United States Patent Application Publication	20250266731
Kind Code	A1
Publication Date	August 21, 2025
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Electric Motors with Coil Units Having Radially Offset Ends Extending from Stators

Abstract

Described herein are electric motors with stators comprising multiple sets of fluidic pathways, e.g., a plurality of fluid-passage slots, a plurality of first-fluid-recirculating slots, and a plurality of second-fluid-recirculating slots. The plurality of fluid-passage slots extends through the stator parallel to the primary axis between the coil-interconnection side and the bus-bar side and circumferentially offset from each other. The cooling fluid can pass through the stator using these slots. The plurality of first-fluid-recirculating slots and the plurality of second-fluid-recirculating slots extend to and open only at one of the coil-interconnection side or the bus-bar side. Furthermore, each of the plurality of first-fluid-recirculating slots is fluidically coupled to one of the plurality of second-fluid-recirculating slots. As such, the cooling fluid enters and leaves these recirculating slots from the same side of the stator. Overall, the stator cooling may be also used to redistribute the cooling fluid within a drive unit.

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Family ID: **1000008586958**

Appl. No.: **19/194387**

Filed: **April 30, 2025**

Related U.S. Application Data

parent US continuation 18462219 20230906 parent-grant-document US 11949306 child US 18591339
parent US continuation-in-part 18591339 20240229 parent-grant-document US 12316184 child US 19194387
us-provisional-application US 63374714 20220906

Publication Classification

Int. Cl.: **H02K3/50** (20060101); **B60K1/00** (20060101); **H02K1/20** (20060101); **H02K3/14** (20060101); **H02K3/24** (20060101)

U.S. Cl.:

CPC **H02K3/50** (20130101); **H02K1/20** (20130101); **H02K3/14** (20130101); **H02K3/24** (20130101); B60K1/00 (20130101); H02K2203/09 (20130101)

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation-in-part of U.S. patent application Ser. No. 18/591,339, filed on 2024 Feb. 29, which is a continuation of U.S. patent application Ser. No. 18/462,219, filed on 2023 Sep. 6 and issued as U.S. Pat. No. 11,949,306 on 2024 Apr. 2, which claims the benefit under 35 U.S.C. § 119 (e) of U.S. Provisional Patent Application 63/374,714, filed on 2022 Sep. 6, both of which are incorporated herein by reference in their entirety for all purposes.

BACKGROUND
[0002] Electric motors are used in electric vehicles and other applications to produce mechanical energy from electrical energy. An electric motor can include a rotor rotating within a stator such that both components generate respective magnetic fields causing the rotation. A stator can include a coil (e.g., a wire) protruding through the stator and forming windings through the stator. An electric current is passed through the coil to generate magnetic fields. In some electric motors, multi-phase electric currents are used. A specific example of such electric motors is fractional-slot-winding motors, in which the conductors carrying the same phase occupy a fractional number of slots. However, conventional fractional-slot-winding motors are hard to manufacture and tend to have large offsets on each side of the stator, which can be referred to as winding extensions. Because of these winding complexities and offsets, fractional-slot-winding motors can be bulky, which negatively impacts the torque density. Furthermore, conventional fractional-slot-winding motors tend to have many unique components (to form these complex windings), which makes these motors difficult to fabricate and expensive.
[0003] What is needed are new fractional-slot-winding motors with increased torque densities and fewer unique components.
SUMMARY
[0004] Described herein are electric motors with stators comprising multiple sets of fluidic pathways, e.g., a plurality of fluid-passage slots, a plurality of first-fluid-recirculating slots, and a plurality of second-fluid-recirculating slots. The plurality of fluid-passage slots extends through the stator parallel to the primary axis between the coil-interconnection side and the bus-bar side and circumferentially offset from each other. The cooling fluid can pass through the stator using these slots. The plurality of first-fluid-recirculating slots and the plurality of second-fluid-recirculating slots extend to and open only at one of the coil-interconnection side or the bus-bar side. Furthermore, each of the plurality of first-fluid-recirculating slots is fluidically coupled to one of the plurality of second-fluid-recirculating slots. As such, the cooling fluid enters and leaves these recirculating slots from the same side of the stator. Overall, the stator cooling may be also used to redistribute the cooling fluid within a drive unit.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. **1**A is a schematic perspective view of an electric vehicle comprising a fractional-slot-winding motor integrated into a powertrain assembly further comprising a gearbox and a differential, in accordance with some examples.

[0006] FIG. **1**B is a schematic perspective view of a powertrain assembly comprising a fractional-slot-winding motor, a gearbox, and a differential, in accordance with some examples.

[0007] FIG. **1**C is a schematic top view of the powertrain assembly in FIG. **1**B, in accordance with some examples.

[0008] FIG. **2**A is a schematic perspective view of a fractional-slot-winding motor, in accordance with some examples.

[0009] FIG. **2**B is a schematic top view of the fractional-slot-winding motor in FIG. **2**A and an expanded view of a portion of the rotor illustrating a plurality of stator slots, a plurality of fluid-passage slots, and a plurality of assembly slots, in accordance with some examples.

[0010] FIG. **2**C is a schematic side view of the fractional-slot-winding motor in FIG. **2**A illustrating the ends of coil units at the coil-interconnection side positioned closer to the motor primary axis than the protruding portions of the same coil units, in accordance with some examples.

[0011] FIG. **2**D is a schematic perspective view of a stator, which can be used in an electric motor, such as a fractional-slot-winding motor, in accordance with some examples.

[0012] FIG. **2**E is a schematic front view of a stator or, more specifically, of a return-passage cover and various openings through the return-passage cover, in accordance with some examples.

[0013] FIG. **2**F is a schematic back view of a stator or, more specifically, of a stator base and various openings through the stator base, in accordance with some examples.

[0014] FIG. **2**G is a schematic planar view of a portion of a return-passage cover and various openings through the return-passage cover, in accordance with some examples.

[0015] FIG. **2**H is a schematic planar view of a portion of a return-passage ring and various openings through the return-passage ring, in accordance with some examples.

[0016] FIG. **2**I is a schematic planar view of a portion of a stator base and various openings through the stator base, in accordance with some examples.

[0017] FIG. **2**J is a schematic cross-sectional of a stator illustrating a fluid-passage slot and a stator slot extending through each of the stator base, return-passage ring, and return-passage cover, in accordance with some examples.

[0018] FIG. **2**K is a schematic cross-sectional of a stator illustrating an inlet-fluid passage and an outlet fluid passage extending through each of the stator base and also illustrating a return passage extending through the return-passage ring and fluidically connecting the inlet-fluid passage and outlet fluid passage, in accordance with some examples.

[0019] FIG. **3**A is a schematic perspective view of a bus-bar assembly for use in a fractional-slot-winding motor, in accordance with some examples.

[0020] FIG. **3**B is a schematic perspective view of the bus-bar assembly in FIG. **3**A without the insulator, in accordance with some examples.

[0021] FIG. **3**C is a schematic top view of the bus-bar assembly in FIG. **3**A illustrating the circumferential span of the bus-bar assembly, in accordance with some examples.

[0022] FIGS. **4**A and **4**B are schematic side views of a dual-leg coil unit and a single-leg coil unit, identifying various components of these coil units, in accordance with some examples.

[0023] FIG. **5**A is a schematic side view of one example of a dual-leg coil unit, which may be referred to as a first-type-dual-leg coil unit or a layer-jump coil unit/hairpin.

[0024] FIG. **5**B is a schematic side view of the dual-leg coil unit in FIG. **5**A, protruding through a stator, in accordance with some examples.

[0025] FIG. **5**C is a schematic top view of the dual-leg coil unit in FIG. **5**A, protruding through a stator, in accordance with some examples.
[0026] FIG. **6**A is a schematic side view of another example of a dual-leg coil unit, which may be referred to as a second-type-dual-leg coil unit or a plus-one-type-one coil unit/hairpin.
[0027] FIG. **6**B is a schematic side view of the dual-leg coil unit in FIG. **6**A, protruding through a stator, in accordance with some examples.
[0028] FIG. **6**C is a schematic top view of the dual-leg coil unit in FIG. **6**A, protruding through a stator, in accordance with some examples.
[0029] FIG. **7**A is a schematic side view of yet another example of a dual-leg coil unit, which may be referred to as a third-type-dual-leg coil unit or a plus-one-type-two coil unit/hairpin.
[0030] FIG. **7**B is a schematic side view of the dual-leg coil unit in FIG. **7**A, protruding through a stator, in accordance with some examples.
[0031] FIG. **7**C is a schematic top view of the dual-leg coil unit in FIG. **7**A, protruding through a stator, in accordance with some examples.
[0032] FIG. **8**A is a schematic side view of a further example of a dual-leg coil unit, which may be referred to as a fourth-type-dual-leg coil unit or a standard-type-one coil unit/hairpin.
[0033] FIG. **8**B is a schematic side view of the dual-leg coil unit in FIG. **8**A, protruding through a stator, in accordance with some examples.
[0034] FIG. **8**C is a schematic top view of the dual-leg coil unit in FIG. **8**A, protruding through a stator, in accordance with some examples.
[0035] FIG. **9**A is a schematic side view of another example of a dual-leg coil unit, which may be referred to as a fifth-type-dual-leg coil unit or a standard-type-two coil unit/hairpin.
[0036] FIG. **9**B is a schematic side view of the dual-leg coil unit in FIG. **9**A, protruding through a stator, in accordance with some examples.
[0037] FIG. **9**C is a schematic top view of the dual-leg coil unit in FIG. **9**A, protruding through a stator, in accordance with some examples.
[0038] FIG. **10**A is a schematic side view of yet another example of a dual-leg coil unit, which may be referred to as a sixth-type-dual-leg coil unit or a looped-type-one coil unit/hairpin.
[0039] FIG. **10**B is a schematic side view of the dual-leg coil unit in FIG. **10**A, protruding through a stator, in accordance with some examples.
[0040] FIG. **10**C is a schematic top view of the dual-leg coil unit in FIG. **10**A, protruding through a stator, in accordance with some examples.
[0041] FIG. **11**A is a schematic side view of a further example of a dual-leg coil unit, which may be referred to as a seventh-type-dual-leg coil unit or a looped-type-two coil unit/hairpin.
[0042] FIG. **11**B is a schematic side view of the dual-leg coil unit in FIG. **11**A, protruding through a stator, in accordance with some examples.
[0043] FIG. **11**C is a schematic top view of the dual-leg coil unit in FIG. **11**A, protruding through a stator, in accordance with some examples.
[0044] FIG. **12**A is a schematic side view of one example of a single-leg coil unit, which may be referred to as a first-type-single-leg coil unit or an extended-type-one coil unit/hairpin.
[0045] FIG. **12**B is a schematic side view of the single-leg coil unit in FIG. **12**A, protruding through a stator, in accordance with some examples.
[0046] FIG. **12**C is a schematic top view of the single-leg coil unit in FIG. **12**A, protruding through a stator, in accordance with some examples.
[0047] FIG. **13**A is a schematic side view of another example of a single-leg coil unit, which may be referred to as a second-type-single-leg coil unit or an extended-type-two coil unit/hairpin.
[0048] FIG. **13**B is a schematic side view of the single-leg coil unit in FIG. **13**A, protruding through a stator, in accordance with some examples.
[0049] FIG. **13**C is a schematic top view of the single-leg coil unit in FIG. **13**A, protruding through a stator, in accordance with some examples.

DETAILED DESCRIPTION

[0050] In the following description, numerous specific details are outlined to provide a thorough understanding of the presented concepts. The presented concepts may be practiced without some or all these specific details. In other instances, well-known process operations have not been described in detail to not unnecessarily obscure the described concepts. While some concepts will be described in conjunction with the specific embodiments, it will be understood that these embodiments are not intended to be limiting.

INTRODUCTION

[0051] Electric motors can be used in various power systems, such as electric vehicles. Often, such applications require high power densities from electric motors, e.g., restricting the motor size while demanding high power outputs. The motor size can be reduced while the efficiency can be increased by increasing the volume of coil units passing through the stator, which can be achieved by using certain cross-sectional shapes (e.g., shapes with relatively sharp corners) to achieve higher slot-to-fill ratios by reducing the spacing around the coil units. The volume of coil units passing through the stator can be also increased by increasing the cross-sectional area of each coil unit by minimizing the number of coil units passing through a given cross-sectional area. Specifically, the spacing and the insulator between individual coil units need to be minimized.

[0052] Furthermore, the routing (e.g., winding) difficulty often results in larger winding extensions at each side of the stator. Larger (tall) winding extensions increase the overall motor size thereby reducing its power density. Using individual coil units, rather than a continuous wound wire, can simplify these windings complexities but increases the number of connections required among these coil units. Furthermore, the type and connections among the coil units depend on the motor type and can be quite complex for fractional-slot-winding motors. As a result, fractional-slot-winding motors are not commonly used because of these complexities resulting in higher costs.

[0053] However, fractional-slot-winding motors offer several advantages over other motor types, such as integer slot electric motors. One notable benefit is their ability to significantly reduce cogging torque, which occurs when the rotor poles align with magnetic stator features, resulting in an oscillatory torque. By minimizing cogging torque, fractional-slot-winding motors effectively decrease noise, vibration, and harshness in the motor itself and surrounding structures like vehicle frames. Cogging torque is a phenomenon that affects the smooth operation of electric motors. It occurs when the magnetic attraction between the rotor and stator poles causes irregularities in the motor's rotational movement. This can lead to noticeable vibrations, audible noise, and undesirable effects on the motor's performance.

[0054] Fractional-slot-winding motors utilize a unique winding configuration that reduces cogging torque compared to motors with integer slot windings. The winding arrangement divides each slot into smaller fractional slots, increasing the number of pole pairs. This design effectively spreads the rotor poles across a greater number of stator teeth, minimizing the chances of pole alignment and reducing cogging torque. By reducing cogging torque, fractional-slot-winding motors provide smoother and quieter operation. This is particularly beneficial in applications where noise, vibration, and harshness (NVH) levels need to be minimized, such as in electric vehicles. NVH reduction not only improves the overall comfort of vehicle occupants but also enhances the longevity and reliability of the motor by minimizing stress on its components. Additionally, the lower cogging torque of fractional-slot-winding motors can have a positive impact on energy efficiency. Reduced cogging torque means less energy is wasted in overcoming the resistance caused by cogging, resulting in improved overall motor efficiency.

[0055] Described herein are fractional-slot-winding motors addressing various issues described above. Specifically, a fractional-slot-winding motor can be used in electric vehicles, one example of which is presented in FIG. **1**A. FIG. **1**A illustrates electric vehicle **100** or, more specifically, the frame portion of electric vehicle **100** such as medium-duty trucks (e.g., delivery trucks, Class 2-5 trucks). For example, Class 2 medium-duty trucks have a gross vehicle weight rating (GVWR) between 2,722 and 4,536 kilograms and are used, e.g., for local delivery, small-scale construction, and utility services (as box trucks, flatbed trucks, and tow trucks). Class 3 medium-duty trucks have a GVWR ranging from 4,536 to 6,350 kilograms; Class 4 trucks have a GVWR between 6,350 and 7,257 kilograms; Class 5 trucks have a GVWR between from 7,257 to 8,845 kilograms (e.g., used for towing large trailers, carrying construction materials, and operating specialized equipment). All of the listed classes are within the scope.

[0056] It should be noted that medium-duty trucks tend to have different drive cycles than, e.g., passenger cars and light-duty trucks. For example, medium-duty trucks (e.g., used for delivery) may be operated at lower speeds and require higher torques, which translates into different requirements/design features for fractional-slot-winding motors as further described below. For example, a fractional-slot-winding motor may have a plurality of stator slots and a plurality of coil units that are arranged into a 1.5-slot per pole per phase configuration, which enables these lower speed and higher torque operating characteristics. Lighter/faster vehicles tend to have a higher number of slots per pole per phase.

[0057] In some examples, a fractional-slot-winding motor has a nominal power of between about 300-350 kW. In the same or other examples, the fractional-slot-winding motor has a nominal torque of between about 2000-3500 Nm. In some examples, a fractional-slot-winding motor has a top rotational speed of between about 8,000-12,000 RPM. In some examples, the components of the fractional-slot-winding motor are such that the fractional-slot-winding motor is operational at a temperature of up to 220° C. For comparison, conventional fractional-slot-winding motors are capable of operating up to only 180° C.

[0058] Referring to FIG. **1**A, in some examples, electric vehicle **100** comprises powertrain assembly **110** comprising fractional-slot-winding motor **200** and other components (e.g., a gearbox). Electric vehicle **100** further comprises frame **130** used for supporting powertrain assembly **110** relative to other components of electric vehicle **100**. Frame **130** can be specially configured to accommodate powertrain assembly **110** while maintaining frame **130** close to the ground. For example, a portion of powertrain assembly **110** can protrude in between the two rails of frame **130**. Electric vehicle **100** further comprises one or more battery packs **120**, which can be attached to and supported by frame **130**. In some examples, battery packs **120** are positioned between the frame rails such that these frame rails protect these battery pack **120** and provide a compact arrangement.

[0059] Referring to FIG. **1**B, in some examples, powertrain assembly **110** comprises fractional-slot-winding motor **200**, which provides its output to gearbox **190**. In some examples, fractional-slot-winding motor **200** and gearbox **190** share the same housing, cooling systems, and/or lubrication systems. For example, a plurality of fluid-passage slots in fractional-slot-winding motor **200** can be fluidically coupled to the common fluid management system (e.g., a pump) of powertrain assembly **110**. In some examples, powertrain assembly **110** comprises differential **195**, which may be a separate unit or integrated into gearbox **190**. Differential **195** is mechanically coupled to the wheels of electric vehicle **100** and provides torque to these wheels.

[0060] FIG. **1**C is a schematic top view of powertrain assembly **110** illustrating the orientation of fractional-slot-winding motor **200** relative to half-shafts **197** connecting differential **195** to the wheels of electric vehicle **100**. In some examples, primary axis **201** of fractional-slot-winding motor **200** is parallel to the half-shafts **197**. As such, the axis defining torque input (provided by fractional-slot-winding motor **200**) and the axis defining the torque output by powertrain assembly **110** are parallel in this example.

Examples of Fractional-Slot-Winding Motors

[0061] Referring to FIGS. **2**A-**2**C, in some examples, fractional-slot-winding motor **200** comprises stator **290**, bus-bar assembly **270**, and plurality of coil units **280**. Stator **290** has coil-interconnection side **291** and bus-bar side **292**. Furthermore, stator **290** comprises plurality of stator slots **299** extending through stator **290** between coil-interconnection side **291** and bus-bar side **292** and circumferentially offset relative to each other. In some examples, stator **290** comprises sixty three (63) stator slots **299**. Each coil slot can accommodate four coil units **280**. The radial positions of each of the four coil units in each stator slot is identified in the expanded partial view of stator **290** in FIG. **1**B by four diameters (D**1**, D**2**, D**3**, and D**4**). These diameters define the radial offset (from primary axis **201**). Besides the radial offset with stator slots **299** (i.e., the portions of coil units **280** extending through stator **290**), plurality of coil units **280** can also have various radial outside of stator **290**.

[0062] In some examples, stator **290** comprises plurality of fluid-passage slots **293** extending through stator **290** between coil-interconnection side **291** and bus-bar side **292** and circumferentially offset relative to each other. Plurality of fluid-passage slots **293** is configured to provide a coolant flow between coil-interconnection side **291** and bus-bar side **292** and through stator **290** for cooling stator **290**. The cross-sectional area of each cooling slot **293** can be smaller than that of stator slots **299**. However, the number of cooling slot **293** can be greater than that of stator slots **299**. Each of plurality of fluid-passage slots **293** can have a greater radial offset from primary motor axis **201** than each of plurality of stator slots **299**. In some examples, fluid-passage slots **293** are positioned proximate to the outer surface of stator **290**.

[0063] Furthermore, in some examples, stator **290** comprises plurality of assembly slots **296** extending through stator **290** between coil-interconnection side **291** and bus-bar side **292** and circumferentially offset relative to each other. Each of plurality of assembly slots **296** has a greater radial offset from a primary motor axis **201** than each of plurality of fluid-passage slots **293**. For example, stator **290** can be formed by stacking a large number of thin sheets that are laminated together. A set of fasteners can be protruded through assembly slots **296**, e.g., to maintain this stack together and/or to support fractional-slot-winding motor **200** relative to its attachment point (e.g., within powertrain assembly **110**).

Examples of Fluid Circulations Through Stators

[0064] FIG. **2**D is a schematic perspective view of a stator **290**, which can be used in an electric motor, such as a fractional-slot-winding motor, in accordance with some examples. As noted above, the stator **290** comprises a coil-interconnection side **291** and a bus-bar side **292**, opposite the coil-interconnection side **291**. These sides may be also referred to as a first side and a second side, simply to differentiate from each other and provide a spatial reference. FIG. **2**D also illustrates the stator **290** comprising a stator base **290***a*, a return passage ring **290***b*, and a return-passage cover **290***c* axially stacked along the primary axis **201** such that the return passage ring **290***b* is positioned between the stator base **290***a* and the return-passage cover **290***c*. Various configurations of these components provide fluid circulation pathways described below.

[0065] FIG. **2**E is a schematic front view of a stator **290** or, more specifically, of a return-passage cover and various openings through the return-passage cover **290***c*, in accordance with some examples. FIG. **2**F is a schematic back view of a stator **290** or, more specifically, of a stator base **290***a* and various openings through the stator base, in accordance with some examples. In the illustrated examples, the plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295** extend to the bus-bar side **292**. In other examples, the plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295** extend to the coil-interconnection side **291**. In either example, the plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295** extend through the stator base **290***a* but not through the return-passage cover **290***c*. Furthermore, the plurality of fluid-passage slots **293** and the plurality of stator slots **299** extend through both the stator base **290***a* and return-passage cover **290***c* as well as the return passage ring **290***b*.

[0066] Overall, the stator **290** comprises a plurality of stator slots **299** used for extending the plurality of coil units **280** through the stator **290**. The stator **290** also comprises a plurality of fluid-passage slots **293** providing a coolant flow between coil-interconnection side **291** and bus-bar side **292** and through the stator **290** for cooling the stator **290**. It should be noted the coolant can enter on the bus-bar side **292** and leave from the coil-interconnection side **291** or, alternately, enter on the coil-interconnection side **291** and leave from the bus-bar side **292**. For example, the coolant may be then delivered to other components of the electric motor and/or powertrain assembly **110**.

[0067] Finally, the stator **290** comprises the plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295**, which are fluidically interconnected in pairs, i.e., each of the plurality of first-fluid-recirculating slots **294** is fluidically coupled to one of the plurality of second-fluid-recirculating slots **295**. The plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295** also provide a coolant flow through the stator **290** for cooling the stator **290**. However, the coolant enters and exits from the same side of the stator **290**, e.g., either the coil-interconnection side **291** or the bus-bar side **292**. Specifically, the plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295** extend to and open only at one of the coil-interconnection side **291** or the bus-bar side **292**. In some examples (e.g., shown in FIG. **2**K), the plurality of first-fluid-recirculating slots **294** is used for incoming coolant, while the plurality of second-fluid-recirculating slots **295** is used for discharging the coolant from the stator **290**. Alternatively, the plurality of second-fluid-recirculating slots **295** is used for incoming coolant, while the plurality of first-fluid-recirculating slots **294** is used for discharging the coolant from the stator **290**.

[0068] The primary distinction between the plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295** is their radial offset from the primary axis **201**. Specifically, the plurality of first-fluid-recirculating slots **294** is radially offset from the primary axis **201** by a first radius (R**1**). The plurality of second-fluid-recirculating slots **295** is radially offset from the primary axis **201** by a second radius (R**2**), smaller than the first radius (R**1**). In other words, the plurality of second-fluid-recirculating slots **295** may be positioned closer to the primary axis **201** than the plurality of first-fluid-recirculating slots **294**. For purposes of this disclosure, the radial offset is measured between the primary axis **201** and the geometric center of the cross-section (of slots) within a plane perpendicular to the primary axis **201**.

[0069] Referring to FIG. **2**F, in some examples, the plurality of fluid-passage slots **293** and the plurality of first-fluid-recirculating slots **294** are circumferentially offset from each other. When the plurality of fluid-passage slots **293** and the plurality of first-fluid-recirculating slots **294** also have the same radial offset, the plurality of fluid-passage slots **293** and the plurality of first-fluid-recirculating slots **294** may be alternating along the circumference of the stator **290**. Overall, in some examples, the plurality of fluid-passage slots **293** is radially offset from the primary axis **201** by a third radius (R**3**), the same as the first radius (R**1**).

[0070] Referring to FIGS. **2**G and **2**F, in some examples, the plurality of stator slots **299** is radially offset from the primary axis **201** by a fourth radius (R**4**), smaller than the first radius (R**1**). As shown, the plurality of stator slots **299** may be positioned closer to the inner diameter of the stator **290** and, in some examples, may be open to the inner cavity of the stator **290** (e.g., have small slots interconnecting the plurality of stator slots **299** with the inner cavity).

[0071] Referring to FIG. **2**F, in some examples, the plurality of stator slots **299** and the plurality of second-fluid-recirculating slots **295** are circumferentially offset from each other. Specifically, the plurality of stator slots **299** and the plurality of second-fluid-recirculating slots **295** may be alternating along the circumference of the stator **290**. In some examples, at least a portion of the plurality of second-fluid-recirculating slots **295** protrudes in between the plurality of stator slots **299** (based on the radial offset). This feature allows for more efficient heat transfer between the plurality of coil units **280** (protruding through the plurality of stator slots **299**) and the coolant flowing through the plurality of second-fluid-recirculating slots **295**.

[0072] Referring to FIGS. **2**F, **2**H, and **2**I, in some examples, each of the plurality of first-fluid-recirculating slots **294** is circumferentially aligned with one of the plurality of second-fluid-recirculating slots **295**. This alignment allows for more efficient interconnecting of the plurality of second-fluid-recirculating slots **295** and the plurality of first-fluid-recirculating slots **294** using a plurality of return passages **297**, e.g., shown in FIG. **2**H. For example, the plurality of return passages **297** may extend radially between the plurality of second-fluid-recirculating slots **295** and the plurality of first-fluid-recirculating slots **294**.

[0073] Referring to FIG. **2**K, in some examples, the stator **290** is defined by a stator length (L) extending along the primary axis **201** between the coil-interconnection side **291** and the bus-bar side **292**. Each of the plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295** extends parallel to the primary axis **201** along at least 80%, at least 90%, or even at least 95% of the stator length (L). It should be noted that this ratio is less than 100% since the plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295** are not open on one side of the stator **290** (e.g., the bus-bar side **292** as shown in FIG. **2**K).

[0074] Referring to FIG. **2**K, in some examples, the first end of each of the plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295** extends to and is open only at one of the coil-interconnection side **291** (e.g., shown in FIG. **2**K) or the bus-bar side **292**. The second end of each of the plurality of first-fluid-recirculating slots **294** is fluidically coupled to the second end of one of the plurality of second-fluid-recirculating slots **295** (e.g., proximate to the bus-bar side **292** as shown in FIG. **2**K). As shown in FIGS. **2**H and **2**K, the second end of each of the plurality of first-fluid-recirculating slots **294** is fluidically coupled to the second end of one of the plurality of second-fluid-recirculating slots **295** by a return passage **297**, extending radially within the stator **290**.

[0075] Referring to FIGS. **2**G-**2**K, in some examples, the stator **290** comprises a stator base **290***a*, a return passage ring **290***b*, and a return-passage cover **290***c* axially stacked along the primary axis **201** such that the return passage ring **290***b* is positioned between the stator base **290***a* and the return-passage cover **290***c*.

[0076] The plurality of return passages **297** is formed by the return passage ring **290***b*, e.g., by a set of slots extending radially. One end of each of the plurality of return passages **297** is aligned with a corresponding one of the plurality of first-fluid-recirculating slots **294**, while the other end is aligned with a corresponding one of the plurality of second-fluid-recirculating slots **295** (e.g., as shown in FIG. **2**H). Furthermore, each of the plurality of return passages **297** is circumferentially aligned with a corresponding one of the plurality of first-fluid-recirculating slots **294** and is also circumferentially aligned with a corresponding one of the plurality of second-fluid-recirculating slots **295**.

[0077] Referring to FIG. **2**J, in some examples, each of the plurality of stator slots **299**, the plurality of fluid-passage slots **293**, the plurality of first-fluid-recirculating slots **294**, and the plurality of second-fluid-recirculating slots **295** extends through the stator base **290***a*. The plurality of first-fluid-recirculating slots **294** and the plurality of second-fluid-recirculating slots **295** extend to the return passage ring **290***b* but do extend through the return-passage cover **290***c*. The plurality of stator slots **299** and the plurality of fluid-passage slots **293** further extend through the return passage ring **290***b* and the return-passage cover **290***c*.

[0078] In some examples, the return passage ring **290***b* has a thickness of 3-7 millimeters or, more specifically, the 4-6 millimeters. In the same or other examples, the stator return-passage cover **290***c* has a thickness of 1-5 millimeters or, more specifically, the 1-3 millimeters. Furthermore, one of all of the stator base **290***a*, the return passage ring **290***b*, and the stator return-passage cover **290***c* may be formed as a collection of sheets stacked together along the primary axis **201**.

Examples of Bus-Bars

[0079] Referring to FIGS. **2**A-**2**C as well as FIGS. **3**A-**3**B, bus-bar assembly **270** comprises first bus bar **271**, second bus bar **272**, and third bus bar **273**, each connected to at least one of coil units **280**. In some examples, first bus bar **271** is connected to only one of plurality of coil units **280** (e.g., single-leg coil unit **260**). Similarly, second bus bar **272** can be connected to only one of plurality of coil units **280** (e.g., another single-leg coil unit **260**). Finally, third bus bar **273** can be connected to only one of plurality of coil units **280** (e.g., yet another single-leg coil unit **260**). Bus-bar assembly **270** is positioned adjacent to bus-bar side **292** of stator **290**.

[0080] In some examples, bus-bar assembly **270** further comprises neutral busbar **274**, electrically coupled to three of plurality of coil units **280**. Neutral busbar **274** is connected to three different coil units **280** (e.g., three different single-leg coil units **260**). In some examples, plurality of coil units **280** comprises only six single-leg coil units **260**, three of which are connected to first bus bar **271**, second bus bar **272**, and third bus bar **273** and three of which are connected to neutral busbar **274**. All other coil units **280** are dual-leg coil units **250**. In these examples, fractional-slot-winding motor **200** does not have any coil jumpers, which interconnect single-leg coil units **260** at bus-bar side **292** (besides the connections provided by neutral busbar **274**).

[0081] Furthermore, in some examples, bus-bar assembly **270** insulator **275**, which provides insulation among different bus bars while mechanically supporting these bus bars relative to each other. For example, insulator **275** can comprise a first insulator component, positioned between and supporting first bus bar **271** relative to neutral busbar **274**. Insulator **275** can also comprise a second insulator component, positioned between and supporting second bus bar **272** relative to the neutral busbar **274**. Finally, insulator **275** can also comprise a third insulator component, positioned between and supporting third bus bar **273** relative to neutral busbar **274**. In some examples, these three components of insulator **275** are disjoined structures.

[0082] Referring to FIG. **3**C, in some examples, bus-bar assembly **270** has a circumferential span (angle α) of less than 180 degrees, less than 90 degrees, or even less than 60°. This limited circumferential span reduces the size of fractional-slot-winding motor **200** by providing space for other components. This circumferential span is enabled by special locations of coil units **280** or, more specifically, single-leg coil units **260** within stator **290**. Furthermore, as noted above, each non-neutral bus bar forms only one attachment to the corresponding coil unit. As a reference, bus-bar assemblies typically form a full circle in these types of motors because of the multiple attachments and locations of these attachments.

[0083] Returning to FIG. **2**C, each coil unit **280** extends through stator **290** and is electrically coupled to at least one other coil unit **280** at coil-interconnection side **291**. For example, each single-leg coil unit is electrically coupled to only one other coil unit **280** at coil-interconnection side **291**. Each dual-leg coil unit is electrically coupled to two other coil units **280** at coil-interconnection side **291**. Furthermore, in some examples, one of the single-leg coil units is electrically coupled to first bus bar **271**, another one—to second bus bar **272**, and yet another one—to third bus bar **273**. Additional (three) single-leg coil units can be coupled to neutral busbar **274**. In some examples, plurality of coil units **280** form **14** electric poles in fractional-slot-winding motor **200**.

[0084] Referring to FIG. **2**C, in some examples, the ends of each coil unit **280** can be bent toward primary axis **201** of fractional-slot-winding motor **200** at least at coil-interconnection side **291** of stator **290**, therefore, reducing the size of the winding extensions and the overall size of fractional-slot-winding motor **200**. In other words, the end of each coil unit **280** extending from coil-interconnection side **291** is radially offset closer to primary axis **201** than the corresponding portion of that coil units **280** protruding through stator **290**. These coil portions may be also referred to as an interconnection-side extending portion and a protruding portion. In some examples, the radial offset is between 0.5 mm and 6 mm or, more specifically, between 1 mm and 5 mm. It should be noted that this radial offset can be used to reduce the overall size of fractional-slot-winding motor **200**, e.g., by pushing the protruding portions closer to primary axis **201**.

[0085] In some examples, the radial offset is different for different radial slot positions of the protruding portion. These radial slot positions are defined above with reference to FG. **1**B as D**1** (representing to the innermost slot position), D**2**, D**3**, and D**4** (representing to the outermost slot position). For example, the radial offset (RO**1**) for the innermost slot position (D**1**) can be greater than the radial offset (RO**4**) for the outermost slot position (D**4**). This difference in radial offset is used to simplify the wire routing on coil-interconnection side **291** and effectively reduce the protruding dimension (along primary axis **201**/Z-axis in FIG. **2**C). In some examples, the ratio of the innermost radial offset (RO**1**) to the outermost radial offset (RO**4**) is at least 2 or even at least 3 or even at least 4 such as between 2 and 10 or, more specifically, between 3 and 6. In some examples, the ratio of the innermost radial offset (RO**1**) is between 2 mm and 8 mm or, more specifically, between 3 mm and 5 mm. In the same or other examples, the ratio of the outermost radial offset (RO**4**) is between 0.2 mm and 4 mm or, more specifically, between 0.5 mm and 3 mm. As a reference, the diameter of the stator opening is between 250 mm and 300 mm.

Examples of Coil Units

[0086] Coil units **280** may have a rectangular cross-sectional profile (within the plane parallel to coil-interconnection side **291** or bus-bar side **292** of stator **290**). The rectangular profile ensure that more metal (a larger volume portion of coil units **280**) is positioned in each stator slot **299**. Furthermore, a large size of this rectangular cross-sectional profile may help to increase the metal fill. In some examples, each side of this rectangular cross-sectional profile is at least 2 mm, e.g., between 2-6 mm or, more specifically, between 3-5 mm.

[0087] As noted above, coil units **280** comprises dual-leg coil units **250** and single-leg coil units **260**. Dual-leg coil units **250** are only connected at coil-interconnection side **291** of stator **290**, e.g., to other dual-leg coil units **250** and single-leg coil units **260**. Single-leg coil units **260** are connected at both coil-interconnection side **291** and bus-bar side **292** of stator **290**. As noted above, single-leg coil units **260** are connected to bus-bar assembly **270** at bus-bar side **292**. In some examples, single-leg coil units **260** are only connected to bus-bar assembly **270** at bus-bar side **292**. Various examples of dual-leg coil units **250** and single-leg coil units **260** will now be described with reference to FIGS. **4**A-**13**C.

[0088] Referring to FIG. **4**A, each dual-leg coil unit **250** comprises turn portion **250***c*, first leg **250***d* comprising first end **250***a*, and second leg **250***e* comprising second end **250***b* such that turn portion **250***c* interconnects first leg **250***d* and second leg **250***e* and such that turn portion **250***c*, first leg **250***d*, and second leg **250***e* form a continuous monolithic structure. It should be noted that turn portion **250***c* of each dual-leg coil unit **250** extends from stator **290** at bus-bar side **292**. Turn portion **250***c* may be also referred to as a bus-bar-side extending portion of dual-leg coil unit **250**. A virtual interface between turn portion **250***c* and each of first leg **250***d* and second leg **250***e* can be defined by the start of straight portions of these legs. It should be noted that these straight portions at least partially protrude through stator **290**, which can be referred to as protruding portions. In some examples, the straight portions coincide with the protruding portions. Alternatively, the straight portions are longer than the protruding portions. Additional portions of first leg **250***d* and second leg **250***e* extend past the protruding portions and can be referred to as interconnection-side extending portions. These interconnection-side extending portions comprise first end **250***a* and second end **250***b*.

[0089] Referring to FIG. **4**B, in some examples, single-leg coil unit **260** comprises leg **260***b*, extending between first end **260***a* and second end **260***c*, opposite of first end **260***a*. Leg **260***b* partially protrudes through stator **290** and can be referred to as a protruding portion. In some examples, the straight portion of leg **260***b* coincides with the protruding portion. Alternatively, the straight portion is longer than the protruding portion.

[0090] Different types of dual-leg coil units **250** and/or different types of single-leg coil units **260** are within the scope as further described below with reference to FIGS. **5**A-**13**C. In some examples, the same fractional-slot-winding motor **200** can include multiple different types of dual-leg coil units **250** and/or multiple different types of single-leg coil units **260**, e.g., as indicated in the table below.

TABLE-US-00001 Quantity in One Motor Type of Coil Unit Alternative Name Example First-type-dual-leg coil unit Layer-jump coil unit 3 Second-type-dual-leg coil unit Plus-one-type-one coil unit 3 Third-type-dual-leg coil unit Plus-one-type-two coil unit 3 Fourth-type-dual-leg coil unit Standard-type-one coil unit 54 Fifth-type-dual-leg coil unit Standard-type-two coil unit 54 Sixth-type-dual-leg coil unit Looped-type-one coil unit 3 Seventh-type-dual-leg coil unit Looped-type-two coil unit 3 First-type-single-leg coil unit Extended-type-one coil unit 3 Second-type-single-leg coil unit Extended-type-two coil unit 3

Examples of Dual-Leg Coil Units

[0091] FIG. **5**A is a schematic side view of one example of dual-leg coil unit **250**, which may be referred to as first-type-dual-leg coil unit **251** or a layer-jump coil unit/hairpin. FIGS. **5**B and **5**C are schematic views of first-type-dual-leg coil unit **251** in FIG. **5**A, protruding through stator **290**, in accordance with some examples. Specifically, first-type-dual-leg coil unit **251** comprises turn portion **251***c*, first leg **251***d* terminating with first end **251***a*, and second leg **251***e* terminating with second end **251***b*. Turn portion **251***c*, first leg **251***d*, and second leg **251***e* of first-type-dual-leg coil unit **251** collectively form a continuous monolithic structure. Referring to FIG. **5**C, first leg **251***d* of first-type-dual-leg coil unit **251** protrudes through first first-type-dual-leg-coil slot **231***a* of plurality of stator slots **299**. Second leg **251***e* protrudes through second first-type-dual-leg-coil slot **231***b* of plurality of stator slots **299**. In this example, first first-type-dual-leg-coil slot **231***a* and second first-type-dual-leg-coil slot **231***b* are offset by 4 slots.

[0092] In some examples, (a) a portion of first leg **251***d* of first-type-dual-leg coil unit **251** protruding through stator **290** and (b) a portion of second leg **251***e* of first-type-dual-leg coil unit **251** protruding through stator **290** has different radial offsets from primary axis **201** (e.g., D**3** for the protruding portion of first leg **251***d* vs. D**2** for the protruding portion of second leg **251***e*). In other words, turn portion **251***c* of first-type-dual-leg coil unit **251** makes a radial “jump”. This radial jump should be distinguished from the radial offset that turn portion **251***c* of first-type-dual-leg coil unit **251** can have relative to the protruding portion of first leg **251***d* and also relative to the protruding portion of second leg **251***e*.

[0093] In some examples, first end **251***a* of first leg **251***d* of first-type-dual-leg coil unit **251** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of first leg **251***d* of first-type-dual-leg coil unit **251** protruding through stator **290**. Furthermore, second end **251***b* of second leg **251***e* of first-type-dual-leg coil unit **251** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of second leg **251***e* of first-type-dual-leg coil unit **251** protruding through stator **290**. However, in some examples, turn portion **251***c* of first-type-dual-leg coil unit **251** is radially offset further away from primary axis **201** than the portions of first leg **251***d* and second leg **251***e* of first-type-dual-leg coil unit **251** protruding through stator **290**, e.g., by between 1-5 millimeters, such as 2-4 millimeters, or about 3 millimeters.

[0094] FIG. **6**A is a schematic side view of another example of dual-leg coil unit **250**, which may be referred to as second-type-dual-leg coil unit **252** or a plus-one-type-one coil unit/hairpin. FIGS. **6**B and **6**C are schematic views of second-type-dual-leg coil unit **252** in FIG. **6**A, protruding through stator **290**, in accordance with some examples. Specifically, second-type-dual-leg coil unit **252** comprises turn portion **252***c*, first leg **252***d* terminating with first end **252***a*, and second leg **252***e* terminating with second end **252***b*. Turn portion **252***c*, first leg **252***d*, and second leg **252***e* of second-type-dual-leg coil unit **252** collectively form a continuous monolithic structure. Referring to FIG. **6**C, first leg **252***d* of second-type-dual-leg coil unit **252** protrudes through first second-type-dual-leg-coil slot **232***a* of plurality of stator slots **299**. Second leg **252***e* protrudes through second second-type-dual-leg-coil slot **232***b* of plurality of stator slots **299**. In this example, first second-type-dual-leg-coil slot **232***a* and second second-type-dual-leg-coil slot **232***b* are offset by 5 slots.

[0095] In some examples, (a) a portion of first leg **252***d* of second-type-dual-leg coil unit **252** protruding through stator **290** and (b) a portion of second leg **252***e* of second-type-dual-leg coil unit **252** protruding through stator **290** has different radial offsets from primary axis **201** (e.g., D**1** for the protruding portion of first leg **252***d* vs. D**2** for the protruding portion of second leg **252***e*). In other words, turn portion **252***c* of second-type-dual-leg coil unit **252** makes a radial “jump”. This radial jump should be distinguished from the radial offset that turn portion **252***c* of second-type-dual-leg coil unit **252** can have relative to the protruding portion of first leg **252***d* and also relative to the protruding portion of second leg **252***e*.

[0096] In some examples, first end **252***a* of first leg **252***d* of second-type-dual-leg coil unit **252** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of first leg **252***d* of second-type-dual-leg coil unit **252** protruding through stator **290**. Furthermore, second end **252***b* of second leg **252***e* of second-type-dual-leg coil unit **252** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of second leg **252***e* of second-type-dual-leg coil unit **252** protruding through stator **290**. However, in some examples, turn portion **252***c* of second-type-dual-leg coil unit **252** is radially offset further away from primary axis **201** than the portions of first leg **252***d* and second leg **252***e* of third-type-dual-leg coil unit **252** protruding through stator **290**, e.g., by between 1-5 millimeters, such as 2-4 millimeters, or about 3 millimeters.

[0097] FIG. **7**A is a schematic side view of yet another example of dual-leg coil unit **250**, which may be referred to as third-type-dual-leg coil unit **253** or a plus-one-type-two coil unit/hairpin. FIGS. **7**B and **7**C are schematic views of third-type-dual-leg coil unit **253** in FIG. **7**A, protruding through stator **290**, in accordance with some examples. Specifically, third-type-dual-leg coil unit **253** comprises turn portion **253***c*, first leg **253***d* terminating with first end **253***a*, and second leg **253***e* terminating with second end **253***b*. Turn portion **253***c*, first leg **253***d*, and second leg **253***e* of third-type-dual-leg coil unit **253** collectively form a continuous monolithic structure. Referring to FIG. **7**C, first leg **253***d* of third-type-dual-leg coil unit **253** protrudes through first third-type-dual-leg-coil slot **233***a* of plurality of stator slots **299**. Second leg **253***e* protrudes through second third-type-dual-leg-coil slot **233***b* of plurality of stator slots **299**. In this example, first third-type-dual-leg-coil slot **233***a* and second third-type-dual-leg-coil slot **233***b* are offset by 5 slots.

[0098] In some examples, (a) a portion of first leg **253***d* of third-type-dual-leg coil unit **253** protruding through stator **290** and (b) a portion of second leg **253***e* of third-type-dual-leg coil unit **253** protruding through stator **290** has different radial offsets from primary axis **201** (e.g., D**3** for the protruding portion of first leg **253***d* vs. D**4** for the protruding portion of second leg **253***e*). In other words, turn portion **253***c* of third-type-dual-leg coil unit **253** makes a radial “jump”. This radial jump should be distinguished from the radial offset that turn portion **253***c* of third-type-dual-leg coil unit **253** can have relative to the protruding portion of first leg **253***d* and also relative to the protruding portion of second leg **253***e*.

[0099] In some examples, first end **253***a* of first leg **253***d* of third-type-dual-leg coil unit **253** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of first leg **253***d* of third-type-dual-leg coil unit **253** protruding through stator **290**. Furthermore, second end **253***b* of second leg **253***e* of third-type-dual-leg coil unit **253** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of second leg **253***e* of third-type-dual-leg coil unit **253** protruding through stator **290**. However, in some examples, turn portion **253***c* of third-type-dual-leg coil unit **253** is radially offset further away from primary axis **201** than the portions of first leg **253***d* and second leg **253***e* of third-type-dual-leg coil unit **253** protruding through stator **290**, e.g., by between 1-5 millimeters, such as 2-4 millimeters, or about 3 millimeters.

[0100] FIG. **8**A is a schematic side view of a further example of dual-leg coil unit **250**, which may be referred to as fourth-type-dual-leg coil unit **254** or a standard-type-one coil unit/hairpin. FIGS. **8**B and **8**C are schematic views of fourth-type-dual-leg coil unit **254** in FIG. **8**A, protruding through stator **290**, in accordance with some examples. Specifically, fourth-type-dual-leg coil unit **254** comprises turn portion **254***c*, first leg **254***d* terminating with first end **254***a*, and second leg **254***e* terminating with second end **254***b*. Turn portion **254***c*, first leg **254***d*, and second leg **254***e* of fourth-type-dual-leg coil unit **254** collectively form a continuous monolithic structure. Referring to FIG. **8**C, first leg **254***d* of fourth-type-dual-leg coil unit **254** protrudes through first fourth-type-dual-leg-coil slot **234***a* of plurality of stator slots **299**. Second leg **254***e* protrudes through second fourth-type-dual-leg-coil slot **234***b* of plurality of stator slots **299**. In this example, first fourth-type-dual-leg-coil slot **234***a* and second fourth-type-dual-leg-coil slot **234***b* are offset by 4 slots.

[0101] In some examples, (a) a portion of first leg **254***d* of fourth-type-dual-leg coil unit **254** protruding through stator **290** and (b) a portion of second leg **254***e* of fourth-type-dual-leg coil unit **254** protruding through stator **290** has different radial offsets from primary axis **201** (e.g., D**1** for the protruding portion of first leg **254***d* vs. D**2** for the protruding portion of second leg **254***e*). In other words, turn portion **254***c* of fourth-type-dual-leg coil unit **254** makes a radial “jump”. This radial jump should be distinguished from the radial offset that turn portion **254***c* of fourth-type-dual-leg coil unit **254** can have relative to the protruding portion of first leg **254***d* and also relative to the protruding portion of second leg **254***e*.

[0102] In some examples, first end **254***a* of first leg **254***d* of fourth-type-dual-leg coil unit **254** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of first leg **254***d* of fourth-type-dual-leg coil unit **254** protruding through stator **290**. Furthermore, second end **254***b* of second leg **254***e* of fourth-type-dual-leg coil unit **254** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of second leg **254***e* of fourth-type-dual-leg coil unit **254** protruding through stator **290**. However, in some examples, turn portion **254***c* of fourth-type-dual-leg coil unit **254** is radially offset further away from primary axis **201** than the portions of first leg **254***d* and second leg **254***e* of fourth-type-dual-leg coil unit **254** protruding through stator **290**, e.g., by between 1-5 millimeters, such as 2-4 millimeters, or about 3 millimeters.

[0103] FIG. **9**A is a schematic side view of another example of dual-leg coil unit **250**, which may be referred to as fifth-type-dual-leg coil unit **254** or a standard-type-two coil unit/hairpin. FIGS. **9**B and **9**C are schematic views of fifth-type-dual-leg coil unit **254** in FIG. **9**A, protruding through stator **290**, in accordance with some examples. Specifically, fifth-type-dual-leg coil unit **255** comprises turn portion **255***c*, first leg **255***d* terminating with first end **255***a*, and second leg **255***e* terminating with second end **255***b*. Turn portion **255***c*, first leg **255***d*, and second leg **255***e* of fifth-type-dual-leg coil unit **255** collectively form a continuous monolithic structure. Referring to FIG. **9**C, first leg **255***d* of fifth-type-dual-leg coil unit **255** protrudes through first fifth-type-dual-leg-coil slot **235***a* of plurality of stator slots **299**. Second leg **255***e* protrudes through second fifth-type-dual-leg-coil slot **235***b* of plurality of stator slots **299**. In this example, first fifth-type-dual-leg-coil slot **235***a* and second fifth-type-dual-leg-coil slot **235***b* are offset by 4 slots.

[0104] In some examples, (a) a portion of first leg **255***d* of fifth-type-dual-leg coil unit **255** protruding through stator **290** and (b) a portion of second leg **255***e* of fifth-type-dual-leg coil unit **255** protruding through stator **290** has different radial offsets from primary axis **201** (e.g., D**3** for the protruding portion of first leg **255***d* vs. D**4** for the protruding portion of second leg **255***e*). In other words, turn portion **255***c* of fifth-type-dual-leg coil unit **255** makes a radial “jump”. This radial jump should be distinguished from the radial offset that turn portion **255***c* of fifth-type-dual-leg coil unit **255** can have relative to the protruding portion of first leg **255***d* and also relative to the protruding portion of second leg **255***e*.

[0105] In some examples, first end **255***a* of first leg **255***d* of fifth-type-dual-leg coil unit **255** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of first leg **255***d* of fifth-type-dual-leg coil unit **255** protruding through stator **290**. Furthermore, second end **255***b* of second leg **255***e* of fifth-type-dual-leg coil unit **255** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of second leg **255***e* of fifth-type-dual-leg coil unit **255** protruding through stator **290**. However, in some examples, turn portion **255***c* of fifth-type-dual-leg coil unit **255** is radially offset further away from primary axis **201** than the portions of first leg **255***d* and second leg **255***e* of fifth-type-dual-leg coil unit **255** protruding through stator **290**, e.g., by between 1-5 millimeters, such as 2-4 millimeters, or about 3 millimeters.

[0106] FIG. **10**A is a schematic side view of yet another example of dual-leg coil unit **250**, which may be referred to as sixth-type-dual-leg coil unit **256** or a looped-type-one coil unit/hairpin. FIGS. **10**B and **10**C are schematic views of sixth-type-dual-leg coil unit **256**, protruding through stator **290**, in accordance with some examples. Specifically, sixth-type-dual-leg coil unit **256** comprises turn portion **256***c*, first leg **256***d* terminating with first end **256***a*, and second leg **256***e* terminating with second end **256***b*. Turn portion **256***c*, first leg **256***d*, and second leg **256***e* of sixth-type-dual-leg coil unit **256** collectively form a continuous monolithic structure. Referring to FIG. **10**C, first leg **256***d* of sixth-type-dual-leg coil unit **256** protrudes through first sixth-type-dual-leg-coil slot **236***a* of plurality of stator slots **299**. Second leg **256***e* protrudes through second sixth-type-dual-leg-coil slot **236***b* of plurality of stator slots **299**. In this example, first sixth-type-dual-leg-coil slot **236***a* and second sixth-type-dual-leg-coil slot **236***b* are offset by 4 slots.

[0107] In some examples, (a) a portion of first leg **256***d* of sixth-type-dual-leg coil unit **256** protruding through stator **290** and (b) a portion of second leg **256***e* of sixth-type-dual-leg coil unit **256** protruding through stator **290** has the same radial offsets from primary axis **201** (e.g., D**1** for both). In other words, turn portion **256***c* of sixth-type-dual-leg coil unit **256** does not make any radial "jumps" as other dual-leg coil units **250** described above.

[0108] In some examples, first end **256***a* of first leg **256***d* of sixth-type-dual-leg coil unit **256** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of first leg **256***d* of sixth-type-dual-leg coil unit **256** protruding through stator **290**. Furthermore, second end **256***b* of second leg **256***e* of sixth-type-dual-leg coil unit **256** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of second leg **256***e* of sixth-type-dual-leg coil unit **256** protruding through stator **290**. However, in some examples, turn portion **256***c* of sixth-type-dual-leg coil unit **256** is radially offset further away from primary axis **201** than the portions of first leg **256***d* and second leg **256***e* of sixth-type-dual-leg coil unit **256** protruding through stator **290**, e.g., by between 1-5 millimeters, such as 2-4 millimeters, or about 3 millimeters.

[0109] FIG. **11**A is a schematic side view of a further example of dual-leg coil unit **250**, which may be referred to as seventh-type-dual-leg coil unit **257** or a looped-type-two coil unit/hairpin. FIGS. **11**B and **11**C are schematic views of seventh-type-dual-leg coil unit **257** in FIG. **11**A, protruding through stator **290**, in accordance with some examples. Specifically, seventh-type-dual-leg coil unit **257** comprises turn portion **257***c*, first leg **257***d* terminating with first end **257***a*, and second leg **257***e* terminating with second end **257***b*. Turn portion **257***c*, first leg **257***d*, and second leg **257***e* of seventh-type-dual-leg coil unit **257** collectively form a continuous monolithic structure. Referring to FIG. **11**C, first leg **257***d* of seventh-type-dual-leg coil unit **257** protrudes through first seventh-type-dual-leg-coil slot **237***a* of plurality of stator slots **299**. Second leg **257***e* protrudes through second seventh-type-dual-leg-coil slot **237***b* of plurality of stator slots **299**. In this example, first seventh-type-dual-leg-coil slot **237***a* and second seventh-type-dual-leg-coil slot **237***b* are offset by 3 slots.

[0110] In some examples, (a) a portion of first leg **257***d* of seventh-type-dual-leg coil unit **257** protruding through stator **290** and (b) a portion of second leg **257***e* of seventh-type-dual-leg coil unit **257** protruding through stator **290** has the same radial offsets from primary axis **201** (e.g., D**1** for both). In other words, turn portion **257***c* of seventh-type-dual-leg coil unit **257** does not make any radial "jumps" as other dual-leg coil units **250** described above.

[0111] In some examples, first end **257***a* of first leg **257***d* of seventh-type-dual-leg coil unit **257** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of first leg **257***d* of seventh-type-dual-leg coil unit **257** protruding through stator **290**. Furthermore, second end **257***b* of second leg **257***e* of seventh-type-dual-leg coil unit **257** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of second leg **257***e* of seventh-type-dual-leg coil unit **257** protruding through stator **290**. However, in some examples, turn portion **257***c* of seventh-type-dual-leg coil unit **257** is radially offset further away from primary axis **201** than the portions of first leg **257***d* and second leg **257***e* of seventh-type-dual-leg coil unit **257** protruding through stator **290**, e.g., by between 1-5 millimeters, such as 2-4 millimeters, or about 3 millimeters.

Examples of Single-Leg Coil Units

[0112] FIG. **12**A is a schematic side view of one example of single-leg coil unit **260**, which may be referred to as first-type-single-leg coil unit **261** or an extended-type-one coil unit/hairpin. FIGS. **12**B and **12**C are schematic views of first-type-single-leg coil unit **261** in FIG. **12**A, protruding through stator **290**, in accordance with some examples. First-type-single-leg coil unit **261** comprises first end **261***a*, second end **261***c*, and leg **261***b*, interconnecting first end **261***a* and second end **261***c*. A portion of leg **261***b* protrudes through first-single-leg-protruding slot **241***b* of plurality of stator slots **299**. First end **261***a* of first-type-single-leg coil unit **261** of single-leg coil units **260** is aligned over first-end-first-single-leg-coil slot **241***a* of plurality of stator slots **299** such that first-end-first-single-leg-coil slot **241***a* is offset by two slots from first-single-leg-protruding slot **241***b*.

[0113] In some examples, first end **261***a* of first-type-single-leg coil unit **261** of single-leg coil units **260** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of leg **261***b* protruding through first-type-single-leg-protruding slot **241***b* of plurality of stator slots **299**. In the same or other examples, second end **261***c* of first-type-single-leg coil unit **261** of single-leg coil units **260** extends from bus-bar side **292** and is radially offset further from primary axis **201** than portion of leg **261***b* protruding through first-single-leg-protruding slot **241***b* of plurality of stator slots **299**.

[0114] FIG. **13**A is a schematic side view of another example of single-leg coil unit **260**, which may be referred to as second-type-single-leg coil unit **262** or an extended-type-two coil unit/hairpin. FIGS. **13**B and **13**C are schematic side views of second-type-single-leg coil unit **262** in FIG. **13**A, protruding through stator **290**, in accordance with some examples. Second-type-single-leg coil unit **262** comprises first end **262***a*, second end **262***c*, and leg **262***b*, interconnecting first end **262***a* and second end **262***c*. A portion of leg **262***b* protrudes through first-single-leg-protruding slot **242***b* of plurality of stator slots **299**. First end **262***a* of second-type-single-leg coil unit **262** of single-leg coil units **260** is aligned over first-end-first-single-leg-coil slot **242***a* of plurality of stator slots **299** such that first-end-first-single-leg-coil slot **242***a* is offset by two slots from first-single-leg-protruding slot **242***b*.

[0115] In some examples, first end **262***a* of second-type-single-leg coil unit **262** of single-leg coil units **260** extends from coil-interconnection side **291** and is radially offset closer to primary axis **201** than the portion of leg **262***b* protruding through second-type-single-leg-protruding slot **242***b* of plurality of stator slots **299**. In the same or other examples, second end **262***c* of second-type-single-leg coil unit **262** of single-leg coil units **260** extends from bus-bar side **292** and is radially offset further from primary axis **201** than portion of leg **262***b* protruding through first-single-leg-protruding slot **242***b* of plurality of stator slots **299**.

CONCLUSION

[0116] Although the foregoing concepts have been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims. It should be noted that there are many alternative ways of implementing processes, systems, and apparatuses. Accordingly, the present embodiments are to be considered illustrative and not restrictive.

Claims

1. An electric motor having a primary axis, the electric motor comprising: a stator comprising a coil-interconnection side, a bus-bar side, and a plurality of stator slots, wherein the plurality of stator slots extends through the stator parallel to the primary axis between the coil-interconnection side and the bus-bar side and is circumferentially offset from each other; and a plurality of coil units, each extending through the stator, wherein: each of the plurality of coil units is electrically coupled to at least one other of the plurality of coil units at the coil-interconnection side, and an end of each of the plurality of coil units extending from the coil-interconnection side is radially offset closer to the primary axis than a portion of that one of the plurality of coil units protruding through the stator.

2. The electric motor of claim 1, wherein: the stator further comprises a plurality of fluid-passage slots, and the plurality of fluid-passage slots extends through the stator parallel to the primary axis between the coil-interconnection side and the bus-bar side and is circumferentially offset from each other.

3. The electric motor of claim 2, wherein: the stator further comprises a plurality of first-fluid-recirculating slots and a plurality of second-fluid-recirculating slots, each of the plurality of first-fluid-recirculating slots is fluidically coupled to one of the plurality of second-fluid-recirculating slots, and the plurality of first-fluid-recirculating slots and the plurality of second-fluid-recirculating slots extend to and open only at one of the coil-interconnection side or the bus-bar side.

4. The electric motor of claim 3, wherein the plurality of fluid-passage slots and the plurality of first-fluid-recirculating slots are circumferentially offset from each other.

5. The electric motor of claim 3, wherein: the plurality of first-fluid-recirculating slots is radially offset from the primary axis by a first radius (R**1**), and the plurality of second-fluid-recirculating slots is radially offset from the primary axis by a second radius (R**2**), smaller than the first radius (R**1**).

6. The electric motor of claim 5, wherein the plurality of fluid-passage slots is radially offset from the primary axis by a third radius (R**3**), same as the first radius (R**1**).

7. The electric motor of claim 5, wherein the plurality of stator slots is radially offset from the primary axis by a fourth radius (R**4**), smaller than the first radius (R**1**).

8. The electric motor of claim 3, wherein the plurality of stator slots and the plurality of second-fluid-recirculating slots are circumferentially offset from each other.

9. The electric motor of claim 3, wherein each of the plurality of first-fluid-recirculating slots is circumferentially aligned with one of the plurality of second-fluid-recirculating slots.

10. The electric motor of claim 3, wherein: the stator is defined by a stator length (L) extending along the primary axis between the coil-interconnection side and the bus-bar side, and each of the plurality of first-fluid-recirculating slots and the plurality of second-fluid-recirculating slots extends parallel to the primary axis along at least 90% of the stator length (L).

11. The electric motor of claim 3, wherein: a first end of each of the plurality of first-fluid-recirculating slots and the plurality of second-fluid-recirculating slots extends to and is open only at one of the coil-interconnection side or the bus-bar side, and a second end of each of the plurality of first-fluid-recirculating slots is fluidically coupled to a second end of one of the plurality of second-fluid-recirculating slots.

12. The electric motor of claim 11, wherein the second end of each of the plurality of first-fluid-recirculating slots is fluidically coupled to the second end of one of the plurality of second-fluid-recirculating slots by a return passage, extending radially within the stator.

13. The electric motor of claim 12, wherein: the stator comprises a stator base, a return passage ring, and a return-passage cover axially stacked along the primary axis such that the return passage ring is positioned between the stator base and the return-passage cover, and the return passage is formed by the return passage ring.

14. The electric motor of claim 13, wherein: each of the plurality of stator slots, the plurality of fluid-passage slots, the plurality of first-fluid-recirculating slots, and the plurality of second-fluid-recirculating slots extends through the stator base, the plurality of first-fluid-recirculating slots and the plurality of second-fluid-recirculating slots extend to the return passage ring but do extend through the return-passage cover, and the plurality of stator slots and the plurality of fluid-passage slots further extend through the return passage ring and the return-passage cover.

15. The electric motor of claim 13, wherein each of the stator base, the return passage ring, and the return-passage cover are made from same materials.

16. The electric motor of claim 3, wherein the plurality of first-fluid-recirculating slots and the plurality of second-fluid-recirculating slots extend to the coil-interconnection side.

17. The electric motor of claim 3, wherein the plurality of first-fluid-recirculating slots and the plurality of second-fluid-recirculating slots extend to the bus-bar side.

18. The electric motor of claim 3, wherein each of the plurality of fluid-passage slots, the plurality of first-fluid-recirculating slots, and the plurality of second-fluid-recirculating slots is parallel to each other and to the primary axis.

19. The electric motor of claim 3, wherein each of the plurality of fluid-passage slots, the plurality of first-fluid-recirculating slots, and the plurality of second-fluid-recirculating slots is straight along the primary axis.

20. An electric motor having a primary axis, the electric motor comprising: a stator comprising a coil-interconnection side, a bus-bar side, a plurality of stator slots, a plurality of fluid-passage slots, a plurality of first-fluid-recirculating slots, and a plurality of second-fluid-recirculating slots, wherein: the plurality of stator slots extends through the stator parallel to the primary axis between the coil-interconnection side and the bus-bar side and is circumferentially offset from each other, the plurality of fluid-passage slots extends through the stator parallel to the primary axis between the coil-interconnection side and the bus-bar side and is circumferentially offset from each other, each of the plurality of first-fluid-recirculating slots is fluidically coupled to one of the plurality of second-fluid-recirculating slots, the plurality of first-fluid-recirculating slots and the plurality of second-fluid-recirculating slots extend to and open only at one of the coil-interconnection side or the bus-bar side; a plurality of coil units, each extending through the plurality of stator slots and electrically coupled to at least one other of the plurality of coil units at the coil-interconnection side, wherein an end of each of the plurality of coil units extending from the coil-interconnection side has a different radial offset than a portion of that one of the plurality of coil units protruding through the stator.
