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(54) ELECTRIC MACHINE STATOR WITH AXIAL VENTS

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(57) **ABSTRACT**

A stator of an electric machine is provided and includes laminations arranged to form a core packet. Each lamination is formed to define an annular array of teeth at an inner radial portion thereof and an annular array of annular sectors at an outer radial portion thereof.

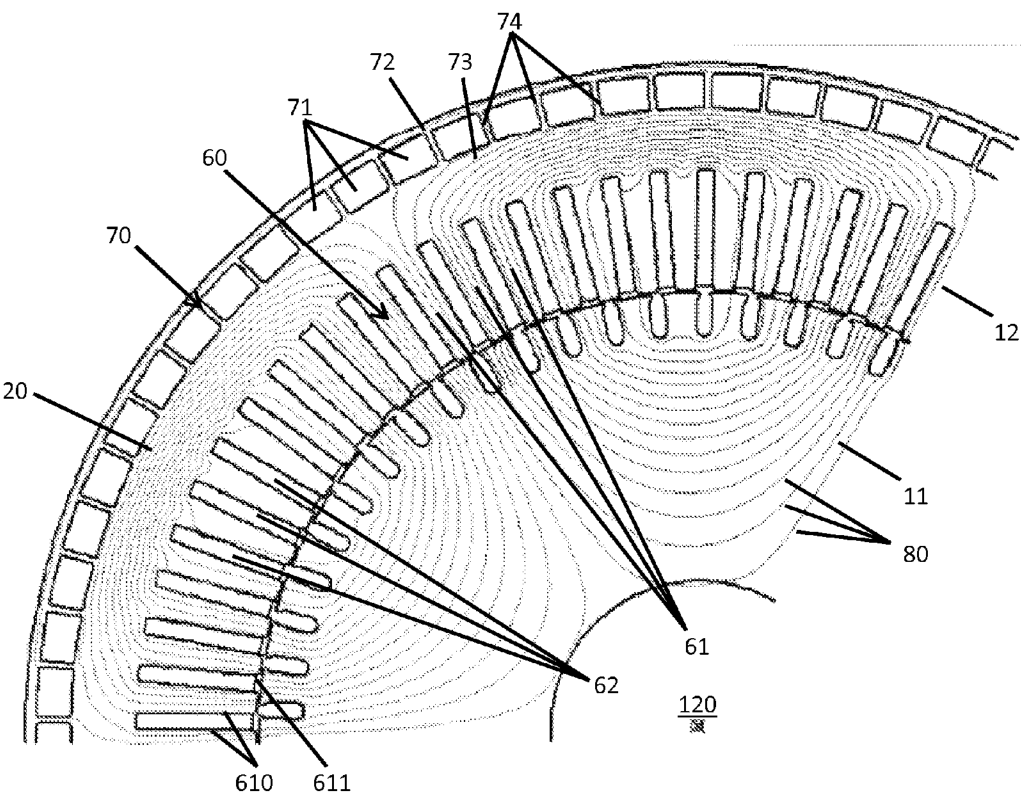


FIG. 1

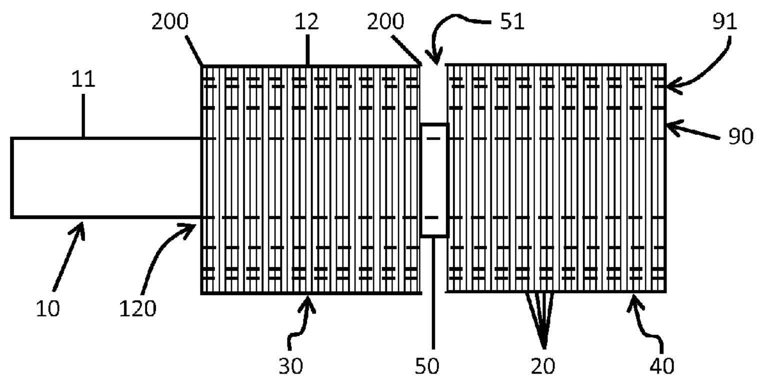

200
12
200
51
91
11
90
10
120
30
50
20
40

FIG. 2

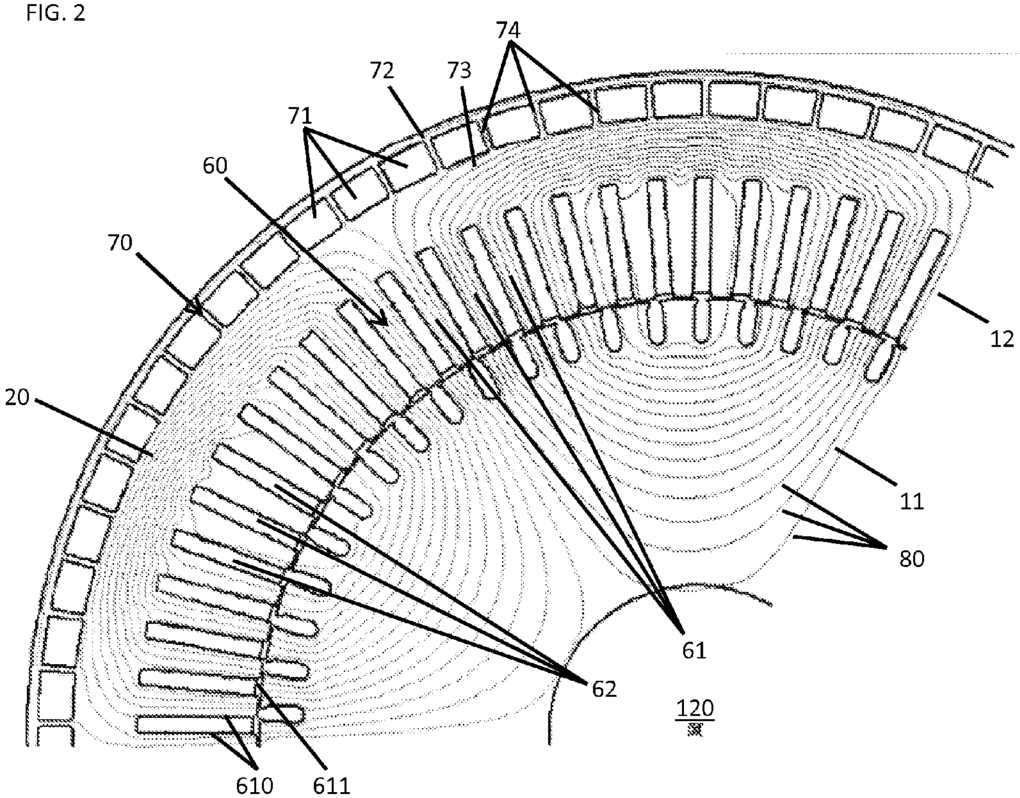

74
72
73
71
60
70
20
12
11
80
61
62
120
610
611

FIG. 3

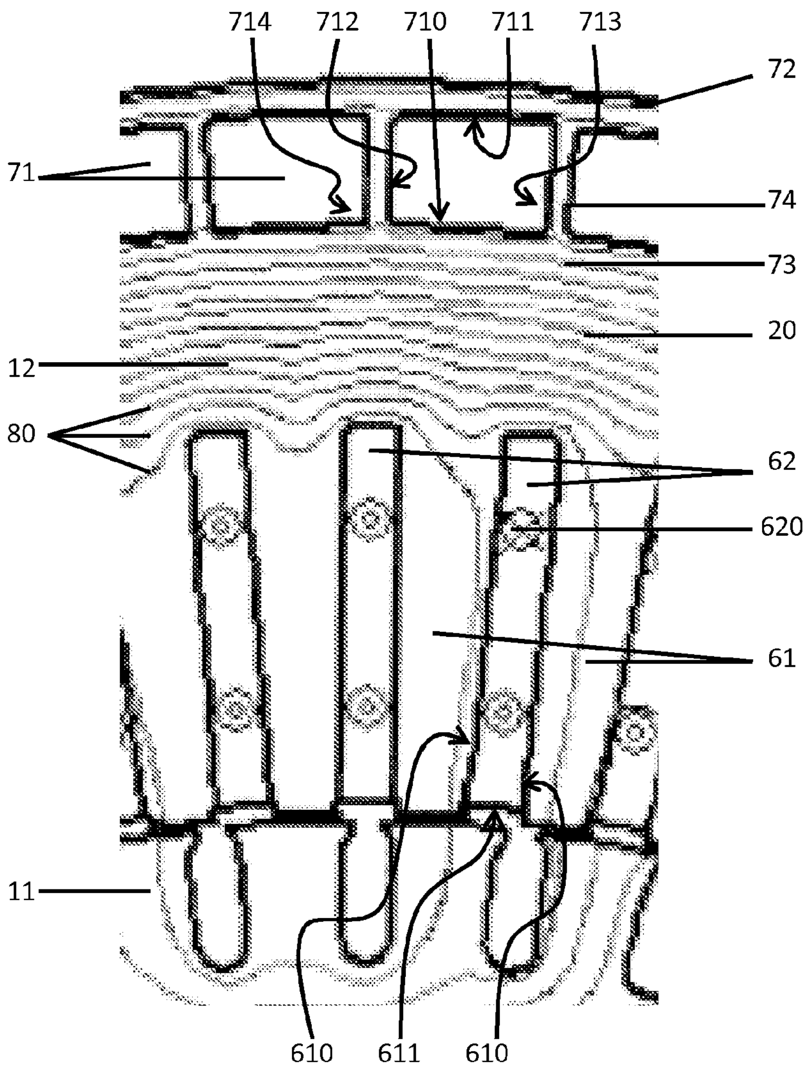


FIG. 4

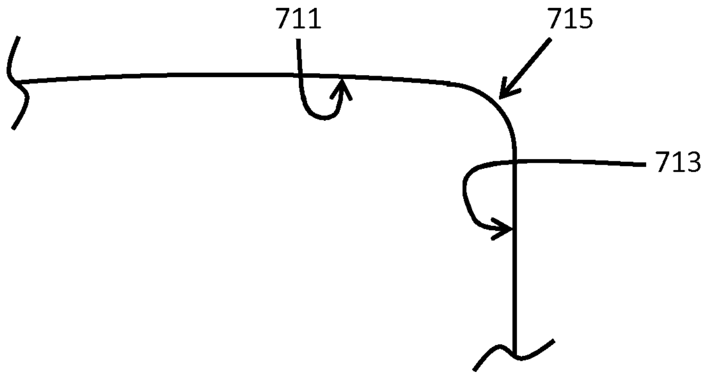


FIG. 5

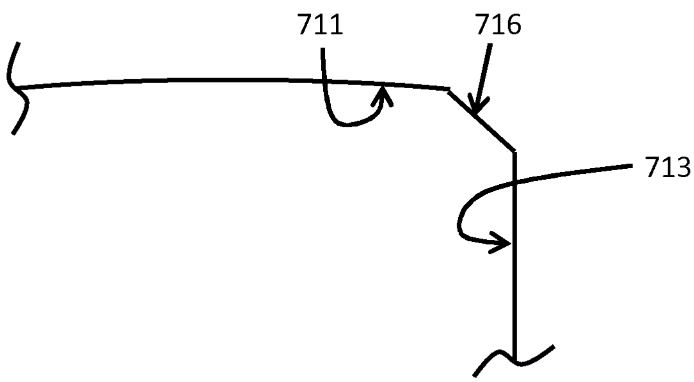
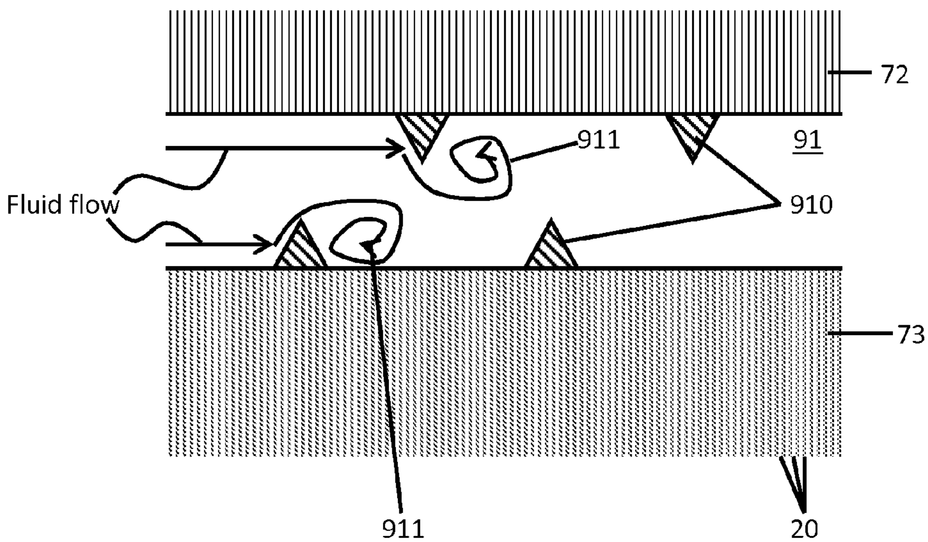


FIG. 6



ELECTRIC MACHINE STATOR WITH AXIAL VENTS

BACKGROUND OF THE INVENTION

[0001] The subject matter disclosed herein relates to an electric machine and, more particularly, to an electric machine stator with axial vents shaped as annular sectors.

[0002] In electric machines, a stator is normally formed to define a bore in which a rotor is rotatably supported. Rotation of the rotor can generate current in conductive elements disposed to extend through the stator when the electric machine is run in a generator mode. By contrast, current applied to such conductive elements can cause the rotor to rotate in a motor mode.

[0003] During operation of the electric machine in either the generator or motor mode, a large amount of heat can be generated in the conductive elements. This heat can lead to damage to the conductive elements, insulation systems, the stator or the rotor if the heat is not removed or the heated elements are not otherwise cooled. One way to remove heat and to cool the various elements in an electric machine is to form cooling or ventilation paths through the stator by which coolant, such as ambient air, is directed through or across heated parts, such as the conductive elements or the stator back iron.

[0004] Often, the cooling or ventilations paths are formed by the removal of material from the stator at the desired locations of the cooling or ventilation paths. Doing so results in an increase in flux density around the area of the removed material. However, saturation exhibits a non-linear thresholding effect, where the sensitivity of a region to change is dependent on the flux density in that region. Moreover, the initial distribution of flux density is dependent on the pole count and bar and slot arrangements and geometries.

BRIEF DESCRIPTION OF THE INVENTION

[0005] According to one aspect of the invention, a stator of an electric machine is provided and includes laminations arranged to form a core packet. Each lamination is formed to define an annular array of teeth at an inner radial portion thereof and an annular array of annular sectors at an outer radial portion thereof.

[0006] According to another aspect of the invention, a stator of an electric machine is provided and includes a stator core defining a bore in which a rotor is rotatably supportable. The stator core includes laminations arranged to form a core packet and each lamination includes an annular array of teeth at an inner radial portion thereof, the annular array of teeth defining an annular array of slots and an annular array of spokes at an outer radial portion thereof, the annular array of spokes defining an annular array of annular sectors.

[0007] According to another aspect of the invention, an electric machine is provided and includes a rotor and a stator defining a bore in which the rotor is rotatably supportable and operable in a motor or generator mode. The stator includes laminations respectively affixed adjacent to at least one or two neighboring laminations to form a core packet and each lamination is formed to define an annular array of teeth at an inner radial portion thereof and an annular array of annular sectors at an outer radial portion thereof.

[0008] According to yet another aspect of the invention, a method of assembling an electric machine is provided such that the electric machine includes a stator core having axial vents with a substantially consistent width between neighboring vents as well as between vents and an outer diameter of the stator core to thereby allow flux density to be adjusted while ensuring that all dimensions are able to be manufactured.

[0009] The method further limits the protrusion of the vents into the area surrounding the slots, which prevents saturation and improves performance, and provides that a number of vents and a number of slots are the same such that there will always be a path for flux lines entering or leaving a circumferential track around the outer diameter of the stator core regardless of the orientation of the field.

[0010] These and other advantages and features will become more apparent from the following description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The subject matter, which is regarded as the invention, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0012] FIG. **1** is a radial view of an electric machine in accordance with embodiments;

[0013] FIG. **2** is an axial view of a portion of a lamination of FIG. **1**;

[0014] FIG. **3** is an enlarged view of a group of annular sectors of FIG. **2**;

[0015] FIG. **4** is an enlarged view of a corner of an annular sector in accordance with an alternative embodiment;

[0016] FIG. **5** is an enlarged view of a corner of an annular sector in accordance with an alternative embodiment; and

[0017] FIG. **6** is a radial view of an axial vent formed by the annular sectors of a plurality of adjacent laminations.

[0018] The detailed description explains embodiments of the invention, together with advantages and features, by way of example with reference to the drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0019] An electric machine is provided and includes a stator core with axial vents having shapes and sizes that provide a consistent width between neighboring vents as well as between vents and the outer diameter (OD) of the stator core. This configuration allows flux density to be adjusted while ensuring that all dimensions are able to be manufactured. It also limits the protrusion of the vents into the area around the slots, which prevents saturation and improves performance. Additionally, since a number of vents and a number of slots are the same, there will always be a path for flux lines entering or leaving the circumferential track around the OD regardless of the orientation of the field.

[0020] With reference to FIG. **1**, an electric machine **10** is provided and configured to operate in a generator mode or a motor mode. The electric machine **10** includes a rotor **11** and a stator **12**. The stator **12** is formed to define a bore **120** in which the rotor **11** is rotatably supportable. Rotation of the rotor **11** within the bore **120** can generate or induce flux that in turn induces a flow of current in conductive elements (to be described below), which are disposed to extend through the stator **12** in a predefined number of windings, when the electric machine **10** is operated in the generator mode. By contrast, current applied to the conductive elements can cause the rotor **11** to rotate when the electric machine **10** is operated in the motor mode.

[0021] The stator **12** is formed of a plurality of laminations **20** that are stacked between end plates **200**. The end plates **200** are used to compress the laminations **20** and to provide support to end turns of the conductive elements. Each lamination **20** is formed from a relatively thin piece of sheet metal that is punched, stamped or otherwise cut into shape and then affixed adjacent to at least one or two neighboring and substantially similarly shaped and sized laminations. The bonding is achieved by an application of heat and pressure in accordance with various known methods.

[0022] With enough laminations **20** affixed adjacent to one another, the laminations **20** may form at least a first core packet **30** and a second core packet **40**. The first and second core packets **30** and **40** may be separated from one another by a spacer **50** that is formed to define a radial vent **51**.

[0023] The laminations **20** may be formed from metals or para-magnetic materials such as electrical steel or the like.

[0024] With reference to FIGS. **2** and **3**, each of the laminations **20** has an inner radial portion **60** and an outer radial portion **70**. At the inner radial portion **60**, the laminations **20** are each formed to define an annular array of teeth **61**. Each tooth **61** includes a pair of opposed radial sidewalls **610** that face an adjacent tooth **61** and a circumferential sidewall **611** that faces radial inwardly toward the bore **120**. The annular array of teeth **61** thus defines a corresponding annular array of conductive element regions or slots **62** in which a plurality of conductive elements **620** are operably disposable.

[0025] The plurality of conductive elements **620** may be formed of a plurality of copper strands or a plurality of strands of another similarly conductive material. The strands are arranged in one or more columns in the slots **62** and have a current carrying capacity in accordance with design parameters. A layer of electrical insulation may be provided to surround each individual strand to thereby electrically insulate that strand from adjacent strands in the column or in adjacent columns

[0026] The electrical insulation surrounding each of the strands may be formed of a high thermal conductivity composite including one or more of polymers/resins, high thermal conductivity fillers and structural reinforcement materials such as E, S or S2 glass fibers, polyester fibers, Kevlar fibers or a like reinforcement material. Fillers made of boron nitride having cubic or hexagonal crystal structure or silica may be used. In this manner, heat transfer from each of the strands through the insulation is improved resulting in reduction of localized hot spot temperatures within individual strands and increased heat removal through axial teeth formation and axial vents (to be described below).

[0027] The plurality of conductive elements **620** may be connected or otherwise coupled to an electrical grid for providing alternating current to the grid. That is, when the electric machine **10** is operating in the above-noted generator mode, the electric machine converts mechanical energy embodied as a rotation of the rotor **11** to electrical energy by means of electromagnetic induction. In addition, the rotor **11** may also be connected to a grid, for example, in case of a doubly fed generator.

[0028] In accordance with embodiments, the plurality of conductive elements **620** may be wired with one another and with an external circuit so as to provide the stator **12** with a wiring configuration of a predefined or desired number of poles. As an example, as shown in FIG. **2**, the wiring configuration may be that of a 6-pole wiring configuration.

[0029] Each of the laminations **20** is formed to define an annular array of annular sectors **71** at the outer radial portion **70** and proximate to an outer diameter of the laminations **20**. Each annular sector **71** has an isosceles crowned-trapezoidal shape with a first circumferential arc-segment edge **710**, a second circumferential arc-segment edge **711**, which is parallel with and disposed radially outwardly from the first circumferential arc-segment edge **710** and first and second radial edges **712** and **713**. The first radial edge **712** is oriented along a radial dimension of the lamination **20** and connects complementary ends of the first and second circumferential arc-segment edges **710** and **711**. The second radial edge **713** is similarly oriented along the radial dimension of the lamination **20** and connects the opposite complementary ends of the first and second circumferential arc-segment edges **710** and **711**. The first and second radial edges **712** and **713** are angled with respect to each other at a predefined radial angle measured at a rotational axis of the rotor **11**.

[0030] With reference to FIGS. **3**, **4** and **5**, the first and second circumferential arc-segment edges **710** and **711** and the first and second radial edges **712** and **713** may be formed such that one or more of the annular sectors **71** has one or more angular corners **714** (see FIG. **3**) or one or more rounded corners **715** (see FIG. **4**). Alternatively or additionally, the first and second circumferential arc-segment edges **710** and **711** and the first and second radial edges **712** and **713** may be formed such that one or more of the annular sectors **71** has one or more chamfered corners **716** (see FIG. **5**).

[0031] In order to define the shape of the annular sectors **71**, the laminations **20** each include a rim portion **72** at a radially outermost portion of the outer radial portion **70**, a circumferential portion **73**, which is proximate to but displaced from the rim portion **72**, and radially oriented spokes **74**. In accordance with embodiments, the rim portion **72** and the circumferential portion **73** may each have a substantially uniform radial width. At each annular sector **71**, the rim portion **72** provides the second circumferential arc-segment edge **711** and the circumferential portion **73** provides the first circumferential arc-segment edge **710**. The radially oriented spokes **74** extend radially outwardly from the circumferential portion **73** to the rim portion **72** and provide the first and second radial edges **712** and **713** on opposite sides thereof.

[0032] With the configuration described above, the rim portion **72** is disposed radially outwardly from the annular sectors **71**, the circumferential portion **73** is disposed radially inwardly from the annular sections **71** and the spokes **74** are disposed circumferentially between adjacent pairs of annular sectors **71**.

[0033] In accordance with embodiments, each annular sector **71** may be circumferentially disposed between a pair of adjacent slots **62** and radially displaced from the pair of adjacent slots **62**. By a similar token, each annular sector **71** may be disposed in circumferential alignment with a corresponding tooth **61**. In this way, as noted above, there will always be a path for flux lines **80** (see FIGS. **2** and **3**). In addition, the teeth **61** may each have substantially similar shapes and sizes, the annular sectors **71** may also have substantially similar shapes and sizes and the spokes **74** may have substantially similar shapes and sizes. In other words, the circumferential displacements between adjacent slots **62** may be substantially uniform and the circumferential displacements between adjacent annular sectors **71** may be substantially uniform.

[0034] When the laminations **20** are affixed adjacent to one another to form the first and second core packets **30** and **40**, the teeth **61** and the annular sectors **71** of each of the laminations **20** circumferentially line up with one another. As such, the teeth **61** form axial teeth formations **90** (see FIG. **1**) around which the conductive elements may be wired and the annular sectors **61** form axial vents **91** (see FIG. **1**). These axial vents **91** fluidly communicate with an exterior of the stator **12** and/or the electric machine **10** and the radial vent **51** (see FIG. **1**) such that coolant, such as ambient air, can flow through the radial vent **51** and the axial vents **91**.

[0035] Although described above as ambient air, it is to be understood that the coolant may include other fluids as well. These other fluids may include, for example, ambient air, nitrogen gas and/or hydrogen gas.

[0036] In accordance with further embodiments of the application and, with reference to FIG. **6**, it will be understood that the axial vents **91** can be formed to permit laminar fluid flow therein or turbulent fluid flow therein. In the latter case, for example, the axial vents **91** can include turbulators **910** or other aerodynamic features that cause fluid flow with the axial vents **91** to become turbulent or form vortices **911** leading to increased heat removal from the surrounding material. The turbulators **910** can be formed from the laminations **20** themselves or as inserts to be inserted into the axial vents **91** following the stacking of the laminations **20**.

[0037] In accordance with further aspects, a configuration or geometry of a cross-sectional shape of the annular sectors **71** may be determined by way of a finite element analysis (FEA) or another similar analytical algorithm.

[0038] In accordance with further embodiments, an amount of fluid flow through the axial vents **91** may be substantially similar to the amount of fluid flow through the radial vent **51**. In this way, continued fluid flow through the electric machine **10** as a whole may be achieved without the risk of backflows or other similar issues. Thus, a size of each of the axial vents **91** may be provided such that the total amount of cross-sectional area through all of the axial vents **91** permits the substantially similar amount of fluid flow between the axial vents **91** and the radial vent **51**.

[0039] While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

1. A stator of an electric machine, comprising:

laminations arranged to form a core packet, each lamination being formed to define an annular array of teeth at an inner radial portion thereof and an annular array of annular sectors at an outer radial portion thereof.

2. The stator according to claim **1**, wherein each lamination comprises a ring defined radially outwardly from the annular array of annular sectors.

3. The stator according to claim **1**, wherein each annular sector is circumferentially disposed between a pair of adjacent slots and is radially displaced from the pair of adjacent slots.

4. The stator according to claim **3**, wherein the teeth have uniform shapes and sizes and the annular sectors have uniform sizes and shapes.

5. The stator according to claim **4**, wherein the annular sectors are each separated from adjacent annular sectors by a uniform distance.

6. The stator according to claim **1**, wherein each annular sector comprises:

first and second parallel arc-segment edges; and

first and second radial edges connecting complementary ends of the first and second parallel arc-segment edges.

7. The stator according to claim **1**, wherein each annular sector comprises a rounded corner.

8. A stator of an electric machine, comprising:

a stator core defining a bore in which a rotor is rotatably supportable, the stator core comprising:

laminations arranged to form a core packet, each lamination comprising:

an annular array of teeth at an inner radial portion thereof, the annular array of teeth defining an annular array of slots; and

an annular array of spokes at an outer radial portion thereof, the annular array of spokes defining an annular array of annular sectors.

9. The stator according to claim **8**, wherein each lamination comprises a ring coupled to distal ends of the spokes.

10. The stator according to claim **9**, wherein each annular sector is delimited by:

first and second parallel arc-segment edges of a central portion of the lamination and the ring; and

first and second radial edges of the corresponding spokes connecting complementary ends of the first and second parallel arc-segment edges.

11. The stator according to claim **8**, wherein each annular sector is circumferentially disposed between a pair of adjacent slots and is radially displaced from the air of adjacent slots.

12. The stator according to claim **11**, wherein the teeth have uniform shapes and sizes, the spokes have uniform shapes and sizes and the annular sectors have uniform sizes and shapes.

13. The stator according to claim **8**, wherein each annular sector is a crowned-trapezoidal shape.

14. The stator according to claim **8**, wherein each annular sector comprises a rounded corner.

15. An electric machine, comprising:

a rotor;

a stator defining a bore in which the rotor is rotatably supportable and operable in a motor or generator mode, the stator comprising:

laminations respectively affixed adjacent to at least one or two adjacent laminations to form a core packet, each lamination being formed to define an annular array of teeth at an inner radial portion thereof and an annular array of annular sectors at an outer radial portion thereof.

16. The electric machine according to claim **15**, further comprising a plurality of conductive elements operably disposed between the teeth.

17. The electric machine according to claim **15**, wherein each annular sector comprises:

first and second parallel arc-segment edges; and

first and second radial edges connecting complementary ends of the first and second parallel arc-segment edges.

18. The electric machine according to claim **15**, wherein each annular sector is circumferentially disposed in alignment with a corresponding tooth and is radially displaced from the corresponding tooth.

19. The electric machine according to claim **15**, wherein the teeth have uniform shapes and sizes and the annular sectors have uniform sizes and shapes.

20. The stator according to claim **8**, wherein each annular sector is a crowned-trapezoidal shape.

* * * * *