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STATOR

Abstract

A first winding and a second winding of two different phases are wound around a predetermined tooth among teeth of a stator core. At the predetermined tooth, the first winding is wound a plurality of times to form a plurality of layers of a conductor wire of the first winding in a first range that extends from a first end portion of the predetermined tooth, which faces radially inward or radially outward, to an intermediate position of the predetermined tooth in a radial direction, and the second winding is wound a plurality of times in a second range that extends in the radial direction from a second end portion of the predetermined tooth, which is opposite to the first end portion in the radial direction, to an overlapping position where the second winding overlaps with the first winding.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation application of International Patent Application No. PCT/JP2023/036720 filed on Oct. 10, 2023, which designated the U.S. and claims the benefit of priority from Japanese Patent Application No. 2022-178136 filed on Nov. 7, 2022. The entire disclosures of all of the above applications are incorporated herein by reference.

TECHNICAL FIELD
[0002] The present disclosure relates to a stator.
BACKGROUND
[0003] In a previously proposed rotary electric machine having a stator and a rotor, stator windings are wound on teeth of a stator core using concentrated winding. Additionally, it has been also proposed to wind two phase windings of different phases around the same tooth (i.e., a common tooth) of the stator core. In one previously proposed configuration, the two phase windings of the different phases are respectively wound on two regions of the tooth, which are divided in the radial direction.
SUMMARY
[0004] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.
[0005] According to the present disclosure, there is provided a stator that includes a stator core and a plurality of stator windings. The stator core includes a back yoke and a plurality of teeth. The back yoke is shaped in a circular ring form. The plurality of teeth radially extend from the back yoke and are arranged at predetermined intervals in a circumferential direction. The plurality of stator windings are provided for a plurality of phases. The plurality of stator windings are formed by a plurality of conductor wires, respectively, which are wound on the plurality of teeth using concentrated winding. Among the plurality of stator windings, a first winding and a second winding, which are respectively provided for two different phases among the plurality of phases, are wound around a predetermined tooth among the plurality of teeth. The first winding is a pre-wound winding, which is wound first around the predetermined tooth, and the second winding is a post-wound winding, which is wound later around the predetermined tooth after the pre-wound winding. At the predetermined tooth, around which the first winding and the second winding are wound, the first winding is wound around the predetermined tooth a plurality of times to form a plurality of layers of the conductor wire of the first winding in a first range that extends from a first end portion of the predetermined tooth, which faces radially inward or radially outward, to an intermediate position of the predetermined tooth in a radial direction, and the second winding is wound around the predetermined tooth a plurality of times in a second range that extends in the radial direction from a second end portion of the predetermined tooth, which is opposite to the first end portion in the radial direction, to an overlapping position where the second winding overlaps with the first winding. A winding start end portion and a winding terminal end portion of the conductor wire of the first winding are placed at the first end portion of the predetermined tooth, and the second winding is wound such that a portion of the second winding overlaps with the first winding.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0006] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

[0007] FIG. **1** is a longitudinal cross-sectional view of an electric motor.

[0008] FIG. **2** is a transverse cross-sectional view of the electric motor.

[0009] FIG. **3** is a diagram showing an electrical structure of a control device.

[0010] FIG. **4** is a perspective view of a stator.

[0011] FIG. **5** is a plan view of the stator.

[0012] FIG. **6** is a perspective view showing a structure of a stator core.

[0013] FIG. **7** is a winding configuration diagram of stator windings.

[0014] FIG. **8** is a diagram showing a corresponding relationship of each winding segment of the stator windings relative to its corresponding tooth.

[0015] FIG. **9** is a diagram showing a structure of a segmented core.

[0016] FIG. **10** is a perspective view showing a state in which the winding segments are wound on one tooth group.

[0017] FIG. **11** is a diagram showing a winding order of conductor wires at a center tooth A**2** of the tooth group.

[0018] FIG. **12** is a perspective view showing a winding structure at the tooth A**2**.

[0019] FIG. **13** is a perspective view of a busbar module.

[0020] FIG. **14** is a perspective view showing structures of busbars.

[0021] FIG. **15** is a perspective view showing a structure of a busbar holder.

[0022] FIG. **16** is a perspective view showing a state where the busbar module is installed to the stator.

[0023] FIG. **17** is a diagram showing a state in which windings are wound around one tooth according to another example.

[0024] FIG. **18** is a diagram showing a state in which windings are wound around one tooth according to another example.

[0025] FIG. **19** is a diagram showing a state in which windings are wound around one tooth according to another example.

[0026] FIG. **20** is a winding configuration diagram of stator windings according to another example.

DETAILED DESCRIPTION

[0027] In a previously proposed rotary electric machine having a stator and a rotor, stator windings are wound on teeth of a stator core using concentrated winding. Additionally, it has been also proposed to wind two phase windings of different phases around the same tooth (i.e., a common tooth) of the stator core. In one previously proposed configuration, the two phase windings of the different phases are respectively wound on two regions of the tooth, which are divided in the radial direction.

[0028] However, in the above structure where the two phase windings are wound on the two regions of the tooth divided in the radial direction, the conductor wire end portions provided for each phase winding are distributed between the radially inner side and the radially outer side. This raises concerns that terminal processing, such as connecting the conductor wire end portions with each other at a coil end or connecting each conductor wire end portion to a connection member such as a busbar, may become more complex. Additionally, in another configuration where the two phase windings are wound in a stacked state, there is a concern that when winding the two phase windings on the common tooth, post-wound winding (i.e., a later-wound winding) may interfere

with the conductor wire end portions pulled out from a pre-wound winding (i.e., an earlier-wound winding).
[0029] Hereinafter, there will be described measures for achieving the above objective and actions and advantages thereof according to the present disclosure.
[0030] According to measure **1**, there is provided a stator including: [0031] a stator core that includes: [0032] a back yoke that is shaped in a circular ring form; and [0033] a plurality of teeth that radially extend from the back yoke and are arranged at predetermined intervals in a circumferential direction; and [0034] a plurality of stator windings that are provided for a plurality of phases, wherein the plurality of stator windings are formed by a plurality of conductor wires, respectively, which are wound on the plurality of teeth using concentrated winding, wherein: [0035] among the plurality of stator windings, a first winding and a second winding, which are respectively provided for two different phases among the plurality of phases, are wound around a predetermined tooth among the plurality of teeth, wherein the first winding is a pre-wound winding, which is wound first around the predetermined tooth, and the second winding is a post-wound winding, which is wound later around the predetermined tooth after the pre-wound winding; [0036] at the predetermined tooth, around which the first winding and the second winding are wound, the first winding is wound around the predetermined tooth a plurality of times to form a plurality of layers of the conductor wire of the first winding in a first range that extends from a first end portion of the predetermined tooth, which faces radially inward or radially outward, to an intermediate position of the predetermined tooth in a radial direction, and the second winding is wound around the predetermined tooth a plurality of times in a second range that extends in the radial direction from a second end portion of the predetermined tooth, which is opposite to the first end portion in the radial direction, to an overlapping position where the second winding overlaps with the first winding; and [0037] a winding start end portion and a winding terminal end portion of the conductor wire of the first winding are placed at the first end portion of the predetermined tooth, and the second winding is wound such that a portion of the second winding overlaps with the first winding.
[0038] In the structure where the first winding and the second winding, which correspond to the two different phases, are wound as the stator windings on the common tooth of the stator core, there is a concern that the terminal processing (terminal processing at the coil end) of these windings may possibly become more complex. Additionally, in the case where the windings are wound in a stacked state, there is a concern that the winding start end portion and the winding terminal end portion of the first winding (i.e., the pre-wound winding) may interfere with the winding process of the second winding (i.e., the post-wound winding). In this regard, at the tooth, around which the first winding and the second winding are wound, the first winding is wound around the tooth a plurality of times to form a plurality of layers of the conductor wire of the first winding in the first range that extends from the first end portion of the tooth to the intermediate position of the tooth in the radial direction. Therefore, the first winding can be more concentrated at the one radial side of the tooth, and consequently, the end portions (i.e., the winding start end portion and the winding terminal end portion) of the conductor wire of the first winding can be suitably concentrated at the first end portion side of the tooth. As a result, the inconvenience caused by the winding start end portion and the winding terminal end portion of the first winding (i.e., the pre-wound winding) interfering with the winding process of the second winding (i.e., the post-wound winding) can be suppressed. Furthermore, the second winding is wound around the tooth in the second range that extends in the radial direction from the second end portion (the other end portion) of the tooth to the overlapping position where the second winding overlaps with the first winding. Therefore, the second winding can be wound closer to the first end portion in the state where the second winding overlaps with the first winding while utilizing a vacant region around the tooth where the first winding is not wound. As a result, the end portions of the conductor wire of the second winding can also be positioned closer to the first end portion. As a result, it is possible

to optimally wind the first winding and the second winding around the common tooth.

[0039] According to measure **2**, the first winding is wound such that a winding start position of the first winding is at the first end portion, and a winding terminal position of the first winding is where the conductor wire of the first winding at the winding terminal position overlaps with the conductor wire of the first winding at the winding start position of the first winding; and the second winding is wound such that a winding start position of the second winding is on a radial side of the winding start position of the first winding where a tooth center of the predetermined tooth, which is centered between two opposite radial ends of the predetermined tooth in the radial direction, is placed, and the second winding is wound from the winding start position of the second winding toward the tooth center.

[0040] According to the above structure, the first winding is wound such that the winding start position of the first winding is at the first end portion of the tooth, and the winding terminal position of the first winding is where the conductor wire of the first winding at the winding terminal position overlaps with the conductor wire of the first winding at the winding start position of the first winding. With this structure, it is possible to achieve the appropriate configuration where the first winding is concentrated at the one radial side of the tooth. Furthermore, the second winding is wound such that the winding start position of the second winding is on the radial side of the winding start position of the first winding where the tooth center of the tooth, which is centered between the two opposite radial ends of the tooth in the radial direction, is placed, and the second winding is wound from the winding start position of the second winding toward the tooth center. Thus, the second winding can be optimally wound while avoiding interference with the end portions of the first winding.

[0041] According to measure **3**, each of the plurality of conductor wires is a round wire with a circular-cross section, and the first winding and the second winding are wound around the predetermined tooth in a staggered arrangement in which the conductor wire of the first winding and the conductor wire of the second winding are staggered; and the second winding is wound such that the winding start position of the second winding is spaced from the first end portion by an amount that corresponds to one turn of the conductor wire of the second winding.

[0042] In the structure where the round wires are used as the conductor wires, the space factor can be improved by winding the first winding and the second winding in the staggered arrangement. Additionally, according to the staggered arrangement of the round wires, it becomes relatively easy to adjust the radial position for the winding start position of the second winding, and the interference of the second winding with the end portions of the first winding can be effectively avoided.

[0043] The stator according to measure **4**, the second winding is wound around the predetermined tooth such that the second winding starts from the winding start position adjacent to the first end portion, extends toward the second end portion, and folds back at the second end portion to wind the conductor wire of the second winding in a plurality of layers over the predetermined tooth.

[0044] According to the above configuration, the winding start and the winding terminal of the conductor wire of each of the first winding and the second winding can be concentrated at the first end portion side of the tooth. Therefore, the workability of terminal processing can be improved at the time of, for example, connecting a plurality of first windings, which constitute the stator windings, or connecting a plurality of second windings, which constitute the stator windings.

[0045] According to measure **5**, the predetermined tooth is provided with a projection which is placed at a boundary position of the first range where the first winding is wound, wherein the boundary position of the first range is opposite to the first end portion in the radial direction, and the projection extends in a direction perpendicular to the radial direction and away from a tooth surface of the predetermined tooth.

[0046] As described above, in the case where the first winding is wound the plurality of times to form the plurality of layers of the conductor wire of the first winding in the first range that extends

from the first end portion of the tooth to the intermediate position of the tooth in the radial direction, there arises a concern about collapse of the first winding due to displacement of the conductor wire of the first winding at the intermediate position of the tooth. In this regard, since the projection is provided at the boundary position of the first range (the boundary on the intermediate position side) where the first winding is wound on the tooth, the collapse of the first winding can be limited.
[0047] According to measure **6**, at least one electrical insulation member is placed on at least one of two opposite axial end portions of the predetermined tooth, and the first winding and the second winding are wound in a state where the at least one electrical insulation member is interposed between the predetermined tooth and each of the first winding and the second winding; and [0048] the at least one electrical insulation member has a first insulation portion, which corresponds to the first range in the radial direction, and a second insulation portion, which is a portion of the at least one electrical insulation member located outside of the first range, and an axial wall thickness dimension of the first insulation portion and an axial wall thickness dimension of the second insulation portion are set differently such that the axial wall thickness dimension of the first insulation portion is smaller than the axial wall thickness dimension of the second insulation portion.
[0049] In the at least one electrical insulation member placed on the at least one of the two opposite axial end portions of the tooth, the axial wall thickness dimension of the first insulation portion, which corresponds to the first range, and the axial wall thickness dimension of the second insulation portion, which is located outside of the first range, are set differently such that the axial wall thickness dimension of the first insulation portion is smaller than the axial wall thickness dimension of the second insulation portion. In this case, a step can be formed between the first insulation portion and the second insulation portion, and this step can limit the collapse of the first winding.
[0050] Additionally, on the tooth, both the first winding and the second winding are wound in a stacked state in the first range, whereas only the second winding is wound in the range outside the first range. In this configuration, since the axial wall thickness dimension of the first insulation portion, which corresponds to the first range, is smaller than the axial wall thickness dimension of the second insulation portion, an axial length dimension in the first range is limited from becoming excessively larger than in the other region, enabling uniformity in the winding axial length dimension along the tooth in the radial direction of the tooth.
[0051] According to measure **7**, the plurality of stator windings include a plurality of phase windings, each of which is provided for a corresponding one of the plurality of phases and is wound around corresponding two or more of the plurality of teeth using the concentrated winding; [0052] three teeth among the plurality of teeth, which are consecutively arranged in the circumferential direction in the stator core, are defined as a first tooth, a second tooth and a third tooth, wherein a first phase winding among the plurality of phase windings is wound continuously around the first tooth and the second tooth, and a second phase winding among the plurality of phase windings is wound continuously around the second tooth and the third tooth, and thereby the second tooth is wound with the first phase winding and the second phase winding; [0053] one end portion of the first phase winding is pulled out from one of two opposite radial end portions of the first tooth, which is adjacent to the back yoke, and another end portion of the first phase winding is pulled out from one of two opposite radial end portions of the second tooth which is adjacent to the back yoke; [0054] one end portion of the second phase winding is pulled out from one of two opposite radial end portions of the third tooth, which is adjacent to the back yoke, and another end portion of the second phase winding is pulled out from the one of the two opposite radial end portions of the second tooth which is adjacent to the back yoke; and [0055] among the first phase winding and the second phase winding, the first phase winding is a pre-wound winding, which is wound first at a time of winding the first phase winding and the second phase winding, and the

second phase winding is a post-wound winding, which is wound later after the pre-wound winding, wherein the first phase winding has a link portion, which extends between the first tooth and the second tooth along the back yoke in the circumferential direction to continuously extend the first phase winding between the first tooth and the second tooth.

[0056] For example, in order to reduce the ripple electric current in the stator, it is conceivable to wind two phase windings of different phases (the first phase winding and the second phase winding) on three teeth consecutively arranged in the circumferential direction. Specifically, in the stator core, it is conceivable to continuously wind the first phase winding around the first tooth and the second tooth, respectively, among the first to third teeth consecutively arranged in the circumferential direction in the stator core, and to continuously wind the second phase winding around the second tooth and the third teeth, respectively. Furthermore, in the structure described above, the one end portion of the first phase winding is pulled out from the radial end portion of the first tooth, which is adjacent to the back yoke, and the other end portion of the first phase winding is pulled out from the radial end portion of the second tooth which is adjacent to the back yoke, and the one end portion of the second phase winding is pulled out from the radial end portion of the third tooth, which is adjacent to the back yoke, and the other end portion of the second phase winding is pulled out from the radial end portion of the second tooth which is adjacent to the back yoke. This allows for the optimal implementation of connecting the conductor wire end portions of each phase winding to the power source and the neutral point while grouping the three teeth together as one set. Furthermore, the first phase winding, which is the pre-wound winding, has the link portion, which extends between the first tooth and the second tooth along the back yoke in the circumferential direction to continuously extend the first phase winding between the first tooth and the second tooth. Therefore, the plurality of conductor wire end portions generated for the tooth basis are all processed at the back yoke side.

[0057] According to measure **8**, at least one electrical insulation member is placed on at least one of two opposite axial end portions of the stator core and is configured to electrically insulate between one or more of the plurality of teeth and one or more of the plurality of stator windings; the at least one electrical insulation member has at least one rising portion, wherein the at least one rising portion is placed on the one or more of the plurality of teeth at a location adjacent to the back yoke and axially extends; and the at least one rising portion has a plurality of holding portions that hold: the link portion, which forms one end portion among a winding start end portion and a winding terminal end portion of the first phase winding wound around the second tooth; and another end portion among the winding start end portion and the winding terminal end portion of the first phase winding.

[0058] In the structure where the first phase winding is continuously wound around the first tooth and the second tooth, the link portion, which extends from the first tooth, forms the winding start end portion of the first winding, and the other end portion of the first winding is the winding terminal end portion of the first winding. Alternatively, the link portion, which extends from the first tooth, may form the winding terminal end portion of the first winding, and the other end portion of the first winding may be the winding start end portion of the first winding. In this case, the rising portion formed at the back yoke side of the electrical insulation member is used to hold the winding start end portion and the winding terminal end portion of the first winding. As a result, the winding start end portion and the winding terminal end portion of the first winding can be held on the back yoke side, thereby effectively avoiding interference during the winding process of the second winding.

First Embodiment

[0059] Hereinafter, embodiments will be described with reference to the drawings. Among the following embodiments, portions, which are the same or equivalent to each other, will be indicated by the same reference signs, and redundant description of these portions are omitted for the sake of simplicity. In the first embodiment, an electric motor **10**, which serves as a rotary electric machine, is exemplified and is explained.

[0060] The electric motor **10** shown in FIG. **1** is a permanent magnet field motor, specifically a permanent magnet synchronous machine having three-phase windings. In other words, the electric motor **10** is a brushless motor. The three-phase windings may include two systems of three phase windings. The electric motor **10** includes: a housing **20**; a stator **30** that is fixed to the housing **20**; a rotor **40** that rotates relative to the stator **30**; and a rotatable shaft **11** to which the rotor **40** is fixed. In the present embodiment, an axial direction refers to an axial direction of a central axis of the rotatable shaft **11**, and a radial direction refers to a radial direction of the central axis of the rotatable shaft **11**. Furthermore, a circumferential direction refers to a circumferential direction around the central axis of the rotatable shaft **11**.

[0061] The housing **20** is shaped in a cylindrical tubular form, and the stator **30** and the rotor **40** are received in the housing **20**. Two bearings **23**, **24** are installed in the housing **20**, and the rotatable shaft **11** is rotatably supported by the bearings **23**, **24**. A central axis of an inner peripheral surface of the housing **20** is coaxial with the central axis of the rotatable shaft **11**. An angle sensor **12** is installed to an axial end portion of the rotatable shaft **11**. The angle sensor **12** may be a magnetic sensor or a resolver.

[0062] The stator **30** is axially placed generally at a center portion of the housing **20** and is shaped in a cylindrical tubular form along an inner periphery of the housing **20**. The stator **30** is fixed to an inner peripheral surface of the housing **20** such that the stator **30** is centered on the central axis O of the rotatable shaft **11**. The stator **30** forms part of a magnetic circuit. The stator **30** includes: a stator core **31** which is shaped in a circular ring form and is positioned on a radially outer side of the rotor **40**; and a plurality of stator windings **32** which are wound on the stator core **31**.

[0063] As shown in FIG. **2**, the stator core **31** includes: a back yoke **33** which is shaped in a circular ring form; and a plurality of teeth **34** which radially inwardly project from the back yoke **33** and arranged at predetermined intervals in the circumferential direction. Each of a plurality of slots **35** is formed between corresponding adjacent two of the teeth **34**. In the stator core **31**, the teeth **34** are arranged at equal intervals in the circumferential direction, and the stator windings **32** are wound on these teeth **34**. As a result, conductors of the stator windings **32** are respectively received in each corresponding one of the slots **35**. In the present embodiment, the number of the teeth **34** and the number of the slots **35** are each set to 18. For the sake of explanation, the teeth **34** are designated with reference signs T**1** to T**18**, respectively, in this order in a counterclockwise direction along the circumferential direction. When it is necessary to indicate the tooth number, the teeth **34** are also referred to as teeth T**1**, T**2**, T**3**, and so on. The stator windings **32** are held in a state where the stator windings **32** are respectively received in each corresponding one of the slots **35**, and the stator windings **32** generate a magnetic flux when an electric power (AC power) is supplied to the stator windings **32**.

[0064] The stator core **31** is formed by stacking a plurality of thin steel plates (core sheets), which are made of a magnetic material, in the axial direction of the stator core **31**. The steel plates may be formed, for example, by pressing and punching a strip of electromagnetic steel sheet.

[0065] The rotor **40** forms part of the magnetic circuit. The rotor **40** has a plurality of magnetic poles arranged in the circumferential direction and are opposed to the stator **30** in the radial direction. In the present embodiment, the number of the magnetic poles of the rotor **40** is 14 (i.e., the number of magnetic pole pairs is 7). The rotor **40** includes: a rotor core **41** made of a magnetic material; and a plurality of permanent magnets **42** fixed to the rotor core **41**. Specifically, as shown in FIG. **2**, the rotor **40** has fourteen permanent magnets **42**, which serve as magnet parts and are arranged to form alternating polarities in the circumferential direction. These permanent magnets **42** are embedded in receiving holes of the rotor core **41** each of which extends in the axial direction of the rotor core **41**.

[0066] The rotor **40** may have a known structure, such as an IPM (Interior Permanent Magnet) type rotor or an SPM (Surface Permanent Magnet) type rotor. Additionally, a field winding type rotor may be employed as the rotor **40**. In the present embodiment, the IPM type rotor is employed. The rotatable shaft **11** is inserted through the rotor **40** such that the rotor **40** is fixed to the rotatable shaft **11** to rotate integrally with the rotatable shaft **11** about the rotatable shaft **11**.

[0067] A control device **50** is connected to the electric motor **10**. The control device **50** includes a microcomputer, which has a CPU, a ROM, a RAM and I/O device, as a main component of the control device **50**. The control device **50** implements various functions when the CPU executes a program(s) stored in the ROM. The various functions may be realized by an electronic circuit(s), which is hardware, or at least partially by software, i.e., processes executed on the computer.

[0068] One of the functions of the control device **50** is a function of converting the electric power supplied from an external source (e.g., a battery) and supplying the converted electric power to the electric motor **10** to generate a drive force at the electric motor **10**. Additionally, for example, the control device **50** also has a function of controlling the electric motor **10** (such as electric current control) by using information about the rotational angle inputted from the angle sensor **12**.

[0069] FIG. **3** is a diagram showing an electrical structure of the control device **50** according to the present embodiment.

[0070] In the present embodiment, the stator windings **32** include a first set of stator windings **32***a* and a second set of stator windings **32***b*. The control device **50** includes a first inverter circuit **51** and a second inverter circuit **52** which are respectively provided to the first set of stator windings **32***a* and the second set of stator windings **32***b*. Each inverter circuit **51**, **52** is formed by a full-bridge circuit that includes a plurality of pairs of upper and lower arms while the number of the pairs of upper and lower arms is equal to the number of phases of the three-phase system. The control device **50** controls the electric current in each phase by turning the switching device provided in each corresponding arm on and off.

[0071] Specifically, the first inverter circuit **51** includes a series connection of an upper arm switch Sp and a lower arm switch Sn as switching devices for each of the three phases, i.e., a U-phase, a V-phase and a W-phase. In the present embodiment, a voltage-controlled semiconductor switching device is used as each of the upper arm switch Sp and the lower arm switch Sn for each phase, specifically using an IGBT (Insulated Gate Bipolar Transistor). Alternatively, a MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) may be used. A freewheeling diode (recirculating diode) Dp, Dn is connected in reverse parallel to each of the upper arm switch Sp and the lower arm switch Sn for each phase.

[0072] A high-potential side terminal (collector) of the upper arm switch Sp for each phase is connected to a positive terminal of the battery. Additionally, a low-potential side terminal (emitter) of the lower arm switch Sn for each phase is connected to a negative terminal (ground) of the battery. An intermediate connection point between the upper arm switch Sp and the lower arm switch Sn for each phase is connected to one end of a corresponding phase winding among the first set of stator windings **32***a*. The first set of stator windings **32***a* includes a U-phase winding, a V-phase winding and a W-phase winding. In the first inverter circuit **51**, one end of each of the U-phase winding, the V-phase winding and the W-phase winding is connected to the corresponding intermediate connection point between the corresponding upper arm switch Sp and the corresponding lower arm switch Sn.

[0073] Since the second inverter circuit **52** has the same structure as the first inverter circuit **51**, a detailed explanation of the second inverter circuit **52** is omitted here. The second set of stator windings **32***b* include an X-phase winding, a Y-phase winding and a Z-phase winding. In the second inverter circuit **52**, one end of each of the X-phase winding, the Y-phase winding and the Z-phase winding is connected to the intermediate connection point between the corresponding upper arm switch Sp and the corresponding lower arm switch Sn.

[0074] The three-phase current supplied from the first inverter circuit **51** and the three-phase current supplied from the second inverter circuit **52** have a predetermined current phase difference from each other.

[0075] Hereinafter, the structure of the stator **30** will be described in detail. FIG. **4** is a perspective view of the stator **30**, and FIG. **5** is a plan view of the stator **30**. Furthermore, FIG. **6** is a perspective view showing a structure of the stator core **31**. The stator **30** shown in FIGS. **4** and **5** corresponds to the stator **30** shown in FIG. **2**.

[0076] In the stator **30**, the stator core **31** is formed by a plurality of segmented cores **61**. These segmented cores **61** are arranged in the circumferential direction, forming the stator core **31** into a cylindrical tubular form. Each segmented core **61** has the corresponding tooth **34** (see (a) of FIG. **9**). When the segmented cores **61** are arranged in the circumferential direction, the teeth **34** and slots **35** are alternately arranged in the circumferential direction as shown in FIG. **2**. In the present embodiment, the stator core **31** is formed by eighteen segmented cores **61**. Each of the stator windings **32** is formed by using a round wire with a circular cross-section as the conductor wire, and this conductor wire is wound around each corresponding tooth **34** by concentrated winding.

[0077] FIG. **7** is a winding configuration diagram of the stator windings **32** according to the present embodiment. Here, (a) of FIG. **7** shows the configuration of the U-phase winding, the V-phase winding and the W-phase winding of the first set of stator windings **32***a*. Furthermore, (b) of FIG. **7** shows the configuration of the phase windings for the X-phase winding, the Y-phase winding and the Z-phase winding of the second set of stator windings **32***b*. In each set of stator windings **32***a*, **32***b*, the phase windings are connected with each other by a star connection (Y-connection).

[0078] As shown in (a) of FIG. **7**, in the first set of stator windings **32***a*, the U-phase winding includes four winding segments U**1**, U**2**, U**3**, U**4**, and the V-phase winding includes four winding segments V**1**, V**2**, V**3**, V**4**, and the W-phase winding include four winding segments W**1**, W**2**, W**3**, W**4**. One end of a series-connected winding section with the winding segments U**1**, U**2** connected in series, one end of a series-connected winding section with the winding segments V**1**, V**2** connected in series, and one end of a series-connected winding section with the winding segments W**1**, W**2** connected in series are connected together at a neutral point N**1***a*. Furthermore, one end of a series-connected winding section with the winding segments U**3**, U**4** connected in series, one end of a series-connected winding section with the winding segments V**3**, V**4** connected in series, and one end of a series-connected winding section with the winding segments W**3**, W**4** connected in series are connected together at a neutral point N**1***b*.

[0079] As shown in (b) of FIG. **7**, in the second set of stator windings **32***b*, the X-phase winding includes four winding segments X**1**, X**2**, X**3**, X**4**, and the Y-phase winding includes four winding segments Y**1**, Y**2**, Y**3**, Y**4**, and the Z-phase winding includes four winding segments Z**1**, Z**2**, Z**3**, Z**4**. One end of a series-connected winding section with the winding segments X**1**, X**2** connected in series, one end of a series-connected winding section with the winding segments Y**1**, Y**2** connected in series, and one end of a series-connected winding section with the winding segments Z**1**, Z**2** connected in series are connected together at a neutral point N**2***a*. Furthermore, one end of a series-connected winding section with the winding segments X**3**, X**4** connected in series, one end of a series-connected winding section with the winding segments Y**3**, Y**4** connected in series, and one end of a series-connected winding section with the winding segments Z**3**, Z**4** connected in series are connected together at a neutral point N**2***b*.

[0080] Besides the above-described configuration where in each set of stator windings **32***a*, **32***b*, the four winding segments of each phase winding are divided to form two series-connected winding sections each with the two winding segments connected in series, and the corresponding series-connected winding sections are connected together to form the star connection, the following arrangement may be employed. That is, in each set of stator windings **32***a*, **32***b*, the four winding segments of each phase winding may be divided to form two winding sections connected in parallel, and the corresponding winding sections may be connected together to form the star connection. In this case, the two neutral points (N**1***a*, N**1***b*) in the first set of stator windings **32***a* are integrated into one neutral point, and the two neutral points (N**2***a*, N**2***b*) in the second set of stator windings **32***b* are also integrated into one neutral point.

[0081] The winding segments U**1**-U**4**, V**1**-V**4**, W**1**-W**4** of the respective phases in the first set of stator windings **32***a*, and the winding segments X**1**-X**4**, Y**1**-Y**4**, Z**1**-Z**4** of the respective phases in the second set of stator windings **32***b* are wound on the teeth **34** of the stator core **31** using concentrated winding. In the present embodiment, the twelve winding segments of the first set of stator windings **32***a* and the twelve winding segments of the second set of stator windings **32***b* are distributed and wound on the eighteen teeth **34** of the stator core **31**. Hereinafter, this feature will be described in detail.
[0082] In the stator core **31**, the total of eighteen teeth **34** are divided into a plurality of tooth groups each of which is formed by corresponding three of the teeth **34**, and the winding segments of corresponding two different phase windings are wound on these three teeth **34** of each tooth group. Specifically, as shown in FIG. **5**, in the stator **30**, all of the teeth **34** (T**1**-T**18**) of the stator core **31** are divided into six tooth groups G**1**-G**6**. Corresponding two of the winding segments U**1**-U**4**, V**1**-V**4**, W**1**-W**4** of the first set of stator windings **32***a* and corresponding two of the winding segments X**1**-X**4**, Y**1**-Y**4**, Z**1**-Z**4** of the second set of stator windings **32***b* are distributed to and are wounded at each corresponding tooth group G**1**-G**6**. In this case, at each tooth group G**1**-G**6**, one of the two winding segments of the corresponding one of the first set of stator windings **32***a* is wound around one of circumferentially opposite two of the three teeth **34**, and one of the two winding segments of the corresponding one of the second set of stator windings **32***b* is wound around the other one of the circumferentially opposite two of the three teeth **34**. Furthermore, at each tooth group G**1**-G**6**, the other one of the two winding segments of the corresponding one of the first set of stator windings **32***a* and the other one of the winding segments of the corresponding one of the second set of stator windings **32***b* are wound around the center tooth among the three teeth **34**.
[0083] Here, it is assumed that in each of the tooth groups G**1**-G**6**, the three teeth **34**, which are consecutively arranged in the circumferential, are defined as a first tooth, a second tooth and a third tooth, respectively, in this order. Among the phase windings, two winding segments of a first phase winding are wound continuously around the first tooth and the second tooth, respectively, and two winding segments of a second phase winding are wound continuously around the second tooth and the third tooth, respectively. Among the three consecutive teeth **34**, the center tooth, which is the second tooth, serves as a common tooth around which both the first phase winding and the second phase winding are wound. In this case, the first phase winding is any one of the six phase windings in the first and second sets of stator windings **32***a*, **32***b*, and the second phase winding is a different phase winding, which is different from the first phase winding among the same six phase windings.
[0084] FIG. **8** is a diagram showing a corresponding relationship of each of the winding segments of the stator windings **32***a*, **32***b* relative to its corresponding tooth T**1**-T**18**. In FIG. **8**, in, for example, the tooth group G**1**, the winding segment W**1** of one of the second set of stator windings **32***b* is wound around the tooth T**1**, and the winding segment W**2** of the one of the second set of stator windings **32***b* and the winding segment X**2** of one of the first set of stator windings **32***a* are wound around the tooth T**2**, and the winding segment X**1** of the one of the first set of stator windings **32***a* is wound around the tooth T**3**. These three teeth T**1**-T**3** serve as first to third teeth, respectively. The explanation for the other tooth groups G**2**-G**6** is omitted, but the winding segments at each of the remaining tooth groups G**2**-G**6** are wound in the same manner as that of the tooth group G**1**. Furthermore, the three teeth in each of the other groups G**2**-G**6** serve as the first to third teeth respectively.
[0085] The winding structure of each winding segment in each tooth group will be explained below. Here, prior to explaining the winding structure of each winding segment, the structure of the stator core **31** will be described in more detail.
[0086] In FIG. **9**, (a) is a perspective view of the segmented core **61**, and (b) is an exploded perspective view of the segmented core **61**. The segmented core **61** includes: a core main body **62**, which is a steel sheet laminate; and two electrical insulation members **63**, **64**, which are provided at one axial end and the other axial end (the upper and lower sides in the drawing) of the core main

body **62**. The core main body **62** includes: the tooth **34** extending in the radial direction (the radial direction of the stator core **31**); a yoke portion **62***a* formed at one end of the tooth **34** in the radial direction; and a flange portion **62***b* formed at the other end of the tooth **34** in the radial direction. The yoke portion **62***a* corresponds to the back yoke **33** of the stator core **31** shown in FIG. **2**. In the state where the plurality of segmented cores **61** are arranged in the circumferential direction, the yoke portions **62***a* of each adjacent two of the segmented cores **61** are coupled with each other, forming the back yoke **33** in a circular ring form. It is preferable that the yoke portions **62***a* of the adjacent segmented cores **61** are joined together by an adhesive or other means.
[0087] the electrical insulation members **63**, **64** are made of, for example, a dielectric resin material and are installed to the two opposite axial ends, respectively, of the tooth **34**. The electrical insulation member **63** includes: a covering portion **63***a* that covers an axial end surface (the upper surface in the drawing) of the tooth **34**; and two rising portions **63***b*, **63***c* which are provided at one radial end and the other radial end, respectively, of the covering portion **63***a* and extend in the axial direction (the upward direction in the drawing). The rising portion **63***b* is positioned on the yoke portion **62***a* side of the tooth **34** in the radial direction, i.e., on the proximal end side of the tooth **34**. Furthermore, the rising portion **63***c* is positioned on the opposite side of the tooth **34** opposite to the yoke portion **62***a* in the radial direction, i.e., on the distal end side of the tooth **34**. The rising portion **63***b* has two grooves **65***a*, **65***b* which are arranged one after another in the circumferential direction. Each of the grooves **65***a*, **65***b* is configured to receive the conductor wire of the corresponding winding segment. Similarly, the electrical insulation member **64** includes a covering portion **64***a* and two rising portions **64***b*, **64***c*.
[0088] The segmented core **61** is formed by installing the electrical insulation members **63**, **64** to the core main body **62**, and the corresponding conductor wire is wound a plurality of times across each electrical insulation member **63**, **64**, thereby winding the winding segment around the tooth **34** of the segmented core **61**.
[0089] FIG. **10** is a perspective view showing the state where the winding segments are wound on one of the tooth groups G, with (a) in FIG. **10** being a perspective view taken from the radially inner side of the one of the tooth groups G, and (b) in FIG. **10** being a perspective view taken from the radially outer side of the one of the tooth groups G.
[0090] In (a) and (b) of FIG. **10**, in the tooth group G, three teeth **34**, which are arranged consecutively in the circumferential direction, are defined as a tooth A**1** (a first tooth), a tooth A**2** (a second tooth) and a tooth A**3** (a third tooth) in the order of their arrangement in the circumferential direction. The first phase winding C**1** is continuously wound around the tooth A**1** and the tooth A**2**, and the second phase winding C**2** is continuously wound around the tooth A**2** and the tooth A**3**. Among the teeth A**1**-A**3**, the center tooth A**2**, which is centered among the teeth A**1**-A**3**, serves as a common tooth around which both the first phase winding C**1** and the second phase winding C**2** are wound. The tooth group G shown in (a) and (b) of FIG. **10** corresponds, for example, to the tooth group G**1** shown in FIGS. **2** and **8**. Furthermore, the tooth T**1** of the tooth group G**1** in FIGS. **2** and **8** corresponds to the tooth A**3** of the tooth group G in (a) and (b) of FIG. **10**, and the tooth T**2** of the tooth group G**1** in FIGS. **2** and **8** corresponds to the tooth A**2** of the tooth group G in (a) and (b) of FIG. **10**. Additionally, the tooth T**3** of the tooth group G**1** in FIGS. **2** and **8** corresponds to the tooth A**1** of the tooth group G in (a) and (b) of FIG. **10**. In other words, in (a) and (b) of FIG. **10**, winding segments X**1**, X**2** of the first phase winding C**1** are wound around the teeth A**1**, A**2**, and winding segments W**1**, W**2** of the second phase winding C**2** are wound around the teeth A**2**, A**3**. Among the first phase winding C**1** and the second phase winding C**2**, the first phase winding C**1** is a pre-wound winding, which is wound first at a time of winding the first phase winding C**1** and the second phase winding C**2**, and the second phase winding C**2** is a post-wound winding, which is wound later after the pre-wound winding.
[0091] In the first phase winding C**1**, which is the pre-wound winding, the conductor wire is wound in the order of the tooth A**1** and then the tooth A**2** during the winding process of the conductor

wire. At these teeth A**1**, A**2**, a winding direction of the conductor wire (the conductor wire segment) around the tooth A**1** and a winding direction of the conductor wire (the conductor wire segment) around the tooth A**2** are opposite to each other. In (a) of FIG. **10**, the conductor wire (the conductor wire segment) is wound around the tooth A**1** in the counterclockwise direction with the number of turns Na, and is then wound around the tooth A**2** in the clockwise direction with the number of turns Nb. In the first phase winding C**1**, one conductor wire end portion of the first phase winding C**1**, which forms a winding start side of the first phase winding C**1**, and another conductor wire end portion of the first phase winding C**1**, which forms a winding terminal side of the first phase winding C**1**, are pulled out from the segmented cores **61** in the axial direction and form a lead-out portion H**11** and a lead-out portion H**12**, respectively, each of which extends a predetermined length from the corresponding segmented core **61**.

[0092] The lead-out portion H**11** at the winding start side is pulled out from the proximal end portion (the back yoke **33** side) of the tooth A**1**, and the lead-out portion H**12** at the winding terminal side is pulled out from the proximal end portion (the back yoke **33** side) of the tooth A**2**. In this case, particularly, the grooves **65***a*, **65***b* are formed at the rising portion **63***b* of the electrical insulation member **63** of each segmented core **61**, and the lead-out portion H**11** is pulled out in a state where the lead-out portion H**11** is inserted into the groove **65***a* of the electrical insulation member **63** which corresponds to the tooth A**1**. Furthermore, the lead-out portion H**12** is pulled out in a state where the lead-out portion H**12** is inserted into the groove **65***a* of the electrical insulation member **63** which corresponds to the tooth A**2**.

[0093] A portion of the first phase winding C**1**, which is located between and couples the winding segment X**1** wound around the tooth A**1** and the winding segment X**2** wound around the tooth A**2**, forms a link portion H**13** that spans between these teeth A**1**, A**2**. This link portion H**13** is guided to the outside of the rising portion **63***b* of the electrical insulation member **63**. Specifically, the link portion H**13** is a conductor wire section between a tooth winding terminal position of the winding segment X**1** and a tooth winding start position of the winding segment X**2**, and this link portion H**13** is pulled out to the outside of the rising portion **63***b* between the groove **65***b* at the tooth A**1** and the groove **65***b* at the tooth A**2**. As shown in (b) of FIG. **10**, a guide groove **65***c* is formed at outer surfaces of the adjacent rising portions **63***b*, and the link portion H**13** is guided in a state where the link portion H**13** is installed into the guide groove **65***c*.

[0094] In the second phase winding C**2**, which is the post-wound winding, the conductor wire is wound in the order of the tooth A**3** and then the tooth A**2** during the winding process of the conductor wire. Here, the first and second phase windings C**1**, C**2** are compared. The winding process of the first and second phase windings C**1**, C**2** is performed such that each of the first and second phase windings C**1**, C**2** is wound in an opposite sequence in the circumferential direction compared to the other one of the first and second phase windings C**1**, C**2** from one of the corresponding circumferentially adjacent two of the teeth to the other one of the circumferentially adjacent two of the teeth. In other words, in the first phase winding C**1**, which is the pre-wound winding, the two winding segments X**1**, X**2** are wound from left to right in (a) of FIG. **10**. In contrast, in the second phase winding C**2**, which is the post-wound winding, the two winding segments W**1**, W**2** are wound from right to left in (a) of FIG. **10**.

[0095] At each of the teeth A**2**, A**3**, the conductor wire is wound in a direction opposite to that of the conductor wire wound around the other one of the teeth A**2**, A**3**. Specifically, in (a) of FIG. **10**, the conductor wire is wound around the tooth A**3** in the counterclockwise direction with the number of turns Na, and is then wound around the tooth A**2** in the clockwise direction with the number of turns Nb. In the second phase winding C**2**, one conductor wire end portion of the second phase winding C**2**, which forms a winding start side of the second phase winding C**2**, and another conductor wire end portion of the second phase winding C**2**, which forms a winding terminal side of the second phase winding C**2**, are pulled out from the segmented cores **61** in the axial direction and form a lead-out portion H**21** and a lead-out portion H**22**, respectively, each of which extends a predetermined length from the corresponding segmented core **61**.

[0096] The lead-out portion H**21** at the winding start side is pulled out from the proximal end portion (the back yoke **33** side) of the tooth A**3**, and the lead-out portion H**22** at the winding terminal side is pulled out from the proximal end portion (the back yoke **33** side) of the tooth A**2**. In this case, particularly, the lead-out portion H**21** is pulled out in a state where the lead-out portion H**21** is inserted into the groove **65***a* of the electrical insulation member **63** which corresponds to the tooth A**3**. Furthermore, the lead-out portion H**22** is pulled out in a state where the lead-out portion H**22** is inserted into the groove **65***b* of the electrical insulation member **63** which corresponds to the tooth A**2**.

[0097] A portion of the second phase winding C**2**, which is located between and couples the winding segment W**1** wound around the tooth A**3** and the winding segment W**2** wound around the tooth A**2**, forms a link portion H**23** that spans between these teeth A**3**, A**2**. This link portion H**23** is not guided to the outside of the rising portion **63***b* of the electrical insulation member **63** unlike the link portion H**13** of the first phase winding C**1** and is set to span directly from the tooth A**3** to the tooth A**2**.

[0098] With the above structure, the two lead-out portions H**11**, H**12** of the first phase winding C**1** and the two lead-out portions H**21**, H**22** of the second phase winding C**2** are arranged in the circumferential direction at the same radial position (i.e., at the proximal end portion of the corresponding respective teeth). Each of the teeth groups G**1**-G**6** shown in FIG. **2** have the same winding structure as the winding structure described above.

[0099] As described above, in the first phase winding C**1**, the number of turns of the winding segment around the tooth A**1** is Na, and the number of turns of the winding segment around the tooth A**2** is Nb. Furthermore, in the second phase winding C**2**, the number of turns of the winding segment around the tooth A**3** is Na, and the number of turns of the winding segment around the tooth A**2** is Nb. The relationship between these numbers of turns is such that Na/2<Nb. That is, in the present embodiment, the number of turns for each of the two teeth A**1**, A**3**, which are at two circumferentially opposite ends of the three teeth A**1**-A**3** consecutively arranged in the circumferential direction, is Na, and the number of turns for the center tooth A**2** is 2Nb. The relationship between them is Na<2Nb. The upper limit of the number of turns Nb is, for example, the number of turns Na.

[0100] In this case, since the amount of conductor wire on the center tooth A**2** (the common tooth) among the three teeth A**1**-A**3** consecutively arranged in the circumferential direction is larger than that on each of the end teeth A**1**, A**3**, there is a concern that winding irregularities may occur at the time of winding the conductor wire around the common tooth. In this regard, according to the present embodiment, the lead-out positions of the conductor wire end portions of each phase winding are specified, and the link portion H**13** of the first phase winding C**1** (the pre-wound winding) is guided by the adjacent rising portions **63***b* of the electrical insulation members **63**, and the conductor wire end portions are held by the grooves **65***a* of the electrical insulation members **63**. The above arrangement limits inconveniences caused by the winding irregularities of the conductor wires.

[0101] As described above, in the winding structure where the plurality of windings are wound around the common tooth of the stator core **31**, there are concerns that the terminal processing (terminal processing at the coil end) of each winding may possibly become more complex, and that the winding start end portion and the winding terminal end portion of the pre-wound winding may possibly interfere with the winding process of the post-wound winding. In the present embodiment, the winding structure improves these inconveniences, and the details of this winding structure are described below.

[0102] FIG. **11** is a diagram showing a winding order of conductor wires at the center tooth A**2** of the tooth group G. Here, the winding segment of the first phase winding C**1**, which is wound around the tooth A**2** is referred to as a first winding **101**, and the winding segment of the second phase winding C2, which is wound around the tooth A2, is referred to as a second winding **102**. For convenience of explanation, the first winding **101** is represented by a single circle, and the second winding **102** is represented by a double circle. In FIG. **11**, the numbers assigned to each of the windings **101**, **102** indicate the winding order, and each winding **101**, **102** starts its winding at the position marked as No. 1 and finishes its winding at the position marked as No. 8. However, the number of turns is not limited to this. The left-right direction in the drawing represent the circumferential direction. Additionally, the up-down direction in the drawing represent the radial direction, and the up side in the drawing corresponding to the back yoke **33** side, i.e., the radially outer side (the outer peripheral side). Here, (b) of FIG. **11** shows a state where the first winding **101** is wound around tooth A2 (the tooth **34**), and (c) of FIG. **11** shows a state where the second winding **102** is wound after the first winding **101** has been wound.

[0103] As shown in FIG. **11**, the first winding **101** is wound around the tooth **34** in a state where the conductor wire of the first winding **101** is stacked in a plurality of layers in a first range R1 that extends from an end portion (a first end portion **34***a*) of the tooth **34**, which is adjacent to the back yoke **33**, to an intermediate position of the tooth **34** in the radial direction. In this case, the first winding **101** is wound such that a winding start position (i.e., a position of a single circle No. 1) of the first winding **101** is at the first end portion **34***a* of the tooth **34**, and a winding terminal position (i.e., a position of a single circle No. 8) of the first winding **101** is where the conductor wire of the first winding **101** at the winding terminal position overlaps with the conductor wire of the first winding **101** at the winding start position of the first winding **101**. As a result, the first winding **101** is more concentrated at one radial side of the tooth **34**, and the two end portions (i.e., a winding start end portion and a winding terminal end portion) of the conductor wire of the first winding **101** are concentrated at the first end portion side of the tooth **34**.

[0104] Furthermore, the second winding **102** is wound such that a winding start position (i.e., a position of a double circle No. 1) of the second winding **102** is on a radial side of the winding start position of the first winding **101** where a tooth center of the tooth **34**, which is centered between two opposite radial ends of the tooth **34** in the radial direction, is placed, and the second winding **102** is wound from the winding start position of the second winding **102** toward the tooth center. In other words, the second winding **102** is wound around the tooth **34** a plurality of times in a second range R2 that extends in the radial direction from the other end portion (i.e., a second end portion **34***b*) of the tooth **34**, which is opposite to the back yoke in the radial direction, to an overlapping position where the second winding **102** overlaps with the first winding **101**. Here, the second winding **102** is wound around the tooth **34** such that the second winding **102** starts from the winding start position adjacent to the first end portion **34***a*, extends toward the second end portion **34***b*, and folds back at the second end portion **34***b* to wind the conductor wire of the second winding **102** in a plurality of layers over the tooth **34**.

[0105] In this instance, the first winding **101** and the second winding **102** are wound around the tooth in a staggered arrangement in which the conductor wire (i.e., the round wire) of the first winding **101** and the conductor wire (i.e., the round wire) of the second winding **102** are staggered, and the second winding **102** is wound such that the winding start position of the second winding **102** is spaced from the first end portion **34***a* by an amount that corresponds to one turn of the conductor wire of the second winding **102**. Additionally, in comparison of the radially inner side and the radially outer side, it is noted that the number of turns of the conductor wire in the radially outer side (the back yoke **33** side) is larger than the number of turns of the conductor wire in the radially inner side. However, it should be noted that the number of turns of the conductor wire in the radially outer side (the back yoke **33** side) and the number of turns of the conductor wire in the radially inner side may be set to be equal to each other.

[0106] According to the above configuration, since the winding start end portion and winding terminal end portion of the first winding **101** are concentrated on the first end portion side of the tooth **34**, the inconvenience of the winding start end portion and the winding terminal end portion

of the first winding **101** interfering with the winding process of the second winding **102** is limited.
[0107] FIG. **12** is a perspective view showing the winding structure at the tooth A**2**. As shown in FIG. **12**, the first winding **101** is wound in a state where the link portion H**13** and the lead-out portion H**12** are held by the grooves **65***a*, **65***b* of the electrical insulation member **63**. The second winding **102** is wound so as to overlap with the first winding **101**. In this case, the grooves **65***a*, **65***b* of the electrical insulation member **63** serve as holding portions that hold the link portion H**13** and the lead-out portion H**12** of the first winding **101**.
[0108] Hereinafter, a busbar module **70**, which is installed on one axial end side of the stator **30**, will be described. FIG. **13** is a perspective view of the busbar module **70**.
[0109] The busbar module **70** includes: a plurality of busbars **71**; and a busbar holder **72** that holds each of these busbars **71**. The busbars **71** include: a plurality of phase-specific busbars **73**, each provided for the corresponding phase of the first and second sets of stator windings **32***a*, **32***b*; and a plurality of neutral point busbars **74**. Each of the phase-specific busbars **73** is a conductive member that connects the winding segments of the same phase together. Furthermore, each of the neutral point busbars **74** is a conductive member that connects the winding segments of each phase together in a star connection. In the present embodiment, six busbars, which include a U-phase busbar, a V-phase busbar, a W-phase busbar, an X-phase busbar, a Y-phase busbar and a Z-phase busbar, are provided as the phase-specific busbars **73**. Additionally, two neutral point busbars **74** are provided as the neutral point busbar for the first set of stator windings **32***a* and the neutral point busbar for the second set of stator windings **32***b*. Here, there is exemplified the structure where the single neutral point is provided to each of the first set of stator windings **32***a* and the second set of stator windings **32***b*.
[0110] In FIG. **14**, (a) is a perspective view showing a structure of one busbar which is the phase-specific busbar **73**. Each phase-specific busbar **73** is shaped generally in an arcuate form as a whole, and an arm portion **73***a*, which radially extends, is formed at each of two opposite circumferential ends of the phase-specific busbar **73**. A winding connector **73***b*, which is connected to a corresponding one of the phase windings, is formed at a distal end portion of each arm portion **73***a*. Additionally, an electric power terminal **73***c* for inputting/outputting the electric power is formed at the arcuate portion of the phase-specific busbar **73**. As shown in FIG. **13**, a radial length of the respective arm portions **73***a* and a circumferential position of the electric power terminal **73***c* differ for each phase-specific busbar **73**.
[0111] In FIG. **14**, (b) is a perspective view showing a structure of one busbar which is the neutral point busbar **74**. Each neutral point busbar **74** is shaped generally in an arcuate form as a whole, and an arm portion **74***a*, which radially extends, is formed at a plurality of locations (six locations in the present embodiment) along a longitudinal direction of the neutral point busbar **74**. A neutral point connector **74***b*, which is connected to a neutral point side end portion of the corresponding phase winding, is formed at a distal end portion of each arm portion **74***a*.
[0112] FIG. **15** is a perspective view showing a structure of the busbar holder **72**. The busbar holder **72** is made of, for example, a dielectric resin material and is shaped in a circular ring form. The busbar holder **72** has a plurality of grooves **72***a* that respectively extend in an arcuate form in the circumferential direction. These grooves **72***a* are formed in a plurality of layers arranged in the radial direction, and each busbar **73**, **74** is assembled in a corresponding one of the grooves **72***a* such that busbar plate surfaces of each radially adjacent two of the busbars **73**, **74** face each other in the radial direction. Additionally, a plurality of projections **72***b* are formed at an upper surface of the busbar holder **72**. Each of the projections **72***b* is a support portion that supports a corresponding one of the arm portions **73***a*, **74***a* of the busbars **73**, **74**. The projections **72***b* are dispersed in the circumferential direction according to the positions of the arm portions **73***a*, **74***a*.
[0113] A plurality of through-holes **72***c*, which extend through the busbar holder **72** in the axial direction (the up-down direction in the drawing), are formed at an outer periphery of the busbar holder **72**, i.e., on the radially outer side of the grooves **72***a*. The through-holes **72***c* are insertion

holes for inserting the lead-out portions which are the conductor wire end portions of the phase windings, i.e., the lead-out portions H**11**, H**12**, H**21**, H**22** shown in (a) of FIG. **10**. In this embodiment, the through-holes **72***c*, which are conductor wire connectors, are collectively provided at the outer periphery of the busbar holder **72** in the busbar module **70**. Additionally, a plurality of installation portions **72***d* are formed at the busbar holder **72** for installing the busbar module **70** to the stator core **31**.

[0114] FIG. **16** is a perspective view showing a state where the busbar module **70** is installed to the stator **30**. In FIG. **16**, the busbar module **70** is installed coaxially with the stator core **31** at one axial end of the stator core **31**.

[0115] The lead-out portions, which are the conductor wire end portions of the phase windings, are inserted through the through-holes **72***c* of the busbar holder **72** and are connected to the busbars **73**, **74** at the upper surface of the busbar holder **72**. Specifically, each of the conductor wire end portions of the phase windings is joined to the corresponding one of the connectors **73***b*, **74***b* of the busbars **73**, **74** by welding or the like. As a result, at each set of stator windings **32***a*, **32***b*, the phase windings are connected to each other in the desired configuration. Additionally, the electric power lines **75** are connected to the electric power terminals **73***c* of the phase-specific busbars **73**.

[0116] By the way, in the rotary electric machine, noise and vibration caused by torque ripple are disadvantageously generated. The torque ripple mainly consists of 6th harmonic components or 12th harmonic components, so it is desirable to suppress these. Therefore, it is desirable to perform the following control in the control device **50** using the electric motor **10** with the above configuration.

[0117] In the electric motor **10** of the above-described structure, the first tooth (T**3**, T**6**, T**9**, T**12**, T**15**, T**18**) of each tooth group is wound with the winding segment (a first coil body) of the corresponding one of the U-phase, V-phase and W-phase of the first set of stator windings **32***a*, and the second tooth (T**2**, T**5**, T**8**, T**10**, T**14**, T**17**) of each tooth group is wound with the winding segment (a second coil body) of the corresponding one of the U-phase, V-phase and W-phase of the first set of stator windings **32***a* and the winding segment (a second coil body) of the corresponding one of the X-phase, Y-phase and Z-phase of the second set of stator windings **32***b*, and the third tooth (T**1**, T**4**, T**7**, T**10**, T**13**, T**16**) of each tooth group is wound with the winding segment (a third coil body) of the corresponding one of the X-phase, Y-phase and Z-phase of the second set of stator windings **32***b*.

[0118] In this structure, a cumulative phase difference, which is a sum of each phase difference between a magnetomotive force generated by the winding segment of the corresponding phase of the first set of stator windings **32***a* wound around the second tooth and a magnetomotive force generated by the winding segment of the corresponding phase of the second set of stator windings **32***b* wound around the second tooth in each of the tooth groups, is set by the control device **50** such that each phase difference of the magnetomotive force of the second coil body of the corresponding phase relative to the magnetomotive force of the first coil body of the corresponding phase and each phase difference of the magnetomotive force of the third coil body of the corresponding phase relative to the magnetomotive force of the second coil body of the corresponding phase are within a predetermined phase range that includes 20 degrees in electrical angle, or each phase difference of the magnetomotive force of the third coil body of the corresponding phase relative to the magnetomotive force of the first coil body of the corresponding phase and each phase difference of the magnetomotive force of the second coil body of the corresponding phase relative to the magnetomotive force of the third coil body of the corresponding phase are within a predetermined phase range that includes 20 degrees in electrical angle. The cumulative phase difference is preferably set within, for example, a range of 72 to 88 degrees in electrical angle. Alternatively, the control device **50** may set a cumulative phase difference as a sum of each phase difference between the electric current flowing through the winding segment of the first set of stator windings **32***a* wound around the second tooth and the electric current flowing through the winding segment of the second set of stator windings **32***b* wound around the same second tooth in each of the tooth groups. The details of this control are described in JP7103299B2 (corresponding to US2020/336058A1, the entire disclosure of which is incorporated herein by reference) filed by the applicant of this application.

[0119] The embodiment described above can achieve the following advantages.

[0120] In the structure where the first winding **101** and the second winding **102**, which correspond to the two different phases, are wound as the stator windings **32** on the common tooth **34** of the stator core **31**, there is a concern that the terminal processing (terminal processing at the coil end) of these windings **101**, **102** may possibly become more complex. Additionally, there is a concern that the winding start end portion and the winding terminal end portion of the first winding **101** (i.e., the pre-wound winding) may interfere with the winding process of the second winding **102** (i.e., the post-wound winding). In this regard, at the tooth **34**, around which the first winding **101** and the second winding **102** are wound, the first winding **101** is wound around the tooth **34** the plurality of times to form the plurality of layers of the conductor wire of the first winding **101** in the first range R**1** that extends from the first end portion **34***a* of the tooth **34** to the intermediate position of the tooth in the radial direction. Therefore, the first winding **101** can be more concentrated at the one radial side of the tooth **34**, and consequently, the end portions (i.e., the winding start end portion and the winding terminal end portion) of the conductor wire of the first winding **101** can be suitably concentrated at the first end portion **34***a* side of the tooth **34**. As a result, the inconvenience caused by the winding start end portion and the winding terminal end portion of the first winding **101** (i.e., the pre-wound winding) interfering with the winding process of the second winding **102** (i.e., the post-wound winding) can be suppressed. Furthermore, the second winding **102** is wound around the tooth **34** in the second range R**2** that extends in the radial direction from the second end portion **34***b* of the tooth **34** to the overlapping position where the second winding **102** overlaps with the first winding **101**. Therefore, the second winding **102** can be wound closer to the first end portion **34***a* in the state where the second winding **102** overlaps with the first winding **101** while utilizing a vacant region around the tooth **34** where the first winding **101** is not wound. As a result, the end portions of the conductor wire of the second winding **102** can also be positioned closer to the first end portion **34***a*. As a result, it is possible to optimally wind the first winding **101** and the second winding **102** around the common tooth.

[0121] There is implemented the structure where the first winding **101** is wound such that the winding start position of the first winding **101** is at the first end portion **34***a* of the tooth **34**, and the winding terminal position of the first winding **101** is where the conductor wire of the first winding **101** at the winding terminal position overlaps with the conductor wire of the first winding **101** at the winding start position of the first winding **101**. With this structure, it is possible to achieve the appropriate configuration where the first winding **101** is concentrated at the one radial side of the tooth **34**. Furthermore, the second winding **102** is wound such that the winding start position of the second winding **102** is on the radial side of the winding start position of the first winding **101** where the tooth center of the tooth **34**, which is centered between the two opposite radial ends of the tooth **34** in the radial direction, is placed, and the second winding **102** is wound from the winding start position of the second winding **102** toward the tooth center. Thus, the second winding **102** can be optimally wound while avoiding interference with the end portions of the first winding **101**.

[0122] In the structure where the round wires are used as the conductor wires, the space factor can be improved by winding the first winding **101** and the second winding **102** in the staggered arrangement. Additionally, according to the staggered arrangement of the round wires, it becomes relatively easy to adjust the radial position for the winding start position of the second winding, making it easy to implement the configuration where the winding start position of the second winding **102** is spaced from the first end portion **43***a* by the amount that corresponds to the one turn of the conductor wire of the second winding **102**. As a result, the interference with the end portions of the first winding can be effectively avoided for the second winding.

[0123] Additionally, the second winding **102** is wound around the tooth **34** such that the second winding **102** starts from the winding start position adjacent to the first end portion **34***a* of the tooth **34**, extends toward the second end portion **34***b*, and folds back at the second end portion **34***b* to wind the conductor wire of the second winding **102** in the plurality of layers over the tooth **34**. As a result, similar to the first winding **101**, the winding start and the winding terminal of the conductor wire of the second winding **102** can also be concentrated at the first end portion **34***a* side of the tooth **34**. Therefore, the workability of terminal processing can be improved at the time of, for example, connecting a plurality of first windings **101**, which constitute the stator windings **32**, or connecting a plurality of second windings **102**, which constitute the stator windings **32**.

[0124] In the stator core **31**, among the first to third teeth, which are consecutively arranged in the circumferential direction, the first phase winding C**1** is wound continuously around the first tooth and the second tooth, and the second phase winding C**2** is wound continuously around the second tooth and the third tooth. Furthermore, in the structure described above, the one end portion of the first phase winding C**1** is pulled out from the radial end portion of the first tooth, which is adjacent to the back yoke **33**, and the other end portion of the first phase winding C**1** is pulled out from the radial end portion of the second tooth which is adjacent to the back yoke **33**, and the one end portion of the second phase winding C**2** is pulled out from the radial end portion of the third tooth, which is adjacent to the back yoke **33**, and the other end portion of the second phase winding C**2** is pulled out from the radial end portion of the second tooth which is adjacent to the back yoke **33** (see (a) and (b) of FIG. **10**). This allows for the optimal implementation of connecting the conductor wire end portions of each phase winding to the electric power source and the neutral point while grouping each set of three teeth **34** together as one group. Furthermore, the first phase winding C**1**, which is the pre-wound winding, has the link portion H**13**, which extends between the first tooth and the second tooth along the back yoke **33** in the circumferential direction to continuously extend the first phase winding C**1** between the first tooth and the second tooth. Therefore, the plurality of conductor wire end portions generated for the tooth basis are all processed at the back yoke **33** side.

[0125] In the structure where the first phase winding C**1** is continuously wound around the first tooth A**1** and the second tooth A**2**, which are adjacent to each other in the circumferential direction, the link portion H**13**, which extends from the first tooth A**1**, forms the winding start end portion of the first winding **101**, and the other end portion of the first winding **101** is the winding terminal end portion of the first winding **101**. In this case, the rising portion **63***b* formed at the back yoke **33** side of the electrical insulation members **63**, **64** is used to hold the winding start end portion (the link portion H**13**) and the winding terminal end portion of the first winding **101**. As a result, the winding start end portion and the winding terminal end portion of the first winding **101** can be held on the back yoke **33** side, thereby effectively avoiding interference during the winding of the second winding **102**.

Other Embodiments

[0126] The above embodiment may be modified, for example, as follows.

[0127] In the structure where the first winding **101** is wound in the first range R**1**, which extends from the first end portion **34***a* of the center tooth A**2** (the tooth **34**) of the tooth group G to the intermediate position of the center tooth A**2** (the tooth **34**) in the radial direction, there is a concern that the first winding **101** may collapse during the winding process. Therefore, the following configuration may be employed to limit the collapse of the first winding **101**.

[0128] As shown in FIG. **17**, the tooth may be provided with one or more projections (two projections in this instance) **81**, each of which is placed at a boundary position of the first range R**1** where the first winding **101** is wound, and this boundary position of the first range R**1** is opposite to the first end portion **34***a* in the radial direction, and each projection **81** extends in a direction perpendicular to the radial direction and away from a tooth surface of the tooth **34**. In other words, each projection **81** is provided at the position that serves as the boundary between the first winding **101** and the second winding **102** in the radial direction. The projection(s) **81** may, for example, be integrally formed with the electrical insulation member(s) **63**, **64** and provided so as to extend in at least one of the axial direction and the circumferential direction from the tooth surface. However, the projection(s) **81** may be formed by the electromagnetic steel sheet(s) on the tooth **34**. According to the above configuration, even in the structure where the first winding **101** is wound in the first range R**1**, which extends from the first end portion **34***a* of the tooth **34** to the intermediate position in the radial direction, the collapse of the first winding **101** can be effectively limited.

[0129] Additionally, in a configuration shown in (a) and (b) of FIG. **18**, each of the electrical insulation members **63**, **64** is provided with a stepped portion **82** on the covering portion **63***a*, **64***a*, which covers the axial end surface of the tooth **34**, to differentiate the axial wall thickness dimensions between the first range R**1** and a range outside the first range R**1**. In this case, the first range R**1** is the winding range of the first winding **101** on the tooth **34**, and the axial wall thickness dimension of the covering portion **63***a*, **64***a* in the first range R**1** is reduced in comparison to the range outside the first range R**1**. In the segmented core **61**, in relation to an axial end surface of a coil side CS, a height dimension, which is measured from the axial end surface of the coil side CS, is smaller in the first range R**1** compared to the range outside the first range R**1**. A portion of each of the covering portions **63***a*, **64***a*, which is located in the first range R**1**, serves as a first insulation portion, and another portion of the covering portion **63***a*, **64***a*, which is located outside of the first range R**1**, serves as a second insulation portion.

[0130] In the above configuration, since the first range R**1**, in which the first winding **101** is wound, and the range outside the first range R**1** are formed in the stepped manner on the segmented core **61**, the collapse of the first winding **101** can be limited. Additionally, as described above, in the first range R**1** of the tooth **34**, both the first winding **101** and the second winding **102** are wound in the stacked state, and in the range outside the first range R**1**, only the second winding **102** is wound. In view of this point, the axial length dimension in the first range R**1** can be limited with the above configuration from becoming excessively large compared to the range outside the first range R**1**, thereby achieving uniformity in the axial length dimension of the windings in the radial direction of the tooth **34**.

[0131] In the configuration described above, the stepped portion **82** is provided to each of the electrical insulation members **63**, **64** which are placed at the two opposite axial sides, respectively. Alternatively, the stepped portion **82** may be provided only to one of the electrical insulation members **63**, **64**.

[0132] Additionally, as shown in (a) of FIG. **19**, a section of the covering portion **63***a* of the electrical insulation member **63**, which corresponds to the first range R**1**, may be formed as an inclined portion **83**, a height of which decreases toward the back yoke **33** (the right side in the drawing). In this case, the first winding **101** can be wound in a state where the first winding **101** is more concentrated toward the rising portion **63***b* placed adjacent to the back yoke **33**, thereby limiting the collapse of the first winding **101**.

[0133] Additionally, as shown in (b) of FIG. **19**, an entire region of the covering portion **63***a* of the electrical insulation member **63**, on which the first winding **101** and the second winding **102** are wound, may be formed as the inclined portion **83**, the height of which decreases toward the back yoke **33** (the right side in the drawing). The configuration of FIG. **17**, in which the projection(s) **81** is provided at the boundary position of the first range R**1**, may be combined with each of the configurations shown in (a) and (b) of FIG. **18** and (a) and (b) of FIG. **19**. For example, the projection **81** may be provided to the electrical insulation member(s) **63**, **64** such that the projection **81** projects from a circumferential side surface(s) of the electrical insulation member(s) **63**, **64** in the circumferential direction.

[0134] In each of the stator windings **32**, the conductor wire may be formed by a plurality of wires arranged in parallel, and this conductor wire may be wound around the corresponding tooth. In this case, by reducing a wire thickness of the conductor wire, the collapse of the first winding **101** can be limited.

[0135] In the above embodiment, the first phase winding C**1**, which is the pre-wound winding, is wound such that the two winding segments of the first phase winding C**1** are wound around in the order of the first tooth and then the second tooth. However, this configuration may be modified such that the two winding segments of the first phase winding C**1** are wound around in the order of the second tooth and then the first tooth. Furthermore, in the above embodiment, the second phase winding C**2**, which is the post-wound winding, is wound such that the two winding segments of the second phase winding C**2** are wound around in the order of the third tooth and then the second tooth. However, this configuration may be modified such that the two winding segments of the second phase winding C**2** are wound around in the order of the second tooth and then the third tooth.

[0136] In the above embodiment, as shown in (a) of FIG. **7**, the first set of stator windings **32***a* are configured such that the winding segments U**1**-U**4**, V**1**-V**4**, W**1**-W**4** of each phase are divided into the two groups each including corresponding two of the winding segments U**1**-U**4**, V**1**-V**4**, W**1**-W**4**, and these winding segments U**1**-U**4**, V**1**-V**4**, W**1**-W**4** are connected by the star connection. However, this structure may be modified. For example, as shown in (a) of FIG. **20**, the first set of stator windings **32***a* may be configured such that the winding segments U**1**-U**4**, V**1**-V**4**, W**1**-W**4** of each phase may be connected in series, and the three series-connected phase windings may be connected by a star connection. Furthermore, as shown in (b) of FIG. **20**, the second set of stator windings **32***b* may be configured such that the winding segments X**1**-X**4**, Y**1**-Y**4**, Z**1**-Z**4** of each phase may be connected in series, and the three series-connected phase windings may be connected by a star connection.

[0137] In each set of stator windings **32***a*, **32***b*, it is also possible to connect the phase windings using a delta connection (A connection) instead of the star connection (Y connection).

[0138] In the stator core **31**, each segmented core **61** may have a plurality of teeth **34**. For example, each segmented core **61** may have three teeth **34**. Additionally, the stator core **31** may have a non-segmented structure, i.e., an integrally formed circular ring form that is not divided in the circumferential direction.

[0139] The number of teeth in the stator core **31** may be other than eighteen (**18**). However, in this case, the number of teeth is preferably 3×n, where n is an integer.

[0140] In the above embodiment, the stator windings **32** include the first set of stator windings **32***a* and the second set of stator windings **32***b* and thereby include the total of the six phase windings for the six phases. However, this can be modified such that the stator windings **32** include only one set of three phase windings for three phases.

[0141] The rotary electric machine may be an outer rotor type instead of the inner rotor type. In the outer rotor type rotary electric machine, the back yoke **33** is positioned on the radially inner side of the stator core **31**, and the teeth **34** project radially outward from the back yoke **33**. In this case, each of the winding start end portion and the winding terminal end portion of each of the first winding **101** and the second winding **102** may be placed at the proximal end portion of the corresponding tooth **34** (the back yoke **33** side).

[0142] Technical aspects, which are obtained based on the embodiments described above, will be recited below.

Configuration 1

[0143] According to configuration 1, there is provided a stator including: [0144] a stator core that includes: [0145] a back yoke that is shaped in a circular ring form; and [0146] a plurality of teeth that radially extend from the back yoke and are arranged at predetermined intervals in a circumferential direction; and [0147] a plurality of stator windings that are provided for a plurality of phases, wherein the plurality of stator windings are formed by a plurality of conductor wires, respectively, which are wound on the plurality of teeth using concentrated winding, wherein:

[0148] among the plurality of stator windings, a first winding and a second winding, which are respectively provided for two different phases among the plurality of phases, are wound around a predetermined tooth among the plurality of teeth, wherein the first winding is a pre-wound winding, which is wound first around the predetermined tooth, and the second winding is a post-wound winding, which is wound later around the predetermined tooth after the pre-wound winding; [0149] at the predetermined tooth, around which the first winding and the second winding are wound, the first winding is wound around the predetermined tooth a plurality of times to form a plurality of layers of the conductor wire of the first winding in a first range that extends from a first end portion of the predetermined tooth, which faces radially inward or radially outward, to an intermediate position of the predetermined tooth in a radial direction, and the second winding is wound around the predetermined tooth a plurality of times in a second range that extends in the radial direction from a second end portion of the predetermined tooth, which is opposite to the first end portion in the radial direction, to an overlapping position where the second winding overlaps with the first winding; and [0150] a winding start end portion and a winding terminal end portion of the conductor wire of the first winding are placed at the first end portion of the predetermined tooth, and the second winding is wound such that a portion of the second winding overlaps with the first winding.

Configuration 2

[0151] According to configuration 2, there is provided the stator according to configuration 1, wherein: [0152] the first winding is wound such that a winding start position of the first winding is at the first end portion, and a winding terminal position of the first winding is where the conductor wire of the first winding at the winding terminal position overlaps with the conductor wire of the first winding at the winding start position of the first winding; and [0153] the second winding is wound such that a winding start position of the second winding is on a radial side of the winding start position of the first winding where a tooth center of the predetermined tooth, which is centered between two opposite radial ends of the predetermined tooth in the radial direction, is placed, and the second winding is wound from the winding start position of the second winding toward the tooth center.

Configuration 3

[0154] According to configuration 3, there is provided the stator according to configuration 2, wherein: [0155] each of the plurality of conductor wires is a round wire with a circular-cross section, and the first winding and the second winding are wound around the predetermined tooth in a staggered arrangement in which the conductor wire of the first winding and the conductor wire of the second winding are staggered; and [0156] the second winding is wound such that the winding start position of the second winding is spaced from the first end portion by an amount that corresponds to one turn of the conductor wire of the second winding.

Configuration 4

[0157] According to configuration 4, there is provided the stator according to configuration 2 or 3, wherein the second winding is wound around the predetermined tooth such that the second winding starts from the winding start position adjacent to the first end portion, extends toward the second end portion, and folds back at the second end portion to wind the conductor wire of the second winding in a plurality of layers over the predetermined tooth.

Configuration 5

[0158] According to configuration 5, there is provided the stator according to any one of configurations 1 to 4, wherein the predetermined tooth is provided with a projection which is placed at a boundary position of the first range where the first winding is wound, wherein the boundary position of the first range is opposite to the first end portion in the radial direction, and the projection extends in a direction perpendicular to the radial direction and away from a tooth surface of the predetermined tooth.

Configuration 6

[0159] According to configuration 6, there is provided the stator according to any one of configurations 1 to 5, wherein: [0160] at least one electrical insulation member is placed on at least one of two opposite axial end portions of the predetermined tooth, and the first winding and the second winding are wound in a state where the at least one electrical insulation member is interposed between the predetermined tooth and each of the first winding and the second winding; and [0161] the at least one electrical insulation member has a first insulation portion, which corresponds to the first range in the radial direction, and a second insulation portion, which is a portion of the at least one electrical insulation member located outside of the first range, and an axial wall thickness dimension of the first insulation portion and an axial wall thickness dimension of the second insulation portion are set differently such that the axial wall thickness dimension of the first insulation portion is smaller than the axial wall thickness dimension of the second insulation portion.

Configuration 7

[0162] According to configuration 7, there is provided the stator according to any one of configurations 1 to 6, wherein: [0163] the plurality of stator windings include a plurality of phase windings, each of which is provided for a corresponding one of the plurality of phases and is wound around corresponding two or more of the plurality of teeth using the concentrated winding; [0164] three teeth among the plurality of teeth, which are consecutively arranged in the circumferential direction in the stator core, are defined as a first tooth, a second tooth and a third tooth, wherein a first phase winding among the plurality of phase windings is wound continuously around the first tooth and the second tooth, and a second phase winding among the plurality of phase windings is wound continuously around the second tooth and the third tooth, and thereby the second tooth is wound with the first phase winding and the second phase winding; [0165] one end portion of the first phase winding is pulled out from one of two opposite radial end portions of the first tooth, which is adjacent to the back yoke, and another end portion of the first phase winding is pulled out from one of two opposite radial end portions of the second tooth which is adjacent to the back yoke; [0166] one end portion of the second phase winding is pulled out from one of two opposite radial end portions of the third tooth, which is adjacent to the back yoke, and another end portion of the second phase winding is pulled out from the one of the two opposite radial end portions of the second tooth which is adjacent to the back yoke; and [0167] among the first phase winding and the second phase winding, the first phase winding is a pre-wound winding, which is wound first at a time of winding the first phase winding and the second phase winding, and the second phase winding is a post-wound winding, which is wound later after the pre-wound winding, wherein the first phase winding has a link portion, which extends between the first tooth and the second tooth along the back yoke in the circumferential direction to continuously extend the first phase winding between the first tooth and the second tooth.

Configuration 8

[0168] According to configuration 8, there is provided the stator according to configuration 7, wherein: [0169] at least one electrical insulation member is placed on at least one of two opposite axial end portions of the stator core and is configured to electrically insulate between one or more of the plurality of teeth and one or more of the plurality of stator windings; [0170] the at least one electrical insulation member has at least one rising portion, wherein the at least one rising portion is placed on the one or more of the plurality of teeth at a location adjacent to the back yoke and axially extends; and [0171] the at least one rising portion has a plurality of holding portions that hold: [0172] the link portion, which forms one end portion among a winding start end portion and a winding terminal end portion of the first phase winding wound around the second tooth; and [0173] another end portion among the winding start end portion and the winding terminal end portion of the first phase winding.

[0174] Although the present disclosure has been described with reference to the embodiments and the modifications, it is understood that the present disclosure is not limited to the embodiments and the modifications and structures described therein. The present disclosure also includes various variations and variations within the equivalent range. Also, various combinations and forms, as well as other combinations and forms that include only one element, more, or less, are within the scope and ideology of the present disclosure.

Claims

1. A stator comprising: a stator core that includes: a back yoke that is shaped in a circular ring form; and a plurality of teeth that radially extend from the back yoke and are arranged at predetermined intervals in a circumferential direction; and a plurality of stator windings that are provided for a plurality of phases, wherein the plurality of stator windings are formed by a plurality of conductor wires, respectively, which are wound on the plurality of teeth using concentrated winding, wherein: among the plurality of stator windings, a first winding and a second winding, which are respectively provided for two different phases among the plurality of phases, are wound around a predetermined tooth among the plurality of teeth, wherein the first winding is a pre-wound winding, which is wound first around the predetermined tooth, and the second winding is a post-wound winding, which is wound later around the predetermined tooth after the pre-wound winding; at the predetermined tooth, around which the first winding and the second winding are wound, the first winding is wound around the predetermined tooth a plurality of times to form a plurality of layers of the conductor wire of the first winding in a first range that extends from a first end portion of the predetermined tooth, which faces radially inward or radially outward, to an intermediate position of the predetermined tooth in a radial direction, and the second winding is wound around the predetermined tooth a plurality of times in a second range that extends in the radial direction from a second end portion of the predetermined tooth, which is opposite to the first end portion in the radial direction, to an overlapping position where the second winding overlaps with the first winding; and a winding start end portion and a winding terminal end portion of the conductor wire of the first winding are placed at the first end portion of the predetermined tooth, and the second winding is wound such that a portion of the second winding overlaps with the first winding.
2. The stator according to claim 1, wherein: the first winding is wound such that a winding start position of the first winding is at the first end portion, and a winding terminal position of the first winding is where the conductor wire of the first winding at the winding terminal position overlaps with the conductor wire of the first winding at the winding start position of the first winding; and the second winding is wound such that a winding start position of the second winding is on a radial side of the winding start position of the first winding where a tooth center of the predetermined tooth, which is centered between two opposite radial ends of the predetermined tooth in the radial direction, is placed, and the second winding is wound from the winding start position of the second winding toward the tooth center.
3. The stator according to claim 2, wherein: each of the plurality of conductor wires is a round wire with a circular-cross section, and the first winding and the second winding are wound around the predetermined tooth in a staggered arrangement in which the conductor wire of the first winding and the conductor wire of the second winding are staggered; and the second winding is wound such that the winding start position of the second winding is spaced from the first end portion by an amount that corresponds to one turn of the conductor wire of the second winding.
4. The stator according to claim 2, wherein the second winding is wound around the predetermined tooth such that the second winding starts from the winding start position adjacent to the first end portion, extends toward the second end portion, and folds back at the second end portion to wind the conductor wire of the second winding in a plurality of layers over the predetermined tooth.
5. The stator according to claim 1, wherein the predetermined tooth is provided with a projection which is placed at a boundary position of the first range where the first winding is wound, wherein the boundary position of the first range is opposite to the first end portion in the radial direction,

and the projection extends in a direction perpendicular to the radial direction and away from a tooth surface of the predetermined tooth.

6. The stator according to claim 1, wherein: at least one electrical insulation member is placed on at least one of two opposite axial end portions of the predetermined tooth, and the first winding and the second winding are wound in a state where the at least one electrical insulation member is interposed between the predetermined tooth and each of the first winding and the second winding; and the at least one electrical insulation member has a first insulation portion, which corresponds to the first range in the radial direction, and a second insulation portion, which is a portion of the at least one electrical insulation member located outside of the first range, and an axial wall thickness dimension of the first insulation portion and an axial wall thickness dimension of the second insulation portion are set differently such that the axial wall thickness dimension of the first insulation portion is smaller than the axial wall thickness dimension of the second insulation portion.

7. The stator according to claim 1, wherein: the plurality of stator windings include a plurality of phase windings, each of which is provided for a corresponding one of the plurality of phases and is wound around corresponding two or more of the plurality of teeth using the concentrated winding; three teeth among the plurality of teeth, which are consecutively arranged in the circumferential direction in the stator core, are defined as a first tooth, a second tooth and a third tooth, wherein a first phase winding among the plurality of phase windings is wound continuously around the first tooth and the second tooth, and a second phase winding among the plurality of phase windings is wound continuously around the second tooth and the third tooth, and thereby the second tooth is wound with the first phase winding and the second phase winding; one end portion of the first phase winding is pulled out from one of two opposite radial end portions of the first tooth, which is adjacent to the back yoke, and another end portion of the first phase winding is pulled out from one of two opposite radial end portions of the second tooth which is adjacent to the back yoke; one end portion of the second phase winding is pulled out from one of two opposite radial end portions of the third tooth, which is adjacent to the back yoke, and another end portion of the second phase winding is pulled out from the one of the two opposite radial end portions of the second tooth which is adjacent to the back yoke; and among the first phase winding and the second phase winding, the first phase winding is a pre-wound winding, which is wound first at a time of winding the first phase winding and the second phase winding, and the second phase winding is a post-wound winding, which is wound later after the pre-wound winding, wherein the first phase winding has a link portion, which extends between the first tooth and the second tooth along the back yoke in the circumferential direction to continuously extend the first phase winding between the first tooth and the second tooth.

8. The stator according to claim 7, wherein: at least one electrical insulation member is placed on at least one of two opposite axial end portions of the stator core and is configured to electrically insulate between one or more of the plurality of teeth and one or more of the plurality of stator windings; the at least one electrical insulation member has at least one rising portion, wherein the at least one rising portion is placed on the one or more of the plurality of teeth at a location adjacent to the back yoke and axially extends; and the at least one rising portion has a plurality of holding portions that hold: the link portion, which forms one end portion among a winding start end portion and a winding terminal end portion of the first phase winding wound around the second tooth; and another end portion among the winding start end portion and the winding terminal end portion of the first phase winding.