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DRIVING APPARATUS

Abstract

A driving apparatus to be mounted on a vehicle includes a first electric motor that includes multi-phase coils and rotates a driving wheel of the vehicle, a rotation inhibiting device that inhibits rotation of the driving wheel caused by the first electric motor, and a processor that controls an electric current to be passed through the first electric motor. The processor executes a temperature raising process to raise temperatures of the multi-phase coils of the first electric motor by passing the electric current to the multi-phase coils. The rotation inhibiting device inhibits the rotation of the driving wheel and a q-axis electric current is included in the electric current passed through the multi-phase coils in the temperature raising process.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION
[0001] This application claims priority to Japanese Patent Application No. 2024-018952 filed on Feb. 9, 2024, incorporated herein by reference in its entirety.
BACKGROUND
1. Technical Field
[0002] The present disclosure relates to a driving apparatus. In particular, the present disclosure relates to a driving apparatus including an electric motor having multi-phase coils.
2. Description of Related Art
[0003] Japanese Unexamined Patent Application Publication No. 2009-118659 discloses a vehicle including a motor generator having three-phase coils.
SUMMARY
[0004] In the motor generator as disclosed in JP 2009-118659 A, the temperatures of the coils may be raised. However, if there is a temperature difference between the coils of the respective phases when the temperatures of the multi-phase coils are raised, the motor generator may not be able to exhibit intended magnetic characteristics. The present disclosure provides a technique that can, when the temperatures of multi-phase coils of an electric motor are raised, reduce the temperature difference between the coils of the respective phases.
[0005] According to an aspect of the present disclosure, a driving apparatus to be mounted on a vehicle includes a first electric motor that includes multi-phase coils and is configured to rotate a driving wheel of the vehicle, a rotation inhibiting device configured to inhibit rotation of the driving wheel caused by the first electric moto, and a processor configured to control an electric current to be passed through the first electric motor. The processor is configured to execute a temperature raising process to raise temperatures of the multi-phase coils of the first electric motor by passing the electric current to the multi-phase coils. The rotation inhibiting device inhibits the rotation of the driving wheel and a q-axis electric current is included in the electric current passed through the multi-phase coils in the temperature raising process.
[0006] In the driving apparatus described above, the electric current including the q-axis electric current is passed through the multi-phase coils of the first electric motor with the rotation inhibiting device inhibiting the rotation of the driving wheel. Accordingly, even when the q-axis electric current causes the first electric motor to generate torque, it is possible to cause the multi-phase coils to generate heat while restraining the driving wheel from rotating. Since the passage of the q-axis electric current is allowed, it is possible to raise the temperature of each of the multi-phase coils of the first electric motor regardless of the rotation position of the rotor. This makes it possible to reduce the temperature difference between the coils of the respective phases when the temperatures of the multi-phase coils are raised.
[0007] In addition, for example, a comparative example in which the temperatures of the multi-phase coils of the first electric motor are raised by passing an electric current including only a d-axis electric current through the multi-phase coils of the first electric motor is assumed. The comparative example makes it possible to raise the temperatures of the multi-phase coils of the first electric motor while restraining the generation of torque in the first electric motor. However, in the comparative example, electric currents of different magnitudes may be continuously passed through the multi-phase coils. In this case, the amount of electric current to be passed may differ between the multi-phase coils. As a result, the amounts of heat generated in the multi-phase coils

may not be equalized, and a temperature difference may occur between the multi-phase coils. When the temperature difference occurs between the multi-phase coils, the first electric motor may not be able to exhibit the intended magnetic characteristics. In the driving apparatus of the present disclosure, since the electric current including the q-axis electric current is passed through the multi-phase coils of the first electric motor, the magnitudes of the electric currents passed through the multi-phase coils can be made more uniform than in the comparative example. This makes it possible to appropriately raise the temperature of each of the multi-phase coils of the first electric motor.

[0008] Details of the present disclosure will be described below.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Features, advantages, and technical and industrial significance of exemplary embodiments of the present disclosure will be described below with reference to the accompanying drawings, in which like signs denote like elements, and wherein:

[0010] FIG. **1** shows a block diagram of an electrified vehicle **10** including a driving apparatus **20** of a first embodiment;

[0011] FIG. **2** shows a sectional view taken along line II-II of FIG. **1**;

[0012] FIG. **3** shows a circuit diagram of the driving apparatus **20**; and

[0013] FIG. **4** shows a flowchart of a process executed by a control device **90** of the driving apparatus **20**.

DETAILED DESCRIPTION OF EMBODIMENTS

[0014] The multi-phase coils may be three-phase coils. However, in another embodiment, the multi-phase coils may be two-phase coils.

[0015] The rotation inhibiting device may include a lock component configured to mechanically lock an axle connected to the driving wheel.

[0016] With such a configuration, the temperature raising process can be executed with the rotation of the driving wheel reliably inhibited by the lock component.

[0017] The processor may execute the temperature raising process while traveling of the vehicle is stopped.

[0018] With such a configuration, since the rotation inhibiting device inhibits the rotation of the driving wheel while the traveling of the vehicle is stopped, the temperature raising process can be executed without affecting the traveling of the vehicle.

[0019] The driving apparatus may further include a second electric motor that includes multi-phase coils and rotates a driving wheel of the vehicle. However, in another embodiment, the driving apparatus does not have to include the second electric motor. Note that the second electric motor may drive the driving wheel that is the same as the driving wheel driven by the first electric motor, or may drive the driving wheel that differs from the driving wheel driven by the first electric motor.

[0020] The first electric motor and the second electric motor may rotate a common drive shaft. However, in another embodiment, for example, the first electric motor may rotate a drive shaft connected to a front wheel of the vehicle and the second electric motor may rotate a drive shaft connected to a rear wheel of the vehicle. That is, the first electric motor and the second electric motor may rotate different drive shafts.

[0021] The driving apparatus may further include a second electric power conversion device electrically connected to the second electric motor. In this case, the second electric motor and the second electric power conversion device may constitute a charging circuit configured to supply electric power of an external power source to a battery of the vehicle through a neutral point of the second electric motor, and the processor may be configured to execute the temperature raising process in accordance with charging of the battery through the charging circuit.

[0022] When the charging circuit executes charging of the battery, the temperature of the second electric motor rises. With such a configuration, since the temperature of the first electric motor is raised by the temperature raising process in accordance with the charging of the battery through the charging circuit, the temperature difference between the second electric motor and the first electric motor can be reduced.

[0023] The processor may be configured to execute the temperature raising process in at least a part of a charging period in which the battery is charged by the charging circuit.

[0024] The temperature of the second electric motor rises during the charging period in which the battery is charged by the charging circuit. With such a configuration, since the temperature of the first electric motor is raised by the temperature raising process in at least a part of the charging period of the battery, the temperature difference between the second electric motor and the first electric motor can be reduced.

[0025] The processor may be configured to determine timing to start the execution of the temperature raising process in accordance with a scheduled start-of-use time of the vehicle.

[0026] For example, when the temperature raising process is started regardless of the start-of-use time, the temperature raising process may be executed for an unnecessarily long time, and an excessive electric current may be passed through the multi-phase coils. With such a configuration, it is possible to restrain an excessive electric current from being passed through the multi-phase coils. Thus, the temperature raising process can be executed in an energy-efficient manner.

[0027] The processor may be configured to determine timing to finish the execution of the temperature raising process in accordance with a scheduled start-of-use time of the vehicle.

[0028] For example, when the temperature raising process is finished regardless of the start-of-use time, the temperature raising process may be executed for an unnecessarily long time, and an excessive electric current may be passed through the multi-phase coils. With such a configuration, it is possible to restrain an excessive electric current from being passed through the multi-phase coils. Thus, the temperature raising process can be executed in an energy-efficient manner.

[0029] The processor may be configured to change the magnitude of the electric current to be passed through the multi-phase coils of the first electric motor in accordance with a temperature difference between the first electric motor and the second electric motor.

[0030] With such a configuration, for example, when the temperature difference between the first electric motor and the second electric motor is small, the magnitude of the electric current to be passed through the multi-phase coils can be reduced. Thus, the temperature raising process can be executed in an energy-efficient manner.

[0031] The vehicle may further include a heating medium circuit configured to circulate a heating medium. In this case, the heating medium circuit may circulate the heating medium at least between the first electric motor and a battery of the vehicle in the temperature raising process.

[0032] With such a configuration, the temperature of the battery of the vehicle can be raised using heat of the first electric motor generated by the temperature raising process.

Embodiment

[0033] FIG. **1** shows a block diagram of an electrified vehicle **10** equipped with a driving apparatus **20** of a first embodiment viewed from above. In the present specification, the front side of the electrified vehicle **10** (that is, the upper side of the sheet of FIG. **1**) may be simply referred to as “front”, and the opposite side thereof may be simply referred to as “rear”. Furthermore, the left side of the electrified vehicle **10** (that is, the left side of the sheet of FIG. **1**) may be simply referred to as “left”, and the opposite side thereof may be simply referred to as “right”. In addition, the upper side of the electrified vehicle **10** (that is, the near side of the sheet of the FIG. **1**) may be simply referred to as “up”, and the opposite side thereof may be simply referred to as “down”. Note that the “electrified vehicle” in the present specification includes, for example, a rechargeable battery electric vehicle that is charged by an external power source, a fuel cell electric vehicle that includes

a fuel cell as a power source, and a hybrid electric vehicle that also includes an engine.
[0034] The electrified vehicle **10** further includes, in addition to the driving apparatus **20**, a vehicle body **2**, a battery pack **3**, a pair of left and right front wheels **4**L, **4**R, a pair of left and right rear wheels **5**L, **5**R, a charging inlet **6**, a parking brake **9**, a radiator **12**, and a radiator heat circuit **16**. The driving apparatus **20** includes a first electric motor **30**L, a second electric motor **30**R, a first inverter **40**L, a second inverter **40**R, a first power transmission mechanism **50**L, and a second power transmission mechanism **50**R. In the following description, “a pair of left and right” may be simply referred to as “a pair”.
[0035] The driving apparatus **20** drives the pair of front wheels **4**L, **4**R by supplying electric power of the battery pack **3** to each of the electric motors **30**L, **30**R. Accordingly, the electrified vehicle **10** is driven. That is, the pair of front wheels **4**L, **4**R are driving wheels of the electrified vehicle **10**. In a modification, the pair of rear wheels **5**L, **5**R may be the driving wheels of the electrified vehicle **10**, or the pair of front wheels **4**L, **4**R and the pair of rear wheels **5**L, **5**R may be the driving wheels of the electrified vehicle **10**.
[0036] The first electric motor **30**L and the second electric motor **30**R are symmetrically disposed with respect to a center line C**1** of the electrified vehicle **10** in the left-right direction and have the same structure as each other. The first electric motor **30**L is located on the left of the center line C**1**, and the second electric motor **30**R is located on the right of the center line C**1**. The first inverter **40**L is disposed above the first electric motor **30**L, and the second inverter **40**R is disposed above the second electric motor **30**R. The first electric motor **30**L and the first inverter **40**L are electrically connected to each other, and the second electric motor **30**R and the second inverter **40**R are electrically connected to each other. The power transmission mechanisms **50**L, **50**R are mechanically connected to the electric motors **30**L, **30**R, respectively. Details of the structure of each of the power transmission mechanisms **50**L, **50**R will be described further below with reference to FIG. **2**.
[0037] The charging inlet **6** is disposed on a right side face of the vehicle body **2**. The charging inlet **6** is configured to be connected to an external power source **7** (e.g., a charging station) through a power cable **8**. When the charging inlet **6** is connected to the external power source **7**, charging electric power of the external power source **7** is supplied to the battery pack **3**.
[0038] The radiator **12** is disposed at a front end of the vehicle body **2** of the electrified vehicle **10**. The radiator **12** is a device that exchanges heat between a heating medium (e.g., antifreeze or water) circulating through the radiator heat circuit **16** and outside air. The radiator **12** cools the heating medium, for example, using traveling wind that enters the inside of the vehicle body **2** when the electrified vehicle **10** is traveling. The heating medium functions as, for example, a coolant that cools each of the electric motors **30**L, **30**R when the electrified vehicle **10** is traveling. Although details will be described further below, the heating medium also functions as, for example, a heating medium that raises the temperature of the battery pack **3** under low temperatures.
[0039] The radiator heat circuit **16** includes a radiator pump **17**, a first pipe **18**L, a second pipe **19**L, a third pipe **18**R, and a fourth pipe **19**R. The first pipe **18**L connects the radiator **12** and the first electric motor **30**L. The second pipe **19**L connects the first electric motor **30**L and the battery pack **3**. Similarly, the third pipe **18**R connects the radiator **12** and the second electric motor **30**R, and the fourth pipe **19**R connects the second electric motor **30**R and the battery pack **3**. The radiator pump **17** pressure-feeds the heating medium in the radiator heat circuit **16**. In the present embodiment, the radiator pump **17** circulates the heating medium in the order of the first pipe **18**L, the first electric motor **30**L, the second pipe **19**L, the battery pack **3**, the third pipe **18**R, the second electric motor **30**R, the fourth pipe **19**R, and then the radiator **12**.
[0040] The detailed structure of the driving apparatus **20** will be described with reference to FIG. **2**. In addition to each of the electric motors **30**L, **30**R, and the like described above, the driving apparatus **20** further includes a control device **90**. The control device **90** is a computer including a

CPU, and is, for example, configured to be communicable with each of the electric motors **30**L, **30**R, the parking brake **9**, and the radiator pump **17** and controls the operation of these devices.
[0041] The first electric motor **30**L of the driving apparatus **20** includes a first motor case **32**L, a first motor bearing **33**L, a first rotor **34**L, a first stator **35**L, and a first temperature sensor **39**L. The first motor case **32**L houses the first rotor **34**L, the first stator **35**L, and the first temperature sensor **39**L. The first rotor **34**L has a first permanent magnet **36**L. The first stator **35**L faces the first rotor **34**L from the outside in the radial direction of the first rotor **34**L. An outer periphery of the first stator **35**L is covered with a U-phase coil **35**U, a V-phase coil **35**V, and a W-phase coil **35**W (refer to FIG. **3**). The coils **35**U, **35**V and **35**W of the respective phases are arranged in the circumferential direction of the first stator **35**L. The first temperature sensor **39**L is fixed to a left end face of the first stator **35**L. The first temperature sensor **39**L detects a temperature T**1** of the first electric motor **30**L and transmits the detected temperature T**1** to the control device **90**. Note that, in a modification, the first temperature sensor **39**L may be fixed to, for example, an inner wall of the first motor case **32**L. The first motor bearing **33**L is, for example, a ball bearing. The first motor bearing **33**L rotates a first motor shaft **51**L by rolling a ball along an inner race. Similarly, the other bearings are also ball bearings. In a modification, each bearing may be a roller bearing instead of a ball bearing.
[0042] As described above, the second electric motor **30**R has the same configuration as the first electric motor **30**L. Thus, as with the first electric motor **30**L, the second electric motor **30**R includes a second motor case **32**R, a second motor bearing **33**R, a second rotor **34**R having a second permanent magnet **36**R, a second stator **35**R, and a second temperature sensor **39**R. The second motor bearing **33**R rotates a second motor shaft **51**R. The second temperature sensor **39**R detects a temperature T**2** of the second electric motor **30**R and transmits the detected temperature T**2** to the control device **90**.
[0043] The first power transmission mechanism **50**L transmits the power of the first electric motor **30**L to a drive shaft **14**. The drive shaft **14** connects the pair of front wheels **4**L, **4**R to each other. The first power transmission mechanism **50**L includes a plurality of bearings **53**L, **56**L, **58**L, a plurality of gears **54**L, **57**L, **61**L, **62**L, and a plurality of shafts **55**L, **59**L. The first power transmission mechanism **50**L, for example, reduces the rotation speed of the first electric motor **30**L using the gears **54**L, **57**L, **61**L, **62**L to drive the drive shaft **14**. In addition, the first power transmission mechanism **50**L further includes a parking gear **70**. The parking gear **70** meshes with a parking lock (not shown) in response to the parking brake **9** (refer to FIG. **1**) being operated to stop the rotation of the first motor shaft **51**L. That is, the parking gear **70** locks the drive shaft **14** connected to the front wheels **4**L, **4**R, thereby inhibiting the rotation of the front wheels **4**L, **4**R. The parking brake **9** transmits, to the control device **90**, an ON signal S**1** indicating that the parking brake is in operation in response to the parking brake **9** being operated by a user.
[0044] The second power transmission mechanism **50**R transmits the power of the second electric motor **30**R to the drive shaft **14**. The second power transmission mechanism **50**R has a structure left-right symmetric to the structure of the first power transmission mechanism **50**L described above. Thus, the second power transmission mechanism **50**R includes a plurality of bearings **53**R, **56**R, **58**R, a plurality of gears **54**R, **57**R, **61**R, **62**R, and a plurality of shafts **55**R, **59**R. The second power transmission mechanism **50**R, for example, reduces the rotation speed of the second electric motor **30**R using the gears **54**R, **57**R, **61**R, **62**R and the like to rotate the drive shaft **14**.
[0045] As shown in FIG. **1**, in the present embodiment, the drive shaft **14** connects the pair of front wheels **4**L, **4**R. Thus, the pair of front wheels **4**L, **4**R are driven by the two electric motors **30**L, **30**R. Note that, in a modification, the drive shaft **14** may be separated at the center of the electrified vehicle **10** in the left-right direction. That is, the pair of front wheels **4**L, **4**R may be independently driven by the electric motors **30**L, **30**R, respectively.
[0046] An electric circuit of the driving apparatus **20** will be described with reference to FIG. **3**. The first electric motor **30**L is a three-phase motor including the U-phase coil **35**U, the V-phase coil

35V, and the W-phase coil **35**W. One end of the U-phase coil **35**U, one end of the V-phase coil **35**V, and one end of the W-phase coil **35**W are connected to a neutral point NP**1**. The other end of the U-phase coil **35**U of the first electric motor **30**L is connected to a U-phase arm **42**U of the first inverter **40**L. Similarly, the other end of the V-phase coil **35**V of the first electric motor **30**L is connected to a V-phase arm **42**V of the first inverter **40**L, and the other end of the W-phase coil **35**W is connected to a W-phase arm **42**W. In this manner, the first inverter **40**L is electrically connected to the first electric motor **30**L.

[0047] Similarly, the second electric motor **30**R is also a three-phase motor. One end of the U-phase coil **35**U, one end of the V-phase coil **35**V, and one end of the W-phase coil **35**W of the second electric motor **30**R are connected to a neutral point NP**2**. The other end of the U-phase coil **35**U of the second electric motor **30**R is connected to a U-phase arm **42**U of the second inverter **40**R. Similarly, the other end of the V-phase coil **35**V of the second electric motor **30**R is connected to a V-phase arm **42**V of the second inverter **40**R, and the other end of the W-phase coil **35**W is connected to a W-phase arm **42**W. In this manner, the second inverter **40**R is electrically connected to the second electric motor **30**R.

[0048] As shown in FIG. **3**, the driving apparatus **20** further includes a charging circuit **11**. The charging circuit **11** is a circuit for supplying direct-current charging electric power supplied from the external power source **7** to the battery pack **3**. In the charging circuit **11**, one terminal of the charging inlet **6** is connected to a positive electrode of the battery pack **3** through the neutral point NP**2** of the second electric motor **30**R and the second inverter **40**R. That is, the charging circuit **11** supplies the charging electric power supplied from the external power source **7** to the neutral point NP**2** of the second electric motor **30**R. In addition, the other terminal of the charging inlet **6** is connected to a negative electrode of the battery pack **3** through the second inverter **40**R. The charging circuit **11** supplies the charging electric power to the battery pack **3** through the neutral point NP**2** of the second electric motor **30**R. This enables the second electric motor **30**R and the second inverter **40**R to function as three booster circuits that are connected in parallel between the charging inlet **6** and the battery pack **3**. This enables the driving apparatus **20** to boost the output voltage of the external power source **7** using the second electric motor **30**R and the second inverter **40**R. Accordingly, even if the output voltage of the external power source **7** is lower than the voltage of the battery pack **3**, rapid charging can be executed. In addition, the one terminal of the charging inlet **6** is directly connected to the positive electrode of the battery pack **3** through a switch **13**. When the output voltage of the external power source **7** is substantially equal to the voltage of the battery pack **3**, the charging circuit **11** can cause the output voltage of the external power source **7** to bypass the neutral point NP**2** of the second electric motor **30**R by turning on the switch **13**. In addition, although not shown in the drawings, the charging circuit **11** further includes a charging unit including a relay, a capacitor, and the like. The charging unit is connected to the neutral point NP**2** and the second inverter **40**R.

[0049] Here, in the present embodiment, while the charging inlet **6** is connected to the external power source **7** and the charging electric power of the external power source **7** is supplied to the neutral point NP**2** of the second electric motor **30**R, an electric current flows in the coils **35**U, **35**V, **35**W of the respective phases of the second electric motor **30**R. As a result, the coils **35**U, **35**V, and **35**W of the respective phases generate heat, and the temperature T**2** of the second electric motor **30**R rises. On the other hand, even when the charging inlet **6** is connected to the external power source **7**, no electric current flows in the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L, and the temperature T**1** of the first electric motor **30**L thus does not rise. Thus, while the charging electric power of the external power source **7** is supplied to the neutral point NP**2** of the second electric motor **30**R, the temperature difference between the electric motors **30**L, **30**R increases. In this case, the output torques of the electric motors **30**L, **30**R may become unbalanced, which may reduce the traveling stability of the electrified vehicle **10**.

[0050] A temperature raising setting process executed by the control device **90** of the driving

apparatus **20** will be described with reference to FIG. **4**. The temperature raising setting process is a process for executing a temperature raising process to cause the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L to generate heat by passing an electric current including a q-axis electric current through the coils **35**U, **35**V, **35**W of the respective phases. The control device **90** starts the temperature raising setting process in response to the charging inlet **6** being connected to the external power source **7**. That is, the control device **90** executes the temperature raising process in accordance with the charging of the battery pack **3** through the charging circuit **11**. This makes it possible to restrain an increase in the temperature difference between the electric motors **30**L, **30**R caused by the charging of the battery pack **3**.
[0051] In a temperature obtaining process S**2**, the control device **90** obtains the temperature T**1** of the first electric motor **30**L from the first temperature sensor **39**L and obtains the temperature T**2** of the second electric motor **30**R from the second temperature sensor **39**R.
[0052] In a temperature raising determination process S**4**, the control device **90** calculates a temperature difference T**2**−T**1** from the temperature T**1** and the temperature T**2** obtained in the temperature obtaining process S**2**, and compares the temperature difference with a threshold temperature difference Tth that is previously stored. Here, the threshold temperature difference Tth is a threshold for determining whether the temperature difference T**2**−T**1** causes a reduction in the stability of the driving apparatus **20** during driving. The threshold temperature difference Tth is determined based on the size and the output torque and the like of each of the electric motors **30**L, **30**R, but can be changed later by the user. When the temperature difference T**2**−T**1** is smaller than the threshold temperature difference Tth (NO in the temperature raising determination process S**4**), the output torques of the electric motors **30**L, **30**R are maintained relatively uniform even if the temperature raising process for the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L is not executed. Thus, the driving apparatus **20** can be stably driven. When the control device **90** determines NO in the temperature raising determination process S**4**, the control device **90** finishes the process in FIG. **4**. This makes it possible to restrain an unnecessary temperature raising process from being executed even though the temperature difference T**2**−T**1** is smaller than the threshold temperature difference Tth and the electric motors **30**L, **30**R can be driven in a well-balanced manner. On the other hand, when the temperature difference T**2**−T**1** is equal to or larger than the threshold temperature difference Tth (YES in the temperature raising determination process S**4**), the control device **90** determines that temperature raising process is necessary because the output torques of the electric motors **30**L, **30**R may become unbalanced and the stability of each of the electric motors **30**L, **30**R during driving may be reduced, and proceeds to an electric current adjusting process S**6**.
[0053] In the electric current adjusting process S**6**, the control device **90** adjusts the magnitude of the electric current to be passed through the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L in the temperature raising process in accordance with the temperature difference T**2**−T**1** calculated in the temperature raising determination process S**4**. Specifically, the control device **90** calculates the value of the electric current to be passed by multiplying the temperature difference T**2**−T**1** by a predetermined conversion value. Thus, the value of the electric current to be passed increases as the temperature difference T**2**−T**1** increases. That is, the value of the electric current to be passed is proportional to the temperature difference T**2**−T**1**. For example, when the temperature difference T**2**−T**1** is small, the magnitude of the electric current to be passed can be made smaller than that when the temperature difference T**2**−T**1** is large. This makes it possible to execute the temperature raising process in an energy-efficient manner. Hereinbelow, the electric current to be passed adjusted in the electric current adjusting process S**6** may be referred to as the “adjusted electric current”.
[0054] In a time calculating process S**10**, the control device **90** calculates a start-of-use time. The start-of-use time is the estimated time at which the charging of the battery pack **3** is completed and the electrified vehicle **10** starts traveling again after the charging of the battery pack **3** is started.

The control device **90** stores, for example, a charging amount per unit time and an actual value of the time from the completion of charging to the start of traveling. Thus, the control device **90** first calculates a charging time required to complete charging based on the amount of electric power remaining in the battery pack **3** at the present point in time. The control device **90** calculates the start-of-use time by adding an estimated time from the completion of charging to the resumption of traveling to the calculated charging time. The estimated time from the completion of charging to the resumption of traveling may be, for example, the mean of actual values or the shortest actual value. In another modification, the estimated time may be any time input by the user.

[0055] In a first monitoring process S**12**, the control device **90** monitors the arrival of a temperature raising start time. The temperature raising start time is the time indicating the timing to start energizing the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L. The temperature raising start time is determined in accordance with the start-of-use time calculated in the time calculating process S**10** and the adjusted electric current calculated in the electric current adjusting process S**6**. Specifically, the temperature raising start time is calculated by subtracting the time required for the temperature to rise until the current temperature difference T**2**−T**1** becomes smaller than the threshold temperature difference Tth when the adjusted electric current is passed through the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L from the start-of-use time calculated in the time calculating process S**10**. For example, when the difference between the temperature difference T**2**−T**1** and the threshold temperature difference Tth is large, the temperature raising start time is set to a relatively early time. Thus, the temperature T**1** rises relatively early, and the temperature difference T**2**−T**1** can be reliably made smaller than the threshold temperature difference Tth before the start-of-use time arrives.

[0056] On the other hand, when the difference between the temperature difference T**2**−T**1** and the threshold temperature difference Tth is small, the temperature raising start time is set to a time later than that when the difference between the temperature difference T**2**−T**1** and the threshold temperature difference Tth is large. The control device **90** repeats the first monitoring process S**12** until the temperature raising start time arrives. This makes it possible to restrain the first electric motor **30**L from being energized for an unnecessarily long time due to the temperature raising process starting before the temperature raising start time. In this manner, by determining the timing to start energizing the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L corresponding to the start-of-use time of the electrified vehicle **10**, the temperature of the first electric motor **30**L can be raised in an energy-efficient manner. When the start-of-use time arrives, the control device **90** determines YES in the first monitoring process S**12** and proceeds to a brake determination process S**20**.

[0057] In the brake determination process S**20**, the control device **90** determines whether the parking brake **9** is in operation. Specifically, the control device **90** determines whether the ON signal S**1** from the parking brake **9** is received. When the control device **90** does not receive the ON signal S**1** (NO in S**20**), the control device **90** proceeds to a brake operating process S**22**. When the control device **90** receives the ON signal S**1** (YES in S**20**), the control device **90** proceeds to an energization process S**24**.

[0058] In the brake operating process S**22**, the control device **90** turns on the parking brake **9** to operate the parking brake **9**. This locks the drive shaft **14** and can restrain the electrified vehicle **10** from traveling during the temperature raising process. After the brake operating process **22** is finished, the control device **90** proceeds to the energization process S**24**.

[0059] In the energization process S**24**, the control device **90** passes the adjusted electric current calculated in the electric current adjusting process S**6** through the first electric motor **30**L. Accordingly, the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L generate heat, and the temperature T**1** of the first electric motor **30**L rises.

[0060] Furthermore, in a pump operating process S**26**, the control device **90** turns on the radiator pump **17** to operate the radiator pump **17**. Accordingly, the radiator pump **17** circulates the heating medium in the radiator heat circuit **16**. As a result, for example, the heating medium circulates between the first electric motor **30**L and the battery pack **3**. This enables the heat generated in the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L to be supplied to the battery pack **3** through the heating medium. As a result, it is possible to raise the temperature of the battery pack **3**.

[0061] In a second monitoring process S**30**, the control device **90** monitors the arrival of a temperature raising finish time. The temperature raising finish time is the time indicating the timing to finish the energization of the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L. The temperature raising finish time is the estimated time at which the temperature difference T**2**−T**1** becomes smaller than the threshold temperature difference Tth after the temperature raising start time arrives (YES in the first monitoring process S**12**) and the energization of the first electric motor **30**L is started in the energization process S**24**, and determined in accordance with the start-of-use time calculated in the time calculating process S**10**. The control device **90** repeats the second monitoring process S**30** until the temperature raising finish time arrives, and proceeds to an energization finishing process S**32** when the temperature raising finish time arrives (YES in the second monitoring process S**30**).

[0062] In the energization finishing process S**32**, the control device **90** finishes the energization of the first electric motor **30**L. In this manner, by finishing the energization at the temperature raising finish time corresponding to the temperature raising start time determined in accordance with the start-of-use time, it is possible to restrain the first electric motor **30**L from being energized for an unnecessarily long time. When the energization finishing process S**32** is finished, the control device **90** finishes the temperature raising setting process of FIG. **4**.

Effects of Embodiment

[0063] In the driving apparatus **20** of the present embodiment, the electric current including the q-axis electric current is passed through the coils **35**U, **35**V, **35**W of the respective phases of the first electric motor **30**L with the parking gear **70** inhibiting the rotation of the pair of front wheels **4**L, **4**R (the energization process S**24** in FIG. **4**). Accordingly, even when the q-axis electric current causes the first electric motor **30**L to generate torque, it is possible to cause the three-phase coils **35**U, **35**V, **35**W to generate heat while restraining the pair of front wheels **4**L, **4**R from rotating. Since not only the passage of a d-axis electric current but also the passage of the q-axis electric current is allowed, it is possible to raise the temperature of each of the multi-phase coils **35**U, **35**V, **35**W of the first electric motor **30**L regardless of the rotation position of the first rotor **34**L. This makes it possible to reduce the temperature difference between the coils **35**U, **35**V, **35**W of the respective phases when the temperatures of the coils **35**U, **35**V, **35**W of the respective phases are raised.

Correspondences

[0064] The parking gear **70** is an example of the “rotation inhibiting device” and the “lock component”. The energization process S**24** of FIG. **4** is an example of the “temperature raising process”. The second inverter **40**R is an example of the “second electric power conversion device”.

[0065] Although the specific examples of the present disclosure have been described in detail above, these are merely examples and do not limit the scope of the claims. The technique described in the claims includes various modifications and changes of the specific examples illustrated above. Modifications of the embodiment will be listed below.

First Modification

[0066] Each of the first electric motor **30**L and the second electric motor **30**R may include two-phase coils. In another modification, each of the first electric motor **30**L and the second electric motor **30**R may include coils of four or more phases.

Second Modification

[0067] The gear **62**L of the first power transmission mechanism **50**L may be configured to be disconnectable from the drive shaft **14**. In this case, the control device **90** may disconnect the gear

62L and the drive shaft **14** instead of turning on the parking brake **9** in the brake operating process S**22** of FIG. **4**. This inhibits the rotation of the drive shaft **14**. In this modification, the gear **62**L is an example of the "rotation inhibiting device".

Third Modification

[0068] The control device **90** does not have to execute the temperature raising setting process of FIG. **4** in response to the charging inlet **6** being connected to the external power source **7** as a trigger. The control device **90** may execute the process of FIG. **4**, for example, in response to an instruction from the user. In this case, the control device **90** may execute the process of FIG. **4** while the electrified vehicle **10** is traveling.

Fourth Modification

[0069] The driving apparatus **20** does not have to include the second electric motor **30**R. The driving apparatus **20** may include only the first electric motor **30**L. In this case, the control device **90** may obtain the temperatures of the coils **35**U, **35**V, and **35**W of the respective phases of the first electric motor **30**L in the temperature obtaining process S**2** of FIG. **4**. In this modification, in the temperature raising determination process S**4**, the control device **90** may execute the temperature raising process when the temperature difference between the coils **35**U, **35**V, and **35**W of the respective phases exceeds a threshold. In this case, in the electric current adjusting process S**6**, the control device **90** may adjust the magnitude of the electric current to be passed such that the coil of the phase having the lowest temperature generates heat most.

Fifth Modification

[0070] The second electric motor **30**R and the second inverter **40**R do not have to constitute the charging circuit **11**. In this case, the control device **90** may execute the process of FIG. **4** on both the first electric motor **30**L and the second electric motor **30**R.

Sixth Modification

[0071] The control device **90** does not have to execute the time calculating process S**10** and the first monitoring process S**12** of FIG. **4**. In this modification, for example, the energization of the first electric motor **30**L may be started after an elapse of a predetermined time after the charging inlet **6** is connected to the external power source **7**.

Seventh Modification

[0072] The control device **90** does not have to execute the second monitoring process S**30** of FIG. **4**. In this modification, for example, the control device **90** may execute the energization finishing process S**32** when the temperature difference T**2**-T**1** becomes smaller than the threshold temperature difference Tth.

Eighth Modification

[0073] The control device **90** does not have to execute the pump operating process S**26** of FIG. **4**. In this case, the radiator heat circuit **16** of the electrified vehicle **10** does not have to include the second pipe **19**L and the fourth pipe **19**R.

[0074] The technical elements described in the present specification or the drawings exhibit technical usefulness alone or in various combinations, and are not limited to the combinations described in the claims at the time of filing the application. In addition, the technique illustrated in the present specification or the drawings can achieve multiple objectives simultaneously, and achieving one of the objectives itself has technical usefulness.

Claims

1. A driving apparatus to be mounted on a vehicle, the driving apparatus comprising: a first electric motor that includes multi-phase coils and is configured to rotate a driving wheel of the vehicle; a rotation inhibiting device configured to inhibit rotation of the driving wheel caused by the first electric motor; and a processor configured to control an electric current to be passed through the first electric motor, wherein the processor is configured to execute a temperature raising process to raise temperatures of the multi-phase coils of the first electric motor by passing the electric current to the multi-phase coils, and the rotation inhibiting device inhibits the rotation of the driving wheel and a q-axis electric current is included in the electric current passed through the multi-phase coils in the temperature raising process.

2. The driving apparatus according to claim 1, wherein the multi-phase coils are three-phase coils.

3. The driving apparatus according to claim 1, wherein the rotation inhibiting device includes a lock component configured to mechanically lock an axle connected to the driving wheel.

4. The driving apparatus according to claim 1, wherein the processor executes the temperature raising process while traveling of the vehicle is stopped.

5. The driving apparatus according to claim 1, further comprising a second electric motor that includes multi-phase coils and is configured to rotate a driving wheel of the vehicle.

6. The driving apparatus according to claim 5, wherein the first electric motor and the second electric motor are configured to rotate a common drive shaft.

7. The driving apparatus according to claim 5, further comprising a second electric power conversion device electrically connected to the second electric motor, wherein the second electric motor and the second electric power conversion device constitute a charging circuit configured to supply electric power of an external power source to a battery of the vehicle through a neutral point of the second electric motor, and the processor is configured to execute the temperature raising process in accordance with charging of the battery through the charging circuit.

8. The driving apparatus according to claim 7, wherein the processor is configured to execute the temperature raising process in at least a part of a charging period in which the battery is charged by the charging circuit.

9. The driving apparatus according to claim 7, wherein the processor is configured to determine timing to start the execution of the temperature raising process in accordance with a scheduled start-of-use time of the vehicle.

10. The driving apparatus according to claim 7, wherein the processor is configured to determine timing to finish the execution of the temperature raising process in accordance with a scheduled start-of-use time of the vehicle.

11. The driving apparatus according to claim 5, wherein the processor is configured to change a magnitude of the electric current to be passed through the multi-phase coils of the first electric motor in accordance with a temperature difference between the first electric motor and the second electric motor.

12. The driving apparatus according to claim 1, wherein the vehicle further includes a heating medium circuit configured to circulate a heating medium, and the heating medium circuit circulates the heating medium at least between the first electric motor and a battery of the vehicle in the temperature raising process.