United States Patent Application Publication	20250260291
Kind Code	A1
Publication Date	August 14, 2025
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ELECTRIC MOTOR STATOR VARNISH OPTIMIZATION

Abstract

An electric motor includes a stator having a stator core constructed from a ferromagnetic material and having an external stator surface. The stator core includes a stator core body and a plurality of stator teeth extending therefrom. The plurality of stator teeth define conductor slots therebetween. The stator also includes a plurality of stator conductors arranged within the conductor slots. The stator additionally includes a slot liner arranged within each conductor slot and surrounding the corresponding stator conductors. A first gap is established between each stator conductor and the corresponding slot liner, and a second gap is established between each slot liner and the neighboring stator teeth. A predetermined amount of varnish arranged within the first and second gaps to limit an amount of open space within the first and second gaps that is free from the varnish and regulate viscous damping of the electric motor.

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Appl. No.: **18/437840**

Filed: **February 09, 2024**

Publication Classification

Int. Cl.: **H02K5/24** (20060101); **H02K3/34** (20060101); **H02K9/19** (20060101); **H02K21/14** (20060101)

U.S. Cl.:

CPC **H02K5/24** (20130101); **H02K3/345** (20130101); **H02K9/19** (20130101); **H02K21/14** (20130101);

Background/Summary

INTRODUCTION

[0001] The disclosure relates to optimization of varnish application in a stator of an electric motor.

[0002] An electric motor is a machine that converts electric energy into mechanical energy. Electric motors may be configured as an alternating current (AC) or a direct current (DC) type. An electric motor's operation is based on an electromagnetic interaction between permanent magnets and the magnetic field created by the machine's selectively energized coils. Electric motors are classified into two categories based on the direction of the magnetic field-axial flux motors and radial flux motors. Generally, axial flux motors include rotors internal to the corresponding stators, while radial flux motors include rotors positioned alongside the stators.

[0003] As a byproduct of generated torque, electric motors produce thermal energy which may adversely affect motor performance and reliability. Cooling of an electric motor may therefore remove thermal stress seen by motor poles or windings and provide longer motor life under or close to peak load. Cooling of an electric motor may also enhance motor operation at higher speeds, as well as facilitate reduced motor inertia and packaging. Motor cooling is generally provided by a circulating oil, which may be also used to reduce friction between internal motor components.

SUMMARY

[0004] An electric motor includes a stator having a stator core constructed from a ferromagnetic material and having an external stator surface. The stator core includes a stator core body and a plurality of stator teeth extending therefrom. The plurality of stator teeth define conductor slots therebetween. The stator also includes a plurality of stator conductors arranged within the conductor slots. The stator additionally includes a slot liner arranged within each conductor slot and surrounding the corresponding stator conductors. A first gap is established between each stator conductor and the corresponding slot liner, and a second gap is established between each slot liner and the neighboring stator teeth. A predetermined amount of varnish arranged within each of the first gap and the second gap and thereby configured to limit an amount of open space within the first and second gaps that is free from the varnish. Thus arranged, the subject amount of varnish regulates viscous damping and noise, vibration, and harshness (NVH) characteristics of the electric motor.

[0005] The electric motor may additionally include a lubrication system configured to supply oil to the stator. A portion of the oil may fill the open space free from the varnish within the first and second gaps during operation of the electric motor to thereby affect noise, vibration, and harshness (NVH) characteristics of the electric motor.

[0006] The varnish may fill up to 80% of each of the first and second gaps.

[0007] The varnish may be arranged away from relatively high vibration or resonance angular positions.

[0008] The varnish arranged away from the relatively high vibration angular positions may fill greater than 90% of each of the first and second gaps.

[0009] The varnish arranged proximate the relatively high vibration angular positions may fill 50% of each of the first and second gaps.

[0010] In a side view, the stator core may include a plurality of adjacent stator laminations arranged along the rotational axis. The amount of varnish may be varied axially, i.e., along the rotational axis.

[0011] In a plan view, the stator core may include a plurality of circumferentially arranged mounting bosses defining motor constraint locations. The relatively high vibration angular positions may be disposed between the mounting bosses, and the predetermined amount of varnish may be applied within the first and second gaps between the mounting bosses.
[0012] In a side view, the stator core may include a first stator end and an opposite second stator end. The mounting bosses may be arranged on the first stator end, and the varnish may fill greater than 90% of each of the first and second gaps axially proximate the mounting bosses.
[0013] The stator may include a stator inside diameter (ID) and a stator outside diameter (OD), and the amount of varnish may be varied in a radial direction between the stator ID and the stator OD.
[0014] Each slot liner may include a first slot liner section and a second slot liner section. In such an embodiment, the first slot liner section may be configured to wrap partially around the corresponding stator conductors and the second slot liner section may be configured to wrap partially around the subject stator conductors and overlap the first slot liner section.
[0015] The electric motor may have either a radial or an axial flux construction,
[0016] A motor vehicle having such an electric motor as described above is also disclosed.
[0017] The above features and advantages, and other features and advantages of the present disclosure, will be readily apparent from the following detailed description of the embodiment(s) and best mode(s) for carrying out the described disclosure when taken in connection with the accompanying drawings and appended claims.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0018] FIG. **1** is a schematic illustration of a motor vehicle having a powertrain employing an electric motor-generator for propulsion.
[0019] FIG. **2** is a schematic close-up partial cut-away perspective view of a radial flux embodiment of the electric motor-generator shown in FIG. **1**, depicting a stator defining stator teeth, and having conductors arranged within conductor slots and slot liners surrounding the conductors, according to the disclosure.
[0020] FIG. **3** is a schematic partial plan or front view of an embodiment of the stator shown in FIG. **2**, illustrating representative neighboring stator teeth, two-piece slot liners surrounding the conductors, first and second gaps established via the slot liners, and a variable amount of varnish arranged in the gaps, according to the disclosure.
[0021] FIG. **4** is a schematic plan or front view of electric motor-generator shown in FIG. **2**, illustrating high resonance locations arranged between stator mounting bosses, according to an embodiment of the disclosure.
[0022] FIG. **5** is a schematic close-up cross-sectional side view of the radial flux motor-generator shown in FIG. **2**, depicting a fluid circulation system configured to supply oil to the first and second gaps between the stator teeth, according to the disclosure.
DETAILED DESCRIPTION
[0023] Embodiments of the present disclosure as described herein are intended to serve as examples. Other embodiments may take various and alternative forms. Additionally, the drawings are generally schematic and not necessarily to scale. Some features may be exaggerated or minimized to show details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art to variously employ the present disclosure.
[0024] Certain terminology may be used in the following description for the purpose of reference only, and thus are not intended to be limiting. For example, terms such as “above” and “below” refer to directions in the drawings to which reference is made. Terms such as “front”, “back”,

“fore”, “aft”, “left”, “right”, “rear”, “side”, “upward”, “downward”, “top”, and “bottom”, etc., describe the orientation and/or location of portions of the components or elements within a consistent but arbitrary frame of reference, which is made clear by reference to the text and the associated drawings describing the components or elements under discussion.

[0025] Furthermore, terms such as “first”, “second”, “third”, and so on may be used to describe separate components. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import, and are used descriptively for the figures, and do not represent limitations on the scope of the disclosure, as defined by the appended claims. Moreover, the teachings may be described herein in terms of functional and/or logical block components and/or various processing steps. It should be realized that such block components may include a number of hardware, software, and/or firmware components configured to perform the specified functions.

[0026] Referring to FIG. **1**, a motor vehicle **10** having a powertrain **12** is depicted. The motor vehicle **10** may include, but not be limited to, a commercial vehicle, industrial vehicle, passenger vehicle, aircraft, watercraft, train or the like. It is also contemplated that the motor vehicle **10** may be a mobile platform, such as an airplane, all-terrain vehicle (ATV), boat, personal movement apparatus, robot and the like to accomplish the purposes of this disclosure. The powertrain **12** includes a first power-source **14** depicted as an electric motor-generator and configured to generate a first power-source torque T.sub.1 (shown in FIG. **1**) for propulsion of the motor vehicle **10** via driven wheels **16** relative to a road surface. The motor-generator **14** may be configured as a radial flux electric motor (shown for example in FIGS. **2** and **4**), where the magnetic flux is generated perpendicular to the motor's axis of rotation and the airgap between the machine's rotor and stator is arranged concentrically with the rotational axis. Alternatively, the motor-generator **14** may be configured an axial flux electric motor (not shown but understood by those skilled in the art) where the magnetic flux is generated coaxially with the motor's axis of rotation and the airgap between the machine's rotor and stator is arranged perpendicular to the rotational axis. For the purposes of compact disclosure, the remainder of present description will focus primarily on the radial flux construction of the motor-generator **14**.

[0027] As shown in FIG. **1**, the powertrain **12** may also include a second power-source **20**, such as an internal combustion engine configured to generate a second power-source torque T.sub.2. The power-sources **14** and **20** may act in concert to power the motor vehicle **10** and be operatively connected to a transmission assembly **22**. The transmission assembly **22** may be configured to transmit first and/or second power-source torques T.sub.1, T.sub.2 to a final drive unit **24**, which in turn may be connected to the driven wheels **16**. The first power-source **14**, which for the remainder of the present disclosure will be referred to as a motor-generator or electric motor, may, for example, be mounted to the second power-source **20**, mounted to (or incorporated into) the transmission assembly **22**, mounted to the final drive unit **24**, or be a stand-alone assembly mounted to the structure of the vehicle **10**. As shown, the motor vehicle **10** additionally includes a programmable electronic controller **26** configured to communicate via a high-voltage BUS **27** and control the powertrain **12** to generate a predetermined amount of power-source torque (such as the sum of T.sub.1 and T.sub.2), and various other vehicle systems. Motor vehicle **10** additionally includes an energy storage system **28**, such as one or more batteries, configured to generate and store electrical energy for powering the power-sources **14** and **20**.

[0028] FIG. **2** illustrates a general cross-section of the radial flux embodiment of the motor-generator **14**. As shown, the motor-generator **14** includes a rotationally fixed stator assembly or stator **30** having a generally cylindrical stator core **32** defining a stator core body or back iron **33** and a plurality of stator teeth **34** extending therefrom. The stator core **32** is constructed from a ferromagnetic material and has a stator inside diameter (ID) defining a radially inner stator surface **32**A and a stator outside diameter (OD) defining a radially outer stator surface **32**B, as shown for example in FIG. **2**. The stator teeth **34** define multiple conductor slots **36** therebetween. The stator core **32** may include or be constructed from a plurality of adjacent, e.g., bonded, stator laminations **38** arranged along the rotational axis X.

[0029] As shown in FIG. **2**, the stator **30** also includes multiple conductors or wire windings **40** arranged within the conductor slots **36**. Specifically, a plurality of conductors **40** may be arranged within each of the conductor slots **36**. Although the stator conductors **40** are generally contained within the conductor slots **36**, the end turns of the conductors typically extend beyond the limits of the cylindrical core **32** at axially opposite stator ends—a first end **32-1** and a second end **32-2**. The motor-generator **14** also includes at least one rotor **42** arranged on a shaft defining a rotational axis X and thereby mounted for rotation inside the stator **30**. Specifically, the axial flux motor-generator **14** may have two rotors **42**, each arranged on one side of the stator **30**, while the radial flux motor-generator **14** includes a single rotor **42** mounted inside the corresponding stator **30**.

[0030] The rotor(s) **42** have respective external rotor surface(s) **42**A. Each rotor **42** has a ferromagnetic rotor core **44**. The rotor core **44** has axially opposite rotor core ends—a first end **44-1** and a second end **44-2**. In the case of the radial flux motor-generator **14**, the external rotor surface **42**A is a radially outer surface, while in the radial flux motor-generator, the external rotor surface **42**A is defined by either the first end **44-1** or the second end **44-2**. The rotor core **44** may be constructed from a relatively soft magnetic material, such as laminated silicon or ferrous steel. As shown in FIG. **2**, in the radial flux motor-generator **14** the rotor core outer surface **44**A establishes an airgap **46** between the rotor **42** and the stator **30**, i.e., between the external rotor surface **42**A and the external stator surface **32**A.

[0031] With continued reference to FIG. **2**, each rotor **42** includes a plurality of magnetic poles **48**, with each pole being configured to generate a magnetic flux. The stator conductors **40** are configured to establish a rotating magnetic field exerting a torque on the rotor(s) **42** via interaction with the rotor's magnetic poles **48**. The stator conductors **40** receive multiphase AC from a power inverter to establish a rotating magnetic field exerting torque upon the rotor(s) **42**. As shown in FIG. **3**, the stator **30** also includes a plurality of slot liners **50**, each slot liner being arranged within a respective conductor slot **36** and surrounding the corresponding stator conductors **40**. Each slot liner **50** may include a first slot liner section **50-1** and a second slot liner section **50-2**. The first slot liner section **50-1** is configured to wrap partially around the corresponding stator conductors **40** arranged within a respective conductor slot **36**. The second slot liner section **50-2** is configured to also wrap partially around the same stator conductors **40** and overlap a portion of the first slot liner section **50-1** such that the subject conductors are encased by the two slot liner sections as seen in a stator plan view (shown in FIG. **3**). Each of the conductor slots **36** may have an enlarged section **36**A to accommodate the overlapping first and second slot liner sections **50-1**, **50-2**.

[0032] As seen in the stator **30** partial plan view (shown in FIG. **3**), a first gap **52-1** is established between each stator conductor **40** and the corresponding slot liner **50**. A second gap **52-2** is established between each slot liner **50** and the neighboring stator teeth **34**, to each side of the subject conductor slot **36**. Respective first and second gaps **52-1**, **52-2** are thereby arranged entirely within their corresponding conductor slots **36**. A predetermined or controlled amount of varnish **54** is arranged within each of the first and second gaps **52-1**, **52-2**. To establish a requisite amount of varnish **54** within the first and second gaps **52-1**, **52-2**, the varnish may be applied to specific conductors **40** and into strategically identified areas of the conductor slots **36** via capillary action. Such varnish application may be accomplished following twisting and welding of stator wire windings and prior to curing of the stator assembly **30**. Thus arranged, a specific amount of varnish **54** is configured to limit an amount of open space **56**, i.e., free from the varnish, within the first and second gaps **52-1**, **52-2** to regulate or tune viscous damping, including noise, vibration, and harshness (NVH) characteristics, of the electric motor **14**, as will be described in detail below. The amount of varnish **54** may, for example, be varied in a radial direction between the stator ID and the stator OD.

[0033] As shown in FIG. **5**, the motor-generator **14** may also include a lubrication or fluid circulation system **60** configured to supply oil **62** to the stator **30**, such as via a fluid pump **64**. During operation of the motor-generator **14**, a portion of the oil **62** may fill the open space **56** within the first and second gaps **52-1**, **52-2** to thereby affect the electric motor's NVH characteristics. For example, the varnish **54** may fill up to 80% of each of the first and second gaps **52-1**, **52-2** of the entire stator **30**, leaving the remaining 20% to be filled by the oil **62**. With resumed reference to the plan view shown in FIG. **4**, the predefined amount of varnish **54** may be applied in slots **36** arranged distal or away from relatively high vibration or resonance angular positions **66** on the stator **30**. In such an embodiment, during electric motor **14** operation, the oil **62** would variably fill the open spaces **56** in the remaining slots (identified with numeral **36**′) bracketing or proximate the relatively high resonance positions **66** to damp out stator vibrations.

[0034] The varnish **54** arranged away from the relatively high vibration angular positions **66** may fill greater than 90% and up to 100% of each of the first and second gaps **52-1**, **52-2**. On the other hand, the varnish **54** arranged proximate the relatively high resonance angular positions **66** may fill approximately 50% of each of the first and second gaps **52-1**, **52-2**. The amount of varnish **54** may be varied among the adjacent stator laminations **38** axially along the rotational axis X, as seen in a side view, shown in FIG. **5**. The variation of varnish **54** amount may be consistent among the multiple stator laminations **38** or be adjusted differently along the rotational axis X according to identified resonance areas of the stator **30**.

[0035] As shown in FIGS. **2** and **4**, the stator core **32** may include a plurality of mounting bosses **68**. The mounting bosses **68** may be circumferentially arranged on the radially outer stator surface **32**B and clocked in structurally advantageous positions. The mounting bosses **68** define constraint locations of the electric motor **14** relative to the motor vehicle **10** structure. In such an embodiment, the relatively high vibration angular positions **66** may be disposed between the mounting bosses **68** (shown in FIG. **4**). Accordingly, the predefined amount of varnish **54** fill may then be arranged within the first and second gaps **52-1**, **52-2** between the mounting bosses **68**. In the stator side view shown in FIG. **5**, the mounting bosses **68** may be arranged on or proximate to the first stator end **32-1**. In such an embodiment, the varnish **54** may be concentrated near the first stator end **32-1** and fill greater than 90% of each of the first and second gaps **52-1**, **52-2** axially proximate the mounting bosses **68**.

[0036] The detailed description and the drawings or figures are supportive and descriptive of the disclosure, but the scope of the disclosure is defined solely by the claims. While some of the best modes and other embodiments for carrying out the claimed disclosure have been described in detail, various alternative designs and embodiments exist for practicing the disclosure defined in the appended claims. Furthermore, the embodiments shown in the drawings, or the characteristics of various embodiments mentioned in the present description are not necessarily to be understood as embodiments independent of each other. Rather, it is possible that each of the characteristics described in one of the examples of an embodiment may be combined with one or a plurality of other desired characteristics from other embodiments, resulting in other embodiments not described in words or by reference to the drawings. Accordingly, such other embodiments fall within the framework of the scope of the appended claims.

Claims

1. An electric motor comprising: a stator having a stator core constructed from a ferromagnetic material and having an external stator surface; wherein: the stator core includes a stator core body and a plurality of stator teeth extending therefrom; and the plurality of stator teeth define conductor slots therebetween; and wherein: the stator additionally includes: a plurality of stator conductors arranged within the conductor slots; and a slot liner arranged within each conductor slot and surrounding the corresponding stator conductors; a first gap is established between each stator conductor and the corresponding slot liner; and a second gap is established between each slot liner and the neighboring stator teeth; and a predetermined amount of varnish is arranged within each of the first gap and the second gap and thereby configured to limit an amount of open space within the first and second gaps that is free from the varnish and regulate viscous damping of the electric motor.

2. The electric motor according to claim 1, further comprising a lubrication system configured to supply oil to the stator, wherein a portion of the oil fills the open space within the first and second gaps during operation of the electric motor to thereby affect noise, vibration, and harshness (NVH) characteristics of the electric motor.

3. The electric motor according to claim 1, wherein the varnish fills up to 80% of each of the first and second gaps.

4. The electric motor according to claim 1, wherein the varnish is arranged away from relatively high vibration angular positions.

5. The electric motor according to claim 4, wherein the varnish arranged away from the relatively high vibration angular positions fills greater than 90% of each of the first and second gaps.

6. The electric motor according to claim 4, wherein the varnish arranged proximate the relatively high vibration angular positions fills 50% of each of the first and second gaps.

7. The electric motor according to claim 4, wherein the stator core includes a plurality of adjacent stator laminations arranged along the rotational axis, and wherein the amount of varnish is varied along the rotational axis.

8. The electric motor according to claim 4, wherein, in a plan view, the stator core includes a plurality of circumferentially arranged mounting bosses defining electric motor constraint locations, wherein the relatively high vibration angular positions are disposed between the mounting bosses, and wherein the predetermined amount of varnish is applied within the first and second gaps between the mounting bosses.

9. The electric motor according to claim 8, wherein, in a side view, the stator core includes a first stator end and an opposite second stator end, and wherein the mounting bosses are arranged on the first stator end, and wherein the varnish fills greater than 90% of each of the first and second gaps axially proximate the mounting bosses.

10. The electric motor according to claim 1, wherein the stator includes a stator inside diameter (ID) and a stator outside diameter (OD), and wherein the amount of varnish is varied in a radial direction between the stator ID and the stator OD.

11. A motor vehicle comprising: an electric motor configured to generate torque for propulsion of the motor vehicle, the electric motor including: a stator having a stator core constructed from a ferromagnetic material and having an external stator surface; wherein: the stator core includes a stator core body and a plurality of stator teeth extending therefrom; and the plurality of stator teeth define conductor slots therebetween; and wherein: the stator additionally includes: a plurality of stator conductors arranged within the conductor slots; and a slot liner arranged within each conductor slot and surrounding the corresponding stator conductors; a first gap is established between each stator conductor and the corresponding slot liner; and a second gap is established between each slot liner and the neighboring stator teeth; and a predetermined amount of varnish is arranged within each of the first gap and the second gap and thereby configured to limit an amount of open space within the first and second gaps that is free from the varnish and regulate viscous damping of the electric motor.

12. The motor vehicle according to claim 11, wherein the electric motor additionally includes a lubrication system configured to supply oil to the stator, and wherein a portion of the oil fills the open space within the first and second gaps during operation of the electric motor to thereby affect noise, vibration, and harshness (NVH) characteristics of the electric motor.

13. The motor vehicle according to claim 11, wherein the varnish fills up to 80% of each of the first and second gaps.

14. The motor vehicle according to claim 11, wherein the varnish is arranged away from relatively high vibration angular position.

15. The motor vehicle according to claim 14, wherein the varnish arranged away from the relatively high vibration angular positions fills greater than 90% of each of the first and second gaps.

16. The motor vehicle according to claim 14, wherein the varnish arranged proximate the relatively high vibration angular positions fills 50% of each of the first and second gaps.

17. The motor vehicle according to claim 14, wherein, in a plan view, the stator core includes a plurality of circumferentially arranged mounting bosses defining electric motor constraint locations, wherein the relatively high vibration angular positions are disposed between the mounting bosses, and wherein the predetermined amount of varnish is applied within the first and second gaps between the mounting bosses.

18. The motor vehicle according to claim 17, wherein, in a side view, the stator core includes a first stator end and an opposite second stator end, and wherein the mounting bosses are arranged on the first stator end, and wherein the varnish fills greater than 90% of each of the first and second gaps axially proximate the mounting bosses.

19. The motor vehicle according to claim 11, wherein the stator includes a stator inside diameter (ID) and a stator outside diameter (OD), and wherein the amount of varnish is varied in a radial direction between the stator ID and the stator OD.

20. An electric motor comprising: a stator having a stator core constructed from a ferromagnetic material and having an external stator surface; wherein: the stator core includes: a stator core body and a plurality of stator teeth extending therefrom; and in a plan view, a plurality of circumferentially arranged mounting bosses defining electric motor constraint locations; and the plurality of stator teeth define conductor slots therebetween; wherein: the stator additionally includes: a plurality of stator conductors arranged within the conductor slots; and a slot liner arranged within each conductor slot and surrounding the corresponding stator conductors; a first gap is established between each stator conductor and the corresponding slot liner; and a second gap is established between each slot liner and the neighboring stator teeth; and a predetermined amount of varnish is arranged within each of the first gap and the second gap away from relatively high vibration angular position and thereby configured to limit an amount of open space within the first and second gaps that is free from the varnish and regulate viscous damping of the electric motor; and wherein: the relatively high vibration angular positions are disposed between the mounting bosses; and the predetermined amount of varnish is applied within the first and second gaps between the mounting bosses.