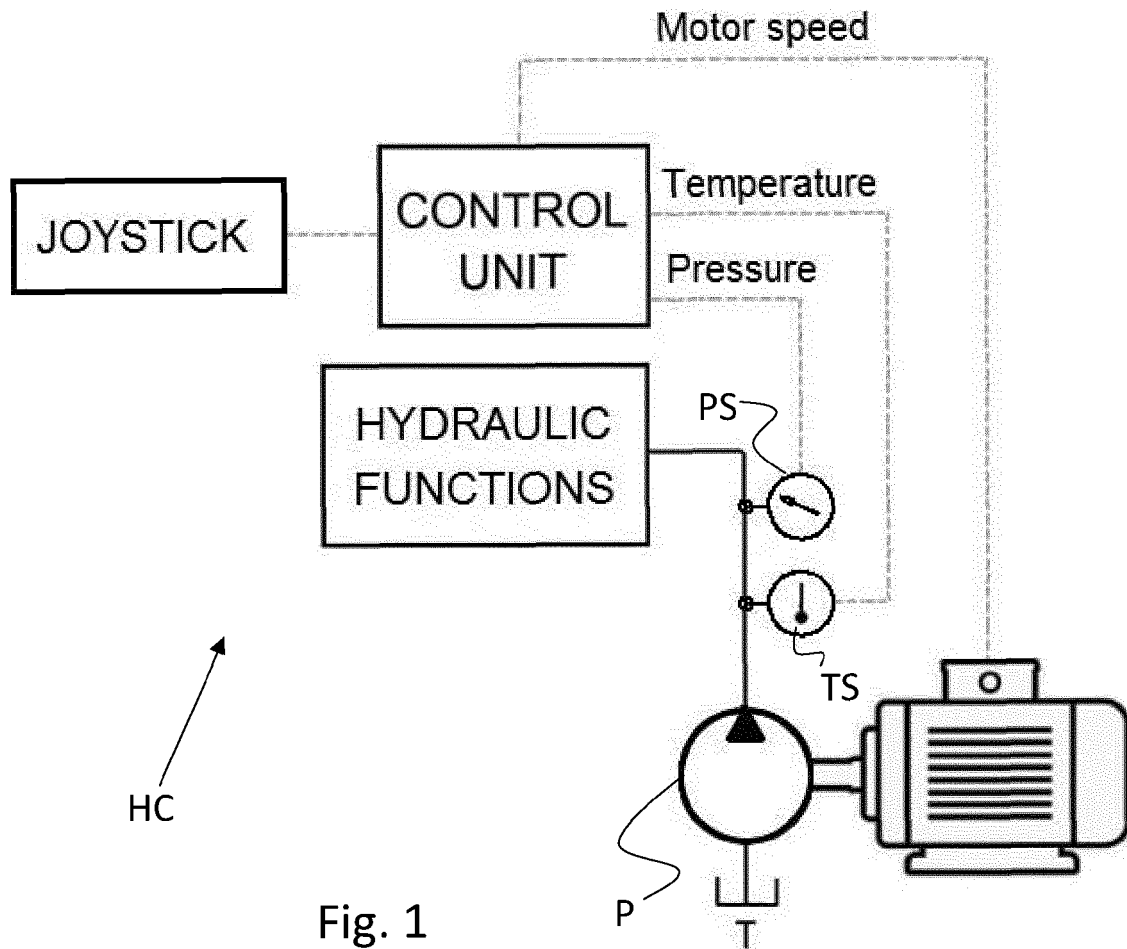


Fig. 1

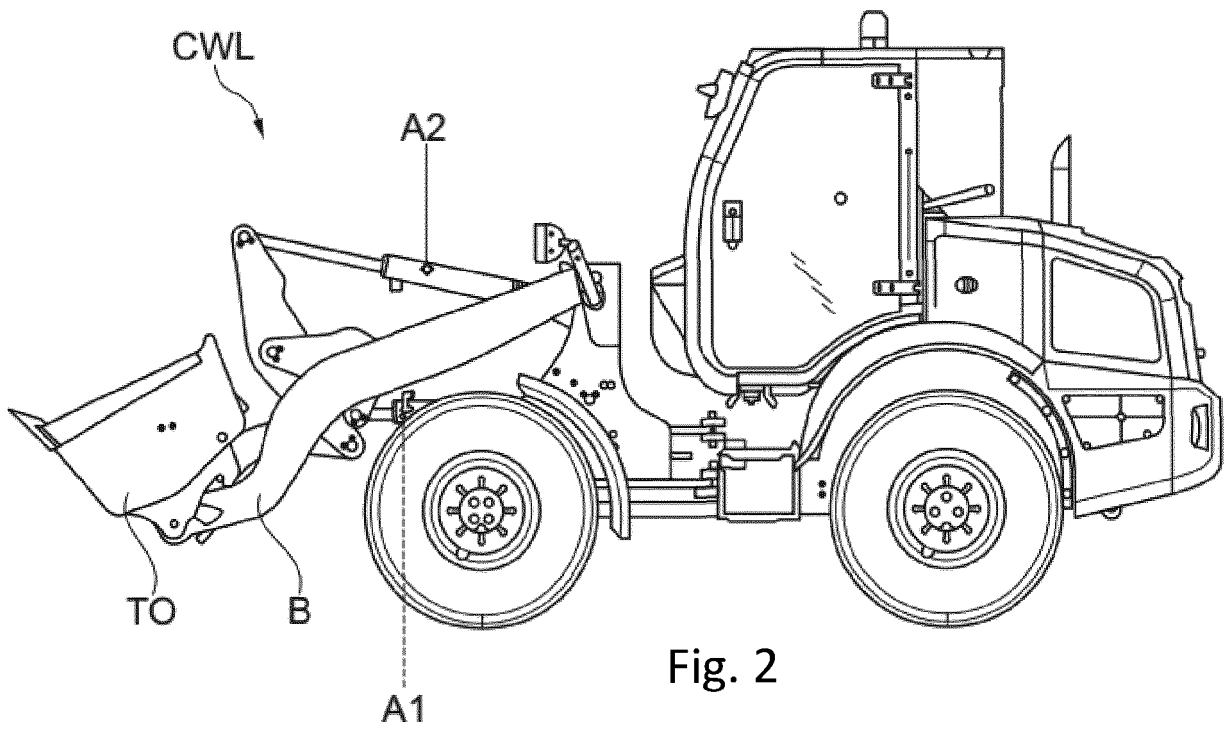


Fig. 2

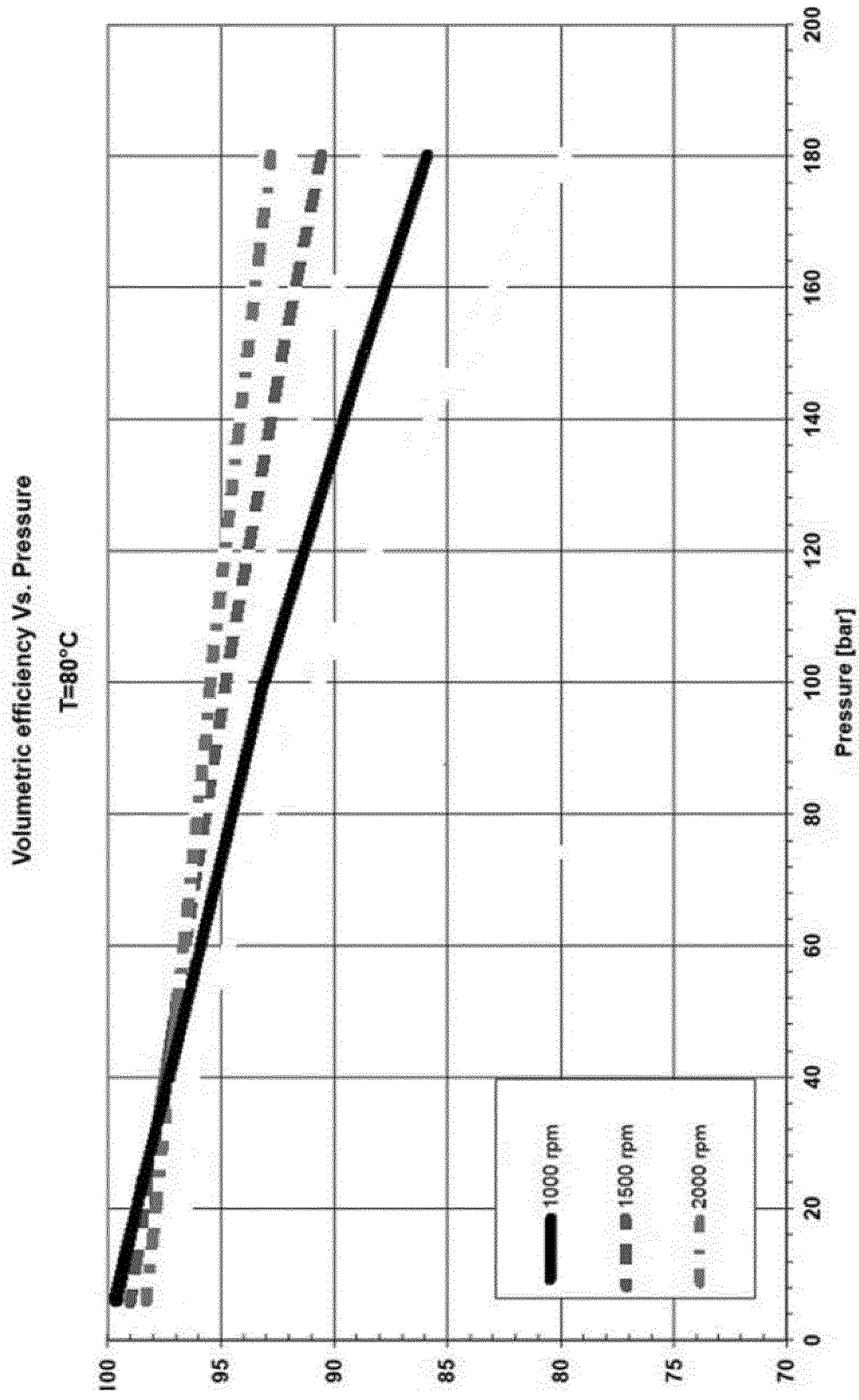


Fig. 3

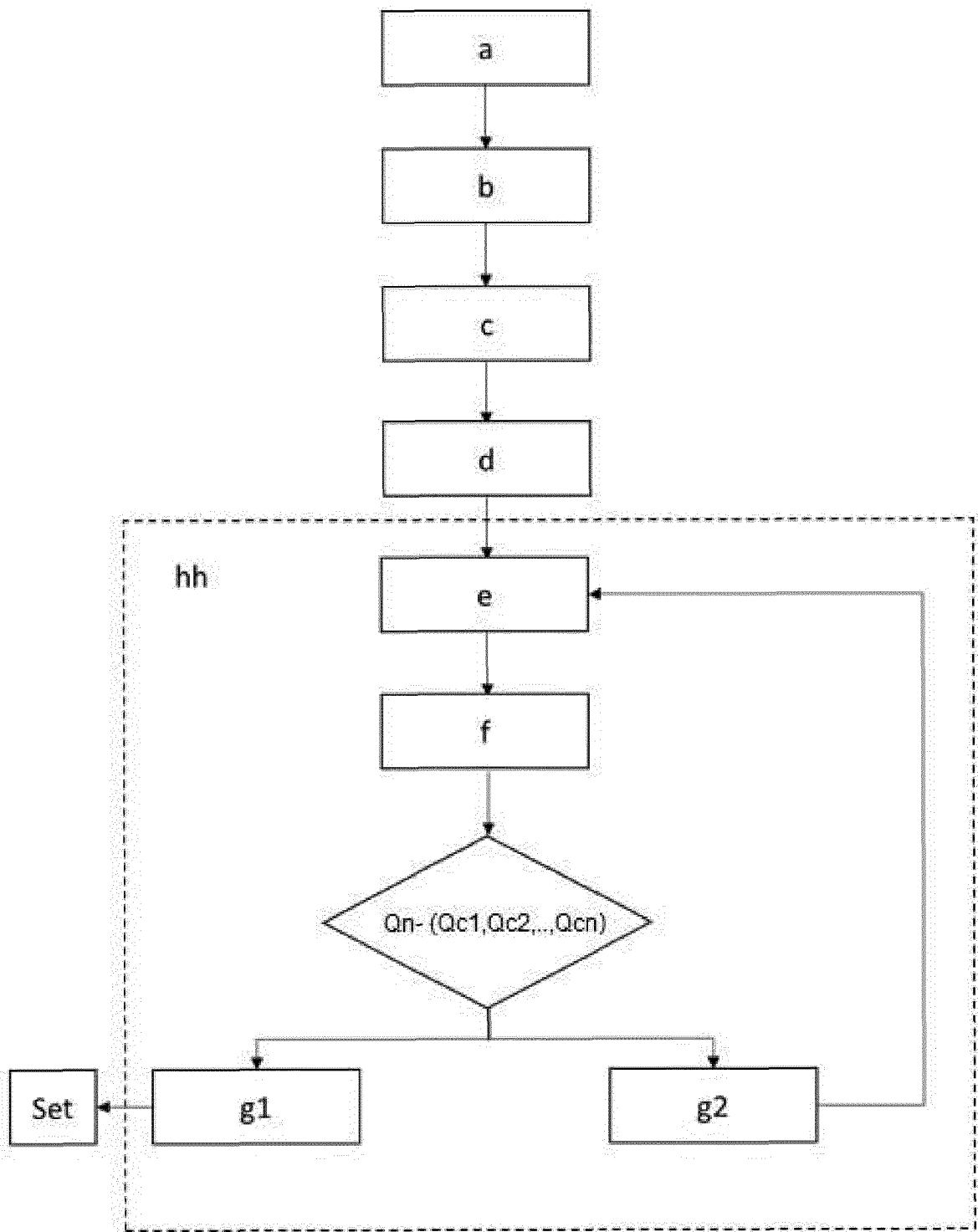


Fig. 4



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Place of search Munich		Date of completion of the search 26 February 2023	Examiner Rocabruna Vilardell
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