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Cooling device for electric motor

Abstract

A cooling device for an electric motor that includes a stator, a rotor and a shaft fixed in an inner circumferential surface of the rotor. The stator includes a stator core and a stator coil wound on the stator core. The stator coil includes a protruding portion which protrudes from the stator core and which constitutes a coil end. The cooling device includes (a) a refrigerant supply mechanism for supplying a refrigerant from an upper side of the electric motor and (b) a refrigerant guide protruding from a motor casing toward an inner peripheral side of the coil end. The refrigerant supply mechanism is configured to supply the refrigerant to the refrigerant guide. The refrigerant guide extends in a direction of a rotation axis of the electric motor to a position that overlaps with the coil end as seen from a radial direction of the electric motor.

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Background/Summary

(1) This application claims priority from Japanese Patent Application No. 2022-038437 filed on Mar. 11, 2022, the disclosure of which is herein incorporated by reference in its entirety.

FIELD OF THE INVENTION

(2) The present invention relates to improvement of cooling performance of a cooling device for an electric motor.

BACKGROUND OF THE INVENTION

(3) There are proposed various kinds of cooling devices for cooling electric motor. For example, JP

6881692 B1 discloses a structure for improving cooling performance for cooling an electric motor, wherein the structure includes a refrigerant guide member provided in a bracket of a casing, so as to make it possible to guide a refrigerant (coolant oil) to a lower portion of a coil end that is located on a lower side of a rotation axis of the electric motor, for appropriately supplying the refrigerant to the lower portion of the coil.

SUMMARY OF THE INVENTION

(4) By the way, the refrigerant guide member disclosed in the above-identified Japanese Patent Publication is a member independent from the casing and attached to the casing, thereby increasing a number of required components. Further, there is a risk of leakage of the refrigerant through a gap between the refrigerant guide member and the casing. Therefore, since a preventive mechanism is required to prevent the leakage of the refrigerant through the gap between the refrigerant guide member and the casing, there is a room for improvement in efficient supply of the refrigerant to the lower portion of the coil end that is located on the lower side of the rotation axis of the electric motor.

(5) The present invention was made in view of the background art described above. It is therefore an object of the present invention to provide a cooling device for an electric motor, wherein the cooling device is capable of improving cooling performance for cooling the electric motor by appropriately supplying a lower portion of a coil end of the electric motor.

(6) The object indicated above is achieved according to the following aspects of the present invention.

(7) According to a first aspect of the invention, there is provided a cooling device for an electric motor that includes: (i) a tubular stator, (ii) a tubular rotor disposed on an inner peripheral side of the stator; and (iii) a shaft fixed in an inner circumferential surface of the rotor, such that the stator includes a tubular stator core and a stator coil wound on the stator core, such that the stator coil includes a protruding portion which protrudes from the stator core and which constitutes a coil end, and such that the shaft is rotatably supported by a motor casing through a bearing. The cooling device includes: (a) a refrigerant supply mechanism configured to supply a refrigerant from an upper side of the electric motor in a vertical direction; and (b) a refrigerant guide protruding from the motor casing toward an inner peripheral side of the coil end. The refrigerant supply mechanism is configured to supply the refrigerant to the refrigerant guide that extends in a direction of a rotation axis of the electric motor to a position that overlaps with the coil end as seen from a radial direction of the electric motor. It is noted that the above-described “upper side of the electric motor in a vertical direction” may be defined also as “outer side of the electric motor in a radial direction of the electric motor”.

(8) According to a second aspect of the invention, in the cooling device according to the first aspect of the invention, the refrigerant supply mechanism has a refrigerant passage located on the upper side of the electric motor in the vertical direction, and a refrigerant release hole through which the refrigerant is released from the refrigerant passage, wherein the refrigerant release hole is provided in a position which does not overlap with the coil end and overlaps with a bearing holding portion holding the bearing as seen from the vertical direction, and wherein the refrigerant guide is configured to receive the refrigerant flowing down from the bearing holding portion. It is noted that the above-described “as seen from the vertical direction” may be defined also as “as seen from the radial direction”.

(9) According to a third aspect of the invention, in the cooling device according to the second aspect of the invention, the refrigerant supply mechanism has, in addition to the refrigerant release hole as a first refrigerant release hole, a second refrigerant release hole through which the refrigerant is released from the refrigerant passage, and the second refrigerant release hole is provided in a position which overlaps with the coil end as seen from the vertical direction.

(10) According to a fourth aspect of the invention, in the cooling device according to any one of the first through third aspects of the invention, the refrigerant guide is disposed on an inner peripheral

side of the coil end, and includes an arc portion extending along an inner periphery of the coil end, and the arc portion includes a portion that overlaps with a lowermost point of the coil end in the vertical direction, as seen from the vertical direction. It is noted that the above-described “lowermost point of the coil end in the vertical direction, as seen from the vertical direction” may be defined also as “most distant point of the coil end that is most distant from the refrigerant supply mechanism, as seen from the radial direction”.
(11) According to a fifth aspect of the invention, in the cooling device according to the fourth aspect of the invention, the refrigerant guide includes a rib provided in a position distant from a lowermost point of the arc portion in the vertical direction, by a predetermined distance in a circumferential direction of the arc portion, and the rib extends inwardly from an inner peripheral wall of the arc portion in the radial direction. It is noted that the above-described “lowermost point of the arc portion in the vertical direction” may be defined also as “most distant point of the arc portion that is most distant from the refrigerant supply mechanism”.
(12) According to a sixth aspect of the invention, in the cooling device according to the fifth aspect of the invention, the arc portion of the refrigerant guide is provided with a cutout located in a position which is adjacent to the rib and which is located between the rib and the lowermost point of the arc portion in the circumferential direction, and the cutout is constituted by a recess provided in an opposed surface of the arc portion that is opposed to the electric motor in the direction of the rotation axis.
(13) According to a seventh aspect of the invention, in the cooling device according to the first aspect of the invention, the refrigerant guide is provided with a cutout located in a distal end portion thereof in the direction of the rotation axis.
(14) According to an eighth aspect of the invention, in the cooling device according to the first aspect of the invention, the refrigerant supply mechanism is a coolant pipe which is disposed on the upper side of the electric motor in the vertical direction and which is provided with a refrigerant release hole through which the refrigerant is to be released.
(15) In the cooling device according to the first aspect of the invention, the refrigerant supply mechanism is configured to supply the refrigerant to the refrigerant guide, and the refrigerant guide protrudes toward the inner peripheral side of the coil end, and extends in the direction of the rotation axis to the position that overlaps with the coil end as seen from the radial direction of the electric motor. Thus, the refrigerant supplied from the refrigerant supply mechanism to the refrigerant guide can be moved along the refrigerant guide and supplied to a lower portion of the coil end in the vertical direction. Consequently, the lower portion of the coil end can be efficiently cooled by the refrigerant, so that cooling performance of the cooling device is improved.
(16) In the cooling device according to the second aspect of the invention, the refrigerant supply mechanism has the refrigerant release hole through which the refrigerant is released from the refrigerant passage, and the refrigerant release hole is provided in the position which does not overlap with the coil end and overlaps with the bearing holding portion holding the bearing, as seen from the vertical direction. The refrigerant released from the refrigerant release hole is supplied to the bearing holding portion, without being interfered by the coil end. Further, the refrigerant supplied to the bearing holding portion flows down along a circumferential wall of the bearing holding portion and is then received by the refrigerant guide. Consequently, the refrigerant released from the refrigerant release hole is supplied to the refrigerant guide without via the coil end.
(17) In the cooling device according to the third aspect of the invention, the refrigerant supply mechanism has the second refrigerant release hole through which the refrigerant is released from the refrigerant passage, and the second refrigerant release hole is provided in the position which overlaps with the coil end as seen from the vertical direction. Thus, the refrigerant released from the second refrigerant release hole is supplied to an upper portion of the coil end in the vertical direction. Therefore, the upper portion of the coil end is appropriately cooled by the refrigerant released from the second refrigerant release hole.

(18) In the cooling device according to the fourth aspect of the invention, the refrigerant guide includes the arc portion extending along the inner periphery of the coil end, and the arc portion includes the portion that overlaps with the lowermost point of the coil end in the vertical direction as seen from the vertical direction. Thus, the refrigerant dropping from above can be received by the arc portion having an arc shape.
(19) In the cooling device according to the fifth aspect of the invention, the refrigerant guide includes the rib provided in the position distant from the lowermost point of the arc portion in the vertical direction, by the predetermined distance in the circumferential direction of the arc portion, and the rib extends inwardly from an inner circumferential wall of the arc portion in the radial direction. Thus, the refrigerant moved downwardly along the inner circumferential wall of the arc portion collides with the rib, and then the refrigerant is moved in the direction of the rotation axis of the electric motor. Further, the refrigerant moved in the direction of the rotation axis to a distal end of the refrigerant guide drops from the distal end of the refrigerant guide toward the coil end. Consequently, since the refrigerant can be supplied to a portion of the coil end that is located on an upper side of the lowermost point of the coil end in the vertical direction, it is possible to cool a wide region of the coil end.
(20) In the cooling device according to the sixth aspect of the invention, the arc portion of the refrigerant guide is provided with the cutout located in the position which is adjacent to the rib and which is located between the rib and the lowermost point of the arc portion in the circumferential direction, and the cutout is constituted by the recess provided in the opposed surface of the arc portion that is opposed to the electric motor in the direction of the rotation axis. Thus, even when the refrigerant, which has collided with the rib and moved in the direction of the rotation axis, passes over a distal end of the rib, the refrigerant can be forcedly caused to drop through a space defined by the cutout of the arc portion.
(21) In the cooling device according to the seventh aspect of the invention, the refrigerant guide is provided with the cutout located in the distal end portion thereof in the direction of the rotation axis. Thus, the distal end portion of the refrigerant guide, which has a continuously curved shape after a casting, is shaped, by the cutout, to have a discontinuous shape, so that it is possible to suppress the refrigerant from passing over the distal end of the refrigerant guide. Consequently, the refrigerant is efficiently caused to drop from the distal end of the refrigerant guide, so as to be appropriately supplied to the coil end.
(22) In the cooling device according to the eighth aspect of the invention, the refrigerant can be supplied to the refrigerant guide from the refrigerant release hole of the coolant pipe that is disposed on the upper side of the electric motor in the vertical direction.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a cross sectional view schematically showing an electric motor and a cooling device for cooling the electric motor;
(2) FIG. **2** is a cross sectional view taken in line A-A shown in FIG. **1**;
(3) FIG. **3** is a view for explaining effect provided by provision of a cutout in a distal end portion of an oil guide in a direction of a rotation axis of an electric motor;
(4) FIG. **4** is a partial view of FIG. **2** showing, in enlargement, a rib provided in an arc portion of the oil guide; and
(5) FIG. **5** is a view as seen from a direction of arrow B shown in FIG. **4**.
DETAILED DESCRIPTION OF PREFERRED EMBODIMENT
(6) There will be described embodiment of the present invention in details with reference to drawings. It is noted that figures of the drawings are simplified or deformed as needed, and each

portion is not necessarily precisely depicted in terms of dimension ratio, shape, etc., for easier understanding of the embodiment.

Embodiment

(7) FIG. **1** is a cross sectional view schematically showing a horizontal-type electric motor MG and a cooling device **10** for cooling the electric motor MG, wherein the cooling device **10** is constructed according to an embodiment of the present invention. The electric motor MG is to be used as, for example, a drive power source to be provided in a vehicle so as to drive the vehicle. The electric motor MG is to be disposed such that its horizontal axis CL (i.e., center line) extends in a horizontal direction. In the following description, the term "assembled state" means a state in which the cooling device **10** is fixed relative to the electric motor MG on a horizontal plane. Therefore, in FIG. **1** showing the assembled state, an upward direction in the drawing sheet corresponds to an upward direction of an assembly of the cooling device **10** and the electric motor MG. The following description assumes that the assembled state is established on the horizontal plane.

(8) The electric motor MG includes a cylindrical tubular stator **12** as a non-rotary member, a cylindrical tubular rotor **14** disposed on an inner peripheral side of the stator **12**, and a rotor shaft **16** fixed in an inner circumferential surface of the rotor **14**. It is noted that the rotor shaft **16** corresponds to "shaft" recited in the appended claims.

(9) The stator **12** includes a stator core **18** formed to have a cylindrical tubular shape and a stator coil **20** wound on the stator core **18**.

(10) The stator core **18** is constituted by a plurality of insulated electromagnetic steel plates that are laminated in the direction of the rotation axis CL. The stator core **18** is unrotatably fixed to a motor casing **22** through screw bolts (not shown). The stator core **18** has a plurality of slots (not shown) that are spaces extending outwardly from an inner circumferential surface of the stator core **18** in a radial direction of the stator core **18**. The slots are arranged at equal angular intervals in a circumferential direction of the stator core **18**, and extend through the stator core **18** in the direction of the rotation axis CL. The stator coil **20** is provided to pass through each of the slots in the direction of the rotation axis CL. A pair of coil ends **24***a*, **24***b* are constituted by protruding portions of the stator coils **20**, which protrude from the stator core **18** in the direction of the rotation axis CL. Each of the coil ends **24***a*, **24***b* has an annular shape and extends in a circumferential direction of the stator core **18**.

(11) The rotor **14** includes a rotor core **26** that is formed to have a cylindrical tubular shape. The rotor core **26** is constituted by a plurality of insulated electromagnetic steel plates that are laminated in the direction of the rotation axis CL. The rotor shaft **16** is integrally fixed in an inner circumferential surface of the rotor core **26**. The rotor shaft **16** is formed to have a cylindrical tubular shape, and supported to be rotatable about the rotation axis CL. The rotor shaft **16** is received at each of end portions that are opposite to each other in the direction of the rotation axis CL, in a receiving hole **28** that is provided in the motor casing **22**, and is rotatably supported by the motor casing **22** through a bearing **30**.

(12) The bearing **30** is held by a cylindrical-tubular-shaped tubular bearing holding portion **32** that extends in the direction of the rotation axis CL, from a perpendicular wall surface of the motor casing **22** perpendicular to the rotation axis CL, toward the electric motor MG. Specifically, an outer race **30***a* of the bearing **30** is fitted in an inner circumferential surface **32***a* of the bearing holding portion **32**, for example, with an interference fit.

(13) There will be described the cooling device **10** for cooling the coil end **24***a* of the electric motor MG, by supplying a refrigerant in the form of oil to the coil end **24***a* of the electric motor MG. The cooling device **10** includes a coolant pipe **38** for supplying the oil from an upper side of the electric motor MG and an oil guide **34** for guiding the oil released from the coolant pipe **38**, to a lower portion of the coil end **24***a* that is located on a lower side of the rotation axis CL in a vertical direction. The oil guide **34** is formed integrally with the motor casing **22** by aluminum casting.

(14) The coolant pipe **38** is disposed on the upper side of the electric motor MG, such that the coolant pipe **38** extends in parallel to the rotation axis CL of the electric motor MG, namely, a longitudinal direction of the coolant pipe **38** corresponds to the direction of the rotation axis CL. The oil, which is scooped up by an oil pump (not shown), is supplied to the coolant pipe **38**. The coolant pipe **38** is provided with first and second oil release holes **40**, **42**, through which the oil flowing in the coolant pipe **38** is to be released. Thus, the oil supplied to the coolant pipe **38** is supplied downwardly in the vertical direction from the first and second oil release holes **40**, **42**. The first oil release holes **40** are located in a position that enables the oil released from the first oil release holes **40** to be supplied to an upper portion of the coil end **24***a* which is located on an upper side of the rotation axis CL in the vertical direction. The second oil release hole **42** is located in a position that enables the oil released from the second oil release hole **42** to be supplied to the oil guide **34**. It is noted that the coolant pipe **38** defines “refrigerant passage” recited in the appended claims, and that the coolant pipe **38** and the first and second release holes **40**, **42** cooperate to constitute “refrigerant supply mechanism” recited in the appended claims.
(15) The oil guide **34** protrudes in the direction of the rotation axis CL, from the perpendicular wall surface of the motor casing **22** perpendicular to the rotation axis CL, toward an inner peripheral side of the coil end **24***a*. The oil guide **34** is disposed on the inner peripheral side of the coil end **24***a* as seen from the direction of the rotation axis CL. Further, the oil guide **34** is formed to cover an outer periphery of a lower portion of the bearing holding portion **32** that is located on the lower side of the rotation axis CL in the vertical direction, such that the oil dropping from the bearing holding portion **32** is received by the oil guide **34**. It is noted that the oil guide **34** corresponds to “refrigerant guide” recited in the appended claims.
(16) The oil guide **34** extends in the direction of the rotation axis CL to a position that overlaps with the coil end **24***a* as seen from a radial direction of the electric motor MG. FIG. **2** is a cross sectional view taken in line A-A shown in FIG. **1**. In FIG. **2**, an upward direction in the drawing sheet corresponds to the upward direction of an assembly of the cooling device **10** and the electric motor MG. Further, in FIG. **2**, hatched part represents a cross section of the coil end **24***a*, which is perpendicular to the rotation axis CL. As shown in FIG. **2**, the rotor shaft **16**, the bearing **30** and the bearing holding portion **32** are arranged sequentially in the radial direction away from the rotation axis CL toward an outer periphery of the coil end **24***a*.
(17) The bearing **30** includes the above-described outer race **30***a* that is fitted in the inner circumferential surface **32***a* of the bearing holding portion **32**, an inner race **30***b* that is fitted on the outer circumferential surface of the rotor shaft **16**, and a plurality of balls **30***c* interposed between the outer and inner races **30***a*, **30***b*.
(18) The oil guide **34** is located on a lower side of the cylindrical-tubular-shaped bearing holding portion **32**. The oil guide **34** is located between the bearing holding portion **32** and the coil end **24***a* in the radial direction orthogonal to the rotation axis CL.
(19) The oil guide **34** includes an arc portion **34***a* having a predetermined thickness as seen from the direction of the rotation axis CL, as shown in FIG. **2**, and formed to have an arc shape (or semicircular shape) whose center corresponds to the rotation axis CL. The oil guide **34** further includes a pair of ribs **34***b* extending from an inner circumferential wall **36** of the arc portion **34***a* inwardly in the radial direction.
(20) The arc portion **34***a* having the predetermined thickness and the arc shape extends along an inner periphery of the coil end **24***a*. The arc shape of the arc portion **34***a* is continuous throughout an entirety of the arc portion **34***a* from a circumferentially end of the arc portion **34***a* to another circumferentially end of the arc portion **34***a*. In the present embodiment, the arc portion **34***a* has a central angle that is slightly larger than 180 degrees, namely, the arc shape is larger than the semicircular shape by a predetermined circumferential length.
(21) The arc portion **34***a* includes a lower portion located on the lower side of the rotation axis CL in the vertical direction, and the lower portion of the arc portion **34***a* is formed to have the arc

shape extending along the inner periphery of the coil end **24***a*. The arc portion **34***a* further includes a pair of upper portions located on the upper side of the rotation axis CL in the vertical direction, and each of the upper portions of the arc portion **34***a* is also formed to have the arc shape extending along the inner periphery of the coil end **24***a*. Each of the upper portions of the arc portion **34***a* circumferentially extends from a corresponding one of circumferentially opposite ends of the lower portion of the arc portion **34** by a predetermined circumferential distance. Thus, the arc portion **34***a* having the arc shape extending along the inner periphery of the coil end **24***a* includes at least a portion that overlaps with a lowermost point of the coil end **24***a* as seen from the vertical direction. Further, the arc shape of the arc portion **34***a* is shaped to cover an outer periphery of a lower portion of the bearing holding portion **32** located on the lower side of the rotation axis CL, so that the oil dropping from an outer circumferential wall surface of the bearing holding portion **32** can be received by the arc portion **34***a*.

(22) The pair of ribs **34***b* are formed to be symmetrical with each other with respect to a straight line M that passes through the rotation axis CL and an axis (i.e., center) CT of the coolant pipe **38**. Each of the ribs **34***b* is located in a position distant from a lowermost point of the arc portion **34***a* in the vertical direction, by a predetermined distance K in a circumferential direction of the arc portion **34***a*, or in position offset from the lowermost point as a reference (or zero) point of the arc portion **34***a* by a predetermined angle θ**1** in the circumferential direction. Thus, each of the ribs **34***b* is located in the position which is distant from the straight line M passing through the rotation axis CL and the axis CT of the coolant pipe **38**, and which is located on an upper side of the lowermost point of the arc portion **34***a* in the vertical direction.

(23) Each of the ribs **34***b* extends inwardly from the inner circumferential wall **36** of the arc portion **34***a* toward the rotation axis CL in the radial direction. Owing to provision of each of the ribs **34***b*, a first oil reservoir **46** is defined between the arc portion **34***a* and each of the ribs **34***b*, for temporarily reserve the oil therein.

(24) The oil guide **34** is provided with a cutout **50** located in its distal end portion in the direction of the rotation axis CL (see FIG. **3**). FIG. **3** is a view for explaining effect provided by provision of the cutout **50** in the distal end portion of the oil guide **34** in the direction of the rotation axis CL. It is noted that, in FIG. **3**, components or parts such as the electric motor MG and the oil guide **34** are illustrated in a simplified manner, and dimension ratio is different from in reality. Further, for example, the bearing **30** and the bearing holding portion **32** are not illustrated in FIG. **3**. It is noted that the cutout **50** corresponds to “cutout” recited in the appended claims.

(25) The motor casing **22** and the oil guide **34** are formed integrally with each other by aluminum casting. Therefore, the oil guide **34** is formed to have a slope that allows a mould or moulds to be withdrawn in process of the casting. After the casting, the distal end portion of the oil guide **34** has a continuously curved shape as indicated by broken line in FIG. **3**. If the oil were supplied to the oil guide **34** in this state in which the distal end portion of the oil guide **34** has the curved shape, the oil would be likely to pass over a distal end of the oil guide **34** and flow downwardly. Consequently, the oil would be moved downwardly from the distal end portion of the oil guide **34**, along the oil guide **34**, as indicated by arrows of broken lines in FIG. **3**, so that the oil would be unlikely to drop from the distal end of the oil guide **34**. For preventing such a movement of the oil, the cutout **50** is provided in the distal end portion of the oil guide **34**.

(26) With the cutout **50** being provided in the distal end portion of the oil guide **34**, the above-described continuously curved shape of the distal end portion of the oil guide **34** is cut so as to be changed to a discontinuous shape, so that the oil is likely to drop from the distal end of the oil guide **34** as indicated by arrows of solid lines. It is preferable that the cutout **50** is provided in only a portion (e.g., circumferentially intermediate portion) of the arc portion **34***a* in which the oil is to drop from the distal end of the oil guide **34**. However, the cutout **50** may be provided in an entirety of the arc portion **34***a*, so as to extend throughout the arc portion **34***a* in the circumferential direction.

(27) Further, the arc portion **34**_a_ of the oil guide **34** is provided with a cutout **52** located in a position that is adjacent to each of the ribs **34**_b_ in the circumferential direction. FIG. **4** is a partial view of FIG. **2** showing, in enlargement, one of the ribs **34**_b_ provided in the arc portion **34**_a_ of the oil guide **34**. FIG. **5** is a view as seen from a direction of arrow B shown in FIG. **4**, namely, as seen from above in the vertical direction. It is noted that, in FIGS. **4** and **5**, all arrows indicate flow of the oil.
(28) As shown in FIG. **4**, the cutout **52** is located in the position which is adjacent to each of the ribs **34**_b_ in the circumferential direction, and which is located between each of the ribs **34**_b_ and the lowermost point of the arc portion **34**_a_ in the circumferential direction. The cutout **52** is constituted by a recess provided in an opposed surface of the arc portion **34**_a_ that is opposed to the electric motor MG in the direction of the rotation axis CL. It is noted the cutout **52** corresponds to "cutout" recited in the appended claims.
(29) When the oil flowing down along the inner circumferential wall **36** of the arc portion **34**_a_ collides with the ribs **34**_b_, the oil is moved in the direction of the rotation axis CL. There is a risk that the oil having been moved to the distal end of the arc portion **34**_a_ in the direction of the rotation axis CL would pass over a distal end of each of the ribs **34**_b_ without dropping from the distal end of the arc portion **34**_a_, due to viscosity of the oil. However, in the present embodiment, owing to provision of the cutout **52**, even when the oil passes over the distal end of each rib **34**_b_ in the direction of the rotation axis CL, the oil is forcedly caused to drop through a space defined by the cutout **52**. Consequently, the oil having reached the distal end of the arc portion **34**_a_ in the direction of the rotation axis CL drops from the distal end of the arc portion **34**_a_ whereby the oil is appropriately supplied to the oil end **24**_a_. It is noted that a part of the oil having reached the first oil reservoir **46** passes over the distal end of each rib **34** and is moved downwardly, as indicated arrows of broken lines.
(30) In FIGS. **4** and **5**, one-dot chain lines indicate flow of the oil in an arrangement in which the cutout **52** is not provided. In such an arrangement without the cutout **52**, the oil having passed over the distal end of each rib **34** in the direction of the rotation axis CL would not drop from the distal end of the arc portion **34**_a_ in the direction of the rotation axis CL but would be moved downwardly along an outer circumferential wall surface of the arc portion **34**_a_.
(31) There will be described flow of the oil caused by the cooling device **10**. As shown in FIGS. **1** and **2**, arrows of solid lines indicate flow of the oil released from the first oil release holes **40**. The first oil release holes **40** are provided in respective positions that overlap with the coil end **24**_a_ in the direction of the rotation axis CL as seen from the vertical direction. Further, each of the first oil release holes **40** is located in the position offset from a lowermost point as a reference (or zero) point of the coolant pipe **38** by a predetermined angle θ2 in a circumferential direction of the coolant pipe **38**, as shown in FIG. **2**. In the present embodiment, the first oil release holes **40** consist of two first oil release holes **40** that are located in the respective positions that are symmetrical with each other with respect to the above-described straight line M. It is noted that each of the first oil release holes **40** corresponds to "second refrigerant release hole" recited in the appended claims.
(32) The oil released from the first oil release holes **40** is supplied to the upper portion of the coil end **24**_a_ located on the upper side of the rotation axis CL in the vertical direction in an assembles state in which the cooling device **10** is fixed relative to the electric motor MG, so as to cool mainly the upper portion of the coil end **24**_a_. The oil supplied to the upper portion of the coil end **24**_a_ cools the upper portion of the coil end **24**_a_ and is moved downwardly along the coil end **24**_a_.
(33) In FIGS. **1** and **2**, arrows of broken lines indicate flow of the oil released from the second oil release hole **42**. The second oil release hole **42** is provided in a position that does not overlap with the coil end **24**_a_ but overlaps with the bearing holding portion **32** holding the bearing **30**, in the direction of the rotation axis CL as seen from the vertical direction. Further, the second oil release holes **42** is located in the position corresponding to the lowermost point of the coolant pipe **38**.

Therefore, the oil released from the second oil release hole **42** is moved downwardly, without being supplied to the coil end **24***a*, so that the oil released from the second oil release hole **42** reaches an outer circumferential wall **32***b* of the bearing holding portion **32**. It is noted that the second oil release hole **42** corresponds “refrigerant release hole” and “first refrigerant release hole” recited in the appended claims.

(34) The oil having arrived the outer circumferential wall **32***b* of the bearing holding portion **32** is moved downwardly along the outer circumferential wall **32***b*. Further, when the oil has been moved onto the lower side of the rotation axis CL, the oil drops toward the oil guide **34**, owing to gravity. The oil dropping from the outer circumferential wall **32***b* is moved downwardly along the inner circumferential wall **36** of the arc portion **34***a*, and collides with the ribs **34***b*.

(35) The oil having collided with each of the ribs **34***b* is moved toward the distal end of the arc portion **34***a* (oil guide **34**) in the direction of the rotation axis CL and then drops from the distal end of the arc portion **34***a* toward the inner periphery of the coil end **24***a*. Consequently, the oil is supplied to portions of the coil end **24***a* that are located below the respective ribs **34***b* in the vertical direction, and is moved from the portions of the coil end **24***a* downwardly along the coil end **24***a*, whereby a region of the coil end **24***a* indicated by one-dot chain line in FIG. **2** is cooled. This region of the coil end **24***a* indicated by the one-dot chain line is a region that is difficult to be cooled sufficiently by the oil flowing down along the upper portion of the coil end **24***a*. The above-described predetermined distance K and predetermined angle θ1, by which the position of each rib **34***b* is circumferentially distant from the lowermost point of the arc portion **34***a* in the vertical direction, is obtained by experimentation or determined by an appropriate design theory, such that the oil is supplied to the above-described region of the coil end **24***a* indicated by the one-dot chain line.

(36) Since the cutout **50** is provided in the distal end portion of the oil guide **34** in the direction of the rotation axis CL, as shown in FIG. **3**, the oil is reliably caused to drop from the distal end of the oil guide **34**. Further, since the cutout **52** is provided in the position adjacent to each rib **34***b* in the circumferential direction, it is possible to suppress the oil having been moved to the distal end portion of the oil guide **34** in the direction of the rotation axis CL, from passing over the distal end of each rib **34***b* in the direction of the rotation axis CL and being moved toward the outer circumferential wall of the arc portion **34***a*.

(37) Further, a part of the oil having collided with each rib **34***b* is moved from the first oil reservoir **46** defined by the arc portion **34***a* and each rib **34***b* to a distal end of each rib **34** in the radial direction, and then passes over the distal end of each rib **34** in the radial direction so as to be moved downwardly along the inner circumferential wall **36** of the arc portion **34***a*. The oil having been moved downwardly along the inner circumferential wall **36** of the arc portion **34***a* is temporarily reserved in a second oil reservoir **48** that is defined by a lowermost portion of the arc portion **34***a* in the vertical direction. The oil having reached the second oil reservoir **48** is moved in the direction of the rotation axis CL and is supplied from the distal end of the arc portion **34***a* in the direction of the rotation axis CL to a lowermost portion of the coil end **24***a* in the vertical direction.

(38) Thus, the oil released from the second oil release hole **42** is supplied to the region of the coil end **24***a* indicated by the one-dot chain line in FIG. **2**, via the bearing holding portion **32** and the arc portion **34***a* and the ribs **34***b* of the oil guide **34**. Therefore, the lower portion of the coil end **24***a*, which is located on the lower side of the rotation axis CL in the vertical direction, is appropriately cooled by the oil. Meanwhile, the oil released from the first oil release holes **40** is supplied to the upper portion of the coil end **24***a*, which is located on the upper side of the rotation axis CL in the vertical direction, whereby the upper portion of the coil end **24***a* is appropriately cooled by the oil. Consequently, both of the upper and lower portions of the coil end **24***a* are appropriately cooled by the oil released from the coolant pipe **38**.

(39) Thus, the cooled oil is supplied to the lower portion of the coil end **24***a*, so that a temperature difference between the coil end **24***a* and the oil is made large whereby a heat transfer coefficient is

increased. Further, since it is possible to increase an area of the coil end **24***a* with which the oil can be brought into contact, the temperature of the lower portion of the coil end **24***a* can be efficiently reduced. In connection with the efficient reduction of the temperature of the coil end **24***a*, it becomes possible to increase an electric current applied to the electric motor MG, thereby making it possible to reduce a size of the electric motor MG. Therefore, it is possible to reduce an amount of material used to manufacture the electric motor MG. In addition, restrictions on a rated output of the electric motor MG dependent on the temperature increase of the coil end **24***a* are relaxed, enabling further improvements in acceleration performance. Moreover, the reduction of the temperature of the coil end **24***a* leads to reduction of copper loss, thereby resulting in improvement of fuel efficiency.

(40) As described above, in the present embodiment, the cooling device **10** is constructed such that the oil released from the second oil release hole **42** of the coolant pipe **38** can be supplied to the oil guide **34**, and the oil guide **34** protrudes toward the inner peripheral side of the coil end **24***a* and extends in the direction of the rotation axis CL to the position that overlaps with the coil end **24***a* as seen from the radial direction of the electric motor MG. Thus, the oil supplied from the second oil release hole **42** of the coolant pipe **38** to the oil guide **34** can be moved along the oil guide **34** and supplied to the lower portion of the coil end **24***a* in the vertical direction. Consequently, the lower portion of the coil end **24***a* can be efficiently cooled by the oil, so that the cooling performance of the cooling device **10** is improved. Further, since the oil guide **34** is formed integrally with the motor casing **22**, it is possible to prevent leakage of the oil through a gap between

(41) In the present embodiment, the coolant pipe **38** is provided with the second oil release hole **42** through which the oil is released from the coolant pipe **38**, and the second oil release hole **42** is provided in the position which does not overlap with the coil end **24***a* and overlaps with the bearing holding portion **32** holding the bearing **30**, as seen from the vertical direction. The oil released from the second oil release hole **42** is supplied to the bearing holding portion **32**, without being interfered by the coil end **24***a*. Further, the oil supplied to the bearing holding portion **32** flows down along the circumferential wall of the bearing holding portion **32** and is then received by the oil guide **34**. Consequently, the oil released from the second oil release hole **42** is supplied to the oil guide **34** without via the coil end **24***a*.

(42) In the present embodiment, the coolant pipe **38** has the first oil release holes **40** through which the oil is released from the coolant pipe **38**, and each of the first oil release holes **40** is provided in the position which overlaps with the coil end **24***a* as seen from the vertical direction. Thus, the oil released from the first oil release holes **40** is supplied to the upper portion of the coil end **24***a* in the vertical direction. Therefore, the upper portion of the coil end **24***a* is appropriately cooled by the oil released from the first oil release holes **40**.

(43) In the present embodiment, the oil guide **34** includes the arc portion **34***a* extending along the inner periphery of the coil end **24***a*, and the arc portion **34***a* includes the portion that overlaps with the lowermost point of the coil end **24***a* in the vertical direction as seen from the vertical direction. Thus, the oil dropping from the bearing holding portion **32** can be received by the arc portion **34***a* having the arc shape.

(44) In the present embodiment, the oil guide **34** includes the ribs **34***b* each provided in the position distant from the lowermost point of the arc portion **34***a* in the vertical direction, by the predetermined distance K in the circumferential direction of the arc portion **34***a*, and each of the ribs **34***b* extends inwardly from the inner circumferential wall **36** of the arc portion **34***a* in the radial direction. Thus, the oil moved downwardly along the inner circumferential wall **36** of the arc portion **34***a* collides with the ribs **34***b*, and then the oil is moved in the direction of the rotation axis CL of the electric motor MG. Further, the oil moved in the direction of the rotation axis CL to the distal end of the oil guide **34** drops from the distal end of the oil guide **34** toward the coil end **24***a*. Consequently, since the oil can be supplied to a portion of the coil end **24***a* that is located on an upper side of the lowermost point of the coil end **24***a* in the vertical direction, it is possible to cool

a wide region of the coil end **24***a*.
(45) In the present embodiment, the arc portion **34***a* of the oil guide **34** is provided with the cutout **52** located in the position which is adjacent to each rib **34***b* and which is located between each rib **34***b* and the lowermost point of the arc portion **34***a* in the circumferential direction of the arc portion **34***a*, and the cutout **52** is constituted by the recess provided in the opposed surface of the arc portion **34***a* that is opposed to the electric motor MG in the direction of the rotation axis CL. Thus, even when the oil, which has collided with each rib **34***b* and moved in the direction of the rotation axis CL, passes over the distal end of each rib **34***b*, the oil can be forcedly caused to drop through the space defined by the cutout **52** of the arc portion **34***a*.
(46) In the present embodiment, the oil guide **34** is provided with the cutout **50** located in the distal end portion thereof in the direction of the rotation axis CL. Thus, the distal end portion of the oil guide **34**, which has the continuously curved shape after the casting, is shaped, by the cutout **50**, to have the discontinuous shape, so that it is possible to suppress the oil from passing over the distal end of the oil guide **34**. Consequently, the oil is efficiently caused to drop from the distal end of the oil guide **34**, so as to be appropriately supplied to the coil end **24***a*.
(47) While the preferred embodiment of this invention has been described in detail by reference to the drawings, it is to be understood that the invention may be otherwise embodied.
(48) For example, in the above-described embodiment, the oil guide **34** is symmetrical with respect to the straight line M passing through the coolant pipe **38** and the rotation axis CL. However, the oil guide **34** may be asymmetrical with respect to the straight line M
(49) In the above-described embodiment, the arc portion **34***a* of the oil guide **34** has an arc length larger than that of a semicircle. However, this is not essential. Specifically, the arc length of the arc portion **34***a* may be shorter than that of the semicircle, namely, the central angle of the arc portion **34***a* may be smaller than 180 degrees.
(50) In the above-described embodiment, the oil is released from the coolant pipe **38** that is disposed on the upper side of the electric motor MG in the vertical direction. However, this arrangement is not essential. For example, the oil may be released from an oil passage which is defined in an oil casing and which is located on the upper side of the electric motor MG. In short, the present invention is applicable to any arrangement in which the oil is supplied from the upper side of the electric motor MG.
(51) In the above-described embodiment, the cooling device **10** is configured to cool the coil end **24***a* as one of the coil ends **24***a*, **24***b* that are located in respective opposite sides of the stator core **18** of the electric motor MG in the direction of the rotation axis CL. However, the cooling device **10** may be configured to cool the coil end **24***b* as well as the coil end **24***a*.
(52) It is to be understood that the embodiment described above is given for illustrative purpose only, and that the present invention may be embodied with various modifications and improvements which may occur to those skilled in the art.
NOMENCLATURE OF ELEMENTS
(53) **10**: cooling device **12**: stator **14**: rotor **16**: rotor shaft (shaft) **18**: stator core **20**: stator coil **22**: motor casing **24***a*, **24***b*: coil end **30**: bearing **32**: bearing holding portion **34**: oil guide (refrigerant guide) **34***a*: arc portion **34***b*: rib **36**: inner circumferential wall **38**: coolant pipe (refrigerant passage, refrigerant supply mechanism) **40**: first oil release hole (second refrigerant release hole) **42**: second oil release hole (refrigerant release hole, first refrigerant release hole) **50**: cutout **52**: cutout MG: electric motor

Claims

1. A cooling device for an electric motor that includes: (i) a tubular stator, (ii) a tubular rotor disposed on an inner peripheral side of the stator; and (iii) a shaft fixed in an inner circumferential surface of the rotor, such that the stator includes a tubular stator core and a stator coil wound on the

stator core, such that the stator coil includes a protruding portion which protrudes from the stator core and which constitutes a coil end, and such that the shaft is rotatably supported by a motor casing through a bearing, the cooling device comprising: a refrigerant supply mechanism configured to supply a refrigerant from an upper side of the electric motor in a vertical direction; and a refrigerant guide protruding from the motor casing toward an inner peripheral side of the coil end, wherein the refrigerant supply mechanism is configured to supply the refrigerant to the refrigerant guide, wherein the refrigerant guide extends in a direction of a rotation axis of the electric motor to a position that overlaps with the coil end as seen from a radial direction of the electric motor, wherein the refrigerant guide is disposed on an inner peripheral side of the coil end, and includes an arc portion extending along an inner periphery of the coil end, wherein the arc portion includes a portion that overlaps with a lowermost point of the coil end in the vertical direction, as seen from the vertical direction, wherein the refrigerant guide includes a rib provided in a position distant from a lowermost point of the arc portion in the vertical direction, by a predetermined distance in a circumferential direction of the arc portion, and wherein the rib extends inwardly from an inner peripheral wall of the arc portion in the radial direction.
2. The cooling device according to claim 1, wherein the refrigerant supply mechanism has a refrigerant passage located on the upper side of the electric motor in the vertical direction, and a refrigerant release hole through which the refrigerant is released from the refrigerant passage, wherein the refrigerant release hole is provided in a position which does not overlap with the coil end and overlaps with a bearing holding portion holding the bearing as seen from the vertical direction, and wherein the refrigerant guide is configured to receive the refrigerant flowing down from the bearing holding portion.
3. The cooling device according to claim 2, wherein the refrigerant supply mechanism has, in addition to the refrigerant release hole as a first refrigerant release hole, a second refrigerant release hole through which the refrigerant is released from the refrigerant passage, and wherein the second refrigerant release hole is provided in a position which overlaps with the coil end as seen from the vertical direction.
4. The cooling device according to claim 1, wherein the arc portion of the refrigerant guide is provided with a cutout located in a position which is adjacent to the rib and which is located between the rib and the lowermost point of the arc portion in the circumferential direction, and wherein the cutout is constituted by a recess provided in an opposed surface of the arc portion that is opposed to the electric motor in the direction of the rotation axis.
5. The cooling device according to claim 1, wherein the refrigerant guide is provided with a cutout located in a distal end portion thereof in the direction of the rotation axis.
6. The cooling device according to claim 1, wherein the refrigerant supply mechanism is a coolant pipe which is disposed on the upper side of the electric motor in the vertical direction and which is provided with a refrigerant release hole through which the refrigerant is to be released.