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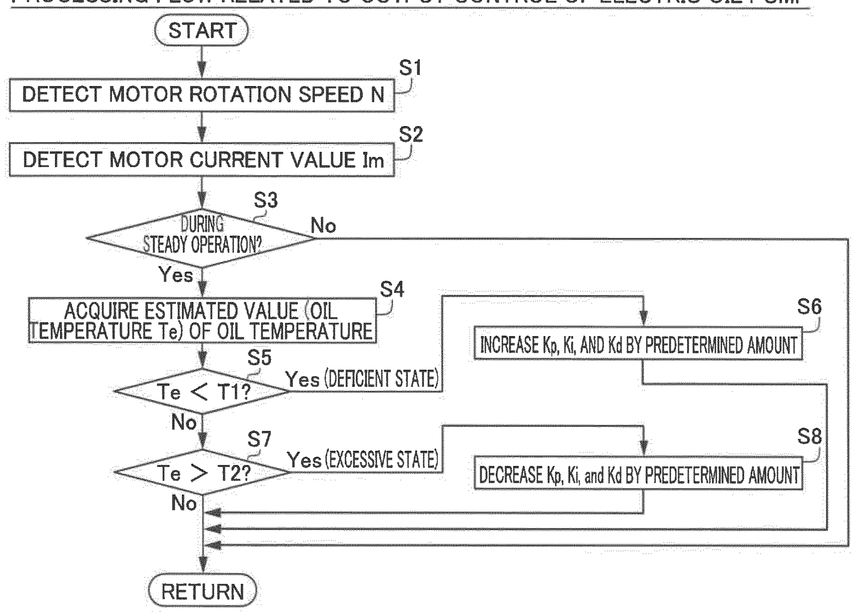
(54) **ELECTRIC OIL PUMP DEVICE**

(57) An electric oil pump device (10) includes an electric oil pump (10) driven by a motor (11) and a microcomputer (30) that adjusts a control parameter (Kp, Ki, Kd) of feedback control related to a motor current value (Im) or a motor rotation speed (N) based on an oil temperature (Te) estimated based on a relationship between at least one of a hydraulic pressure, the motor current value, or a torque of the electric oil pump (10) and at least one of an oil discharge amount or the motor rotation speed of the electric oil pump.

FIG.4

PROCESSING FLOW RELATED TO OUTPUT CONTROL OF ELECTRIC OIL PUMP



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Description

Technical Field

[0001] The present invention relates to an electric oil pump device, and more particularly, it relates to an electric oil pump device including an electric oil pump driven by a motor.

Background Art

[0002] In general, an electric oil pump device including an electric oil pump driven by a motor, for example, is known. Such an electric oil pump device is disclosed in Japanese Patent Laid-Open No. 2005-016460, for example.

[0003] Japanese Patent Laid-Open No. 2005-016460 discloses a control device (electric oil pump device) of an electric liquid pump including a hydraulic pump (electric oil pump) driven by a motor and a microcomputer (controller) that controls rotation of the electric motor. The control device of the electric liquid pump described in Japanese Patent Laid-Open No. 2005-016460 estimates the temperature of oil discharged from the hydraulic pump based on the relationship between a motor current value and a rotation speed detected from the motor rotated by electric power input as a certain initial value. Furthermore, the control device performs current control of calculating the target value of current to be supplied to the motor and shifting the motor current value to the target value in order to obtain a hydraulic pressure required by the hydraulic pump under the estimated oil temperature condition. In this case, a command voltage (duty ratio) to be applied to the motor by proportional control and integral control (PI control) is calculated by the microcomputer based on a deviation between the target value and the present value of the motor current value. With the command voltage control, the motor current value during the rotation is changed and reaches the target value. Therefore, a hydraulic pressure required by a hydraulic circuit is ensured by motor output control according to a change in the oil temperature.

[0004] The electric liquid pump (electric oil pump) described above is activated (driven) when an engine is stopped to idle while an automobile is stopped, for example. Thus, even in the idling stop state, the hydraulic pressure is supplied for clutch engagement of an automatic transmission. In addition, the electric liquid pump is also activated (driven) when cooling oil is supplied to a cooling jacket of the electric motor of a hybrid vehicle. Thus, the cooling oil having a predetermined hydraulic pressure flows through the cooling jacket.

Prior Art

Patent Document

[0005] Patent Document 1: Japanese Patent Laid-Open No. 2005-016460

Summary of the Invention

Problems to be Solved by the Invention

[0006] In the control device of the electric liquid pump described in Japanese Patent Laid-Open No. 2005-016460, a control method (so-called general feedback control) for calculating the command voltage (duty ratio) to be applied to the motor simply by the proportional control and the integral control (PI control) based on the deviation between the target value and the present value of the motor current value is conceivably applied. For this reason, it conceivably takes some time to shift the present value (initial value) of the motor current value to the target value. However, when the electric liquid pump (electric oil pump) is applied to hydraulic control of the automobile, as described above, it is necessary to ensure a quick hydraulic pressure and an oil discharge amount according to the oil temperature condition (oil viscosity condition). Therefore, in drive control of the electric oil pump, high responsiveness is required for the motor output control.

[0007] The present invention has been proposed in order to solve the aforementioned problems, and an object of the present invention is to provide an electric oil pump device capable of quickly ensuring a hydraulic pressure and an oil discharge amount according to an oil temperature condition by improving the responsiveness of motor output control.

Means for Solving the Problems

[0008] In order to attain the aforementioned object, an electric oil pump device according to an aspect of the present invention includes an electric oil pump including a motor and driven by the motor, and a controller that estimates an oil temperature based on a relationship between at least one of a hydraulic pressure, a motor current value, or a torque of the electric oil pump and at least one of an oil discharge amount or a motor rotation speed of the electric oil pump detected during operation of the electric oil pump, and adjusts a control parameter of feedback control related to the motor current value or the motor rotation speed based on the estimated oil temperature.

[0009] As described above, the electric oil pump device according to this aspect of the present invention includes the controller that estimates the oil temperature based on the relationship between at least one of the hydraulic pressure, the motor current value, or the torque of the electric oil pump and at least one of the oil discharge amount or the motor rotation speed of the electric oil pump detected during the operation of the electric oil pump, and adjusts the control parameter of the feedback control related to the motor current value or the motor rotation speed based on the estimated oil temperature. Accordingly, it is possible to control the output (the current of the motor) of the electric oil pump while adjusting the control parameter of the feedback control related to the motor current value or the motor rotation speed based on the estimated oil temperature, and thus it is possible to quickly bring the present motor current value to a target current value unlike the case in which general feedback control without adjusting the control parameter is performed. As a result, the responsiveness of the output control of the motor is improved such that it is possible to quickly ensure the hydraulic pressure and the oil discharge amount according to the oil temperature condition.

[0010] Furthermore, the aforementioned electric oil pump device according to this aspect includes the controller described above such that even when the oil viscosity varies according to the oil temperature (the load of the electric oil pump varies), the responsiveness of the output control of the motor can be improved, and thus it is possible to extend the range of the oil temperature (oil viscosity) at which the electric oil pump can be used. In addition, even when the design tolerance at the time of designing each of a pump and the motor that constitutes the electric oil pump is loosened (the design accuracy is reduced), the output adjustment (the current control of the motor) of the electric oil pump can be quickly performed, and thus it is possible to easily manage the design accuracy and the manufacturing accuracy of the electric oil pump.

[0011] In the aforementioned electric oil pump device according to this aspect, the controller preferably determines an excessive or deficient state of at least one of the hydraulic pressure or the oil discharge amount of the electric oil pump based on the estimated oil temperature, and adjusts the control parameter of the feedback control related to the motor current value or the motor rotation speed so as to avoid the excessive or deficient state.

[0012] According to this structure, a variation in the load (at least one of the hydraulic pressure or the oil discharge amount) of the electric oil pump is grasped according to the estimated oil temperature (oil viscosity), and thus even when the load of the electric oil pump varies with a variation in the oil temperature (oil viscosity) such that the possibility of falling into the excessive or deficient state of at least one of the hydraulic pressure or the oil discharge amount increases, it is possible to reliably avoid falling into this excessive or deficient state by adjusting the control parameter of the feedback control related to the motor current value or the motor rotation speed. As a result, even when the load of the electric oil pump varies due to a variation in the oil temperature (oil viscosity), it is possible to stably operate the electric oil pump and reliably ensure the hydraulic pressure and the oil discharge amount corresponding to the oil temperature condition.

[0013] In this case, the excessive and deficient states preferably include the deficient state of at least one of the hydraulic pressure or the oil discharge amount of the electric oil pump in a case in which the estimated oil temperature is less than a first threshold and the excessive state of at least one of the hydraulic pressure or the oil discharge amount of the electric oil pump in a case in which the estimated oil temperature is greater than a second threshold, and the controller preferably adjusts the control parameter based on the estimated oil temperature so as to avoid at least one of the deficient state or the excessive state.

[0014] According to this structure, it is possible to easily estimate the load state of the electric oil pump depending on whether the estimated oil temperature (oil viscosity) is less than the first threshold or greater than the second threshold. The control parameter of the feedback control related to the motor current value or the motor rotation speed is adjusted according to the estimated load state (deficient state or excessive state) such that it is possible to quickly avoid at least one of the deficient output state or the excessive output state of the electric oil pump. In other words, it is possible to avoid insufficient oil lubrication in a lubricating system caused by the deficient output state, the insufficient operating hydraulic pressure of an automatic transmission, and insufficient cooling of a cooling jacket by oil. In addition, it is possible to avoid occurrence of power loss (energy loss) in the electric oil pump due to the excessive output state.

[0015] The aforementioned electric oil pump device according to this aspect preferably further includes a table in which the estimated oil temperature during the operation of the electric oil pump and the control parameter are associated with each other, and the controller preferably adjusts the control parameter based on the table.

[0016] According to this structure, it is possible to easily control the output (the current of the motor) of the electric oil pump by adjusting the control parameter, referring to the table in which the estimated oil temperature during the operation of the electric oil pump is associated with the control parameter.

[0017] In the aforementioned electric oil pump device according to this aspect, the controller preferably adjusts the control parameter based on a correlation formula in which a correlation between the estimated oil temperature during the operation of the electric oil pump and the control parameter is defined.

[0018] According to this structure, it is possible to easily control the output of the electric oil pump (the current of the motor) by adjusting the control parameter based on the correlation formula in which the correlation between the estimated oil temperature during the operation of the electric oil pump and the control parameter is defined.

[0019] In the aforementioned electric oil pump device according to this aspect, the controller preferably controls the motor by PID control including proportional control, integral control, and differential control, and adjusts a proportional gain of the proportional control, an integral gain of the integral control, and a differential gain of the differential control as the control parameter.

[0020] According to this structure, it is possible to appropriately control the output (the current of the motor) of the electric oil pump while adjusting the proportional gain, the integral gain, and the differential gain of the feedback control related to the motor current value or the motor rotation speed based on the estimated oil temperature.

[0021] In the aforementioned electric oil pump device according to this aspect, the controller preferably estimates the oil temperature at a predetermined control cycle, and repeatedly adjusts the control parameter of the feedback control related to the motor current value or the motor rotation speed based on the oil temperature estimated at the predetermined control cycle.

[0022] According to this structure, it is possible to repeatedly adjust the proportional gain, the integral gain, and the differential gain according to a variation in the oil temperature (a variation in the oil viscosity) in a state in which the oil temperature (oil viscosity) is continuously grasped at the predetermined control cycle during the operation of the electric oil pump, and thus it is possible to constantly obtain high responsiveness to the output control of the motor during the operation of the electric oil pump. Therefore, it is possible to stably follow a variation in the load of the electric oil pump.

[0023] In the aforementioned electric oil pump device according to this aspect, the controller preferably estimates the oil temperature based on the motor current value and the motor rotation speed at least during steady operation of the electric oil pump or at a time of activating the electric oil pump, and adjusts the control parameter of the feedback control related to the motor current value or the motor rotation speed based on the estimated oil temperature.

[0024] According to this structure, it is possible to control driving of the electric oil pump appropriately following the load variation during the steady operation of the electric oil pump as well as at the time of activating the electric oil pump.

Brief Description of the Drawings

[0025]

[Fig. 1] A block diagram showing the structure of an electric oil pump device according to a first embodiment of the present invention.

[Fig. 2] A diagram showing the concept of PID control (feedback control) for an electric oil pump according to the first embodiment of the present invention.

[Fig. 3] A diagram showing the contents of a table used to control the output of the electric oil pump according to the first embodiment of the present invention.

[Fig. 4] A flowchart showing a processing flow of a microcomputer in the output control of the electric oil pump according to the first embodiment of the present invention.

[Fig. 5] A diagram illustrating an equation of motion and a transfer function thereof in a drive system (rotary motion system) of an electric oil pump according to a second embodiment of the present invention.

[Fig. 6] A diagram showing an equivalent conversion table of a block diagram in a feedback control system of the electric oil pump according to the second embodiment of the present invention.

Modes for Carrying Out the Invention

[0026] Embodiments of the present invention are hereinafter described on the basis of the drawings.

[First Embodiment]

[0027] The structure of an electric oil pump device 100 according to a first embodiment of the present invention is now described with reference to Figs. 1 to 3.

[0028] The electric oil pump device 100 according to the first embodiment of the present invention is mounted on a vehicle (automobile). The electric oil pump device 100 includes an electric oil pump 10, a motor drive circuit 20 that drives the electric oil pump 10, and a microcomputer 30 (an example of a controller) that transmits a drive signal to the motor drive circuit 20. The motor drive circuit 20 and the microcomputer 30 may be mounted in a housing of the electric oil pump 10 or may be provided in a control box (not shown) separate from the electric oil pump 10.

[0029] The electric oil pump 10 includes a motor 11 and a pump 12. In the electric oil pump 10, the pump 12 is connected to a hydraulic circuit 101. The hydraulic circuit 101 has a predetermined flow path resistance R. When the pump 12 is driven, a necessary hydraulic pressure is supplied to the hydraulic circuit 101. Here, an internal gear pump, an external gear pump, a centrifugal pump, etc. are applied to the pump 12. The hydraulic circuit 101 includes a circuit that supplies an operating fluid of hydraulic pressure required for clutch engagement of an automatic transmission when an engine (not shown) is stopped to idle while the vehicle is stopped. Also, the hydraulic circuit 101 includes a circuit that supplies cooling oil of necessary hydraulic pressure to a cooling jacket of an electric motor (not shown) of a hybrid vehicle, for example. Unlike a mechanical oil pump driven by the drive force of an engine, the electric oil pump 10 is frequently used as an oil pump driven by electric power supplied from a battery 40.

[0030] A sensorless three-phase brushless DC motor not including a position detection sensor such as a Hall element is used as the motor 11 in the electric oil pump 10. Furthermore, the motor drive circuit 20 includes an FET circuit 21 including a semiconductor switch and a motor drive IC 22. A direct-current voltage of the battery 40 is applied to three wires (a U-phase drive coil, a V-phase drive coil, and a W-phase drive coil) of the motor 11 via the FET circuit 21. Based on a signal from the motor drive IC 22, the FET circuit 21 sequentially applies a voltage between the two wires (between the U phase and the V phase, between the U phase and the W phase, and between the V phase and the W phase) of the three wires of the motor 11 to rotationally drive the motor 11 by a unit rotation angle. At this time, the FET circuit 21 performs PWM control (duty-ratio control) of repeatedly switching between a state in which the voltage applied between the two wires is turned on for a predetermined time and a state in which the voltage between the two wires is turned off for a predetermined time according to the signal from the motor drive IC 22. Thus, the average voltage applied to the motor 11 is controlled so as to be a control command voltage.

[0031] The microcomputer 30 includes an arithmetic unit 31 (an example of a controller) that performs various types of arithmetic processing, a ROM 32 that stores in advance various programs executed by the arithmetic unit 31, etc., a RAM 33 from and in which the arithmetic unit 31 reads and writes data necessary during arithmetic processing, and an input/output circuit 34 that receives a unit angle rotation signal and a motor current signal and outputs, to the motor drive IC 22, a command voltage to drive the motor 11.

[0032] The ROM 32 stores a motor rotation speed calculation program 1, and a motor control program 2 to estimate an oil temperature Te based on a motor current value Im (corresponding to a torque and a hydraulic pressure) and the rotation speed N (corresponding to an oil discharge amount) of the motor 11 and to supply the oil of necessary hydraulic pressure from the pump 12 to the hydraulic circuit 101. The ROM 32 further stores a current control program 3 to calculate a difference (current deviation e (t)) between the motor current value Im detected by a current detection circuit 42 and a target current value Itg, to calculate the command voltage u(t) to be applied to the motor 11 using PID control including proportional control, integral control, and differential control, and to output the same to the motor drive IC 22, and a table 4 (see Fig. 3) referred to at the time of this PID control. The microcomputer 30 is connected to an ECU 102 on the vehicle body side such that mutual communication is possible. Therefore, the microcomputer 30 operates (calculates) based on a control signal from the ECU 102.

[0033] The electric oil pump device 100 includes a shunt resistor 41 and the current detection circuit 42 in its control circuit in addition to the motor drive circuit 20 and the microcomputer 30. The shunt resistor 41 is connected to the FET circuit 21, and the current detection circuit 42 measures a voltage between both terminals of the shunt resistor 41, detects a current value to be supplied to the motor 11, and sends the motor current signal (motor current value Im) to the microcomputer 30.

(Details of Output Control of Electric Oil Pump)

[0034] During operation of the electric oil pump 10, the motor 11 is driven based on the PID control as shown in Fig. 2. That is, it is assumed that a command to rotate the motor 11 with a current value of the target current value Itg is transmitted from the ECU 102 (see Fig. 1) side under certain operating conditions. Note that the target current value Itg indicates a current value with which the motor 11 is rotated to ensure the hydraulic pressure and the oil discharge amount currently required by the hydraulic circuit 101 (see Fig. 1). In this case, in the microcomputer 30 (see Fig. 1), the current deviation e(t) between the present motor current value Im detected by the current detection circuit 42 and the target current value Itg is calculated, and the PID control as feedback control is executed so as to match the motor current value Im to the target current value Itg. Incidentally, control parameters of the PID control include a proportional gain Kp (hereinafter referred to as Kp) of the proportional control, an integral gain Ki (hereinafter referred to as Ki) of the integral control, and a differential gain Kd (hereinafter referred to as Kd) of the differential control. The command voltage u(t) based on the duty ratio generated by the PID control is applied to the motor 11.

[0035] The command voltage u(t) based on the PID control is expressed by a formula (1) shown in a lower region of Fig. 2. That is, the command voltage u(t) is given as a value obtained by adding the product of the proportional gain Kp and the current deviation e(t), the product of the integral gain Ki and the integral value of the current deviation e(t) from integral time 0 to integral time t, and the product of the differential gain Kd and the differential value of the current deviation e(t).

[0036] Here, in the first embodiment, adjustment control described below is added to the PID control applied to the electric oil pump 10 (motor 11) based on a command from the arithmetic unit 31 of the microcomputer 30.

[0037] Specifically, the arithmetic unit 31 estimates the oil temperature Te based on the relationship between the motor current value Im and the motor rotation speed N of the electric oil pump 10 detected during operation of the electric oil pump 10, and internally (automatically) adjusts Kp, Ki, and Kd of the PID control related to the motor current value Im or the motor rotation speed N based on the estimated oil temperature Te so as to perform the PID control.

[0038] The correlation of the estimated oil temperature Te with respect to the motor current value Im (corresponding to the torque and the hydraulic pressure) and the motor rotation speed N (corresponding to the oil discharge amount) is stored in advance in the ROM 32 (see Fig. 1) of the microcomputer 30. In this case, data of the kinematic viscosity of the oil corresponding to the combination of the detected motor current value Im and motor rotation speed N is stored in the ROM 32. The oil temperature Te is calculated (estimated) based on the kinematic viscosity of the oil acquired from the ROM 32 according to the combination of the motor current value Im and the motor rotation speed N.

[0039] To give a specific example, the relationship between the kinematic viscosity (oil viscosity) and the oil temperature of hydrocarbon oil is expressed by the following formula (2), which is widely used as the "empirical formula of Walther".

$$\log(\log(\nu + k)) = n - (m \times \log(Te)) \ldots (2)$$

[0040] In the above formula (2), v is a kinematic viscosity (mm^2/s) of oil, k, m, and n are constants determined by the type of oil, and Te is an oil temperature indicated by an absolute temperature (K).

[0041] Therefore, it is possible to calculate the oil temperature Te corresponding to an arbitrary kinematic viscosity ν (oil viscosity) using the above formula (2). Thus, in the microcomputer 30, the kinematic viscosity ν of the oil to be discharged from the pump 12 is acquired from the relationship between the motor current value Im and the motor rotation speed N detected during operation of the electric oil pump 10. The oil temperature Te corresponding to the acquired oil viscosity (kinematic viscosity ν) is estimated (calculated) using the above formula (2).

[0042] Accordingly, the electric oil pump device 100 controls the output of the electric oil pump 10 (current control of the motor 11) while adjusting Kp, Ki, and Kd of the feedback control related to the motor current value Im or the motor rotation speed N based on the estimated oil temperature Te (oil viscosity). As a result, the present motor current value Im can be quickly brought close to the target current value Itg.

[0043] As shown in Fig. 1, the motor current value Im (see Fig. 2) is grasped by the microcomputer 30 side based on the voltage between both the terminals of the shunt resistor 41 detected by the current detection circuit 42. Furthermore, the motor rotation speed N (see Fig. 2) is grasped by the microcomputer 30 side based on the number of poles of the motor 11 and zero cross point (phase at the time when the induced voltage waveform becomes 1/2 of its amplitude) counts in the waveform of the induced voltage generated in each of the three wires (the U-phase drive coil, the V-phase drive coil, and the W-phase drive coil) of the motor 11 during rotation.

[0044] In the first embodiment, the microcomputer 30 determines the excessive or deficient state of at least one of the hydraulic pressure or the oil discharge amount of the electric oil pump 10 based on the estimated oil temperature Te (oil viscosity), and adjusts Kp, Ki, and Kd of the feedback control related to the motor current value Im or the motor rotation speed N so as to avoid the excessive or deficient state.

[0045] In this case, as the excessive and deficient states, there are the "deficient state (deficient output region)" of the load (at least one of the hydraulic pressure or the oil discharge amount) of the electric oil pump 10 in the case in which the estimated oil temperature Te is less than a threshold T1 (an example of a first threshold) and the "excessive state (excessive output region)" of the load (at least one of the hydraulic pressure or the oil discharge amount) of the electric oil pump 10 in the case in which the estimated oil temperature Te is greater than a threshold T2 (an example of a second threshold). The microcomputer 30 adjusts Kp, Ki, and Kd of the PID control based on the estimated oil temperature Te (oil viscosity) so as to avoid at least one of the deficient state or the excessive state. In order to avoid the deficient state, Kp, Ki, and Kd are increased. In order to avoid the excessive state, Kp, Ki, and Kd are decreased.

[0046] In the ROM 32 (see Fig. 1), the table 4 as shown in Fig. 3 is stored (saved). In the table 4, the estimated oil temperature Te and each of the control parameters (the proportional gain Kp, the integral gain Ki, and the differential gain Kd) corresponding to each oil temperature Te are associated with each other. Therefore, the arithmetic unit 31 (see Fig. 1) adjusts Kp, Ki, and Kd based on the table 4.

[0047] The microcomputer 30 estimates the oil temperature Te based on the motor current value Im and the motor rotation speed N during steady operation of the electric oil pump 10, and adjusts Kp, Ki, and Kd of the feedback control related to the motor current value Im or the motor rotation speed N based on the estimated oil temperature Te. In this case, the microcomputer 30 estimates the oil temperature Te at a predetermined control cycle and repeatedly adjusts Kp, Ki, and Kd of the feedback control related to the motor current value Im or the motor rotation speed N based on the oil temperature Te estimated at the predetermined control cycle.

[0048] A processing flow of the microcomputer 30 (arithmetic unit 31) at the time of activating the electric oil pump 10 in the electric oil pump device 100 is now described with reference to Figs. 1 to 4.

[0049] As shown in Fig. 4, in step S1, the present motor rotation speed N of the motor 11 (see Fig. 1) is detected based on a command from the microcomputer 30 (see Fig. 1). It should be noted that the motor rotation speed N is acquired based on the number of poles of the motor 11 and the zero cross point counts in the waveform of the induced voltage generated in each of the three wires (the U-phase drive coil, the V-phase drive coil, and the W-phase drive coil) when the motor 11 starts to rotate. Then, in step S2, the present motor current value Im of the motor 11 is detected. The motor current value Im is acquired based on the voltage between both the terminals of the shunt resistor 41 (see Fig. 1) detected by the current detection circuit 42

[0050] Thereafter, in step S3, the microcomputer 30 determines whether or not the electric oil pump 10 (motor 11) is in a steady operation. When determining in step S3 that the electric oil pump 10 is not in a steady operation, the microcomputer 30 temporarily terminates the processing flow. After the termination of this control flow, this control flow shown in Fig. 4 is executed again after the predetermined control cycle elapses.

[0051] When determining in step S3 that the electric oil pump 10 is in a steady operation, the microcomputer 30 acquires (estimates) the oil temperature Te of the electric oil pump 10 in step S4. The arithmetic unit 31 (see Fig. 1) calculates the oil temperature Te based on the relationship between the motor rotation speed N detected in step S1 and the motor current value Im detected in step S2 and the kinematic viscosity (empirical formula of Walther: formula (2)) of oil acquired from the ROM 32.

[0052] Thereafter, in step S5, it is determined whether or not the oil temperature Te is less than the threshold T1. When it is determined in step S5 that the oil temperature Te is less than the threshold T1 (the load of the electric oil pump 10 is determined to be in a "deficient state (deficient output region)"), the microcomputer 30 adjusts the respective control parameters of the feedback control so as to increase the proportional gain Kp, the integral gain Ki, and the differential gain Kd (see Fig. 2) in step S6.

[0053] When it is determined in step S5 that the oil temperature Te is equal to or greater than the threshold T1, it is determined in step S7 whether or not the oil temperature Te is greater than the threshold T2. When it is determined in step S7 that the oil temperature Te is greater than the threshold T2 (it is determined that the load of the electric oil pump 10 is in an "excessive state (excessive output region)"), the microcomputer 30 adjusts the respective control parameters of the feedback control so as to decrease the proportional gain Kp, the integral gain Ki, and the differential gain Kd in step S8. After the end of step S6 or step S8, the processing flow is temporarily terminated. After the termination of this control flow, this control flow shown in Fig. 4 is executed again after the predetermined control cycle elapses.

[0054] The processing operations in step S1 to step S8 are performed such that the oil temperature Te is estimated based on the relationship between the motor current value Im and the motor rotation speed N of the electric oil pump 10 detected during operation of the electric oil pump 10, and the control parameters of the feedback control (the proportional gain Kp, the integral gain Ki, and the differential gain Kd) related to the motor current value Im or the motor rotation speed N are adjusted based on the estimated oil temperature Te. That is, the PID control is performed by the microcomputer 30 based on the adjusted Kp, Ki, and Kd such that the optimum command voltage u(t) (i.e. the duty ratio) is determined to ensure the hydraulic pressure and the oil discharge amount currently required by the hydraulic circuit 101 (see Fig. 1). Therefore, the motor 11 quickly produces an output to ensure the hydraulic pressure and the oil discharge amount according to the oil temperature condition. The electric oil pump device 100 according to the first embodiment is configured as described above.

(Advantageous Effects of First Embodiment)

[0055] According to the first embodiment, the following advantageous effects are achieved.

[0056] According to the first embodiment, as described above, the electric oil pump device 100 includes the microcomputer 30 that estimates the oil temperature Te based on the relationship between the motor current value Im and the motor rotation speed N of the electric oil pump 10 detected during operation of the electric oil pump 10 and adjusts the control parameters (the proportional gain Kp, the integral gain Ki, and the differential gain Kd) of the feedback control related to the motor current value Im or the motor rotation speed N based on the estimated oil temperature Te. Accordingly, it is possible to control the output (the current of the motor 11) of the electric oil pump 10 while adjusting Kp, Ki, and Kd (control parameters) of the feedback control related to the motor current value Im or the motor rotation speed N based on the estimated oil temperature Te, and thus it is possible to quickly bring the present motor current value Im to the target current value Itg unlike the case in which general feedback control without adjusting the control parameters is performed. As a result, the responsiveness of the output control of the motor 11 is improved such that it is possible to quickly ensure the hydraulic pressure and the oil discharge amount according to the oil temperature condition.

[0057] According to the first embodiment, the microcomputer 30 controls the motor 11 by the PID control including the proportional control, the integral control, and the differential control, and controls the proportional gain Kp of the proportional control, the integral gain Ki of the integral control, and the differential gain Kd of the differential control as the control parameters. Accordingly, it is possible to appropriately control the output (the current of the motor 11) of the electric oil pump 10 while adjusting the proportional gain Kp, the integral gain Ki, and the differential gain Kd of the feedback control related to the motor current value Im or the motor rotation speed N based on the estimated oil temperature Te.

[0058] According to the first embodiment, the electric oil pump device 100 includes the microcomputer 30 described above such that even when the oil viscosity varies according to the oil temperature Te (the load of the electric oil pump 10 varies), the responsiveness of the output control of the motor 11 can be improved, and thus it is possible to extend the range of the oil temperature Te (oil viscosity) at which the electric oil pump 10 can be used. In addition, even when the design tolerance at the time of designing each of the pump 12 and the motor 11 that constitutes the electric oil pump 10 is loosened (the design accuracy is reduced), the output adjustment (the current control of the motor 11) of the electric oil pump 10 can be quickly performed, and thus it is possible to easily manage the design accuracy and the manufacturing accuracy of the electric oil pump 10.

[0059] According to the first embodiment, the microcomputer 30 determines the excessive or deficient state of at least one of the hydraulic pressure or the oil discharge amount of the electric oil pump 10 based on the estimated oil temperature Te. Furthermore, the microcomputer 30 adjusts the proportional gain Kp, the integral gain Ki, and the differential gain Kd of the feedback control related to the motor current value Im or the motor rotation speed N so as to avoid this excessive or deficient state. Accordingly, a variation in the load (at least one of the hydraulic pressure or the oil discharge amount) of the electric oil pump 10 is grasped according to the estimated oil temperature Te (oil viscosity), and thus even when the load of the electric oil pump 10 varies with a variation in the oil temperature Te (oil viscosity) such that the possibility of falling into the excessive or deficient state of at least one of the hydraulic pressure or the oil discharge amount increases, it is possible to reliably avoid falling into this excessive or deficient state by adjusting the proportional gain Kp, the integral gain Ki, and the differential gain Kd of the feedback control related to the motor current value Im or the motor rotation speed N. As a result, even when the load of the electric oil pump 10 varies due to a variation in the oil temperature Te (oil viscosity), it is possible to stably operate the electric oil pump 10 and reliably ensure the hydraulic pressure and the oil discharge amount corresponding to the oil temperature condition.

[0060] According to the first embodiment, the excessive and deficient states include the deficient state (deficient output region) of at least one of the hydraulic pressure or the oil discharge amount of the electric oil pump 10 in the case in which the estimated oil temperature Te is less than the threshold T1 and the excessive state (excessive output region) of at least one of the hydraulic pressure or the oil discharge amount of the electric oil pump 10 in the case in which the estimated oil temperature Te is greater than the threshold T2. Furthermore, the microcomputer 30 adjusts the proportional gain Kp, the integral gain Ki, and the differential gain Kd based on the estimated oil temperature Te so as to avoid at least one of the deficient state or the excessive state.

[0061] Accordingly, it is possible to easily estimate the load state of the electric oil pump 10 depending on whether the estimated oil temperature Te (oil viscosity) is less than the threshold T1 or greater than the threshold T2. The proportional gain Kp, the integral gain Ki, and the differential gain Kd of the feedback control related to the motor current value Im or the motor rotation speed N are adjusted according to the estimated load state (deficient state or excessive state) such that it is possible to quickly avoid at least one of the deficient output state or the excessive output state of the electric oil pump 10. In other words, it is possible to avoid insufficient oil lubrication in a lubricating system caused by the deficient output state, the insufficient operating hydraulic pressure of the automatic transmission, and insufficient cooling of the cooling jacket by the oil. In addition, it is possible to avoid occurrence of power loss (energy loss) in the electric oil pump 10 due to the excessive output state.

[0062] According to the first embodiment, the electric oil pump device 100 includes the table 4 in which the estimated value (oil temperature Te) of the oil temperature during operation (steady operation) of the electric oil pump 10 and each of the proportional gain Kp, the integral gain Ki, and the differential gain Kd are associated with each other. Furthermore, the microcomputer 30 adjusts the proportional gain Kp, the integral gain Ki, and the differential gain Kd based on the table 4. Accordingly, it is possible to easily control the output (the current of the motor 11) of the electric oil pump 10 by adjusting the control parameters (Kp, Ki, and Kd), referring to the table 4 in which the estimated oil temperature Te during operation of the electric oil pump 10 is associated with each of the proportional gain Kp, the integral gain Ki, and the differential gain Kd.

[0063] According to the first embodiment, the microcomputer 30 estimates the oil temperature Te at the predetermined control cycle and repeatedly adjusts the proportional gain Kp, the integral gain Ki, and the differential gain Kd of the feedback control related to the motor current value Im or the motor rotation speed N based on the oil temperature Te estimated at the predetermined control cycle. Accordingly, it is possible to repeatedly adjust the proportional gain Kp, the integral gain Ki, and the differential gain Kd according to a variation in the oil temperature Te (a variation in the oil viscosity) in a state in which the oil temperature Te (oil viscosity) is continuously grasped at the predetermined control cycle during operation of the electric oil pump 10, and thus it is possible to constantly obtain high responsiveness to the output control of the motor 11 during operation of the electric oil pump 10. Therefore, it is possible to stably follow a variation in the load of the electric oil pump 10.

[0064] According to the first embodiment, the microcomputer 30 estimates the oil temperature Te based on the motor current value Im and the motor rotation speed N during steady operation of the electric oil pump 10, and adjusts the proportional gain Kp, the integral gain Ki, and the differential gain Kd of the feedback control related to the motor current value Im or the motor rotation speed N based on the estimated oil temperature Te. Accordingly, it is possible to control driving of the electric oil pump 10 appropriately following the load variation during steady operation of the electric oil pump 10.

[Second Embodiment]

[0065] A second embodiment is now described with reference to Figs. 1, 2, and 4 to 6. In this second embodiment, a structure is described in which the output of an electric oil pump 10 is controlled based on a correlation formula in which the correlation between an estimated oil temperature Te and each of a proportional gain Kp, an integral gain Ki, and a differential gain Kd is defined instead of referring to the table 4 (see Fig. 3) regarding the adjustment of the proportional gain Kp, the integral gain Ki, and the differential gain Kd in PID control. In the figures, the same structures as those of the aforementioned first embodiment are denoted by the same reference numerals.

[0066] An electric oil pump device 200 (see Fig. 1) according to the second embodiment adjusts Kp, Ki, and Kd of the PID control without using the table 4 (see Fig. 3) in a processing operation in each of step S6 and step S8 in the processing flow shown in Fig. 4.

[0067] Specifically, as an alternative method, when a pump 12 is rotated using a motor 11, the equation of motion (equation of motion in which the load (pump 12) is rotated by the motor 11) is expressed by the following formula (3), as shown in Fig. 5.

$$J \times (d\omega(t)/dt) + B \times \omega(t) = Kt \times u(t) \ldots (3)$$

[0068] In the above formula (3), J represents the moment of inertia (kgm^2) for rotation of the electric oil pump 10, $\omega(t)$ represents the rotation rate (rad/s) of the motor 11, B represents a friction coefficient (oil viscosity), Kt represents the torque constant of the motor 11, and u(t) represents a command voltage (V). Furthermore, Kt $\times$ u(t) represents a physical quantity corresponding to the input torque of the motor 11.

[0069] When the input is K $\times$ u(t) and the output is $\omega(t)$ in the above formula (3), a transfer function G(s) is expressed by the following formula (4), where Kt $\times$ u(s) represents the Laplace transform of Kt $\times$ u(t) and $\omega(s)$ represents the Laplace transform of $\omega(t)$, by Laplace transforming the above equation of motion (formula (3)).

$$G(s) = \omega(s)/(Kt \times u(s)) = (1/B)/((J/B) \times s + 1) \ldots (4)$$

[0070] The above formula (4) shows a transfer function for the response of a so-called primary system.

[0071] On the other hand, a transfer function Gc(s) in the PID control is expressed by the following formula (5) by Laplace transforming the formula (1) for the command voltage u(t) shown in the lower region of Fig. 2.

$$Gc(s) = Kp + Ki \times (1/s) + Kd \times s \ldots (5)$$

[0072] In the above formula (5), Kp represents a proportional gain, Ki represents an integral gain, and Kd represents a differential gain.

[0073] In the second embodiment, the feedback control for the electric oil pump 10 shown in Fig. 2 is replaced with a block diagram (before equivalent transformation) shown in a left-hand frame of Fig. 6. That is, the transfer elements of the PID control are represented by the transfer function Gc(s), and the transfer element of rotation control of the electric oil pump 10 is represented by the transfer function G(s). Furthermore, the transfer element of feedback is represented by H(s). In Fig. 6, a block diagram (within a right-hand frame) after equivalent transformation is shown on the right side of the above block diagram (within the left-hand frame) before equivalent transformation. Here, referring to Fig. 6, the transfer function after equivalent transformation in a control system of the motor 11 (see Fig. 2) is expressed by the following formula (6).

$$(Gc(s) \times G(s))/(1 + G(s) \times Gc(s) \times H(s)) \ldots (6)$$

[0074] In the above formula (6), the feedback is assumed to be H(s) = 1.

[0075] Therefore, in the second embodiment, The microcomputer 30 (see Fig. 1) adjusts the proportional gain Kp, the integral gain Ki, and the differential gain Kd, which are the design parameters of the PID control, based on the transfer function (see Fig. 6) after equivalent transformation shown in the above formula (6). Note that as a specific determination method for Kp, Ki, and Kd, the ultimate sensitivity method or transient response method proposed by Ziegler and Nichols, for example, may be applied. Alternatively, a method other than those described above may be used. Thus, no matter how the estimated oil temperature Te (corresponding to the friction coefficient B (oil viscosity) in the above formula (3)) varies depending on the use conditions of the electric oil pump 10, the control parameters (the proportional gain Kp, the integral gain Ki, and the differential gain Kd) corresponding to the oil temperature Te (friction coefficient B) are appropriately adjusted based on the above formula (6). The remaining structures of the second embodiment are similar to those of the first embodiment.

(Advantageous Effects of Second Embodiment)

[0076] According to the second embodiment, the following advantageous effects are achieved.

[0077] According to the second embodiment, as described above, the microcomputer 30 adjusts the proportional gain Kp, the integral gain Ki, and the differential gain Kd based on the correlation formula (see the above formula (6)) in which the correlation between the friction coefficient B (see the above formula (3)) based on the estimated value (oil temperature Te) of the oil temperature during operation (steady operation) of the electric oil pump 10 and each of the proportional gain Kp, the integral gain Ki, and the differential gain Kd is defined. Accordingly, it is possible to easily control the output of the electric oil pump 10 (the current of the motor 11) by adjusting the control parameters (Kp, Ki, and Pd) based on the correlation formula (see the above formula (6)) in which the correlation between the estimated value (oil temperature Te) of the oil temperature during operation of the electric oil pump 10 and the control parameters (Kp, Ki, and Pd) is defined. The remaining advantageous effects of the second embodiment are similar to those of the aforementioned first embodiment.

[Modified Examples]

[0078] The embodiments disclosed this time must be considered as illustrative in all points and not restrictive. The scope of the present invention is not shown by the above description of the embodiments but by the scope of claims for patent, and all modifications (modified examples) within the meaning and scope equivalent to the scope of claims for patent are further included.

[0079] For example, while the oil temperature Te is estimated based on the relationship between the motor current value Im and the motor rotation speed N of the electric oil pump 10 detected during operation (steady operation) of the electric oil pump 10, and Kp, Ki, and Pd, which are the control parameters of the feedback control parameters related to the motor current value Im or the motor rotation speed N, are adjusted based on the estimated oil temperature Te in each of the aforementioned first and second embodiments, the present invention is not restricted to this. For example, the oil temperature Te may be estimated based on the relationship between the torque directly detected from an acceleration sensor attached to a shaft of the motor 11, for example, and the motor rotation speed N of the motor 11, or the oil temperature Te may be estimated based on the relationship between an oil pressure (oil pressure information) and an oil discharge amount (oil discharge amount information) discharged from the pump 12. Furthermore, the microcomputer 30 may grasp all of the torque, the motor current value Im, and the oil pressure of the electric oil pump 10 and all of the motor rotation speed N and the oil discharge amount of the electric oil pump 10, estimate the oil temperature Te performing a predetermined calculation based on the mutual relationship between these detected values, and adjust the control parameters (Kp, Ki, and Pd) of the PID control based on the estimated oil temperature Te.

[0080] While the oil temperature Te is estimated based on the motor current value Im and the motor rotation speed N during steady operation of the electric oil pump 10, and the control parameters (Kp, Ki, and Pd) of the feedback control related to the motor current value Im or the motor rotation speed N are adjusted based on the estimated oil temperature Te in each of the aforementioned first and second embodiments, the present invention is not restricted to this. For example, the oil temperature Te may be estimated based on the motor current value Im and the motor rotation speed N at the time of activating the electric oil pump 10 as well as during steady operation, and Kp, Ki, and Pd may be adjusted based on the estimated oil temperature Te.

[0081] While the sensorless three-phase brushless DC motor is used as the motor 11 in each of the aforementioned first and second embodiments, the present invention is not restricted to this. That is, the present invention may be applied to the output control of the electric oil pump 10 including the motor 11 provided with a position detection sensor such as a Hall element.

[0082] While the example in which the present invention is applied to the activation control of the electric oil pump 10 mounted on an automobile has been shown in each of the aforementioned first and second embodiments, the present invention is not restricted to this. For example, the present invention may be applied to activation control of an electric oil pump mounted on an internal combustion engine for facility equipment.

Description of Reference Numerals

[0083]

4:	table
10:	electric oil pump
11:	motor
12:	pump
20:	motor drive circuit
21:	FET circuit
22:	motor drive IC
30:	microcomputer (controller)
31:	arithmetic unit (controller)
32:	ROM
40:	battery
41:	shunt resistor
42:	current detection circuit
100, 200:	electric oil pump device
101:	hydraulic circuit
Im:	motor current value
Itg:	target current value
Kp:	proportional gain (control parameter)
Ki:	integral gain (control parameter)
Kd:	differential gain (control parameter)
N:	motor rotation speed
T1:	threshold (first threshold)
T2:	threshold (second threshold)
Te:	oil temperature (estimated oil temperature)

Claims

1. An electric oil pump device comprising:

an electric oil pump including a motor and driven by the motor; and
a controller that estimates an oil temperature based on a relationship between at least one of a hydraulic pressure, a motor current value, or a torque of the electric oil pump and at least one of an oil discharge amount or a motor rotation speed of the electric oil pump detected during operation of the electric oil pump, and adjusts a control parameter of feedback control related to the motor current value or the motor rotation speed based on the estimated oil temperature.

2. The electric oil pump device according to claim 1, wherein the controller determines an excessive or deficient state of at least one of the hydraulic pressure or the oil discharge amount of the electric oil pump based on the estimated oil temperature, and adjusts the control parameter of the feedback control related to the motor current value or the motor rotation speed so as to avoid the excessive or deficient state.

3. The electric oil pump device according to claim 2, wherein
the excessive and deficient states include the deficient state of at least one of the hydraulic pressure or the oil discharge amount of the electric oil pump in a case in which the estimated oil temperature is less than a first threshold and the excessive state of at least one of the hydraulic pressure or the oil discharge amount of the electric oil pump in a case in which the estimated oil temperature is greater than a second threshold, and
the controller adjusts the control parameter based on the estimated oil temperature so as to avoid at least one of the deficient state or the excessive state.

4. The electric oil pump device according to any one of claims 1 to 3, further comprising a table in which the estimated oil temperature during the operation of the electric oil pump and the control parameter are associated with each other, wherein
the controller adjusts the control parameter based on the table.

5. The electric oil pump device according to any one of claims 1 to 3, wherein the controller adjusts the control parameter based on a correlation formula in which a correlation between the estimated oil temperature during the operation of the electric oil pump and the control parameter is defined.

6. The electric oil pump device according to any one of claims 1 to 5, wherein the controller controls the motor by PID control including proportional control, integral control, and differential control, and adjusts a proportional gain of the proportional control, an integral gain of the integral control, and a differential gain of the differential control as the control parameter.

7. The electric oil pump device according to any one of claims 1 to 6, wherein the controller estimates the oil temperature at a predetermined control cycle, and repeatedly adjusts the control parameter of the feedback control related to the motor current value or the motor rotation speed based on the oil temperature estimated at the predetermined control cycle.

8. The electric oil pump device according to any one of claims 1 to 7, wherein the controller estimates the oil temperature based on the motor current value and the motor rotation speed at least during steady operation of the electric oil pump or at a time of activating the electric oil pump, and adjusts the control parameter of the feedback control related to the motor current value or the motor rotation speed based on the estimated oil temperature.

FIG.1

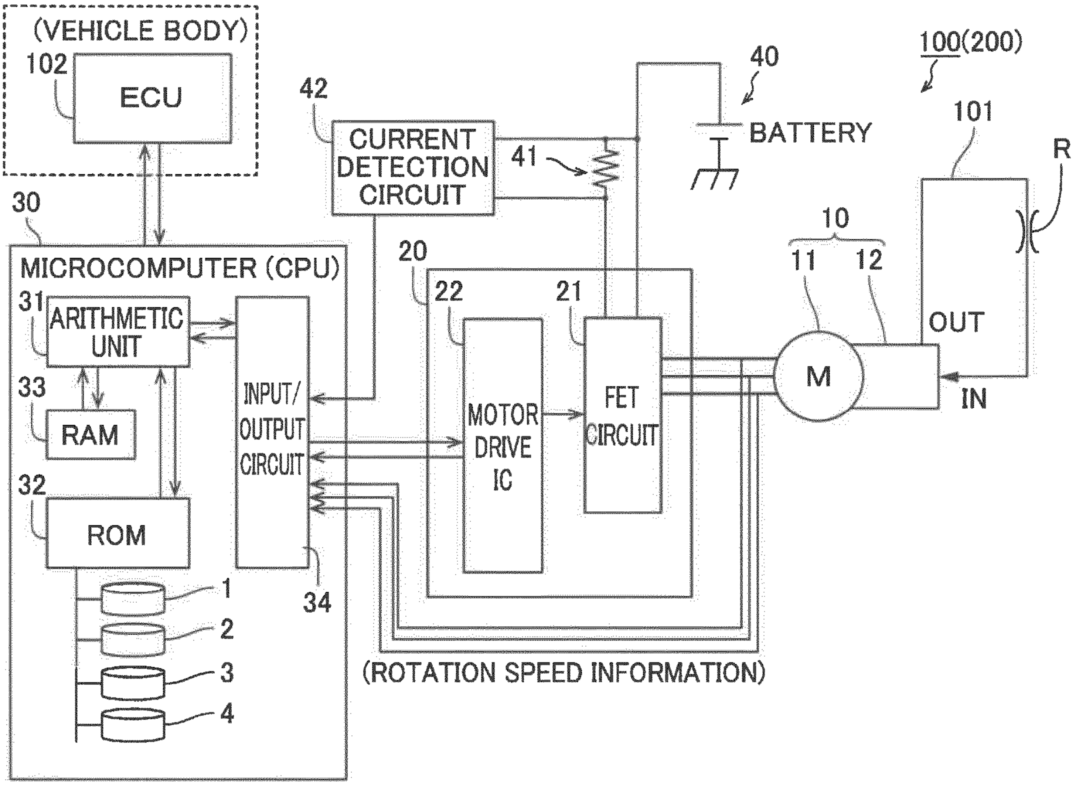
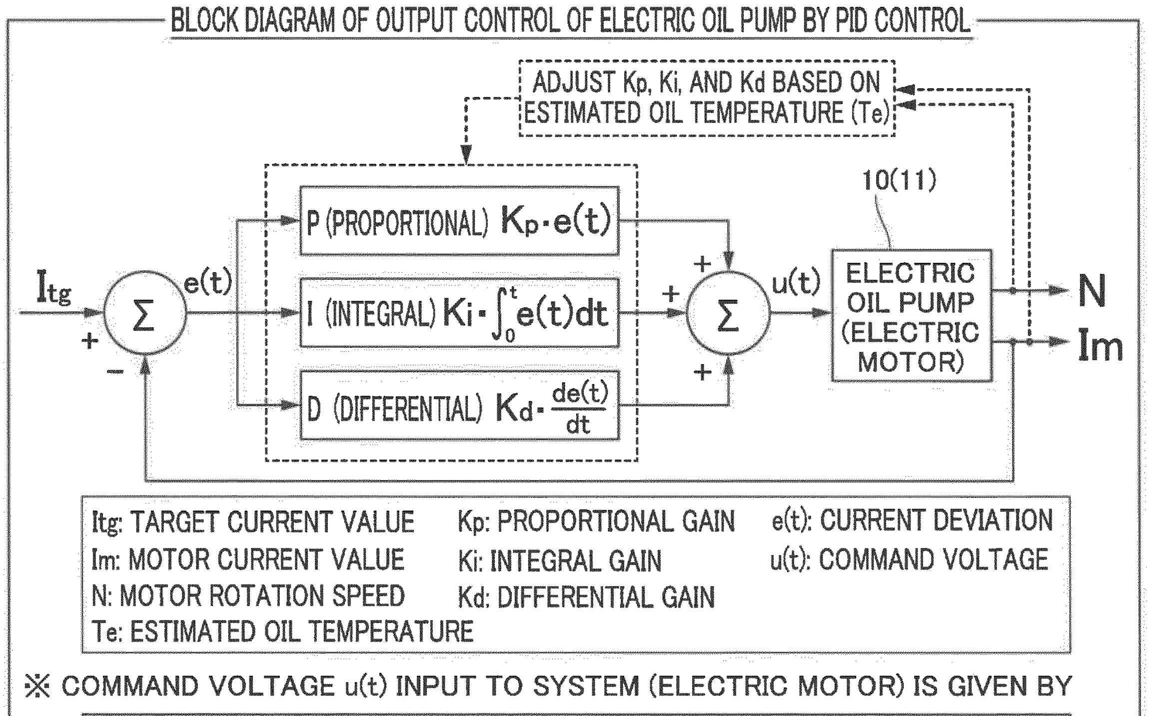


FIG.2



$$u(t) = K_p \cdot e(t) + K_i \cdot \int_0^t e(t)dt + K_d \cdot \frac{de(t)}{dt} \quad \cdots \text{FORMULA (1)}$$

FIG.3

ONE EXAMPLE OF TABLE IN WHICH CORRESPONDENCE RELATIONSHIP BETWEEN ESTIMATED OIL TEMPERATURE Te AND CONTROL PARAMETERS (Kp, Ki, AND Kd) IS DEFINED

4

	CONTROL PARAMETERS		
ESTIMATED OIL TEMPERATURE (Te)	PROPORTIONAL GAIN Kp	INTEGRAL GAIN Ki	DIFFERENTIAL GAIN Kd
−40	0.04	1.8	0.02
−30	0.03	1.6	0.01
−20	0.03	1.5	0.01
−10	0.03	1.3	0.01
0	0.02	1.2	0.01
10	0.02	1.1	0.01
20	0.02	1.0	0.01
30	0.02	0.9	0.01
40	0.02	0.8	0.01
50	0.01	0.7	0.01
60	0.01	0.7	0.01
70	0.01	0.6	0.01
80	0.01	0.5	0.005
90	0.01	0.5	0.004
100	0.01	0.4	0.004
110	0.01	0.4	0.003
120	0.01	0.3	0.003

FIG.4

PROCESSING FLOW RELATED TO OUTPUT CONTROL OF ELECTRIC OIL PUMP

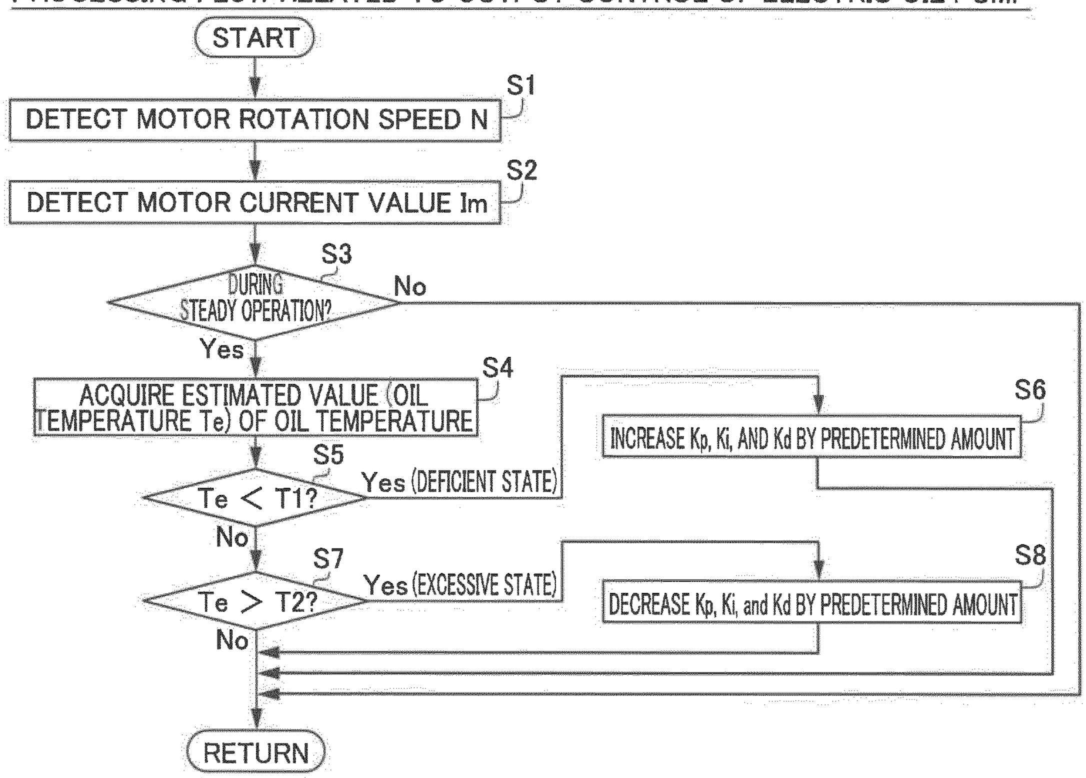


FIG.5

TRANSFER FUNCTION IN ROTARY MOTION SYSTEM

・EQUATION OF MOTION

$$J\cdot\frac{d\omega(t)}{dt}+B\cdot\omega(t)=Kt\cdot u(t)\quad\cdots\text{ FORMULA (3)}$$

⇩ LAPLACE TRANSFORM

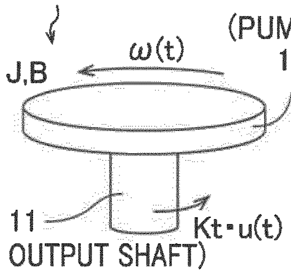
$$Js\,\omega(s)+B\,\omega(s)=Kt\cdot u(s)$$

$$(Js+B)\,\omega(s)=Kt\cdot u(s)$$

$$\omega(s)=\frac{1}{Js+B}\,Kt\cdot u(s)$$

$$=\frac{(1/B)}{(J/B)s+1}\,Kt\cdot u(s)$$

MODEL OF OIL PUMP



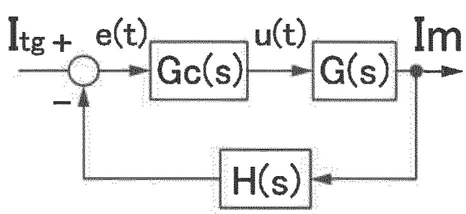
u(t): COMMAND VOLTAGE
Kt·u(t): INPUT TORQUE
ω(t): MOTOR ROTATION RATE
J: MOMENT OF INERTIA
B: FRICTION COEFFICIENT (OIL VISCOSITY)

・TRANSFER FUNCTION

$$G(s)=\frac{\omega(s)}{Kt\cdot u(s)}=\frac{(1/B)}{(J/B)s+1}\quad\cdots\text{ FORMULA (4)}$$

FIG.6

EQUIVALENT TRANSFORMATION TABLE OF BLOCK DIAGRAM

TRANSFORMATION OPERATION	BEFORE EQUIVALENT TRANSFORMATION	AFTER EQUIVALENT TRANSFORMATION
FEEDBACK COUPLING		I_{tg} → $\frac{Gc(s)\cdot G(s)}{1+Gc(s)\cdot G(s)\cdot H(s)}$ → Im
	Gc(s): PID CONTROL BLOCK G(s): ELECTRIC OIL PUMP H(s): FEEDBACK BLOCK	◆TRANSFER FUNCTION $\frac{Gc(s)\cdot G(s)}{1+Gc(s)\cdot G(s)\cdot H(s)}$ ··· FORMULA (6)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/023680

A. CLASSIFICATION OF SUBJECT MATTER
F04B49/06(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04B49/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2005-16460 A (Aisin Seiki Co., Ltd.), 20 January 2005 (20.01.2005), paragraphs [0003], [0016] to [0018]; all drawings (Family: none)	1-8
Y	JP 3-3986 A (Nissan Motor Co., Ltd.), 10 January 1991 (10.01.1991), page 2, upper left column, lines 4 to 9; page 4, lower left column, lines 6 to 7 (Family: none)	1-8
Y	JP 8-121344 A (Hitachi Construction Machinery Co., Ltd.), 14 May 1996 (14.05.1996), paragraphs [0008], [0020] (Family: none)	1-8

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 September 2017 (11.09.17)	26 September 2017 (26.09.17)

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Telephone No.

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2005016460 A **[0002] [0003] [0005] [0006]**