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(54) **EXHAUST CONTROL METHOD FOR PIPELINE LOOP BASED ON CANNED MOTOR PUMP,
CANNED MOTOR PUMP CONTROL APPARATUS, AND CANNED MOTOR PUMP**

(57) The present disclosure provides an exhaust control method for a pipeline loop based on a canned motor pump. The method comprises: monitoring motor parameters during an operation of a canned motor pump in real time; determining whether to initiate an exhaust control phase according to the obtained motor parameters and a preset trigger control condition; performing exhaust control on the canned motor pump according to a

preset rule once the exhaust control phase is initiated; and terminating the exhaust control when a preset termination control condition is satisfied. The present disclosure further discloses a corresponding canned motor pump control apparatus and a canned motor pump. The present disclosure can improve exhaust efficiency and reduce exhaust noise.

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to the technical field of exhaust control for pipeline loops, and specifically, to an exhaust control technology for a pipeline loop based on a canned motor pump.

BACKGROUND

[0002] A canned motor pump is a specially designed seal-less pump. For a heating circulation system or other closed pipeline loop systems employing liquid circulation, the canned motor pump is typically employed to ensure sealing performance and minimize an air content within a pipeline loop. The canned motor pump integrates a pump and a motor into a unit. A rotor of the motor and an impeller of the pump are fixed on a same shaft, and a containment shell separates the rotor of the motor from a stator, preventing motor windings from contacting conveyed liquid. Only the rotor operates within a conveyed medium, isolation between the motor and a pump casing is implemented. This design is characterized by zero leakage, high energy efficiency, high safety, and low noise.

[0003] For a pipeline loop not equipped with a canned motor pump, conventional exhaust methods usually involve opening a water inlet and outlet of the closed pipeline loop system and adding water into the system through a valve while draining simultaneously, in an attempt to flush out air with water flow. However, this approach is largely ineffective. Consequently, a great amount of air remains, system noise levels tend to be high, and water resources are wasted considerably.

[0004] For a pipeline loop equipped with a canned motor pump, the latest method on the current market is implementing exhaust of the closed pipeline loop system by using a software-controlled canned motor pump. According to exhaust using the software-controlled canned motor pump (hereinafter referred to as "software exhaust"), a pipeline is equipped with, in addition to the canned motor pump, an exhaust valve and a water inlet, thereby enabling rapid air discharge without opening a water outlet. Software exhaust primarily works by controlling a speed and direction of rotation of the canned motor pump to circulate air within the pipeline loop, conveying the air to the vicinity of an exhaust valve for discharge. However, existing software exhaust methods primarily rely on simple adjustment of the motor speed to discharge air. Exhaust schemes follow established policies (e.g., the canned motor pump alternate between a maximum speed and a minimum speed for a fixed time). The exhaust process is rigid, inefficient, and inadequate for handling accidents. Particularly in a closed pipeline loop system with complex designs, a great amount of residual air may be trapped in the loop even after the exhaust procedure is complete.

SUMMARY

[0005] In view of this, the present disclosure provides an exhaust control method for a pipeline loop based on a canned motor pump. The method comprises: monitoring motor parameters during an operation of a canned motor pump in real time; determining whether to initiate an exhaust control phase based on the obtained motor parameters and a preset trigger control condition; performing exhaust control on the canned motor pump according to a preset rule once the exhaust control phase is initiated; and terminating the exhaust control when a preset termination control condition is satisfied. The present disclosure further discloses a corresponding canned motor pump control apparatus and a canned motor pump. The present disclosure can improve exhaust efficiency and reduce exhaust noise.

[0006] According to a first aspect of the present disclosure, an exhaust control method for a pipeline loop based on a canned motor pump is disclosed, comprising:

a data acquisition phase: obtaining motor parameters during an operation of a canned motor pump, the motor parameters comprising a motor operating power P_t , a motor speed V_t , and a motor operating time;

an exhaust control trigger determination phase: determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied, and initiating an exhaust control phase when the condition is satisfied; and

the exhaust control phase: performing exhaust control on the canned motor pump according to a preset rule, and terminating the exhaust control to initiate a normal operation phase when a preset termination control condition is satisfied.

[0007] As an alternative, the preset rule comprises: first controlling a motor to increase a speed to break up bubbles within the pipeline loop, and then controlling the motor to reduce the speed to expel the bubbles.

[0008] As an alternative, the preset trigger control condition comprises a first trigger control condition; and the determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied comprises:

calculating a power fluctuation quantity ΔP of the motor according to the motor operating power P_t , and adjusting a current air content Q_t within the pipeline loop when the power fluctuation quantity ΔP is greater than a first power fluctuation threshold P_1 ; and determining that the first trigger control condition is satisfied when the current air content Q_t reaches a first air content threshold Q_1 .

[0009] As an alternative, an initial air content Q_0 is zero when the motor starts operating, and the adjusting a current air content Q_t within the pipeline loop comprises:

$$Q_t = Q_{t-1} * (1 + \Delta Q),$$

wherein Q_{t-1} represents an air content calculated in a previous cycle, and ΔQ represents an incremental air content.

[0010] As an alternative, the determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied further comprises: when the motor speed V_t is greater than or equal to a first speed threshold VA_1 , if the motor power P_t is less than a power corresponding to the speed on a no-load power curve in a preset power-speed fitting curve and a duration reaches a first preset time T_1 , indicating that the current air content Q_t is higher than a second air content threshold Q_2 , and determining that the first trigger control condition is satisfied, wherein $Q_2 > Q_1$, and $VA_1 \geq V_0$, wherein V_0 represents a normal operating speed of motor during a normal operation phase of the canned motor pump.

[0011] As an alternative, the preset trigger control condition further comprises a second trigger control condition, and the exhaust control phase is initiated when both the first and second trigger control conditions are satisfied simultaneously; and

after determining that the first trigger control condition is satisfied, the determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied further comprises:

if the motor speed V_t is greater than a second speed threshold VA_2 or the motor speed V_t is less than a third speed threshold VA_3 , and a duration exceeds a second preset time T_2 , determining that the second trigger control condition is satisfied, wherein $VA_2 \leq V_t \leq VA_3$.

[0012] As an alternative, when the motor is a flux-weakening controlled motor, the motor parameters further comprise a rate of change of magnetic flux linkage of motor B_t ;

the preset trigger control condition further comprises a second trigger control condition, and the exhaust control phase is initiated when both the first and second trigger control conditions are satisfied simultaneously; and

after determining that the first trigger control condition is satisfied, the determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied further comprises: if $B_t > B_1$, determining that the second trigger control condition is satisfied, wherein B_1 represents a rate of change threshold of magnetic flux linkage.

[0013] As an alternative, the preset trigger control condition further comprises a second trigger control condition, and the exhaust control phase is initiated when both the first and second trigger control conditions are satisfied simultaneously; and after determining that the first trigger control condition is

satisfied, the determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied further comprises:

5 after determining that the first trigger control condition is satisfied, increasing the motor speed to V_1 , after an operating time reaches a third preset time T_3 , reducing the motor speed to V_2 , and after an operating time reaches a fourth preset time T_4 , restoring a normal operating speed V_0 ; and
10 if, during the operation at the motor speed V_1 , the power fluctuation quantity ΔP remains within the first power fluctuation threshold P_1 and during the operation at the motor speed V_2 , the power fluctuation quantity ΔP is greater than the first power fluctuation threshold P_1 , determining that the second trigger control condition is satisfied.

[0014] As an alternative, in the exhaust control phase, 20 the performing exhaust control on the canned motor pump according to a preset rule comprises:

when the current air content Q_t within the pipeline loop is higher than the first air content threshold Q_1 , controlling the motor to operate at a high speed V_3 ; and
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if the power fluctuation quantity ΔP of the motor is less than a second power fluctuation threshold P_2 , controlling the motor to operate at a low speed V_4 , wherein $V_4 < V_0 < V_3 \leq V_{\max}$, $V_{\max}$ represents a maximum operating speed of the motor, V_0 represents a normal operating speed of the motor during the normal operation phase of the canned motor pump, and $P_2 < P_1$; and
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the power fluctuation quantity ΔP is calculated from the motor operating power P_t , and the current air content Q_t is correlated with the power fluctuation quantity ΔP .
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[0015] As an alternative, in the exhaust control phase, the performing exhaust control on the canned motor pump according to a preset rule further comprises:

if the current air content Q_t exceeds a third air content threshold Q_3 , controlling the canned motor pump to suspend operation, and controlling the canned motor pump to restart when a suspension time reaches an eighth preset time T_8 , wherein $Q_3 > Q_2 > Q_1$.
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[0016] As an alternative, in the exhaust control phase, the performing exhaust control on the canned motor pump according to a preset rule further comprises:

if a number of restarts reaches a preset count and the motor operating power at a current motor speed remains to be less than a no-load power in the power-speed fitting curve, controlling the canned motor pump to stop operation.
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[0017] As an alternative, in the exhaust control phase, the preset termination control condition is that a total time of the exhaust control phase reaches a fifth preset time
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T5.

[0018] As an alternative, in the exhaust control phase, the preset termination control condition is that the operating time at a low speed V4 reaches a sixth preset time T6, wherein $T6 > T5$.

[0019] As an alternative, in the exhaust control phase, the preset termination control condition is that the power fluctuation quantity ΔP of the motor is less than a third power fluctuation threshold P3 and a duration reaches a seventh preset time T7, wherein $P3 \leq P2 < P1$.

[0020] According to a second aspect of the present disclosure, a canned motor pump control apparatus is disclosed, comprising a MCU and a motor drive controller electrically connected to the MCU, wherein the MCU comprises a processor and a memory. The memory has a program stored therein. The program is loaded and executed by the processor, to implement the exhaust control method for a pipeline loop according to the first aspect of the present disclosure and any one alternative.

[0021] As an alternative, an ADC module and a communication module electrically connected to the processor are further comprised. The ADC module is integrated into the MCU or is independent of the MCU. The communication module is configured for a communication connection between the canned motor pump control apparatus and an upper computer.

[0022] According to a third aspect of the present disclosure, a canned motor pump is disclosed, comprising a canned motor pump body and the canned motor pump control apparatus according to the second aspect of the present disclosure and any one alternative. The canned motor pump body comprises a motor and a pump casing. The canned motor pump control apparatus is configured to control operation of the motor.

[0023] Beneficial Effects:

- (1) According to the present disclosure, motor parameters during an operation of a canned motor pump are monitored and obtained in real time, it is determined whether to initiate an exhaust control phase based on a preset trigger control condition, and exhaust control is performed on the canned motor pump according to a preset rule once the exhaust control phase is initiated. The exhaust control is terminated when a preset termination control condition is satisfied, and a normal operation phase is initiated, thereby implementing automatic control for exhaust based on the canned motor pump, improving exhaust efficiency, and reducing exhaust noise.
- (2) According to the present disclosure, based on the motor parameters during the operation of the canned motor pump and a related preset condition, exhaust control initiation or exhaust control termination can be selected according to an actual working condition, thereby not only improving the exhaust efficiency, but also reducing energy consumption. In addition, the parameters may be flexibly set according to an actual requirement.

(3) According to the present disclosure, in the exhaust control phase, based on the preset rule, a speed is increased first to break up bubbles, and then the speed is reduced to convey the bubbles to a valve for exhaust, thereby greatly improving the exhaust efficiency and shortening an exhaust time.

(4) The present disclosure can further adapt to an adjustment control policy for an abnormal condition, to avoid a risk of motor stalling.

(5) The present disclosure can automatically adapt to various complex pipeline systems, can discharge air within a closed pipeline loop system at a high speed and to the greatest extent, can well resolve the problems of difficult air discharge and high noise encountered when a terminal user uses a canned motor pump, and can assist the terminal user in assembling a pipeline system more conveniently

BRIEF DESCRIPTION OF THE DRAWINGS

[0024]

FIG. 1 is a flowchart 1 of exhaust control based on a canned motor pump;

FIG. 2 is a schematic diagram of a circuit connection of a canned motor pump;

FIG. 3 is a schematic diagram of a power-speed fitting curve of a canned motor pump;

FIG. 4 is a flowchart 1 of determining a first trigger control condition of a canned motor pump;

FIG. 5 is a flowchart 2 of determining a first trigger control condition of a canned motor pump;

FIG. 6 is a flowchart 1 of determining a second trigger control condition of a canned motor pump; and

FIG. 7 is a flowchart 2 of exhaust control based on a canned motor pump.

DETAILED DESCRIPTION

[0025] To make the objectives, technical solutions, and advantages of embodiments of the present disclosure clearer, the following clearly and completely describes the technical solutions in the embodiments. The following embodiments are used for describing the present disclosure but are not used for limiting the scope of the present disclosure.

[0026] With reference to FIG. 1, an embodiment of the present disclosure discloses an exhaust control method for a pipeline loop based on a canned motor pump, which mainly comprises the following steps.

[0027] Step 1 is a data acquisition phase.

[0028] The present disclosure begins to detect electrical parameters of a canned motor pump in real time upon startup of the canned motor pump, such as a motor operating power P_t , a motor speed V_t , a rate of change of magnetic flux linkage of motor B_r , and a motor operating time. The electrical parameters are transmitted to a MCU.

[0029] In a motor control system of the canned motor

pump, a power supply provides a stable AC to an inverter. The inverter converts the AC into a DC. The MCU controls a switching device to be turned on and off to implement electronic commutation, so as to drive and control operation of a motor of the canned motor pump. A bus voltage may be obtained by means of direct sampling based on a voltage divider resistor by using an ADC module built in the MCU. A bus current refers to a current output by the inverter on a DC bus. A three-phase current refers to a current in a three-phase winding of the motor. The three-phase current may be obtained based on a three-phase voltage and the Ohm's law, wherein the three-phase voltage may be directly obtained by using a three-phase sampling resistor. There is a particular known relationship between the bus current and the three-phase current. Therefore, the bus current may be obtained once the three-phase current is obtained. For example, in an ideal case, a DC bus power is equal to a motor input power. A calculation relationship between the bus current and the three-phase current is as follows:

$$I_{bus} = K \cdot \frac{\sqrt{3}I_{phase}}{2}$$

wherein I_{bus} represents the bus current, I_{phase} represents the three-phase current, and K represents a modulation coefficient.

[0030] As shown in FIG. 1, in a specific solution, the bus voltage may be directly obtained by sampling bus voltage divider resistors (R1, R2) through the ADC module built in the MCU. The magnitude of the three-phase current of the motor may be obtained in real time by measuring the voltage of three sampling resistors (R3, R4, R5) integrated on an internal driver within the canned motor pump. One end of each of the three sampling resistors is connected to one of three-phase lines UVW of the motor, and the other end is grounded. Therefore, the three-phase voltage of the motor may be acquired, and the magnitude of the three-phase current may then be calculated by using the Ohm's law ($I=U/R$). The bus current may further be calculated according to the three-phase current. A manner of obtaining or calculating the foregoing parameters may be specifically selected and set according to an actual requirement. This is not limited in the present disclosure.

[0031] In an alternative, the motor operating power (referred to as "power") of the canned motor pump may be calculated based on a bus DC voltage and the three-phase current of the motor. A calculation formula of the motor operating power is as follows:

$$P = V_{dc} * I_{dc} \quad (1)$$

wherein V_{dc} represents a bus DC voltage acquired by using the sampling resistor R2, and I_{dc} represents a bus DC current obtained by converting the three-phase current acquired by the sampling resistors R3, R4, R5.

[0032] In another embodiment, a manner of obtaining the motor operating power may further be selected and set according to an actual requirement. This is not limited in the present disclosure.

5 **[0033]** A back electromotive force (EMF) of the motor is proportional to the motor speed. The three-phase voltage may be used for calculating the back EMF of the motor. Further, an operating speed of the motor (referred to as "motor speed") may be calculated through the following formula:

$$E = K_e \frac{2\pi MV}{60} \quad (2)$$

10 wherein E represents the back EMF of the motor, M represents a number of pole pairs of a stator of the motor, K_e represents a back EMF constant, and V represents a mechanical speed (revolutions per minute) of the motor.

[0034] Alternatively, in another solution, the motor speed V_t may be directly detected by mounting a detection apparatus such as a magnetic encoder or a Hall sensor. It may be understood that different detection manners usually mainly affect costs, and detection precision is not greatly different. For example, the cost of obtaining the motor speed V_t by mounting the magnetic encoder is typically higher than a sensorless estimation method of calculating the motor speed V_t based on the back EMF of the motor. Specifically, a manner of obtaining the motor speed V_t may be selected and set according to an actual requirement. This is not limited in the present disclosure.

[0035] It may be understood that when a load is relatively stable, the motor operating power is also relatively stable, and the rate of change of magnetic flux linkage of motor is also relatively stable. When the load fluctuates, a fluid medium passes through an impeller of the canned motor pump, and air in the fluid medium causes the impeller to be stressed unevenly, thereby affecting a motor flux linkage. The flux linkage fluctuates with the load fluctuation. This phenomenon may be reflected by the rate of change of magnetic flux linkage.

[0036] The three-phase current may be used for calculating power of the motor. The three-phase voltage may be used for calculating the back EMF of the motor. The back EMF of the motor is in turn directly related to the rate of change of magnetic flux linkage. Alternatively, a magnetic field change may be measured by using the Hall sensor or the magnetic encoder, so as to calculate the rate of change of magnetic flux linkage. Alternatively, the rate of change of magnetic flux linkage may be estimated in real time by using an observer algorithm (e.g., a sliding-mode observer or an extended Kalman filter). Specifically, a manner of obtaining the rate of change of magnetic flux linkage of motor may be selected and set according to an actual requirement. This is not limited in the present disclosure.

[0037] In an alternative, the rate of change of magnetic flux linkage may be obtained by converting the back EMF

of the motor. A calculation formula of the rate of change of magnetic flux linkage is as follows:

$$B_t = \frac{d\psi}{dt} = -E \quad (3)$$

wherein B_t represents the rate of change of magnetic flux linkage, and ψ represents the flux linkage.

[0038] Step 2 is an exhaust control trigger determination phase.

[0039] According to the motor operating power of the canned motor pump calculated in step 1, content of air (referred to as "air content") within the pipeline loop may be further determined. When the air content reaches a first air content threshold Q1 (e.g., 25%), the operating speed of the motor (referred to as "motor speed") is adjusted according to the air content.

[0040] When the motor starts, the air content within the pipeline loop is set to an initial value Q_0 (e.g., $Q_0 = 0$). The MCU calculates the motor operating power at a preset frequency (e.g., every two seconds) based on data acquired in step 1, and compares the current motor operating power with the motor operating power calculated in a previous cycle to obtain a power fluctuation quantity ΔP . A calculation formula of the power fluctuation quantity ΔP is as follows:

$$\Delta P = P_t - P_{t-1} \quad (5)$$

wherein P_t represents the current motor operating power, and P_{t-1} represents the motor operating power calculated in a previous cycle.

[0041] With reference to FIG. 4, if the power fluctuation quantity ΔP is greater than a first power fluctuation threshold P1 (e.g., 8 W), the current air content Q_t (proportion of an air space within the pipeline loop) is adjusted, typically increased by ΔQ (e.g., 5%). For example, in a specific solution, when the power fluctuation quantity ΔP is greater than 8 W, an air content proportion is increased by 5%. A calculation formula of the current air content Q_t is as follows:

$$Q_t = Q_{t-1} * (1 + \Delta Q) \quad (6)$$

wherein Q_{t-1} represents the air content calculated in a previous cycle, ΔQ represents an incremental air content.

[0042] When the current air content Q_t reaches the first air content threshold Q1 (e.g., 25%, typically customized according to a water pump model), it is determined that the first trigger control condition is satisfied.

[0043] It should be noted that, in the present disclosure, the current motor operating power P_t is calculated by using the motor parameters acquired in real time, to obtain the current air content Q_t . Then, the motor speed V_t of the canned motor pump is adjusted based on the current air content Q_t . Adjusting the motor speed V_t will change the air content within a pump casing of the

canned motor pump, and the air content change affects the motor parameters of the canned motor pump, thereby forming a feedback mechanism.

[0044] It may be understood that any one canned motor pump corresponds to a particular power-speed fitting curve. The curve may be obtained at a debugging phase of the canned motor pump, as shown in FIG. 3. A specific obtaining manner is: firstly, shutting off valves of a water inlet and a water outlet in a case that the loop is filled with water, and acquiring the motor parameters during the operation of the canned motor pump to obtain a "shut-off curve"; then, draining the water within the loop, allowing the canned motor pump to run dry, and acquiring the motor parameters during the operation of the canned motor pump to obtain a "no-load power curve"; and subsequently, adding a small amount of water to the loop so that there is some water inside the canned motor pump, and acquiring the motor parameters during the operation of the canned motor pump to obtain a "light-load protection point curve" (also referred to as a "dry run protection curve"). It should be noted that the light-load protection point curve should be obviously distinguished from the no-load power curve. Specifically, at least one light-load protection curve between the shut-off curve and the no-load power curve may be obtained by controlling an added amount of water.

[0045] With reference to FIG. 5, during the operation of the canned motor pump, under some working conditions, a user will actively adjust the motor speed through PWM control. If the motor speed $V_t \geq$ a speed threshold VA1 (e.g., 3000 rps), the motor operating power P_t corresponding to the motor speed V_t shall be greater than or equal to a power corresponding to the speed on the no-load power curve in the power-speed fitting curve. It may be understood that there is little difference between the canned motor pump operating at a low speed and a low load. Therefore, only the motor speed exceeding the speed threshold VA1 is analyzed to avoid false alarm. When the calculated motor operating power P_t is less than a minimum normal operating power corresponding to the speed in the power-speed fitting curve, to be specific, the current motor operating power is below the power-speed fitting curve and a duration reaches a first preset time T1 (e.g., 8 seconds), it may be determined that the air content within the pipeline loop is excessive, namely, higher than a second preset air threshold Q2 (e.g., 50%), and it may be determined that the first trigger control condition is satisfied, wherein $Q2 > Q1$, the speed threshold $VA1 \geq V0$, and $V0$ represents a normal operating speed of motor during a normal operation phase of the canned motor pump. It may be understood that, in the normal operation phase, the canned motor pump is not manually controlled, and usually operates according to a constant motor speed.

[0046] It should be noted that the foregoing fitting curve reference scheme is usually used for determining an abnormal working condition of an excessive air content in the pump casing, and it is very difficult to cover most of

air-containing working conditions. The scheme may be used for avoiding abnormal wear of a bearing caused by dry running of the motor. The power fluctuation quantity determining scheme in the foregoing embodiment can cover most of the air-containing working conditions, but cannot be applied to the working conditions where the air content in the pump casing is excessive, resulting in dry running of the canned motor pump. It can be seen that the two are in a complementary relationship.

[0047] It may be understood that, in a stable operating phase of the canned motor pump, the motor speed is relatively stable. Correspondingly, the motor operating power is also relatively stable, and the rate of change of magnetic flux linkage is also relatively stable. There may be a plurality of reasons when the motor operating power greatly fluctuates. There are two common reasons. The first reason is due to the control of external PWM, the motor speed of the canned motor pump is manually adjusted through the control of external PWM, resulting in power fluctuation. The second reason is due to the air within the loop. The air within the loop causes the load of the canned motor pump to suddenly change, and the power will change with the load, resulting in large fluctuation. Usually, the first reason is manual control belonging to active intervention. The second reason is a reason why intervention needs to be performed in the method of the present disclosure. According to the first reason, the rate of change of magnetic flux linkage, the power, and the speed are all quickly stabilized and no longer changed. However, according to the second reason, the rate of change of magnetic flux linkage, the power, and the speed all cannot be stabilized for a long time.

[0048] Further, to avoid wrong exhaust trigger, the present disclosure may further confirm the reason for the power change, and more accurately, confirm whether the reason is the second reason, and set this as a second trigger control condition.

[0049] It may be understood that when the motor operating power fluctuates due to bubbles, the motor speed and the rate of change of magnetic flux linkage will be constantly changed, and it is difficult to stabilize. However, under active control such as PWM control, the speed and the rate of change of magnetic flux linkage will be quickly stabilized. Therefore, the reason for the power fluctuation may be analyzed by using the motor parameters such as the motor speed or the rate of change of magnetic flux linkage.

[0050] With reference to FIG. 6, it is first necessary to eliminate the situation that manual control leads to changes in an operating state of a water pump. In an alternative, based on the motor speed V_t obtained in step 1, if the motor speed V_t is within a preset range ($VA2 \leq V_t \leq VA3$) and a duration is within a second preset time $T2$, it indicates that the motor speed is relatively stable and the motor speed is changed by manual control. It is determined that the reason is the first reason, indicating that the motor speed is changed by manual control to further cause a large power fluctuation of the water pump without

performing exhaust procedure determination. $VA2$ is a second speed threshold, and $VA3$ is a third speed threshold. If the motor speed V_t exceeds the preset range (i.e., $V_t > VA3$ or $V_t < VA2$), it is determined that the reason is the second reason. To be specific, it indicates that the state of the water pump is changed due to air within the pipeline loop. There is air to be discharged from the pipeline loop, and a subsequent exhaust control procedure may be performed.

[0051] In another alternative, determination is implemented by detecting the rate of change of magnetic flux linkage. When the rate of change of magnetic flux linkage B_t is greater than a rate of change threshold of magnetic flux linkage $B1$, it may be determined that the rate of change of magnetic flux linkage of the motor is unstable, and an exhaust operation needs to be performed. This manner is mainly applicable to a flux-weakening controlled motor.

[0052] In still another alternative, a corresponding operation may be performed by controlling the canned motor pump, so as to further determine whether the reason for the power fluctuation is the second reason. For example, the motor speed is first increased temporarily to observe an operating condition of the motor, and the motor speed is then reduced to 30% of a maximum speed for operation within a period of time. If the motor parameters such as the motor power are relatively stable when operating at a high speed, but when operating at 30% of the maximum speed, the motor parameters such as the motor power fluctuate greatly, it will be considered that the presence of air in a pipeline system affects normal operation of the canned motor pump, indicating that an exhaust operation is required, thereby triggering to initiate the exhaust control phase.

[0053] Specifically, the motor speed is increased to $V1$, and the motor operates for a third preset time $T3$ (e.g., 10 S). The motor speed is then reduced to $V2$, wherein $V2 = 30\%V_{max}$. The motor operates for a fourth preset time $T4$ (e.g., 30 S) and the speed is then restored to a normal speed $V0$. If the motor parameters such as power are relatively stable during the operation at the speed $V1$, the power fluctuation quantity ΔP is within the first power fluctuation threshold $P1$ (e.g., 8 W). Furthermore, when the power fluctuation quantity ΔP is greater than the first power fluctuation threshold $P1$ during the operation at the speed $V2$, it is considered that the air content within the pipeline loop has affected the normal operation of the canned motor pump, and it is necessary to start the exhaust operation, thereby triggering to initiate the exhaust control phase.

[0054] In a specific solution, the magnitude of power fluctuation of the canned motor pump is monitored continuously for a period of time in a case that the speed is stable. When the power fluctuation quantity ΔP is greater than 8 W, an air content proportion is increased by 5%. When the air content proportion is greater than 25%, it is determined that the first trigger control condition is satisfied. It is further determined whether the reason for the

power change is the second reason. To be specific, it is determined whether the second trigger control condition is satisfied. When both the first and second trigger control conditions are satisfied, the canned motor pump is triggered to start exhaust control. To be specific, the MCU controls the canned motor pump to execute an exhaust procedure.

[0055] Step 3 is an exhaust control phase.

[0056] It may be understood that air within the pump casing of the canned motor pump usually exists in a form of bubbles, and the magnitude of the air content within the pump casing usually determines the size of the bubbles. Usually, a larger power fluctuation indicates a higher air content within the pump casing. Generally, larger bubbles are formed by the air within the pump casing. When the bubbles are broken up, the power fluctuation quantity in the operation of the water pump is gradually reduced. When the power fluctuation quantity ΔP is less than a second power fluctuation threshold P2 (e.g., 5 W), it may be determined that the bubbles are broken up, wherein $P2 < P1$.

[0057] As shown in FIG. 7, in an alternative, if the current air content Q_t is higher than the first air content threshold Q1 (e.g., 25%), a target motor speed output by an exhaust control model will be significantly increased, usually operating at a high speed V3. For example, the high speed V3 is directly set as the maximum speed V_{max} of the motor operation. Large bubbles flowing through the impeller are broken up into the pipeline by increasing the motor speed. This can not only prevent the water pump from dry running and facilitate the operation of the subsequent exhaust procedure, but also effectively reduce noise caused by cavitation. If the power fluctuation quantity ΔP is less than the second power fluctuation threshold P2, it indicates that the bubbles have been basically broken up, and the canned motor pump is then controlled to operate at a low speed V4. For example, the low speed V4 is 20% of the maximum speed V_{max} . Air slowly passes through an exhaust valve by decelerating, so as to discharge the air at the maximum speed and the maximum efficiency, wherein $V4 < V0 < V3 \leq V_{max}$.

[0058] During the operation of the exhaust procedure, the air content within the pipeline loop will be lower, and the motor operating power and the rate of change of magnetic flux linkage will also tend to be stable. When preset conditions are satisfied, the canned motor pump may be controlled to terminate exhaust. Each time the exhaust procedure is terminated, the air content is returned to zero, and is set to an initial value when the exhaust procedure is restarted.

[0059] In an alternative (from the perspective of control), to reduce impact on a user caused by a departure from user control in an exhaust process, the exhaust procedure may be controlled to be terminated when a total exhaust operation time is set to reach a fifth preset time T5 (e.g., 2 minutes), thereby ensuring normal use by a customer.

[0060] In another alternative (in view of an exhaust

effect), to ensure the exhaust effect, the exhaust procedure may be controlled to be terminated when the operation time at the low speed V4 is set to reach a sixth preset time T6 (e.g., 10 minutes), wherein $T6 > T5$.

[0061] In still another alternative (in view of an exhaust effect and customer control), to minimize impact on the user's control of the canned motor pump while ensuring the exhaust effect, when the power fluctuation quantity ΔP of the motor operation lasts for a seventh preset time T7 (e.g., 30 S) and is less than a third power fluctuation threshold P3 (e.g., 3 W), the canned motor pump may be controlled to terminate the exhaust procedure and resume normal operation. To be specific, the speed may be adjusted to V0, wherein $P3 \leq P2 < P1$.

[0062] It may be understood that during the operation of the exhaust procedure, especially in an early exhaust phase, the air content within the pipeline loop may still be increased in a short term (e.g., if another part of air within the pipeline loop circulates into the pump casing). However, as long as the air is effectively discharged, the air content is gradually reduced as a whole.

[0063] Under some abnormal conditions, for example, the canned motor pump is not exhausted before being mounted or the pipeline is damaged, resulting in constant intake air within the loop. The air content within the pipeline loop is excessive, and the current air content Q_t exceeds a third air content threshold Q3 (e.g., 60%), resulting in dry running of the canned motor pump, wherein $Q3 > Q2 > Q1$. In this case, the canned motor pump may be controlled to suspend operating for a period of time. The canned motor pump can normally drain water upon natural floating of air. After a suspension time reaches an eighth preset time T8 (e.g., 8 s), the canned motor pump is restarted. When the canned motor pump is restarted, if the calculated motor operating power P_t is within a normal operating range (to be specific, the corresponding motor operating power at the motor speed exceeds the no-load power W in the power-speed fitting curve), it may be determined that the air floating is completed. This is also a limit value for determining whether the canned motor pump can operate normally. The normal operation means that the canned motor pump does not cause abnormal wear to a bearing due to dry running in operation.

[0064] It may be understood that when the foregoing abnormal condition occurs, it indicates that the air content is excessive, for example, exceeds 60%. The motor operating power is very small, and cannot satisfy a condition that the power fluctuation is greater than 8 W. Therefore, the power-speed fitting curve may similarly be used for determination. After restarting for a preset N times (e.g., 3 times), if the corresponding motor operating power at the motor speed is still less than the no-load power in the power-speed fitting curve, the current air content Q_t of the pipeline is basically unchanged or even higher, indicating that the air cannot be discharged continuously. In this case, the canned motor pump is controlled to stop operating, and a report is transmitted to an

upper computer (usually referring to a device used by a customer for controlling the water pump) by using own communication means (a communication module integrated on a drive board of the canned motor pump, e.g., PWM communication or LIN communication or flashing a fault light), requesting manual exhaust. The manual exhaust is to disassemble and re-assemble the canned motor pump and fill water into the loop before assembling the canned motor pump, thereby reducing the internal air content of the loop.

[0065] Further, Embodiment 2 of the present disclosure discloses a canned motor pump control apparatus. The canned motor pump control apparatus comprises a MCU for acquiring motor parameters and implementing exhaust control trigger determination and exhaust control, and a motor drive controller electrically connected to the MCU. The MCU comprises a processor and a memory. The memory has a program stored therein. The program, when loaded and executed by the processor, can implement the exhaust control method for a pipeline loop in Embodiment 1. The MCU has an ADC function. Alternatively, an external ADC module is connected to the MCU. The MCU further comprises a communication module that is electrically connected to the processor and is configured for communication connection with an upper computer. The communication module may be specifically a Bluetooth module or the like. The motor drive controller is mainly configured to receive an instruction sent by the MCU, and control, according to the instruction, the motor to operate.

[0066] Further, Embodiment 3 of the present disclosure discloses a canned motor pump. The canned motor pump mainly comprises a canned motor pump body and a canned motor pump control apparatus. The canned motor pump body comprises a motor and a pump casing. The canned motor pump control apparatus may be the canned motor pump control apparatus in Embodiment 2.

[0067] Finally, it should be noted that, although the embodiments of the present disclosure are described above with reference to the accompanying drawings, the present disclosure is not limited to the foregoing specific embodiments and application fields. The foregoing specific embodiments are merely exemplary, instructive, and not restrictive. A person of ordinary skill in the art may make various forms under the teaching of this specification without departing from the protection scope of the claims of the present disclosure, which all fall within the protection of the present disclosure.

Claims

1. An exhaust control method for a pipeline loop based on a canned motor pump, comprising:

a data acquisition phase: obtaining motor parameters during an operation of a canned motor pump, the motor parameters comprising a motor

operating power P_t , a motor speed V_t , and a motor operating time;

an exhaust control trigger determination phase: determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied, and initiating an exhaust control phase when the preset trigger control condition is satisfied; and

the exhaust control phase: performing exhaust control on the canned motor pump according to a preset rule, and terminating the exhaust control to initiate a normal operation phase when a preset termination control condition is satisfied.

2. The exhaust control method for a pipeline loop according to claim 1, wherein the preset rule comprises: first controlling a motor to increase a speed to break up bubbles within the pipeline loop, and then controlling the motor to reduce the speed to expel the bubbles.
3. The exhaust control method for a pipeline loop according to claim 1, wherein the preset trigger control condition comprises a first trigger control condition; and the determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied comprises: calculating a power fluctuation quantity ΔP of the motor according to the motor operating power P_t , and adjusting a current air content Q_t within the pipeline loop when the power fluctuation quantity ΔP is greater than a first power fluctuation threshold P_1 ; and determining that the first trigger control condition is satisfied when the current air content Q_t reaches a first air content threshold Q_1 .
4. The exhaust control method for a pipeline loop according to claim 3, wherein an initial air content Q_0 is zero when the motor starts operating, and the adjusting a current air content Q_t within the pipeline loop comprises:

$$Q_t = Q_{t-1} * (1 + \Delta Q),$$

wherein Q_{t-1} represents an air content calculated in a previous cycle, and ΔQ represents an incremental air content.

5. The exhaust control method for a pipeline loop according to claim 3, wherein the determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied further comprises:

when the motor speed V_t is greater than or equal to a first speed threshold VA_1 , if the motor power P_t is less than a power corresponding to the speed on a

no-load power curve in a preset power-speed fitting curve and a duration reaches a first preset time T1, indicating that the current air content Q_t is higher than a second air content threshold Q2, and determining that the first trigger control condition is satisfied, wherein $Q2 > Q1$, and $VA1 \geq V0$, wherein V0 represents a normal operating speed of motor during a normal operation phase of the canned motor pump.

6. The exhaust control method for a pipeline loop according to claim 3, wherein the preset trigger control condition further comprising a second trigger control condition, and the exhaust control phase is initiated when both the first and second trigger control conditions are satisfied simultaneously; and after determining that the first trigger control condition is satisfied, the determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied further comprises: if the motor speed V_t is greater than a second speed threshold VA2 or the motor speed V_t is less than a third speed threshold VA3, and a duration exceeds a second preset time T2, determining that the second trigger control condition is satisfied, wherein $VA2 \leq V_t \leq VA3$.

7. The exhaust control method for a pipeline loop according to claim 3, wherein when the motor is a flux-weakening controlled motor, the motor parameters further comprises a rate of change of magnetic flux linkage of motor B_t ;

the preset trigger control condition further comprises a second trigger control condition, and the exhaust control phase is initiated when both the first and second trigger control conditions are satisfied simultaneously; and

after determining that the first trigger control condition is satisfied, the determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied further comprises:

if $B_t > B1$, determining that the second trigger control condition is satisfied, wherein B1 represents a rate of change threshold of magnetic flux linkage.

8. The exhaust control method for a pipeline loop according to claim 3, wherein the preset trigger control condition further comprises a second trigger control condition, and the exhaust control phase is initiated when both the first and second trigger control conditions are satisfied simultaneously; and after determining that the first trigger control condition is satisfied, the determining, based on at least one of the motor parameters, whether a preset trigger control condition is satisfied further comprises:

after determining that the first trigger control condition is satisfied, increasing the motor speed to V1, after an operating time reaches a third preset time T3, reducing the motor speed to V2, and after an operating time reaches a fourth preset time T4, restoring a normal operating speed V0; and

if, during the operation at the motor speed V1, the power fluctuation quantity ΔP remains within the first power fluctuation threshold P1 and during the operation at the motor speed V2, the power fluctuation quantity ΔP is greater than the first power fluctuation threshold P1, determining that the second trigger control condition is satisfied.

9. The exhaust control method for a pipeline loop according to any one of claims 3 to 8, wherein in the exhaust control phase, the performing exhaust control on the canned motor pump according to a preset rule comprises:

when the current air content Q_t within the pipeline loop is higher than the first air content threshold Q1, controlling the motor to operate at a high speed V3; and

if the power fluctuation quantity ΔP of the motor is less than a second power fluctuation threshold P2, controlling the motor to operate at a low speed V4, wherein $V4 < V0 < V3 \leq V_{\max}$, $V_{\max}$ represents a maximum operating speed of the motor, V0 represents a normal operating speed of the motor during the normal operation phase of the canned motor pump, and $P2 < P1$; and the power fluctuation quantity ΔP is calculated from the motor operating power P_t , and the current air content Q_t is correlated with the power fluctuation quantity ΔP .

10. The exhaust control method for a pipeline loop according to claim 9, wherein in the exhaust control phase, the performing exhaust control on the canned motor pump according to a preset rule further comprises:

if the current air content Q_t exceeds a third air content threshold Q3, controlling the canned motor pump to suspend operation, and controlling the canned motor pump to restart when a suspension time reaches an eighth preset time T8, wherein $Q3 > Q2 > Q1$.

11. The exhaust control method for a pipeline loop according to claim 10, wherein in the exhaust control phase, the performing exhaust control on the canned motor pump according to a preset rule further comprises:

if a number of restarts reaches a preset count and the motor operating power at a current motor speed remains to be less than a no-load power in the

power-speed fitting curve, controlling the canned motor pump to stop operation.

12. The exhaust control method for a pipeline loop according to claim 9, wherein in the exhaust control phase, the preset termination control condition is that a total time of the exhaust control phase reaches a fifth preset time T5. 5
13. The exhaust control method for a pipeline loop according to claim 12, wherein in the exhaust control phase, the preset termination control condition is that the operating time at a low speed V4 reaches a sixth preset time T6, wherein $T6 > T5$. 10
14. The exhaust control method for a pipeline loop according to claim 9, wherein in the exhaust control phase, the preset termination control condition is that the power fluctuation quantity ΔP of the motor is less than a third power fluctuation threshold P3 and a duration reaches a seventh preset time T7, wherein $P3 \leq P2 < P1$. 15 20
15. A canned motor pump control apparatus, comprising a MCU and a motor drive controller electrically connected to the MCU, wherein the MCU comprises a processor and a memory, the memory has a program stored therein, and the program is loaded and executed by the processor, to implement the exhaust control method for a pipeline loop according to any one of claims 1 to 14. 25 30
16. The canned motor pump control apparatus according to claim 15, further comprising an ADC module and a communication module electrically connected to the processor, wherein the ADC module is integrated into the MCU or is independent of the MCU, and the communication module is configured for a communication connection between the canned motor pump control apparatus and an upper computer. 35 40
17. A canned motor pump, comprising a canned motor pump body and the canned motor pump control apparatus according to claim 15 or 16, wherein the canned motor pump body comprises a motor and a pump casing, and the canned motor pump control apparatus is configured to control operation of the motor. 45

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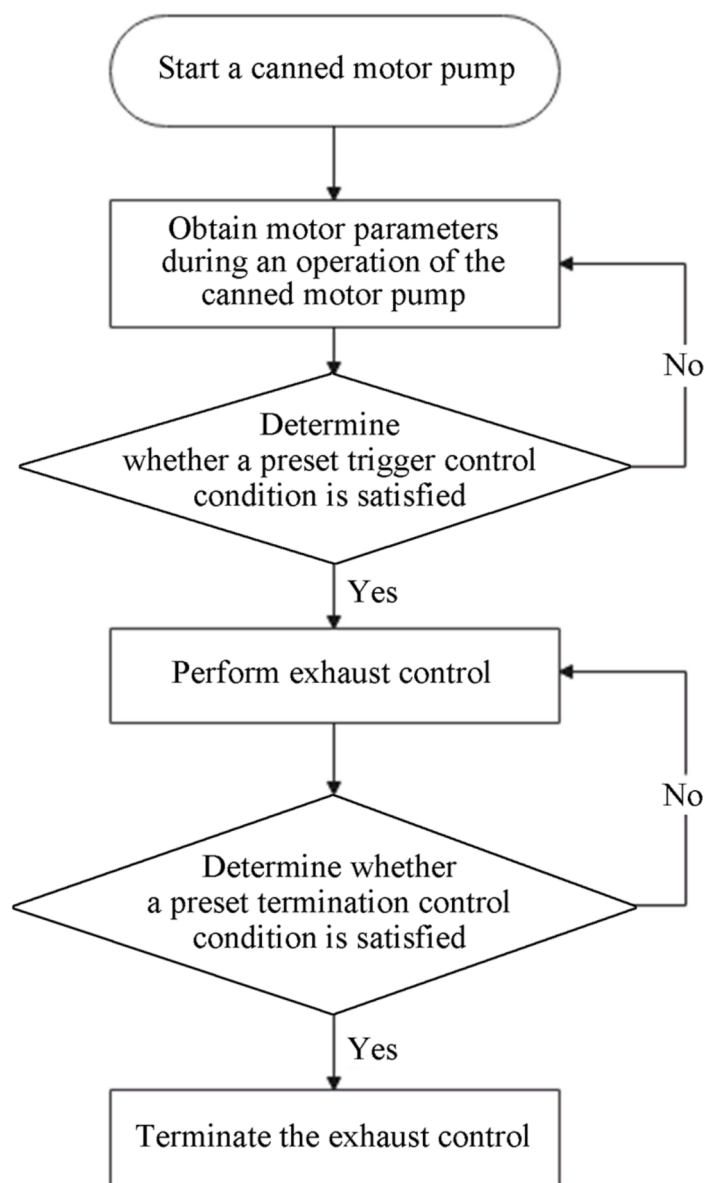


FIG. 1

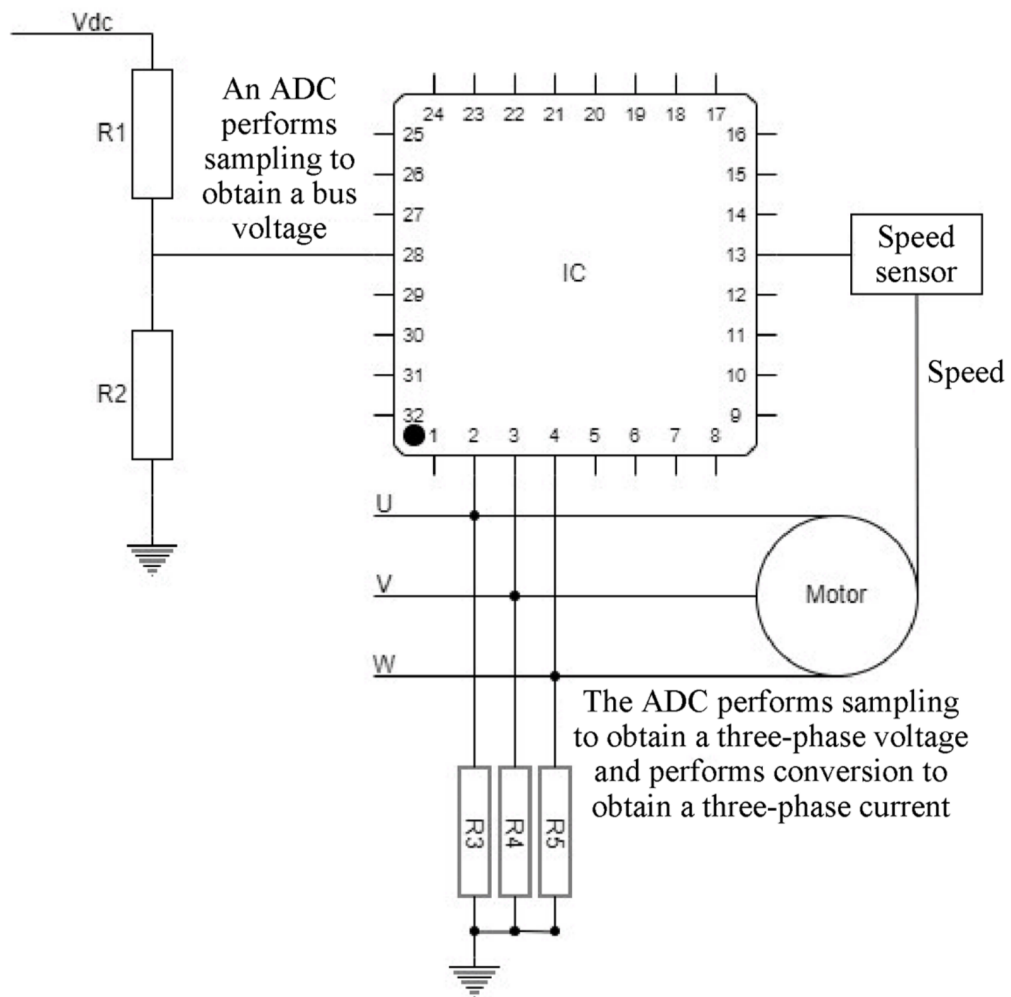


FIG. 2

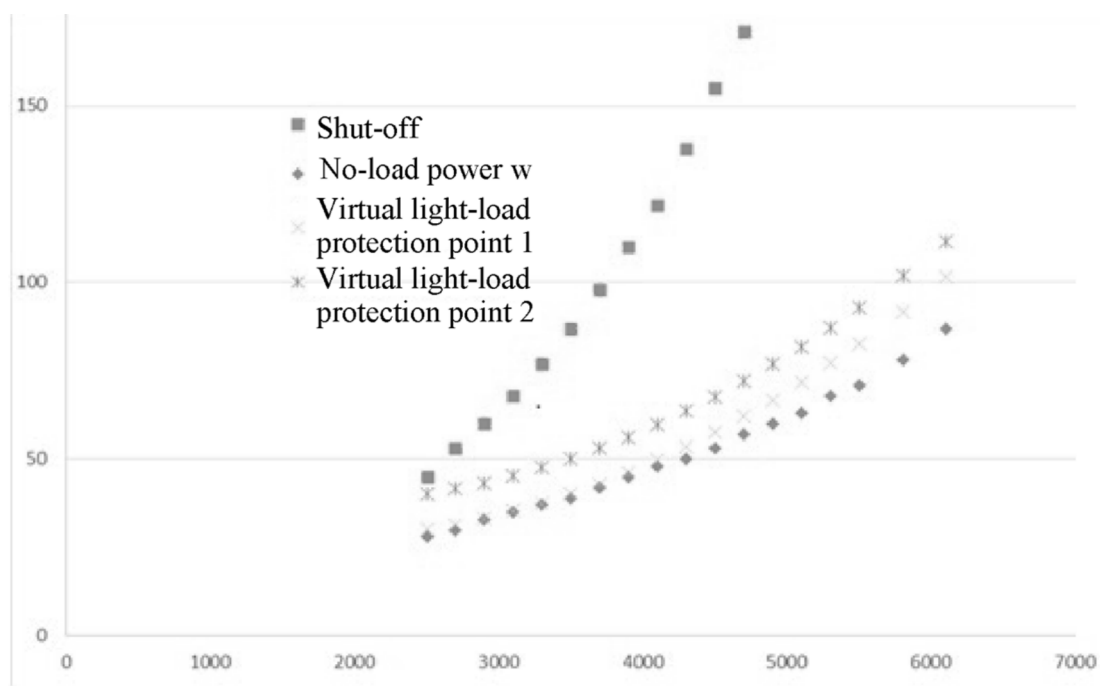


FIG. 3

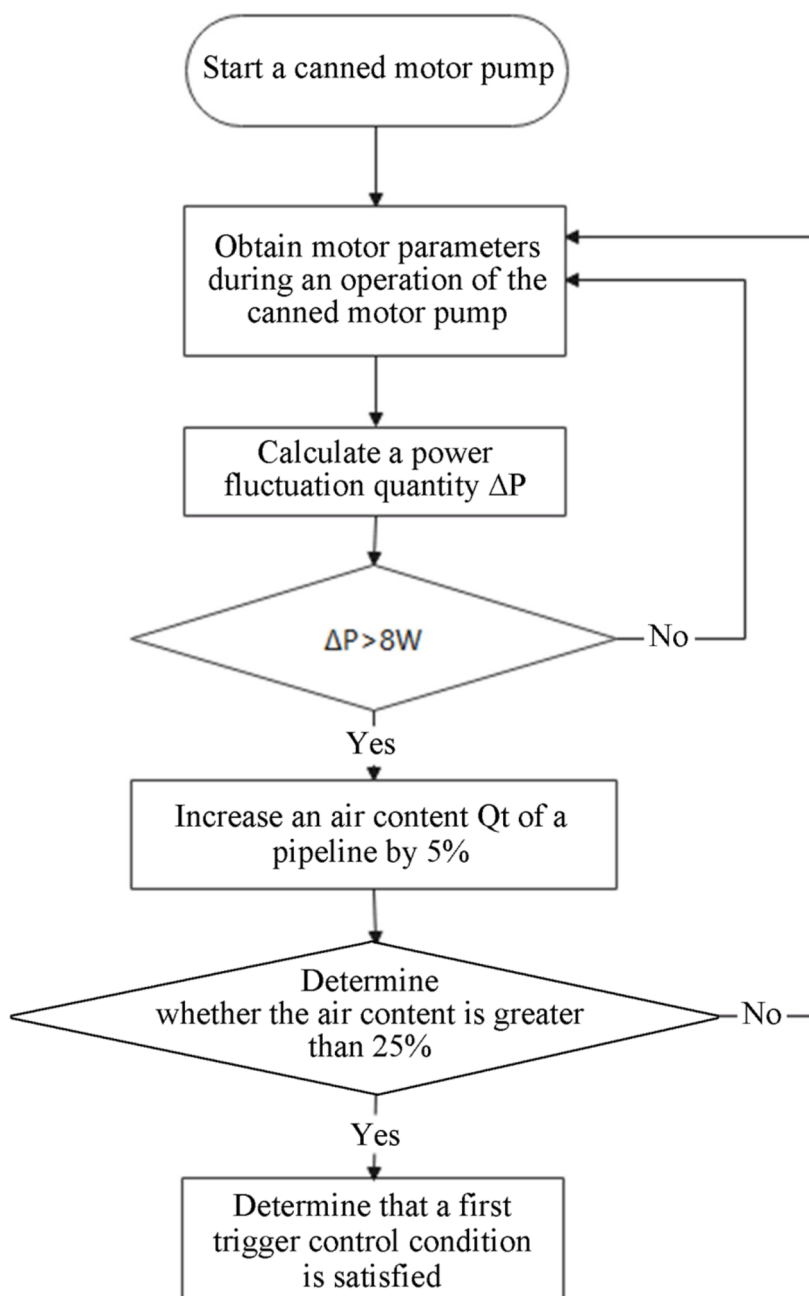


FIG. 4

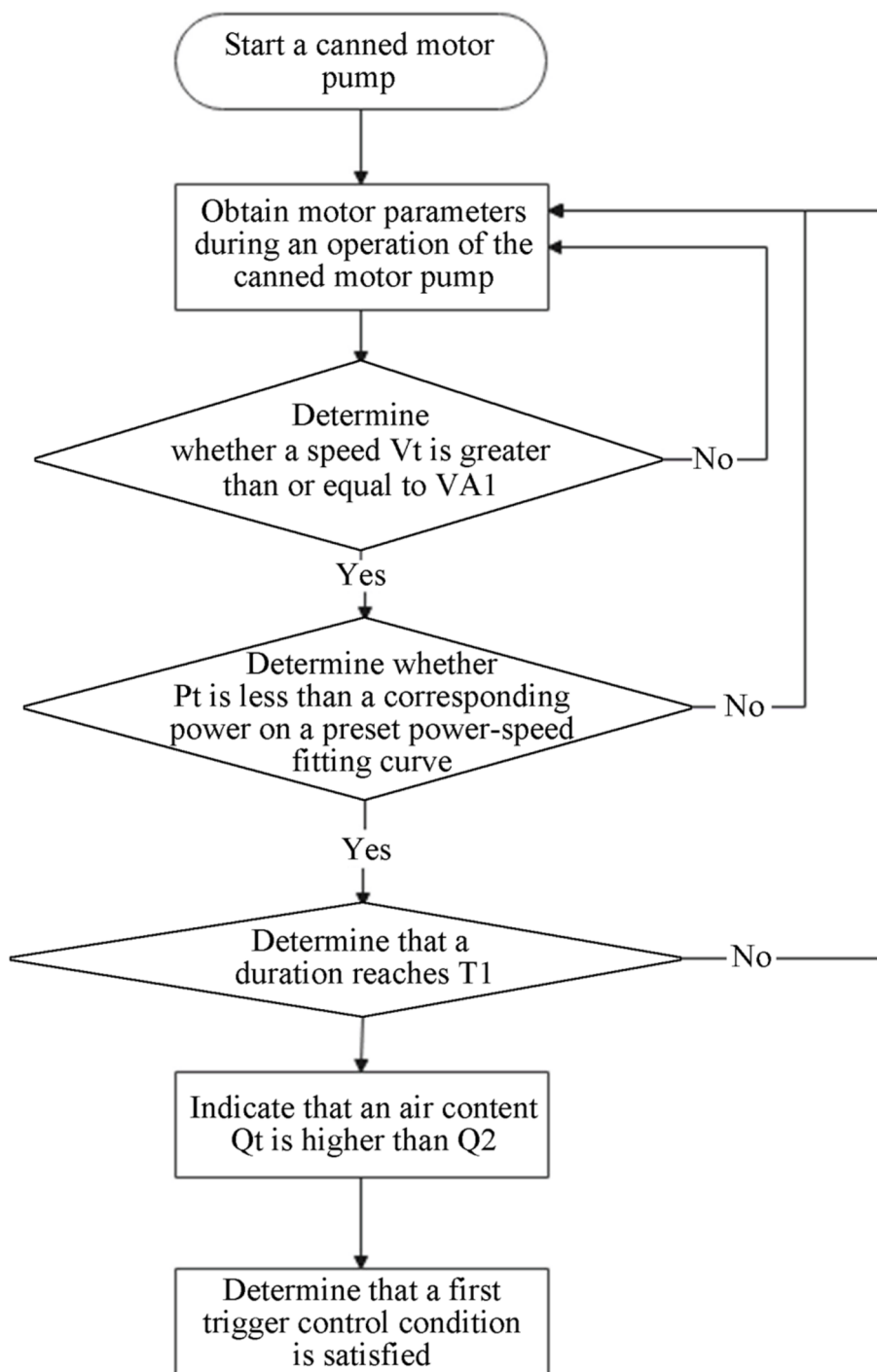


FIG. 5

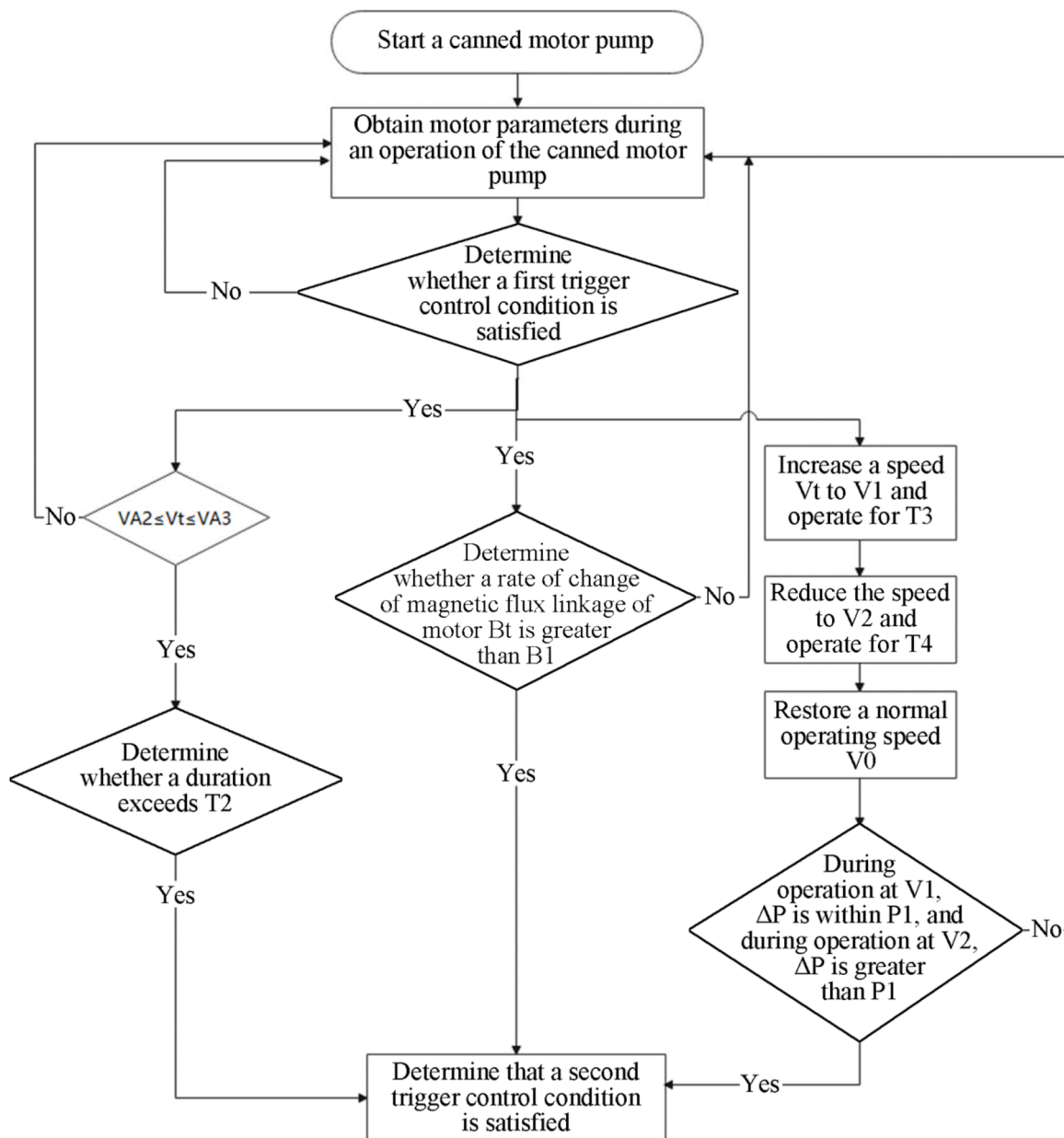


FIG. 6

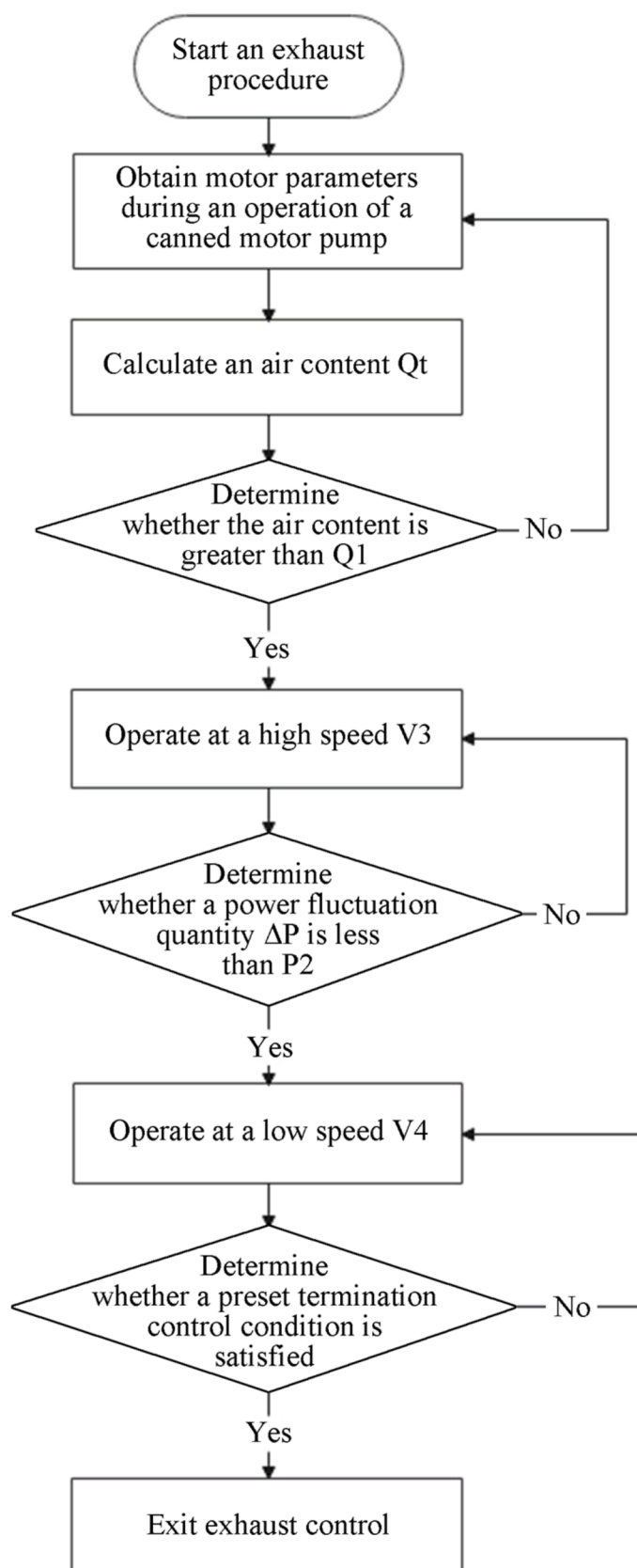


FIG. 7



EUROPEAN SEARCH REPORT

Application Number

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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 10 March 2026	Examiner Hermens, Sjoerd
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