US 20250266725A1

(19) United States
(12) Patent Application Publication
CHASE et al.
(10) Pub. No.: US 2025/0266725 A1
(43) Pub. Date: Aug. 21, 2025

(54) **INDUCTION ELECTRIC MACHINE ROTOR AXIAL EFLUID CORE COOLING CHANNELS**

(71) Applicant: **FORD GLOBAL TECHNOLOGIES, LLC**, Dearborn, MI (US)

(72) Inventors: **Nicholas B. CHASE**, Royal Oak, MI (US); **Matthew SCHMITT**, Salt Lake City, UT (US); **Singar RATHNAM**, Farmington Hills, MI (US); **Joel HETRICK**, Ann Arbor, MI (US)

(21) Appl. No.: **18/444,325**

(22) Filed: **Feb. 16, 2024**

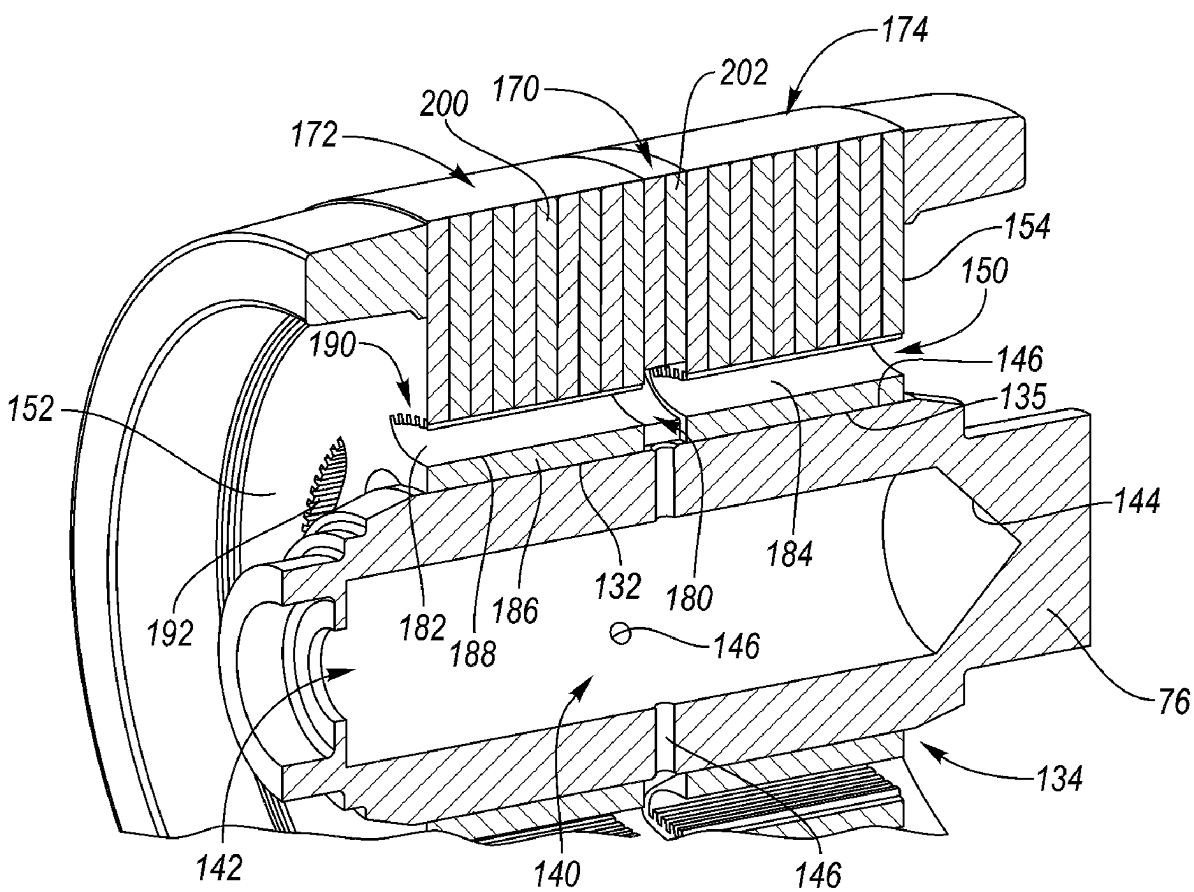
Publication Classification

(51) **Int. Cl.**
H02K 1/32 (2006.01)

(52) **U.S. Cl.**
CPC *H02K 1/32* (2013.01)

(57) **ABSTRACT**

An electric machine includes a shaft defining an axial fluid passage and a radial orifice extending from the fluid passage to an outer circumferential surface of the shaft. The machine further includes a rotor supported on the shaft. The rotor includes a stack of laminations defining a rotor core, an axial fluid channel defined in the rotor core and in fluid communication with the orifice and fluid passage, and a plurality of fins each extending from the rotor core into the fluid passage such that the fins axially extend along at least a portion of the axial fluid channel.



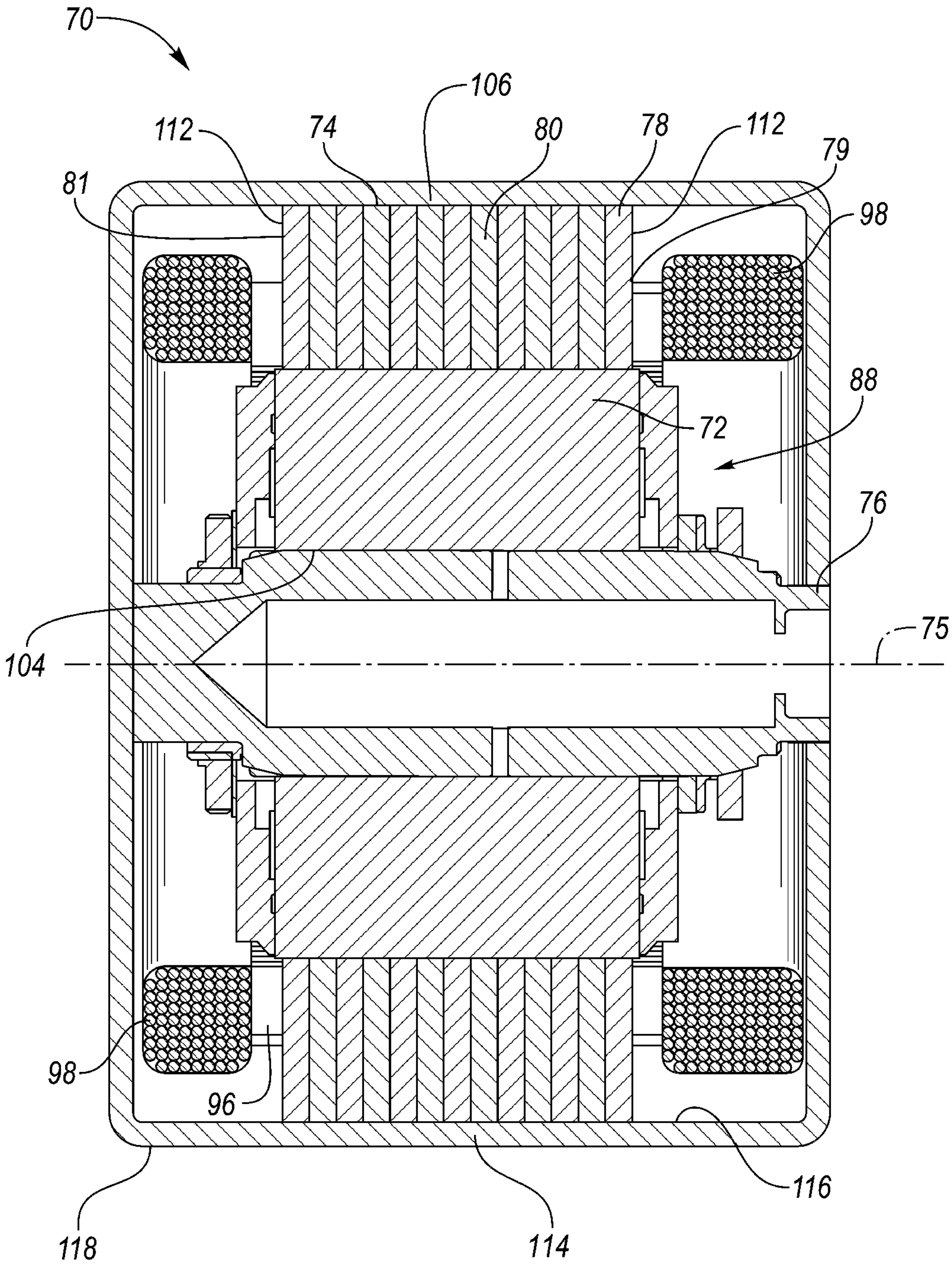


FIG. 1

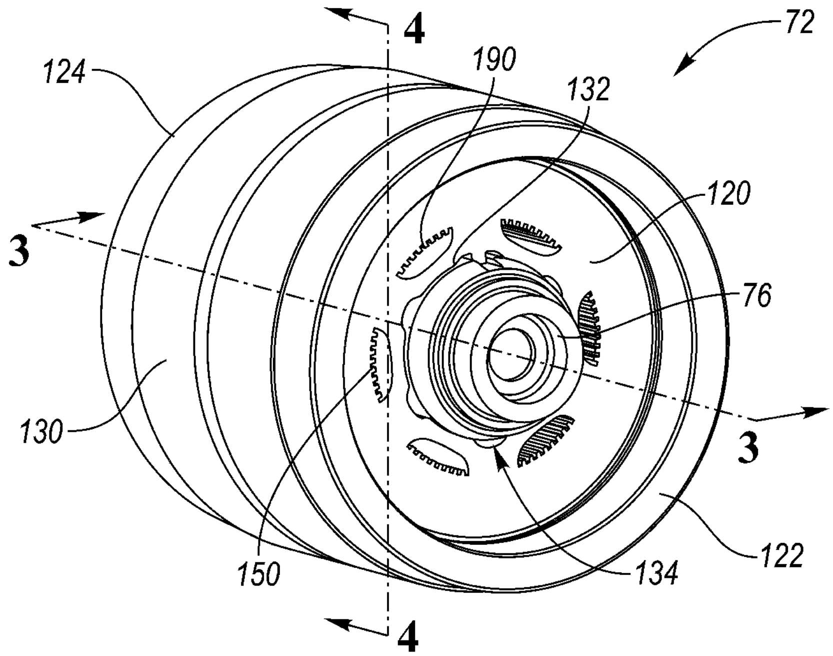

4
72
124
190
132
120
3
76
130
3
150
134
122
4

FIG. 2

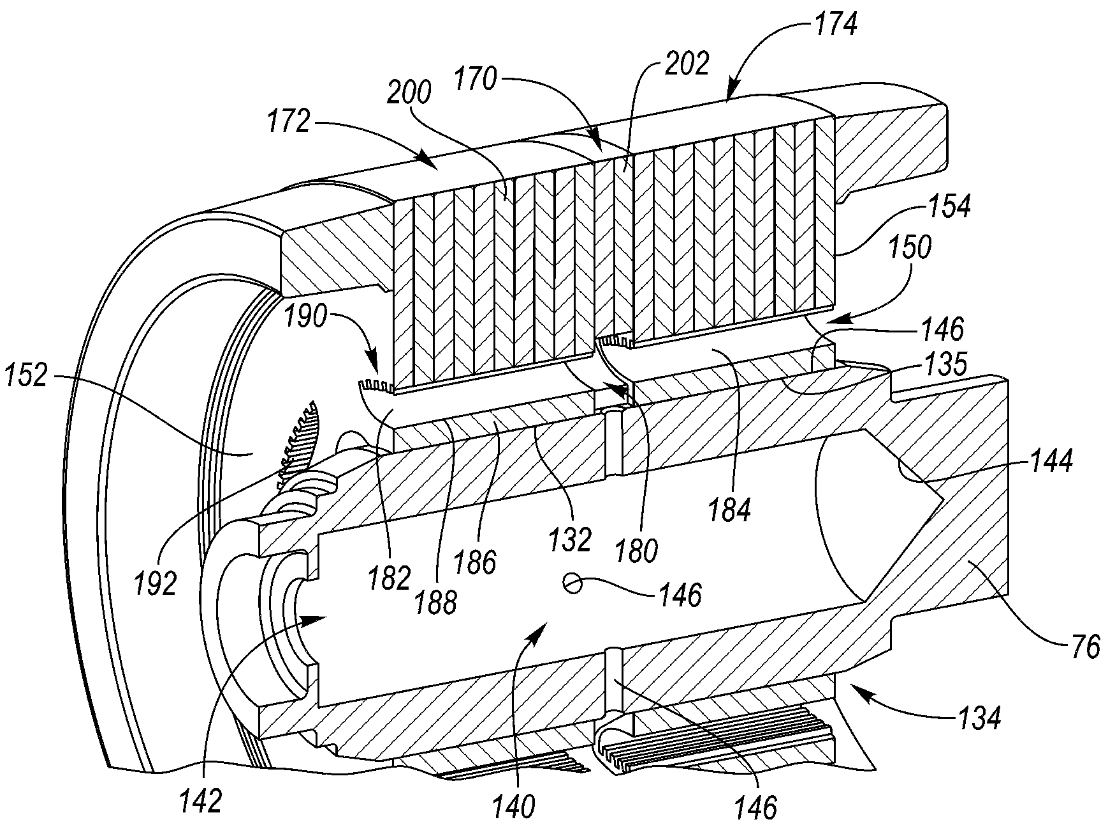

174
202
170
200
172
154
150
190
146
135
152
144
184
192
182
188
186
132
180
146
76
142
140
146
134

FIG. 3

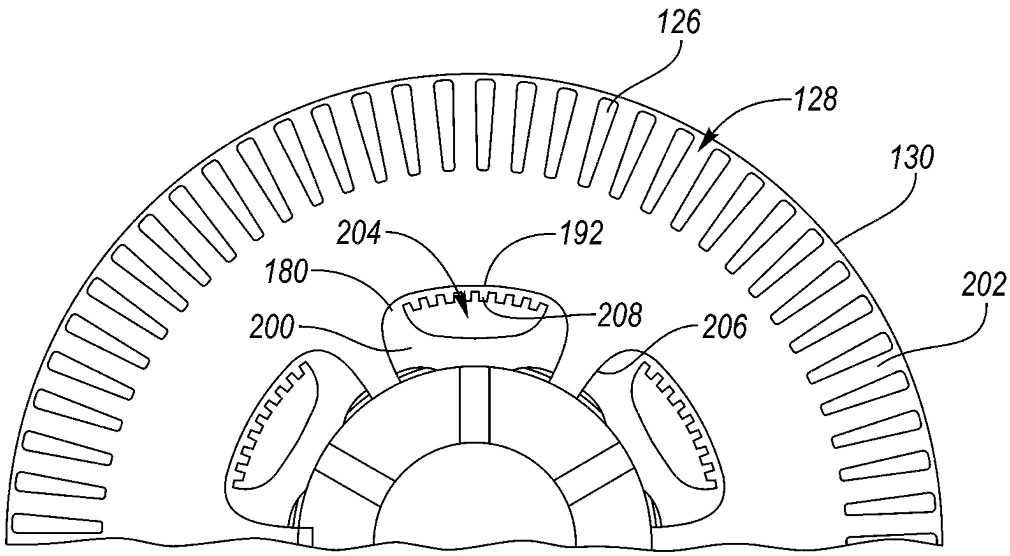

126
128
130
204
192
180
208
200
206
202

FIG. 4

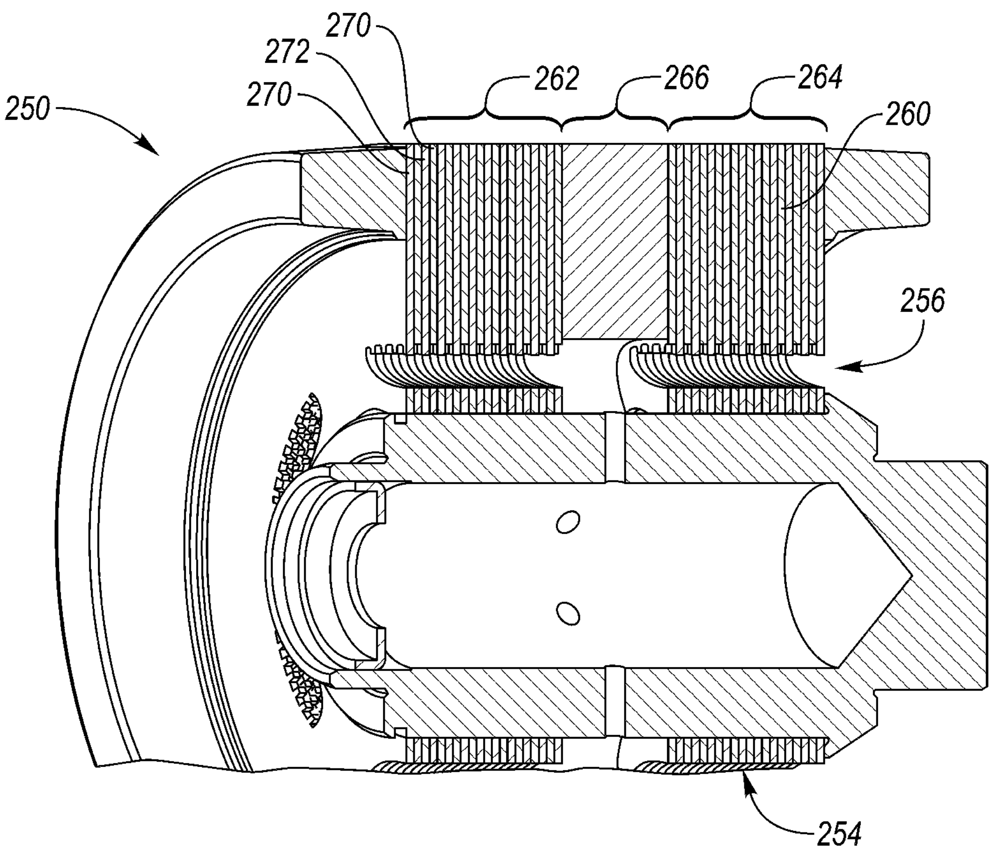

270
272
270
250
262
266
264
260
256
254

FIG. 5

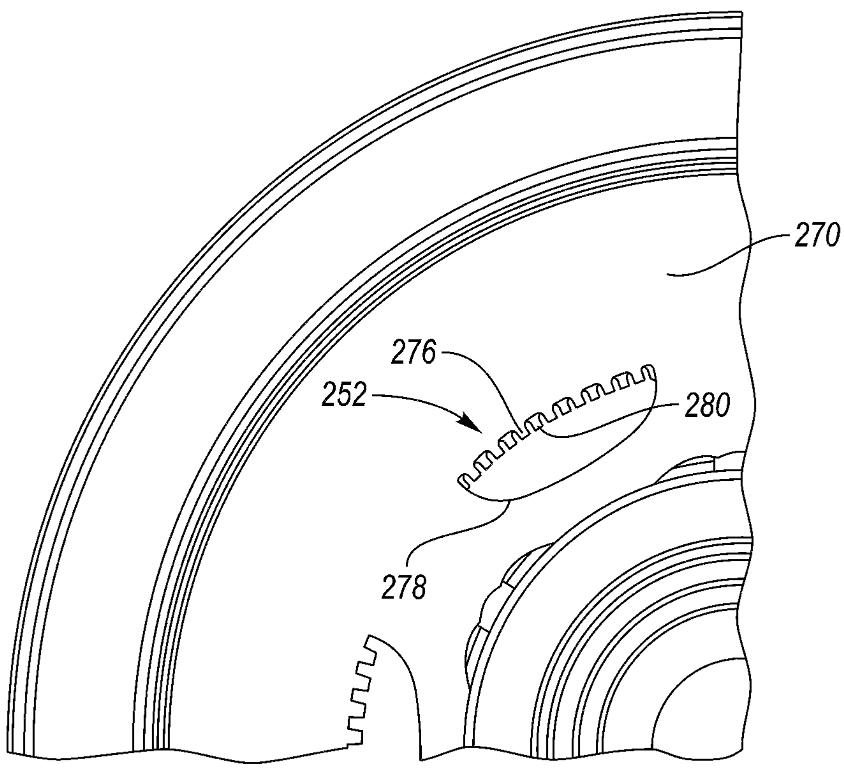


FIG. 6

INDUCTION ELECTRIC MACHINE ROTOR AXIAL EFLUID CORE COOLING CHANNELS

TECHNICAL FIELD

[0001] The present disclosure relates to electric machines and thermal management thereof.

BACKGROUND

[0002] Vehicles such as battery-electric vehicles and hybrid-electric vehicles include a traction-battery assembly that provides an energy source. The traction-battery assembly, for example, is electrically connected to an electric machine that provides torque to driven wheels. The traction-battery assembly may include components and systems to assist in managing vehicle performance and operations. It may also include high-voltage components, and an air or liquid thermal-management system to control temperature.

[0003] Electric machines typically include a stator and a rotor that cooperate to convert electrical energy into mechanical motion or vice versa. Electric machines may include thermal-management systems to cool the stator, rotor, or both.

SUMMARY

[0004] According to one embodiment, an electric machine includes a shaft defining an axial fluid passage and a radial orifice extending from the fluid passage to an outer circumferential surface of the shaft. The machine further includes a rotor supported on the shaft. The rotor includes a stack of laminations defining a rotor core, an axial fluid channel defined in the rotor core and in fluid communication with the orifice and fluid passage, and a plurality of fins each extending from the rotor core into the fluid passage such that the fins axially extend along at least a portion of the axial fluid channel.

[0005] According to another embodiment, a rotor of an electric machine includes a rotor core having a central set of laminations disposed between first and second outer sets of laminations, wherein each of the first and second outer sets of laminations defines an axial fluid channel that has an outboard surface and an inboard surface, and the central set of laminations defines a fluid plenum having an outboard surface that is radially spaced from a central axis of the rotor core by a distance that is greater than a distance between the central axis and the outboard surfaces of the axial fluid channels of the first and second outer sets of laminations.

[0006] According to yet another embodiment, an electric machine includes a rotor core having a central portion with an outer circumferential surface and an inner circumferential surface, the inner surface defining a fluid plenum recessed therein and extending completely through an axial thickness of the central portion, wherein the fluid plenum has an outboard surface spaced from a central axis of the rotor core by a first distance. The rotor further has a first end portion axially thicker than the central portion and disposed against a first end face of the central portion, the first end portion having an outer circumferential surface, an inner circumferential surface, and a first axial fluid channel disposed therebetween, the first axial fluid channel having an outboard surface spaced from the central axis of the rotor core by a second distance that is less than the first distance. The rotor also has a second end portion axially thicker than the central portion and disposed against a second end face of the central portion such that the central portion is disposed between the first and second end portions, the second end portion having an outer circumferential surface, an inner circumferential surface, and a second axial fluid channel disposed therebetween, the second axial fluid channel having an outboard surface spaced from the central axis of the rotor core by a third distance that is less than the first distance. The plenum is circumferentially aligned with the first and second fluid channels forming a continuous opening extending axially through the rotor core.

[0007] In one or more embodiments, an induction rotor may be cooled by fluid (e.g., oil, ATF, or dielectric fluids) that is fed to a center of a rotor shaft axially from one end. Through centrifugal pumping by the shaft, the fluid may be distributed to passages in the rotor core through radial orifices in the center of the rotor shaft. A center portion of the rotor core laminations may include an open inner diameter at the shaft orifices to allow the fluid to enter the rotor core fluid circuit. The rotor core cooling channels are at a larger radial distance than the shaft to allow fluid to contact the core radially closer to the squirrel cage (also known as a “rotor cage”) of the rotor. This reduces thermal resistance between the conductor bars of the squirrel cage the fluid contacting the rotor core. The fluid is distributed axially through the rotor core via channels. Fluid exits the rotor-core channels and flows onto the end rings providing additional cooling to the squirrel cage.

[0008] To further aid cooling, fins may be added to the channels. For example, the fins may be tabs formed on the laminations creating small axial channels that act as a heat sink to the fluid. To distribute fluid more evenly to all the axial channels, an undercut may be included in the center laminations to create a plenum located centrally on the rotor core. The plenum reduces flow resistance and pressure drop and provides a circumferential path to each of the channels creating more even flow distribution. Additionally, the undercut on the sides of the plenum acts as an impeller or centrifugal pump at lower speeds increasing the fluid pressure so that it fills the plenum before entering the axial cooling channels. The fins may also aid cooling of the end rings by more evenly distributing fluid circumferentially in the rotor-core channels and providing smaller outlet passages, acting like nozzles, that more evenly spray exiting fluid onto the rotor cage end ring. Additionally, staggered fin channels may be used. The staggered fins may be formed by having two different fin channel laminations alternating in the axial direction of the rotor core.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** is side view, in cross section, of an example electric machine.

[0010] FIG. **2** is a perspective view of a rotor of the electric machine of FIG. **1**.

[0011] FIG. **3** is a cross-sectional view of the rotor of FIG. **2** along cutline **3-3**.

[0012] FIG. **4** is a cross-sectional view of the rotor of FIG. **2** along cutline **4-4**.

[0013] FIG. **5** is a side cross-sectional view of another rotor.

[0014] FIG. **6** is a detail view of the another rotor illustrating one of the axial cooling channels and fin arrangement.

DETAILED DESCRIPTION

[0015] Embodiments of the present disclosure are described herein. It is to be understood, however, that the disclosed embodiments are merely examples and other embodiments can take various and alternative forms. The figures are not necessarily to scale; some features could 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 invention. As those of ordinary skill in the art will understand, various features illustrated and described with reference to any one of the figures can be combined with features illustrated in one or more other figures to produce embodiments that are not explicitly illustrated or described. The combinations of features illustrated provide representative embodiments for typical applications. Various combinations and modifications of the features consistent with the teachings of this disclosure, however, could be desired for particular applications or implementations.

[0016] Directional terms used herein are made with reference to the views and orientations shown in the exemplary figures. A central axis is shown in the figures and described below. Terms such as "outer" (or "outboard") and "inner" (or "inboard") are relative to the central axis. For example, an "outer" surface means that the surfaces faces away from the central axis, or is outboard of another "inner" surface. Terms such as "radial," "diameter," "circumference," etc. also are relative to the central axis. The terms "front," "rear," "upper" and "lower" designate directions in the drawings to which reference is made. The terms, connected, attached, etc., refer to directly or indirectly connected, attached, etc., unless otherwise indicated explicitly or by context.

[0017] A vehicle may include one or more electric machines that propel the vehicle. Such vehicles include electric vehicles and hybrid-electric vehicles. The vehicle includes an energy storage device, such as a traction battery for storing electrical energy. The battery is a high-voltage battery that is capable of outputting electrical power to operate the electric machine(s). The battery also receives electrical power from the electric machine(s) when it is operating as a generator. The battery may be a battery pack made up of several battery modules, where each battery module contains a plurality of battery cells. Other vehicles may use different types of energy storage devices, such as capacitors and fuel cells that supplement or replace the battery. The vehicle **16** includes a power electronics including a variable voltage converter (VVC), an inverter, etc. connected between the traction battery and the electric machine(s).

[0018] Referring to FIG. **1**, an example electric machine **70** includes a stator **74** that may have a plurality of laminations **78**. The electric machine **70** has a central axis or centerline **75**. Each of the laminations **78** includes a front side and a back side. When stacked, the front and back sides are disposed against adjacent front and back sides to form a stator core **80**. Each of the laminations **78** define a hollow center.

[0019] Each lamination **78** includes an inner diameter defining a plurality of teeth. Adjacent teeth cooperate to define slots. The teeth and the slots of each lamination **78** are aligned with adjacent laminations to define stator slots extending axially through the stator core **80** between the opposing end faces **112**. The end faces **112** define the opposing ends of the core **80** and are formed by the first and last laminations **79**, **81** of the stator core **80**. A plurality of windings (also known as coils, wires, or conductors) **96** are wrapped around the stator core **80** and are disposed within the stator slots. The windings **96** may be disposed in an insulating material (not shown). Portions of the windings **96** generally extend in an axial direction along the stator slots. At the end faces **112** of the stator core, the windings **96** bend to extend circumferentially around the end faces **112** of the stator core **80** forming the end windings **98**. While shown as having distributed windings, the windings could also be of the concentrated or hairpin type.

[0020] A rotor **72** is disposed within the cavity **88** of the stator **74**. The rotor **72** is fixed to a shaft **76** that is operably connected to the gearbox. When current is supplied to the stator **74**, a magnetic field is created causing the rotor **72** to spin within the stator **74** generating a torque that is supplied to the gear box via one or more shafts or gears, or the like. The electric machine may also act as generator by mechanically rotating the rotor **72** to generate electricity. Details of the rotor **72** will be described below.

[0021] Rotors may generate heat during operation and require cooling. In induction rotors, electromagnetic losses in their rotor cage result in heating of the rotor. The rotor may be liquid cooled to maintain desired temperatures. Maintaining desired rotor temperatures may increase part life, reduce cage conduction losses (the cage materials, e.g., aluminum or copper, have temperature dependent resistivity), reduce degradation of the working fluid, and mitigate heat transfer to the stator.

[0022] Many existing induction machines use air cooled or fluid cooling only on the end ring portion of the cages. This may be suitable for lower power applications, but this type of cooling may be insufficient to support higher power-density induction machines.

[0023] The electric motor **70** may be a higher power-density induction machine cooled by circulating a fluid through the rotor and/or the stator in order to target the heat generating areas more directly than spray or air cooling. This may be in addition to any spray cooling (optional). The fluid may be any dielectric fluid such as oil, e.g., automatic transmission fluid (AFT). This fluid is sometimes called "eFluid." The fluid may travel through a fluid path of the electric machine and is connected in fluid communication with a thermal management system (not shown).

[0024] Referring to FIGS. **2**, **3**, and **4**, the rotor **72** may be induction rotor (as shown) or other type. The rotor **72** includes a rotor core **120** and a squirrel cage having end rings **122**, **124** and conductor bars **126** connecting between the end rings. The conductor bars **126** extend through slots **128** located near (or alternatively, recessed into) the outer diameter (also known as an outer circumferential surface) **130** of the rotor core **120**. The inner diameter **132** defines a central hole **134** extending axially (longitudinally) and completely through the rotor core **120**. The shaft **76** extends through the hole **134** with the outer circumferential surface **135** of the shaft **76** disposed against the inner diameter **132** of the rotor **72**. The shaft **76** and the rotor **72** are rotatably coupled such that they rotate in unison. The shaft **76**, the rotor **72**, or both may include an anti-rotation features such as the shown keyway.

[0025] The rotor **72** may be actively cooled by circulating fluid therethrough. The fluid that circulates to the rotor may be part of a larger fluid circuit that cools the entire electric machine **70**. The shaft **76** may be hollow to provide fluid to the rotor **72**. For example, the shaft **76** includes a fluid passageway **140** that extends from an oil inlet **142** to a closed end **144** of the shaft **76**. The shaft includes one or more orifices **146** that extend radially from the central passageway **140** to the outer circumferential surface **135** of the shaft. In the illustrated embodiment, the shaft **76** includes six orifices, which corresponds to the number of fluid channels in the rotor (discussed infra). In the illustrated embodiment, the orifices **146** are located at an axial center of the rotor core **120** but may be axial shifted along the centerline **75** in other embodiments.

[0026] The rotor core **120** includes one or more cooling channels **150** that are in fluid communication with one or more of the orifices **146**. Each of the cooling channels **150** may extend axially completely through the rotor core **120**. That is, the cooling channel **150** extends from a first end face **152** to the other and face **154**. During operation, fluid is supplied to the shaft **76** via the oil inlet **142** and builds within the hollow center **140** of the shaft **76**. The oil is forced radially outward through the orifices **146** and subsequently into the midpoint of the axial cooling channels **150**. From there, the oil splits with some of the oil flowing towards the end face **152** and the rest flowing towards the end face **154**. The oil, which is cooler than the rotor **72**, removes heat from the rotor as it flows therethrough. The electric machine **70** may be designed such that the fluid exiting the axial fluid channels **150** is sprayed or drips onto other components of the electric machine such as the end rings **122**, **124**. This exiting fluid may also aid in cooling of the stator.

[0027] The rotor core **120** may generally have three portions: a central portion **170**, a first end portion **172**, and a second end portion **174**. The central portion **170** is sandwiched between the end portions **172**, **174** and in the illustrated embodiment is axially thinner than the end portions.

[0028] The illustrated embodiment, the purpose of the central portion **170** is to provide access into the channels **150** and to form plenums **180** that feed fluid to the channel portions **182**, **184** of the cooling channels **150**. The plenums **180** are optional. The plenum **180** is enlarged compared to the channel portions **182**, **184** in both the radial and the circumferential directions. The larger plenums **180** allow for pooling of fluid to ensure sufficient flow rates through the channels **150**. In the illustrated embodiment, the plenums **180** are recessed into the inner diameter **132** of the rotor core **120**. As such, the shaft orifices **146** directly open into the plenums **180** to supply fluid to the channels **150**.

[0029] In other embodiments, the plenums may be shifted outwardly and additional openings or orifices may be used to supply fluid from the shaft orifices to the plenums. In other embodiments, the plenums may not be formed directly at the center of the rotor core and instead could be axially shifted towards one end or the other. Here, the shaft orifices would also be shifted so that they remain in fluid communication. In some embodiments, the location of the plenums may be different than each other. That is, some plenums may be shifted towards the end face, others may be located in the center, while others may be shifted towards the other end face. Here again, the shaft orifices would be placed to align with their corresponding plenum. An undercut may be formed on the sides of the plenum, which acts as an impeller or centrifugal pump at lower speeds increasing the fluid pressure so that it fills the plenum radius before entering the axial cooling channels.

[0030] Unlike the plenum **180**, the channel portions **182**, **184** of the channels **150** may be positioned radially outboard of the inner diameter **132** of the rotor core. As best seen in FIG. **3**, a strip of material **186** separates the inboard surface **188** of the channel portions **182**, **184** from the inner diameter **132**. The channel portions **182**, **184** also have an outboard surface **190**. The Plenum **180** does not include inboard surface but does include an outboard surface **192** that is radially spaced from the centerline **75** by a distance that is greater than the distance between the outboard surfaces **190** and the centerline **75**.

[0031] The channels **150** may include fins **192** or other features for increasing heat transfer between the rotor **76** and the fluid. The fins **192** may extend axially through a portion or the entirety of the channel **150**. In the illustrated embodiment, the fins **192** are located within the channel portions **182**, **184** but not within the plenum **180**. The fins may be located on the outboard surfaces **190** of the channels **150**, the inboard surfaces, or both. In the illustrated example, the fins are only disposed on the outboard surfaces **190**. The fins **192** may extend in parallel rows (see, e.g., FIG. **2**) or may be staggered as described below (see e.g., FIG. **5**).

[0032] The rotor core **120** may be a stack of laminations. The stacked laminations may include two or more types of laminations. In the illustrated embodiment of FIG. **3**, the rotor **72** includes two types of laminations. A first type lamination **200** is used in the end portions **172**, **174**, and a second type of lamination **202** is used in the central portion **170**. The laminations are fabricated such that they form the various features of the cooling path when stacked. For example, the laminations **200** include openings **204** that cooperate with the openings of adjacent laminations to form the channel portions **182**, **184** of the channels. The openings **204** also include tabs or projections **208** that form the fins **192**. Similarly, the laminations **202** of the central portion **170** include openings **206** that cooperate with each other to form the plenums.

[0033] Referring to FIGS. **5** and **6**, another rotor **250** is similar to the rotor **72** but has a staggered fin arrangement **252**. The staggered fin arrangement **252** may increase cooling efficiency. The staggered arrangement may be provided along the length of the channel portions **254** of the cooling channels **256**. The staggered arrangement **252** may be created by having a first number of fins or tabs at first axial locations of the cooling channel **256** and a second number of fins or tabs (that is different than the first number of fins) at second axial locations, wherein these first and second number of fins may alternate along the length of the cooling channel **256**. For example, they may alternate every other along the length of the stack. As shown in the illustrated embodiment, the first number of fins includes seven fins, whereas the second number of fins includes six fins. Here, the seven fins of the first locations are positioned to fall in between adjacent ones of the six fins of the second locations.

[0034] As described above, the rotor core **260** of the rotor **250** may or may not be formed by a plurality of laminations. In the illustrated example, the rotor core **260** is formed of a plurality of laminations. The staggered arrangement may be formed by using multiple different types of laminations. In this example, three types of laminations may be used with two types forming the end portions **262**, **264** and another type forming the central portion **266**. (Optional limitations of central portion **266** not shown in FIG. **5**.) In some embodiments, the central portion **266** may be formed of a single solid piece, whereas the end portions **262**, **264** are formed of laminations.

[0035] The example end portion **262** may include a first type lamination **270** and a second type of lamination **272**. The first and second types of laminations **270** and **272** may differ only in the placement of the tabs or fins. For example, the first type of laminations **270** includes seven fins **276** within each of the openings **278**, and the second type of laminations **272** includes six fins **280**. As described above, the fins may be located at the outboard surface of the openings (as shown), at the inboard surface of the openings, or both. In an alternative embodiment, the first type of laminations may have their fins at the outboard surface of the openings whereas the other type of laminations may have their fins at the inboard surfaces of the openings.

[0036] In the illustrated example, the first and second types of laminations **270**, **272** alternate one after the other along the length of the end portions **262**, **264**. The fins **276** and **280** are circumferentially staggered, that is, axially adjacent ones of the fins **280** are not aligned with each other. The fins **276**, **280** of adjacent ones of the laminations are circumferentially offset, i.e., rotated, relative to each other to create the staggered arrangement **252**. In the illustrated embodiment, the fins of adjacent laminations are offset such that the fins **276** are aligned with a midpoint of the gaps between the fins **280** and vice versa.

[0037] In another example (not shown), a partial staggered arrangement of fins may be used. In this embodiment, each fin is axially aligned with one adjacent fin and is circumferentially offset relative to another adjacent fin. This creates a partial staggered arrangement in which the circumferential position of the fins changes every two laminations (this may be called a 2-2pattern). In other embodiments, three (3-3 pattern), four (4-4 pattern), or more laminations may be grouped to have the same fin pattern. Also, the groupings need not have a uniform number of laminations. For example, the stator may include a 1-2 pattern in which a first lamination in sequence has a first fin pattern, the second and third laminations have a second fin pattern, and the fourth fin repeats the sequence and has a fin pattern that matches the first lamination. Of course, 2-3 patterns, etcetera, are also contemplated.

[0038] Embodiments of the present disclosure are described herein. It is to be understood, however, that the disclosed embodiments are merely examples and other embodiments can take various and alternative forms. The figures are not necessarily to scale; some features could 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 invention. As those of ordinary skill in the art will understand, various features illustrated and described with reference to any one of the figures can be combined with features illustrated in one or more other figures to produce embodiments that are not explicitly illustrated or described. The combinations of features illustrated provide representative embodiments for typical applications. Various combinations and modifications of the features consistent with the teachings of this disclosure. however, could be desired for particular applications or implementations.

What is claimed is:

1. An electric machine comprising:
 a shaft defining an axial fluid passage and a radial orifice extending from the fluid passage to an outer circumferential surface of the shaft;
 a rotor supported on the shaft, the rotor including:
  a stack of laminations defining a rotor core,
  an axial fluid channel defined in the rotor core and in fluid communication with the orifice and fluid passage, and
  a plurality of fins each extending from the rotor core into the fluid passage such that the fins axially extend along at least a portion of the axial fluid channel.

2. The electric machine of claim **1**, wherein the axial fluid channel includes an outboard surface and an inboard surface, wherein the fins are disposed on the outboard surface and the inboard surface is without fins.

3. The electric machine of claim **1**, wherein the fins are integrally formed with the laminations.

4. The electric machine of claim **3** wherein the laminations include a first set of laminations having the fins and a second set of laminations without fins so that the fins extend along a portion of the axial fluid channel.

5. The electric machine of claim **4**, wherein the first set of laminations includes an outboard surface radially spaced from the outer surface of the shaft via a first distance, and the second set of laminations includes an outboard surface radially spaced from the outer surface by a second distance that is greater than the first to create a fluid plenum.

6. The electric machine of claim **5**, wherein an outlet end of the orifice opens into the plenum.

7. The electric machine of claim **6**, wherein the first set of laminations is a pair of lamination sets that sandwich the second set of laminations.

8. The electric machine of claim **1**, wherein the axial fluid channel is a plurality of axial fluid channels circumferentially arranged around the rotor.

9. The electric machine of claim **1**, wherein the rotor core includes an inner circumferential surface disposed on the shaft and an outer circumferential surface, wherein the axial fluid channel is radially disposed between the inner and outer surfaces of the rotor core.

10. The electric machine of claim **9**, wherein the inner surface defines an opening connecting the axial fluid channel in fluid communication with the orifice.

11. The electric machine of claim **1** further comprising a stator circumscribing the rotor.

12. The electric machine of claim **1**, wherein the rotor core defines a plurality of slots, and wherein the rotor further includes a pair of end rings and conductor bars connected between the end rings and disposed in the slots to form a squirrel cage.

13. A rotor of an electric machine comprising:
 a rotor core including a central set of laminations disposed between first and second outer sets of laminations, wherein each of the first and second outer sets of laminations defines an axial fluid channel that has an outboard surface and an inboard surface, and the central set of laminations defines a fluid plenum having an outboard surface that is radially spaced from a central axis of the rotor core by a distance that is greater than

a distance between the central axis and the outboard surfaces of the axial fluid channels of the first and second outer sets of laminations.

14. The rotor of claim **13**, wherein the laminations of the first and second outer sets define tabs projecting into their corresponding axial fluid channel.

15. The rotor of claim **14**, wherein the fluid plenum does not have tabs.

16. The rotor of claim **14**, wherein at least some of the tabs are circumferentially staggered relative to other ones of the tabs.

17. The rotor of claim **13**, wherein the first outer set of laminations includes a first type of lamination having first tabs projecting into the axial fluid channel and a second type of lamination having second tabs projecting into the axial fluid channel, wherein the first and second tabs are located at different circumferential positions of the rotor core and the first and second types of laminations alternate along the length of the first set such that the tabs form staggered fins disposed in the axial fluid channel.

18. An electric machine comprising:

a rotor core including:

a central portion having an outer circumferential surface and an inner circumferential surface, the inner surface defining a fluid plenum recessed therein and extending completely through an axial thickness of the central portion, wherein the fluid plenum has an outboard surface spaced from a central axis of the rotor core by a first distance,

a first end portion axially thicker than the central portion and disposed against a first end face of the central portion, the first end portion having an outer circumferential surface, an inner circumferential surface, and a first axial fluid channel disposed therebetween, the first axial fluid channel having an outboard surface spaced from the central axis of the rotor core by a second distance that is less than the first distance, and

a second end portion axially thicker than the central portion and disposed against a second end face of the central portion such that the central portion is disposed between the first and second end portions, the second end portion having an outer circumferential surface, an inner circumferential surface, and a second axial fluid channel disposed therebetween, the second axial fluid channel having an outboard surface spaced from the central axis of the rotor core by a third distance that is less than the first distance,

wherein, the plenum is circumferentially aligned with the first and second fluid channels forming a continuous opening extending axially through the rotor core.

19. The electric machine of claim **18**, wherein the inner circumferential surfaces of the portions define a central hole with a discontinuous sidewall at the plenum, and further comprising a shaft coaxial with the central axis and received through the central hole to couple with the rotor core, the shaft defining an axial fluid passage and a radial orifice extending from the fluid passage to the plenum.

20. The electric machine of claim **18**, wherein the first axial fluid channel further has an inboard surface that is radially spaced from the inner circumferential surface of the first end portion.

* * * * *