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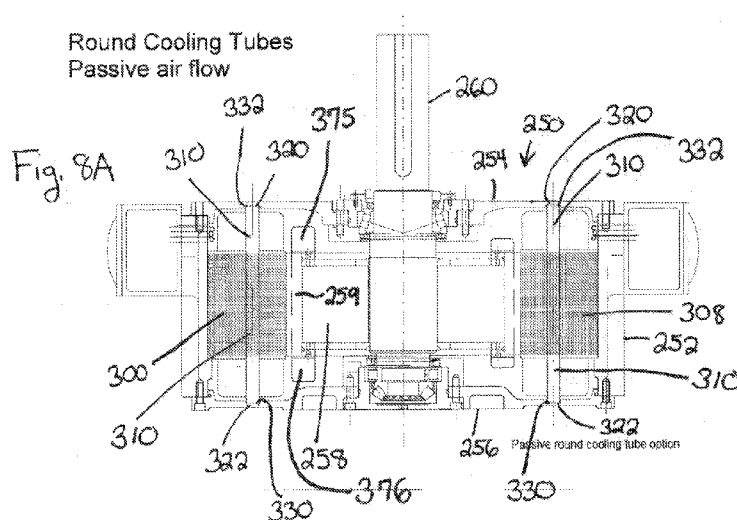
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(54) Title: COOLING SCHEMES AND METHODS FOR COOLING TOWER MOTORS



(57) **Abstract:** The present invention provides techniques, schemes configurations and methods for removing or reducing heat in motors. In one embodiment, the present invention is directed to a cooling tower comprising a cooling tower structure and a motor supported by the cooling tower structure. The motor comprises a motor casing and a rotatable shaft. The cooling tower further comprises a cooling tower fan that comprises a fan hub, a plurality of fan blades attached to the rotatable shaft and a supplemental fan attached to the fan hub such that the supplemental fan is between the fan hub and the motor. Rotation of the cooling tower fan causes rotation of the supplemental fan which increases airflow around the casing of the motor so as to facilitate cooling of the motor. Other embodiments of configurations, schemes, method and techniques for thermally managing motors are described herein in detail.

1 COOLING SCHEMES AND METHODS FOR
2 COOLING TOWER MOTORS

3
4 CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application claims the benefit of and priority to U.S. application no.
6 62/027,100, filed July 21, 2014 and to U.S. application no. 62/049,105, filed September
7 11, 2014. The entire disclosures of the aforesaid U.S. application nos. 62/027,100 and
8 62/049,105 are hereby incorporated by reference.

9
10 TECHNICAL FIELD:

11 The present invention is directed to various schemes and configurations for
12 cooling electric machines having a stator and rotor that that produce flux, such as electric
13 motors.

14
15 BACKGROUND ART:

16 During operation of electric machines having a stator and a rotor, such as motors,
17 excessive heat may be generated in the stator windings or in other portions of the electric
18 machine. In order to prevent such excessive heat from damaging the electric machine,
19 reducing its performance or shortening its operational life, it is necessary to cool the
20 motor so as to reduce or remove the heat. The aforementioned problem with excessive
21 heat is a significant problem in motors used in cooling towers or air-cooled heat
22 exchangers.

1 DISCLOSURE OF THE INVENTION:

2 The present invention provides techniques, schemes configurations and methods
3 for removing or reducing heat in electrical machines having a stator and rotor that
4 cooperate to produce flux. In particular, the present invention provides techniques,
5 schemes configurations and methods for removing or reducing heat in motors that are
6 used in cooling towers or air-cooled heat exchanger towers.

7 In one embodiment, the present invention is directed to a cooling tower
8 comprising a cooling tower structure and a motor supported by the cooling tower
9 structure. The motor comprises a motor casing and a rotatable shaft. The cooling tower
10 further comprises a cooling tower fan that comprises a fan hub, a plurality of fan blades
11 attached to the rotatable shaft and a supplemental fan attached to the fan hub such that the
12 supplemental fan is between the fan hub and the motor. Rotation of the cooling tower fan
13 causes rotation of the supplemental fan which increases airflow around the casing of the
14 motor so as to facilitate cooling of the motor.

15 Other embodiments of configurations, schemes, method and techniques for
16 thermally managing motors are described herein in detail.

17
18 BRIEF DESCRIPTION OF THE DRAWINGS:

19 FIG. 1 is a diagram of a portion of a wet cooling tower.

20 FIG. 2 is a bottom view of a cooling tower fan having a supplemental fan in
21 accordance with one embodiment of the invention;

FIG. 3 is a side view of the cooling tower fan having a supplemental fan in accordance with another embodiment of the invention, the view showing only a portion of the cooling tower fan in order to emphasize the supplemental fan;

FIG. 4A is a side view of the cooling tower fan having a supplemental fan in accordance with another embodiment of the invention

FIG. 4B is a side view of the cooling tower fan having a supplemental fan in accordance with another embodiment of the invention;

FIG. 4C is a side view of the cooling tower fan having a supplemental fan in accordance with another embodiment of the invention, the view showing only a portion of the cooling tower fan in order to emphasize the supplemental fan;

FIG. 5A is a side elevational view, partially in cross-section, of a Totally Enclosed Fan Cooled Motor having an elliptical traction drive device;

FIG. 5B is plan view of the elliptical traction drive device shown in FIG. 5A;

FIG. 6 is a side elevational view, partially in cross-section, of a Totally Enclosed Fan Cooled Motor having an elliptical traction drive device in accordance with another embodiment of the invention;

FIGS. 7A-F are partial, elevational views of various cooling tubes used in the motors of the present invention

FIG. 8A is a diagram of a motor using a passive air-cooling scheme in accordance with one embodiment of the invention;

FIG. 8B is a plan view of the stator of the motor of FIG. 8A, the view not showing other motor components in order to simplify the view of the stator;

1 FIG. 9A is a diagram of a motor using a passive air-cooling scheme in accordance
2 with one embodiment of the invention;

3 FIG. 9B is a plan view of the stator of the motor of FIG. 9A, the view not
4 showing other motor components in order to simplify the view of the stator

5 FIG. 10A is a diagram of a motor using a passive air-cooling scheme in
6 accordance with one embodiment of the invention;

7 FIG. 10B is a plan view of the stator of the motor of FIG. 10A, the view not
8 showing other motor components in order to simplify the view of the stator.

9 FIG. 11 is a diagram of a motor in accordance with another embodiment of the
10 invention;

11 FIG. 12A is a diagram of a motor in accordance with another embodiment of the
12 invention;

13 FIG. 12B is a plan view of the stator of the motor of FIG. 12A, the view not
14 showing other motor components in order to simplify the view of the stator;

15 FIG. 13A is a diagram of a motor in accordance with another embodiment of the
16 invention;

17 FIG. 13B is a plan view of the stator of the motor of FIG. 13A, the view not
18 showing other motor components in order to simplify the view of the stator;

19 FIG. 14A is a diagram of a motor in accordance with another embodiment of the
20 invention;

21 FIG. 14B is a plan view of the stator of the motor of FIG. 14A, the view not
22 showing other motor components in order to simplify the view of the stator;

1 FIG. 15A is a diagram of a motor in accordance with another embodiment of the
2 invention, the view only showing half of the motor in order to simplify the view of the
3 novel features of the motor;

4 FIG. 15B is a diagram of a motor in accordance with another embodiment of the
5 invention, the view only showing half of the motor in order to simplify the view of the
6 novel features of the motor;

7 FIG. 16 is a diagram of a motor in accordance with another embodiment of the
8 invention, the view only showing half of the motor in order to simplify the view of the
9 novel features of the motor;

10 FIG. 17 is a side view, in elevation, of a motor in accordance with another
11 embodiment of the invention;

12 FIG. 18A is plan view of a stator in accordance with another embodiment of the
13 invention;

14 FIG. 18B is a diagram of the serpentine cooling tubes used in the stator of FIG.
15 18A;

16 FIG. 19A is a diagram of a motor in accordance with another embodiment of the
17 invention;

18 FIG. 19B is a plan view of the stator of the motor of FIG. 19A, the view not
19 showing other motor components in order to simplify the view of the stator;

20 FIG. 20A is a diagram showing stator windings wrapped about a cooling tube;

21 FIG. 20B is a diagram showing an electrically insulative layer of material
22 wrapped about a cooling tube, stator windings wrapped about the electrically insulative

1 layer of material and an additional electrically insulative layer wrapped about the stator
2 windings;

3 FIG. 21A is a diagram of a motor in accordance with another embodiment of the
4 invention;

5 FIG. 21B is a plan view of the stator of the motor of FIG. 19A, the view not
6 showing other motor components in order to simplify the view of the stator; and

7 FIG. 21C is a plan view of a heat pipe and heat sink shown in FIG. 21A.

8
9 BEST MODE FOR CARRYING OUT THE INVENTION:

10 It is well known in the industry that motors have “ housings ” or “ casings ” that
11 contain the internal components in the motor, such as the stator and rotor. As used
12 herein, the terms “ casing ” or “ motor casing ”, “ housing ” or “ motor housing ” all have the
13 same meaning and are used interchangeably.

14 Although the ensuing description is in terms of the embodiments of the present
15 invention being used in a cooling tower or air-cooled heat exchanger, it is to be
16 understood that the ensuing embodiments of the present invention may be applied to
17 motors used in applications other than cooling towers or air-cooled heat exchangers.

18 Wet cooling towers are described in U.S. Patent No. 8,111,028 entitled
19 “ Integrated Fan Drive System For Cooling Tower ” and international application no.
20 PCT/US2012/061244 entitled “ Direct Drive Fan System With Variable Process Control ”
21 and published under International Publication No. WO 2013/059764. The entire
22 disclosure of U.S. Patent No. 8,111,028 is hereby incorporated by reference. The entire
23 disclosure of international application no. PCT/US2012/061244 is hereby incorporated by

reference. Dry cooling towers are described in U.S. Patent No. 8,188,698 entitled “Integrated Fan Drive System For Air-Cooled Heat Exchanger (ACHE)”. The entire disclosure of U.S. Patent No. 8,188,698 is hereby incorporated by reference.

The present invention is directed to various methods, techniques, configurations and schemes for cooling motors and to corresponding motor configurations. In accordance with the invention, various cooling mediums are used to cool the motors. Such cooling mediums include clean, dry, filtered air and water, or a combination of clean, dry, filtered air and water, or a combination of clean, dry, filtered air and water mixed with additives such as glycol, ammonia or Freon. Another cooling medium used is chilled air which may be compressed. In other embodiments, a gas or combination of gases are used instead of air.

Although the ensuing description is in terms of the embodiments of the invention being applied to wet cooling towers, it is to be understood that embodiments of the invention may be applied to dry cooling towers or ACHE units as disclosed in the aforementioned U.S. Patent No. 8,188,698. It is also to be understood the embodiments of the invention may be applied to a motor regardless of its orientation (e.g. upside down, right side up, angular orientation, horizontal, etc.). Thus, the techniques, schemes, configurations and methods of the present invention may be applied to a motor regardless of the orientation of its shaft.

Referring to FIG. 1, there is shown a basic block diagram of cooling tower 15 that utilizes motor 20 of the present invention. Cooling tower 15 includes fan stack 22, fan deck 24 and fan 26. Fan stack 22 is connected to fan deck 24. Fan 26 has fan hub 28 and fan blades 29 that are connected to fan hub 28. Motor 20 has rotatable shaft 100 that

1 directly drives fan 26. Fan 26 rotates within fan stack 22. Motor 20 includes casing 30
2 which has exterior surface 32. The height of motor 20 must be in a predetermined range
3 in order to maintain the height of fan 26 in fan stack 22 for sealing and fan performance.
4 Motor 20 is relatively large in diameter in order to produce a significant torque to cause
5 rotation of fan 26. Cooling tower 20 is a “wet cooling tower” which uses the latent heat
6 of evaporation to cool process fluids. “Process fluids” are fluids that are used in a
7 process, e.g. cracking crude, chemical processing, etc. Since motor 20 is directly driving
8 the fan, the air-flow around motor 20 is relatively low.

9 The air-flow around motor 20 is dictated by the diameter of the fan hub, fan
10 blades and fan speed. It has been found that making the fan hub diameter smaller and
11 extending the fan blade to the smaller diameter fan hub increases the air flow around the
12 motor.

13 Referring to FIG. 2, in order to increase the air-flow around motor 20,
14 supplemental fan 50 is connected to the bottom side 28A of fan hub 28. Fan 50
15 comprises hub 52 and blades 54 that are attached to hub 52. In order to simplify the view
16 of FIG. 2, fan blades 29 are not shown in FIG. 2. The function of fan 50 is to draw more
17 airflow around motor 20 wherein the increased air-flow can be used to cool motor 20.

18 Although fan 26 is a multi-piece fan, it is to be understood the fan 50 can be connected to
19 a one-piece fan as well as relatively smaller fans such as the BAC Whisper Quiet Fan.

20 The particular type, design, size and weight of fan 50 depends upon the type of
21 installation required, fan speed, the required air flow for the motor and whether the motor
22 is a single speed or variable speed motor.

1 Referring to FIG. 3, there is shown another embodiment of the invention.
2 Supplemental fan 60 is attached or connected to the bottom 28A of fan hub 28. Fan 60
3 comprises fan blades 62. In one embodiment, supplemental fan 60 is a separate
4 component that is connected or attached to fan hub 28. In another embodiment, fan 60 is
5 integral with fan 28. In other embodiments, fan 60 may be connected to a one-piece fan
6 as well as to smaller fans such as the BAC Whisper Quiet Fan. In another embodiment,
7 fan 60 is configured to have a variable pitch apparatus to provide various fan pitch to fan
8 60 for various air-flows.

9 Referring to FIG. 4A, there is shown another embodiment of the present
10 invention. Supplemental wide chord fan blade 70 is attached or connected to fan blade
11 29 (see FIG. 1) in order to increase air-flow to motor 20. Adjustable pitch device 72 is
12 either a separate component that is attached fan blade 29 or is integrally formed with fan
13 blade 29. Adjustable pitch device 72 allows for adjustment of the pitch of supplemental
14 wide chord fan blade 70. It is to be understood that a supplemental wide chord fan blade
15 70 can be attached to each fan blade 29.

16 Referring to FIG. 4B, there is shown another embodiment of the present
17 invention. Fan pitch adjustment device 80 is attached to the neck of fan blade 29 and
18 supplemental wide chord fan blade 82 is connected to pitch adjustment device 80. Pitch
19 adjustment device 80 allows for the adjustment of the pitch of supplemental wide chord
20 fan blade 82. It is to be understood that a supplemental wide chord fan blade 82 can be
21 attached to each fan blade 29.

22 Referring to FIG. 4C, there is shown another embodiment of the present
23 invention. In this embodiment, adjustable fan pitch devices 90 are either integral with fan

1 hub 28 or are separate components that are attached to bottom side 28A of fan hub 28. A
2 supplemental fan blade 92 is attached to each adjustable fan pitch device 90.

3 Some motors, due to their design, rotate the cooling fan too slow for the cooling
4 fan to produce an appreciable cooling flow. For example, fan speeds below 200 RPM
5 may not generate any appreciable air-flow around the motor. In order to solve this
6 problem, the motor 100, shown in FIGS. 5A, 5B and 6, is presented. Totally Enclosed
7 Fan Cooled (TEFC) motor 100 comprises casing 102, shaft 104 and a stator and rotor
8 (not shown). In order to increase fan speed, motor 100 comprises an Elliptical Traction
9 Drive (ETD) device 110. Elliptical Traction Drive device 110 comprises output ring
10 roller 112, sun roller 114 and star rollers 116. ETD device 110 includes shaft 118 that is
11 connected to the cooling tower fan. Sun roller 114 is integral with motor shaft 104. ETD
12 110 can step up or step down the fan speed as required for cooling with respect to fan
13 design. Such an ETD device 110 is described in international application no.
14 PCT/US2014/014408, entitled "Direct-Drive System For Cooling System Fans, Exhaust
15 Blowers And Pumps", published under international publication no. WO 2014/123804,
16 and is therefore not described in detail herein. The entire disclosure of international
17 application no. PCT/US2014/014408 is hereby incorporated by reference. Thus, motor
18 100 can replace motor 20 shown in FIG. 1. Furthermore, motor 100 can be used with fan
19 26 as modified with any of supplemental fans shown in FIGS. 2, 3 and 4A-C.

20 Referring to FIG. 6, there is shown an alternate TEFC motor 150 in accordance
21 with another embodiment of the invention. Motor 150 includes casing 152, rotational
22 shaft 154 and ETD device 160. ETD device 160 is located at the bottom of motor 150.
23 Supplemental axial fan 170 is mounted to ETD device 160 with a modified mounting

1 arrangement and without the enclosure. Supplemental axial fan 170 provides additional
2 cooling of motor 150.

3 In another aspect of the invention, a motor may be configured to include cooling
4 tubes having particular configurations such as cooling fins, radial fins, oval holes, round
5 holes, round tubes, and thumbnails in order to effect cooling of the motor. Such cooling
6 tube configurations are shown in FIGS. 7A-F. FIG. 7A shows cooling tube 200 having
7 longitudinal fins 202. In a preferred embodiment, cooling tube 200 is a continuous tube.
8 Cooling tube 200 can transfer air and/or water from one location in the motor to another
9 location in the motor without leakage and exchange heat between the motor and the
10 media in cooling tube 200. FIG. 7C shows cooling tube 212 having radial fins 214. In a
11 preferred embodiment, cooling tube 212 is a continuous tube. The cooling tube 212
12 transfers air and/or water from one location in the motor to another location in the motor.
13 Cooling tube 212 exchanges heat between the motor and the media in cooling tube 212.
14 FIG. 7D shows round cooling tube 216 having a smooth configuration. In a preferred
15 embodiment, cooling tube 216 is a continuous tube with a smooth surface. The cooling
16 tube 216 transfers air and/or water from one location in the motor to another location in
17 the motor without leakage and exchanges heat between the motor and the media in
18 cooling tube 216. FIG. 7B shows cooling tube 210 that has round holes 211. FIG. 7E
19 shows cooling tube 218 having oval holes 220. FIG. 7F shows a cooling tube 222 that is
20 configured with thumbnails 224. In preferred embodiments, cooling tubes 210, 218 and
21 222 are continuous tubes that transfer air and/or water from one location in the motor to
22 another location in the motor without leakage and exchanges heat between the motor and
23 the media in the cooling tube.

1 In alternate embodiments, the cooling tubes shown in FIGS. 7A-F may be
2 modified to have other cross-sectional shapes.

3 In another embodiment, air from the cooling tubes is forced through round and/or
4 oval holes and/or thumbnails into the motor cavity imparting swirl and turbulence that
5 facilitates mixing of hot and cold air to improve heat transfer.

6 Referring to FIGS. 8A and 8B, there is shown motor 250 that incorporates a
7 passive air-cooling scheme in accordance with one embodiment of the present invention.
8 Motor 250 comprises casing 252, top cover 254, bottom cover 256, rotor 258, rotatable
9 shaft 260 and stator 300. Rotor 258 includes a plurality of permanent magnets 259.
10 Stator 300 comprises a plurality of lamination sheets 302 that are attached or bonded
11 together to form stack 304. Each lamination sheet 302 has a plurality of slots 306
12 through which windings or coils 308 are wound. During operation of motor 250,
13 significant heat is produced in windings 308. In accordance with this embodiment of the
14 invention, round, continuous cooling tubes 310 are inserted into the windings or coils 308
15 in order to directly cool windings 308 and facilitate transfer of heat from windings 308 to
16 the outside environment. Cooling tube 310 has the same configuration as cooling tube
17 216 shown in FIG. 7D. Cooling tubes 310 are sealed at top cover 254 with O-ring 320
18 and at bottom cover 256 with O-ring 322. O-ring 320 prevents moisture or contaminants
19 enter motor 250 at the junction of tubes 310 and top cover 254. Similarly, O-ring 322
20 prevents moisture or contaminants from entering motor 250 at the junction of tubes 310
21 and bottom cover 256. O-rings 320 and 322 allow for thermal expansion of motor 250
22 and maintain sealing integrity. Each tube 310 has bottom opening 330 that is in
23 communication with a corresponding opening in bottom cover 256. Each tube 310 also

1 has a top opening 332 in communication with a corresponding opening in top cover 254.
2 Cooling air flows into bottom opening 330 and flows through the tube 310 and is ejected
3 from top opening 332 into the fan air stream. This cooling embodiment takes advantage
4 of the available upward moving air under and around motor 250 created by rotation of the
5 direct-drive cooling tower fan or supplemental fan. For a wet cooling tower, the 100%
6 humid air facilitates removal of heat from windings 308. In one embodiment, cooling
7 tubes 310 are fabricated from copper. In one embodiment, cooling tubes 310 are
8 insulated with Teflon, Silicone or an equivalent material for windings 308. Teflon offers
9 the advantage of temperature compatibility with the benefit of suitable electrical
10 insulating properties. Silicone offers excellent thermal conductivity combined with
11 excellent electrical insulating properties. If cooling tubes 310 are made from copper
12 and/or other electrically conductive materials, then the cooling tubes 310 will have to be
13 electrically insulated. However, if windings 308 have been through a Vacuum Pressure
14 Impregnated (VPI) Process, the additional electrical insulation may not be necessary.
15 Cooling tubes 310 may be manufactured from other materials that are thermally
16 conductive and electrically insulative such as Teflon, silicone and high temperature
17 plastics. In an alternate embodiment, a cooling tube 310 is embedded in every other
18 winding 308.

19 Rotor 258 includes fan structure 375 that is attached to or integral with the top
20 end of rotor 258 and fan structure 376 that is attached to or integral with the bottom end
21 of rotor 258. Fan structures 375 and 376 have the same structure, function and purpose
22 as fan structures 850 and 852, respectively, that are shown in FIG. 13A and described
23 herein.

1 Cooling tubes are best used at the source of the generated heat source such as the
2 coil, but are not limited to those locations. It is to be understood that the cooling tube
3 route may be varied as required by application and is not limited to configuration wherein
4 the cooling tubes extend between the top and bottom covers of the motor casing.

5 Referring to FIGS. 9A and 9B, there is shown motor 400 which incorporates a
6 passive air-scheme in accordance with another embodiment of the invention. Motor 400
7 comprises casing 401, top cover 402, bottom cover 403, rotor 404, rotatable shaft 406 and
8 stator 408. Rotor 404 includes a plurality of permanent magnets 409 as is well known in
9 the art. Stator 408 comprises a plurality of lamination sheets 410 that are attached or
10 bonded together to form stack 412. Each lamination sheet 410 has a plurality of slots 411
11 (similar to 306 in FIG. 8A) through which windings or coils 414 are wound. During
12 operation of the motor, significant heat is produced in windings 414. In this embodiment,
13 stator 408 does not use round cooling tubes. Instead, continuous ducts 420 are embedded
14 in stator 408 as windings 414 are inserted into the stator stack 412 during production of
15 stator stack 412. Each duct 420 may have a unique shape other than circular. Each duct
16 420 has a bottom opening 422 that is in communication with a corresponding opening in
17 bottom cover 403. Each duct 420 also has a top opening 424 in communication with a
18 corresponding opening in top cover 402. Cooling air flows into bottom opening 422 of
19 each duct 420 and flows through the ducts 420 and is ejected from top opening 424 into
20 the fan air stream. This passive cooling air-cooling embodiment is suited for use in
21 relative large-diameter direct-drive cooling tower motors, such as motor 400, since such
22 motors are configured with a “pancake motor arrangement” wherein the motor is
23 relatively short in height as required by installation purposes. Motor 400 has relatively

1 large deep slot laminations 410 that make up stator 408 thereby allowing for extra room
2 for ducts 420 to pass air to cool coils windings 414. When combined with deep slot
3 laminations, the shaped ducts 420 can be installed between the inserted windings 414,
4 which are near casing 401, and rotor 404 thereby providing an insulating barrier of air
5 that prevents or minimizes the transfer of heat from the windings to the magnets that are
6 on rotor 404. O-rings 450 seal the junction of ducts 420 and top cover 402 and O-rings
7 460 seal the junction of ducts 420 and bottom cover 403 in the same manner in which
8 cooling tubes 310 are sealed to top cover 254 and bottom cover 256 (see FIGS. 8A and
9 8B).

10 Rotor 404 comprises fan structure 480 that is attached to or integral with the top end of
11 rotor 404 and fan structure 482 that is attached to the bottom end of rotor 404. Fan
12 structures 480 and 482 have the same structure, function and purpose as fan structures
13 850 and 852, respectively, that are shown in FIG. 13A and described herein.

14 Referring to FIGS. 10A and 10B, there is shown motor 500 which uses an
15 alternate passive air-cooling scheme in accordance with another embodiment. In this
16 embodiment, motor 500 comprises casing 502, rotor 504, rotatable shaft 506, stator 508
17 bottom cover 509 and top cover 510. Rotor 504 has a plurality of magnets 511 attached
18 thereto as is well known in the art. Stator 508 comprises a plurality of lamination sheets
19 517 that are attached or bonded together to form stator stack 512. Each lamination sheet
20 517 has a plurality of slots 519 through which windings or coils 514 are wound. Stator
21 508 is configured exactly the same as stator 300 in (see FIGS. 8A and 8B) and uses
22 cooling tubes 515. Cooling tubes 515 have the same shape, configuration and functions
23 as cooling tubes 310. Motor 500 includes inlet ducts 520 and 522 that are mounted or

1 attached to bottom cover 509. Motor 500 further includes exhaust nozzles 530 and 532
2 that are mounted or attached to top cover 510. Inlet ducts 520, 522 and output nozzles
3 530, 532 are in communication with cooling tubes 515. Air-flow, indicated by reference
4 number 540, flows into inlet ducts 520 and 522 and through cooling tubes 515 and then
5 out through exhaust nozzles 530 and 532. Inlet ducts 520, 522 and output nozzles 530,
6 532 enhance the flow of air into cooling tubes 515. Inlet ducts 520 and 522 direct more
7 available air (and water) into cooling tubes 515 and out through exhaust nozzles 530 and
8 532 so as to facilitate acceleration of air back into the fan airstream through controlled
9 expansion. As a result of this configuration, mass airflow through cooling tubes 515 is
10 improved thereby increasing heat transfer.

11 Rotor 504 comprises fan structure 575 that is attached to or integral with the top
12 end of rotor 504 and fan structure 576 that is attached to or integral with the bottom end
13 of rotor 504. Fan structures 575 and 576 have the same structure, function and purpose
14 as fan structures 850 and 852, respectively, that are shown in FIG. 13A and described
15 herein.

16 Referring to FIG. 11, there is shown motor 600 that incorporates a passive air-
17 cooling embodiment in accordance with another embodiment of the invention. Motor
18 600 comprises casing 602, rotor 604, shaft 605 and stator 606. Rotor 604 includes a
19 plurality of magnets 650. Stator 606 has the same configuration as stator 408 (see FIG.
20 9B). Thus, stator 606 comprises continuous ducts 607 which are the same as continuous
21 ducts 420 used in stator 408. Motor 600 further comprises top cover 613 and bottom
22 cover 615. In this embodiment, motor 600 has relatively larger inlet ducts 610 and 612
23 that are mounted or attached to bottom cover 615 and in communication with the

1 continuous ducts 607 embedded in stator 606. Inlet ducts 610 and 612 channel airflow
2 614 into the continuous ducts 607 embedded in stator 606. The air flowing into the
3 continuous ducts 607 flows out through exhaust nozzles 616 and 618 which are mounted
4 or attached to top cover 613.

5 Rotor 604 comprises fan structure 675 that is attached to or integral with the top
6 end of rotor 604 and fan structure 676 that is attached to or integral with the bottom end
7 of rotor 604. Fan structures 675 and 676 have the same structure, function and purpose
8 as fan structures 850 and 852, respectively, that are shown in FIG. 13A and described
9 herein.

10 In alternate embodiments of the invention, the cooling tubes of FIGS. 8A, 8B,
11 10A and 10B and continuous ducts of FIGS. 9A, 9B and 11 are sealed at both ends with a
12 phase change material between the sealed ends. The phase change material may include
13 solids, liquids, gases or any combination thereof which effects meets thermal mass
14 requirements to cool and heat the motor. Suitable phase change material is described in
15 U.S. Patent No. 4,459,949 entitled "Liquid Metal Cooled Internal Combustion Engine
16 Valves With Getter", the disclosure of which patent is hereby incorporated by reference.

17 Referring to FIGS. 12A and 12B, there is shown motor 700 in accordance with
18 another embodiment of the present invention. Motor 700 comprises casing 702, top
19 cover 703, bottom cover 704, stator 705, rotor 706 and rotor shaft 708. Rotor 706
20 includes a plurality of permanent magnets 709. In this embodiment, stator 705 has the
21 same configuration and structure as stator 508 shown in FIGS. 10A and 10B. Thus,
22 stator 705 includes cooling tubes 710 which have the same shape and configuration as
23 cooling tubes 515. Cooling tubes 710 are embedded in the slots of the stator stack as

1 winding 712 are inserted into the stack. Cooling tubes 710 are in communication with
2 the external environment of motor 700. Motor 700 includes manifold 720 that is attached
3 to bottom cover 704. Manifold 720 has intake port 722 that receives air from an air
4 source. One such example of a suitable air source is a blower that is located outside the
5 fan stack of the cooling tower. Manifold 720 may be a separate assembly or integral with
6 bottom cover 704. Manifold 720 receives the pressurized air from the air-source outside
7 of the fan stack and distributes the pressurized air into cooling tubes 710. The
8 pressurized air 730 is ejected into the fan airstream by cooling tubes 710.

9 Rotor 706 comprises fan structure 750 that is attached to or integral with the top
10 end of rotor 706 and fan structure 752 that is attached to or integral with the bottom end
11 of rotor 706. Fan structures 750 and 752 have the same structure, function and purpose
12 as fan structures 850 and 852, respectively, that are shown in FIG. 13A and described
13 herein.

14 In embodiments in which stator 705 uses continuous cooling tubes configured as
15 cooling tube 216 shown in FIG. 7D, the pressurized air could be regular filtered air from
16 a blower or compressor. The pressurized air would be ejected into the surrounding
17 environment in a manner similar to the embodiments shown in in FIGS. 8A, 8B, 9A and
18 9B. This embodiment would allow the pressurized air to be either cooled or heated.
19 Cooled air may be supplied from a chiller or a Transvector Jet by Vortec installed in-line
20 with the air source that is outside of the fan stack. Heating of the air also prevents
21 freezing in colder climates.

22 In alternate embodiments, tubes or ducts having holes therein are embedded in the
23 stator. These embodiments would be used with filtered, clean dry air because the motor

1 is sealed by design and must remain clean of contamination and moisture. The addition of
2 an exhaust nozzle, as show in FIGS. 10A and 11 would enhance the mass flow of air. In
3 an alternate embodiment, exhaust nozzles are replaced or combined with flapper valves
4 or equivalent to seal the motor from contamination. Grainger filters can be combined
5 with flapper valves or equivalent.

6 Referring to FIGS. 13A and 13B, there is shown motor 800 in accordance with
7 another embodiment of the invention. Motor 800 comprises casing 802, top cover 803,
8 bottom cover 804, stator 805, rotor 806 and rotor shaft 808. Rotor 806 has a plurality of
9 permanent magnets 809. In this embodiment, stator 805 has the same configuration and
10 structure as stator 508 shown in FIGS. 10A and 10B. Thus, stator 805 includes cooling
11 tubes 810 which have the same shape and configuration as cooling tubes 515. Cooling
12 tubes 810 are in communication with the external environment of motor 800. Motor 800
13 includes inlet manifold 820 that is attached to bottom cover 804. Manifold 820 has
14 intake port 822 that receives clean, dry, filtered air from an air source that is located
15 outside of the fan stack. Suitable air sources include a blower, chiller, heater,
16 compressor, recirculation system, heat exchanger, or combinations thereof. Manifold 820
17 may be a separate assembly or integral with bottom cover 804. Manifold 820 receives
18 pressurized air from the air-source outside of the fan stack and distributes the pressurized
19 air into cooling tubes 810. Motor 800 further includes outlet manifold 830 that is
20 attached to top cover 803. Outlet manifold 830 receives the pressurized air flowing
21 through cooling tubes 810 and discharges the air 840 outside the fan stack with
22 corresponding piping (not shown).

1 As shown in FIG. 13A, rotor 806 includes fan structure 850 attached to the top
2 end of rotor 806 and fan structure 852 that is attached to the bottom end of rotor 806. Fan
3 structure 850 includes a plurality of blades or vanes. Similarly, fan structure 852 includes
4 a plurality of blades or vanes. As rotor 806 rotates, fan structures 850 and 852 mix the air
5 around the magnets on rotor 806 and mix the air within the interior of the motor in order
6 to create a heat path from the rotor 806 to casing 802. This configuration causes a
7 transfer of heat from rotor 806 to casing 802.

8 In another embodiment, each cooling tube 810 is configured to have holes therein
9 to deliver dry, clean, filtered air into the motor cavity which mixes with existing air
10 inside the motor cavity by fan structures 850 and 852 so as to (i) provide heat transfer of
11 either hot or cold air, (ii) collect any moisture within the motor cavity, and (iii) exhaust
12 that air through outlet manifold 830. Outlet manifold 830 discharges the air outside of
13 the fan stack. In one embodiment, outlet manifold 830 discharges the air to a filter that is
14 located outside of the fan stack. One example of such a filter is the Grainer Part Number
15 3TLA2. This embodiment not only provides thermal management of the motor with
16 heating and cooling options but also provides thermal and motor volume expansion
17 management to maintain motor operating clearances such as rotor-to-stator clearance.
18 This embodiment also maintains sealing integrity and prevents overheating of the motor,
19 especially the temperature sensitive magnets, and prevents freezing of the motor in colder
20 climates. This embodiment allows the use of smaller auxiliary cooling systems that are
21 less costly but highly effective, have smaller footprints and weigh less for places such as
22 cooling towers and skyscrapers that have weight and other structural limitation relative to

1 size and weight. The cooling tubes may be treated with a suitable heat dissipation
2 coating.

3 In an alternate embodiment, cooling tubes 810 are replaced with continuous ducts
4 of the type shown in FIG. 9B. In one embodiment, the continuous ducts do not have
5 holes therein so that air in the duct does not enter the motor cavity. In another
6 embodiment, the continuous ducts have holes therein to allow air to enter the motor
7 cavity for the reasons stated in the foregoing description.

8 The cooling tubes and ducts can be custom designed to have various shapes,
9 routings and volumes and may be formed to fit into the available stator lamination slot
10 and other available space in the motor in order to maximize heat transfer from the motor.

11 In further embodiment, solid tubes are used in stator 805. The solid tubes conduct
12 heat and remove the heat in a manner similar to a radiator or tubes that have various hole
13 configurations that can input air directly to the inside of the motor cavity.

14 Referring to FIGS. 14A and 14B, there is shown another embodiment of the
15 invention. Motor 900 comprises casing 902, top cover 903, bottom cover 904, stator 905,
16 rotor 906 and rotor shaft 908. Rotor 906 includes a plurality of magnets 909. In this
17 embodiment, stator 905 has the same configuration and structure as stator 508 shown in
18 FIGS. 10A and 10B. Thus, stator 905 includes cooling tubes 910 which have the same
19 shape and configuration as cooling tubes 515. Motor 900 includes inlet manifold 920
20 that is attached to bottom cover 904. Manifold 920 has intake port 922 that receives
21 clean, dry, filtered air from an air source that is located outside of the fan stack. Suitable
22 air sources include a blower, chiller, heater, compressor, recirculation system, heat
23 exchanger, or combinations thereof. Manifold 920 may be a separate assembly or

1 integral with bottom cover 904. Cooling tubes 910 are in communication with manifold
2 920. Manifold 920 receives pressurized air from the air source located outside of the fan
3 stack and distributes the air into cooling tubes 910. Motor 900 further includes outlet
4 manifold 930 that is attached to top cover 903. Cooling tubes 910 are in communication
5 with outlet manifold 930. Outlet manifold 930 receives the pressurized air flowing
6 through cooling tubes 910 and discharges this air through discharge filter 950 which is
7 connected to outlet manifold 930. In one embodiment, discharge filter 950 has operating
8 characteristics similar to Grainer Part Number 3TLA2 or an equivalent Pall PFD filter.
9 Discharge filter 950 ejects air into the air stream within the fan stack. In another
10 embodiment, discharge filter 950 ejects air outside the fan stack via additional piping or
11 duct work.

12 In an alternate embodiment, discharge filter 950 is replaced or combined with a
13 flapper valve or equivalent device to prevent contamination and moisture from entering
14 the motor when pressurize air is not present.

15 In another embodiment, outlet manifold 930 is not used and cooling tubes 910
16 eject the air directly into an exit filter that is mounted to top cover 903. Such an
17 embodiment is suitable when the direction of air is from top to bottom (see FIG. 1).

18 In an alternate embodiment, cooling tubes 910 are replaced with continuous ducts
19 of the type shown in FIGS. 9A and 9B.

20 In other embodiments, cooling tubes 910 are replaced with any of the cooling
21 tubes shown in FIGS. 7A-C, 7E and 7F. In a further embodiment, cooling tubes 910 are
22 replaced with any combination of the cooling tubes shown in FIGS. 7A-C, 7E and 7F.

1 Rotor 906 comprises fan structure 960 that is attached to or integral with the top
2 end of rotor 906 and fan structure 962 that is attached to or integral with the bottom end
3 of rotor 906. Fan structures 960 and 962 have the same structure, function and purpose
4 as fan structures 850 and 852, respectively, that are shown in FIG. 13A and described
5 herein.

6 Referring to FIG. 15A, there is shown a partial view of motor 1000 in accordance
7 with another embodiment of the present invention. Motor 1000 comprises casing 1002,
8 top cover 1004 which is attached to casing 1002, bottom cover 1005 which is attached to
9 casing 1002, stator 1006, rotor 1008 and rotatable shaft 1010 which is connected to rotor
10 1008. Rotor 1008 includes permanent magnets 1011. In this embodiment, stator 1006
11 does not utilize continuous cooling tubes or ducts as described in the foregoing
12 description. Motor 1000 further comprises intake manifold 1010. In one embodiment,
13 intake manifold 1010 is a separate assembly that is connected to bottom cover 1004. In
14 another embodiment, intake manifold 1010 is integral with bottom cover 1004.

15 Pressurized, clean, dry, filtered air is provided to the intake port (not shown) of manifold
16 1010 which then delivers this air into the motor cavity. Motor 1000 further comprises
17 outlet manifold 1020 which collects the air out of the motor cavity and ejects the air into
18 the fan stack or outside the fan stack. This is a continuous process wherein pressurized,
19 clean, dry, filtered air is delivered to the motor cavity by intake manifold 1010, the
20 delivered air absorbs heat of the motor components and then the heated air is ejected
21 from the motor 1000 by outlet manifold 1020. In alternate embodiments, discharge
22 filters can be used with the outlet manifold 1020.

1 Referring to FIG. 15A, rotor 1008 includes fan structure 1050 that is attached to
2 or integral with the top end of rotor 1008 and fan structure 1052 that is attached to or
3 integral with the bottom end of rotor 1008. Fan structures 1050 and 1052 have the same
4 structure, function and purpose as fan structures 850 and 852, respectively, that are
5 shown in FIG. 13A and described herein.

6 Referring to FIG. 15B, there is shown another embodiment of the invention.
7 Motor 1200 comprises casing 1202, top cover 1204 which is attached to casing 1202,
8 bottom cover 1205 which is attached to casing 1202, stator 1206, rotor 1208 and rotatable
9 shaft 1210 which is connected to rotor 1208. Rotor 1208 has fan structures 1212 and
10 1214 attached thereto which have the same structure and function as fan structures 850
11 and 852 shown in FIG. 13A. In this embodiment, stator 1206 does not utilize continuous
12 cooling tubes or ducts as described in the foregoing description. Motor 1200 further
13 comprises air input port 1220 which receives air from an air source located outside the
14 fan stack. One example of a suitable air source is a blower. In one embodiment, air input
15 port 1220 is an air inlet duct. Air input port 1220 may be a separate component or it may
16 be integral with bottom cover 1205. Motor 1200 includes air outlet port 1222 on top
17 cover 1204. Air outlet port 1222 can either be a separate component or it can be integral
18 with top cover 1204. Air input port 1220 delivers the pressurized, clean, dry, filtered air
19 into the motor cavity wherein the delivered air is mixed with the air in the motor cavity
20 by fan structures 1212 and 1214 so as to provide heat transfer and moisture control. The
21 heated pressurized air then leaves the motor cavity via air outlet port 1222 wherein it is
22 discharged outside the fan stack. In an alternate embodiment, a discharge or exit filter is
23 used in place of air outlet port 1222.

1 Pressurized, dry, filtered air is required in order to prevent contamination and
2 moisture from entering the motor. A Pall PFD Filter used in combination with the
3 pressurized air systems described herein provides a one-way valve with moisture and
4 volume control if the pressurized air is discontinued. Such a combination also maintains
5 the cleanliness of the motor.

6 Referring to FIGS. 16, there is shown an alternate embodiment of motor 1000
7 shown in FIG. 15A. Motor 1000' includes all of the components of motor 1000 in FIG.
8 15A with the addition of external manifolds 2000 and 2002, and air outlet vent filter
9 2004. External manifolds 2000 and 2002 are located as required to move air and water
10 into and out of motor 1000' as previously discussed herein for heating, cooling, and
11 controlling moisture and volume. Although two external manifolds are shown, it is to be
12 understood that more than two external manifolds can be used.

13 External manifolds can be used in several of the foregoing embodiments in order
14 to satisfy motor thermal design requirements. For example, in the embodiment shown in
15 FIG. 15B, motor 1200 can be modified by adding one or more external manifolds.

16 The external manifolds can be used to deliver air or water into the cooling tubes
17 or ducts in the motor at any point of entry and be used with any combination of the
18 continuous cooling tubes or ducts described in the foregoing description.

19 Referring to FIG. 17, there is shown motor 3000 in accordance with an alternate
20 embodiment of the present invention. This embodiment utilizes Vortec air-amp cooling.
21 Motor 3000 comprises casing 3002, top cover 3004, bottom cover 3006, a rotor (not
22 shown), a stator (not shown) and a rotatable shaft 3008 which is connected to the rotor.
23 This embodiment provides dry, filtered cool air to the motor cavity via the expansion of

1 air through the Vortec device from a compressed air source. Adapter 3010 is connected
2 to motor casing 3002. An air amplifier device 3012 is connected to adapter 3010. Air
3 tube 3014 is connected to air amplifier device 3012. Air tube 3014 extends outside fan
4 stack 3016. Fan stack 3016 is only partially shown in FIG. 17. A complete fan stack is
5 shown in FIG. 1. An air inlet filter 3018 is connected to the end of air tube 3014. A
6 suitable air inlet filter is the Grainger PN 3TLA5 inlet filter. Cool dry air 3020 enters
7 inlet filter 3018, flows through tube 3014, through air amplifier device 3012 and into the
8 motor cavity wherein it mixes with the air in the motor cavity so as to provide heat
9 transfer, moisture and volume control. As the input air is heated by heat transfer process,
10 it exits the motor cavity by at least one outlet filter 3022. In one embodiment, outlet filter
11 3022 is mounted on top cover 3004 as shown. In another embodiment, the outlet filter
12 3022 is located outside the fan stack and a pipe routes the discharged air from casing
13 3002 to the outlet filter. In another embodiment, a Pall PFD Filter is used in combination
14 with inlet filter 3018. The Pall PFD Filter includes the required valve arrangement that
15 prevents contamination and moisture from entering the motor through inlet filter 3018.

16 Referring to FIGS. 18A and 18B, there is shown a stator 4000 in accordance with
17 another embodiment of the invention. Stator 4000 comprises a plurality of lamination
18 sheets 4002 that are bonded or attached together to form a stator stack 4003. Stator stack
19 4003 has slots 4004. Stator 4000 includes windings or coils 4006 that are wound about
20 stator stack 4003. Coils 4006 include end turns 4007. Stator 4000 is pinned or attached
21 to the interior wall of casing 4010. Stator 4000 includes serpentine cooling tubes 4008
22 that can transfer air, water and other fluids (e.g. ammonia) through the motor to cool or
23 heat the motor. Serpentine cooling tubes 4008 are embedded into windings 4006. Stator

4000 can be configured with a single run or multiple run of serpentine cooling tubes or ducts throughout the stator stack 4003. The serpentine cooling tubes can be routed throughout the motor based on the thermal requirements of the motor. In other embodiments, any suitable conduit of any cross-sectional shape may be used in place of round tubes. Suitable materials for fabricating the serpentine cooling tubes are materials that have high thermal conductivity for heat transfer and acceptable electrically insulating properties. Such materials include Silicone, Teflon and other high temperature plastics. Copper and stainless steel are suitable choices only when the motor components (e.g. windings or coils) are sealed and insulated such as by Vacuum Pressure Impregnation (VPI). If Silicone and Teflon are used to form the serpentine cooling tubes or ducts, then the stator windings need not be VPI-processed and the serpentine cooling tubes or ducts may be nested directly in the windings. Silicone or Teflon serpentine cooling tubes or ducts are electrically insulated and offer excellent thermal conductivity to transfer heat away from the windings, prevent damage to the rotor and the magnets, and maintain thermal balance within the motor for proper and efficient operation. Since the motors in the foregoing embodiments are sealed to prevent contamination and manage moisture within the motor, VPI processing is not required. When VPI processing is not used, or when VPI coatings are removed from the windings, Silicone or Teflon serpentine tubing or ducts provide significantly improved thermal management.

In one embodiment, the serpentine cooling tubes are run into 180 degree unions located and fixed in the motor to allow them to expand and contract similar to straight tubes.

1 In alternate embodiments, serpentine tubing or ducts made from stainless steel or
2 copper are insulated with an insulating wrapping material and then wound with the stator
3 coils. Then, the serpentine tubing or ducts and stator coils are then VPI processed.

4 In an alternate embodiment, serpentine tubing or ducts made from stainless steel
5 or copper are wrapped in a thermally conductive and electrically insulating coil wrap.
6 One suitable coil wrap is the Arlon SFT Self Fusing Tape.

7 In alternate embodiments, fluid inlet and outlet taps are utilized to connect tubing
8 or duct sections formed in the coil to create a cooling circuit in the motor. The motor may
9 have more than one cooling circuit.

10 In an alternate embodiment, serpentine cooling tubes or ducts can be used to
11 contain a phase transfer medium.

12 In an alternate embodiment, the serpentine cooling tubes or ducts are configured
13 with holes so that the serpentine cooling tubes or ducts can transfer clean, dry, filtered air
14 to the motor.

15 Referring to FIGS. 19A and 19B, there is shown motor 5000 in accordance with
16 another embodiment of the present invention. Motor 5000 employs a forced-water
17 cooling scheme. The motor 5000 comprises casing 5002, top cover 5003, bottom cover
18 5004, stator 5005, rotor 5006 and rotor shaft 5008. Rotor 5006 includes permanent
19 magnets 5009. In this embodiment, stator 5005 has the same configuration and structure
20 as stator 705 in FIG. 12A. Thus, stator 5005 includes cooling tubes 5010 that have the
21 same shape and configuration as cooling tubes 710. Stator 5005 comprises a plurality of
22 lamination sheets that are stacked together to form stator stack 5012. Cooling tubes 5010
23 are embedded in stator stack 5012 as windings 5014 are inserted. Motor 5000 further

1 comprises a circumferentially extending upper fluid manifold 5016 that is attached to or
2 integral with top cover 5003. The top openings of cooling tubes 5010 are in
3 communication with upper fluid manifold 5016. Fluid manifold 5016 includes fluid inlet
4 5018 so that fluid (e.g. water) can be delivered to upper fluid manifold 5016. The motor
5 5000 further comprises circumferentially extending lower fluid manifold 5020 that is
6 attached to or integral with bottom cover 5004. The bottom openings of cooling tubes
7 5010 are in communication with lower fluid manifold 5020. Lower fluid manifold 5020
8 has fluid outlet 5022 through which fluid exits. During operation, pressurized fluid (e.g.
9 water) from a cooling tower source is delivered to fluid manifold 5016 via fluid inlet
10 5018. The fluid passes through cooling tubes 5010 and absorbs heat from the stator
11 windings 5014. The heated fluid then passes out of cooling tubes 5010 and into lower
12 fluid manifold 5020 and wherein it is then discharged through fluid outlet 5022. In a
13 preferred embodiment, the fluid that is inputted into upper fluid manifold 5016 is filtered
14 water. In a preferred embodiment, the water is obtained from the cooling tower system.
15 For example, in one embodiment, water from the cooling tower distribution system is
16 filtered and then inputted into fluid inlet 5018. The water that is discharged from fluid
17 outlet 5022 is then recirculated back into the cooling tower for cooling. In another
18 embodiment, the water discharged from fluid outlet 5022 is recirculated with a heat
19 exchanger and exchanged with water drawn from a cooling tower source. Drawing water
20 directly from the cooling tower eliminates the use of conventional auxiliary cooling
21 devices.

1 In alternate embodiments, cooling tubes 5010 are replaced with conduits having
2 cross-sectional shapes other than round. In an alternate embodiment, cooling tubes 5010
3 are replaced by cooling ducts.

4 Rotor 5006 includes fan structures 5100 and 5102 which have the same structure,
5 function and purpose as fan structures 850 and 852, respectively, that are shown in FIG.
6 13A and described herein.

7 The embodiment shown in FIGS. 19A and 19B may incorporate thermostats,
8 valves, sensors and solenoids to automatically adjust the water temperature in the motor.
9 In an alternate embodiment, heated water is passed through cooling tubes 5010 in order
10 to prevent the motor from freezing. Such an embodiment is suitable for use in
11 geographical areas that experience very cold temperatures. In one embodiment, the
12 embodiments shown in FIGS. 19A and 19B may be used with the control system
13 described in international application no. PCT/US2012/061244 entitled "Direct Drive
14 Fan System With Variable Process Control" and published under International
15 Publication No. WO 2013/059764.

16 In a preferred embodiment, the cooling tower water is used with a heat exchanger
17 so that the closed loop fluid circulated in cooling tubes or ducts can be mixed with an
18 anti-freeze as required for cold service. In a further embodiment, the pressurized hot
19 water returned from the process can be combined with the pressurized return of cooler
20 water from the basin feed to the process to provide a suitable temperature via mixing
21 valves and thermostats. A third make-up water source can be used as required to provide
22 a suitable temperature to the motor (hot or cold) to maintain optimum motor efficiency

1 through various environmental conditions and process loads similar to an automobile
2 radiator and thermostat.

3 Referring to FIG. 20A, there is shown another embodiment of the present
4 invention. In this embodiment, a motor stator comprises a cooling tube 6000 that is
5 wrapped with individual stator coils 6002 or coil bundles and disposed in the slots of the
6 stator lamination stack. The view shown in FIG. 20A is that of a cooling tube 6000
7 wrapped with stator coils 6002. In such an embodiment, heat is transferred from coils
8 6002 to the cooling tube 6000. Tap riser 6004 delivers air, gases and/or fluids (or
9 combinations thereof) to cooling tube 6000. Tap riser 6004 is insulated from the electric
10 circuit by isolation stack 6006. Cooling tube 6000 may be made from copper, aluminum,
11 silicone, Teflon or equivalent, and may be part of the motor's electric circuit or insulated
12 from the electric circuit. The entire assembly (e.g. cooling tube 6000 wrapped with coils
13 6002) can be potted and insulated as required using a manual or VPI process. Solid
14 tubes, gas and liquid filled tubes can act as heat sinks and work with the heat-pipe
15 embodiments described in the foregoing description. If cooling tubes 6000 are made
16 from materials that are not electrically conductive, then isolation stacks 6006 are not
17 required. Such non-electrically conductive materials include Teflon and Silicone.
18 Cooling tubes 6000 may be used to transfer air, gasses, water, fluids or combinations
19 thereof for cooling stator coils and for heating the coils when the motor is used in cold
20 environments. In an alternate embodiment, cooling tubes 6000 contain a phase change
21 transfer medium.

1 In alternate embodiments, cooling tubes 6000 are replaced by cooling ducts,
2 described in the foregoing description, or any other conduit having a different cross-
3 sectional shape.

4 FIG. 20B is an alternate embodiment of the configuration shown in FIG. 20A
5 wherein the cooling tubes 6000 are isolated from the electric circuit of the motor. In this
6 embodiment, an isolation layers 7000 and 7002 are thermally conductive. Stator coils
7 6002 are wrapped about isolation layer 7000 and cooling tube 6000. An additional
8 isolation layer 7002 is wrapped about stator coils 6002.

9 Referring to FIGS. 21A, 21B and 21C, there is shown an alternate motor
10 embodiment of the present invention. The motor 8000 comprises casing 8002, top cover
11 8004, bottom cover 8006, stator 8008, rotor 8010 and rotatable shaft 8013 that is
12 connected to rotor 8010. Rotor 8010 includes permanent magnets 8011. Stator 8008
13 comprises a stator stack 8009 that is formed by a plurality of lamination sheets as
14 described in the foregoing description. Coils 8012 are wound about stator stack 8009.
15 The motor 8000 further comprises a plurality of heat pipes 8020 that are embedded into
16 coils 8012 and end turns of the coils 8012. Heat pipes are well known in the industry and
17 are therefore not described in detail herein. The heat pipes 8020 remove heat from the
18 motor and ejected it to the surrounding fan stream which is comprised of significant mass
19 air flow of 100% humid air by design in wet cooling towers. Heat pipes 8020 can be
20 positioned so some of the heat pipes 8020 extend upward and other heat pipes 8020
21 extend downward as shown in FIG. 21A. In one embodiment, 50% of the heat pipes
22 8020 extend upward and the remaining 50% of the heat pipes extend downward. In one
23 embodiment, the heat pipes 8020 are arranged so that every other heat pipe 8020 extends

1 upward and the remaining heat pipes 8020 extend downward. In one embodiment, a heat
2 sink 8030 is attached to each heat pipe 8020 as shown in FIGS. 21A and 21C.

3 Rotor 8010 includes fan structures 8100 and 8102 which have the same structure,
4 function and purpose as fan structures 850 and 852, respectively, that are shown in FIG.
5 13A and described herein.

6 Heat pipes can be combined with at least some of the other foregoing
7 embodiments, such as the aforementioned serpentine cooling tubes for removing heat out
8 of the motor. Heating pipes of any orientation and combination and could be located
9 further into the fan air stream.

10 In another embodiment, the motor comprises chill blocks that are in contact with
11 the end turns of the windings. In such an embodiment, the heat pipes are embedded in
12 the chill blocks.

13 The foregoing embodiments allow for thermal management of the motor in the
14 cooling tower. Thus, if motor performance begins to degrade, the present invention
15 allows for changes in the thermal management of the motor to improve or maintain
16 performance. This allows each motor in each cooling tower to be optimize for thermal
17 conditions. The ability to thermally manage the motor also facilitates maintaining a
18 desired rotor-to-stator gap (e.g. 0.030 inch, 0.060 inch).

19 Cooling tubes and heating pipes discussed in the foregoing description can be
20 relatively small in diameter and can be embedded into coils, thermally conductive potting
21 in the gap between the stator and the motor casing, rotors and other motor structure
22 during or after winding the coils on the stator. Motors may be designed to allow room
23 within the motor for routing tubes, pipes, ducts and serpentine cooling tubes through the

1 motor, without being embedded into the coils, and through the slots where “slot fill” is
2 typically applied. The term “slot fill” refers to empty volumes in the motor which are not
3 taken up by windings or coils and are therefore not part of the electrical circuit in the
4 motor.

5 In an alternate embodiment, a water plenum is integrated with the motor cover
6 (e.g. top cover) to provide cooling tower water for cooling the motor. The cooling tower
7 water can be fed into any of the foregoing cooling tubes, ducts, serpentine tubes and
8 ducts or any combination thereof. The use of the cooling tower water that is readily
9 available from the header simplifies the cooling process and avoids the use of secondary
10 auxiliary pumps, valves, controls and skids which can be costly and add significant
11 weight to the cooling tower.

12 In any of the foregoing embodiments involving forced water cooling, the water
13 exiting the motor can be recirculated, or discharged in whole back into the cooling tower,
14 or mixed with new water, as required according to the heat transfer characteristics and the
15 conditions under which the motor must operate. Such configurations also facilitate
16 heating the motor in very cold climates to prevent the motor from freezing.

17 In other embodiments, mixing valves and control devices can be used to maintain
18 predetermined water temperatures according to motor operating parameters, water
19 temperature and environmental stress in order to optimize motor efficiency.

20 In other embodiments, a closed Glycol loop or equivalent and a heat exchanger
21 device is used to provide cooling water, air, ocean water or other medium to cool the
22 motor.

1 It is to be understood that many commercially available surface treatments and
2 chemical compounds may be used on the components of the motors of any of the
3 foregoing embodiments of the invention in order to dissipate heat or retain heat as certain
4 locations within the motor. Such surface treatments and chemical compounds include
5 thermal barrier coatings, thermally conductive epoxies, epoxy resins, thermally
6 conductive potting, thermally conductive insulators and heat dissipation coatings.

7 All of the motor embodiments disclosed herein may be used with or controlled by
8 the control system described in international application no. PCT/US2012/061244
9 entitled "Direct Drive Fan System With Variable Process Control" and published under
10 International Publication No. WO 2013/059764.

11 The foregoing description, for purpose of explanation, has been described with
12 reference to specific embodiments. However, the illustrative discussions above are not
13 intended to be exhaustive or to limit the invention to the precise forms disclosed. Many
14 modifications and variations are possible in view of the above teachings. The
15 embodiments were chosen and described in order to best explain the principles of the
16 invention and its practical applications, to thereby enable others skilled in the art to best
17 utilize the invention and various embodiments with various modifications as are suited to
18 the particular use contemplated

CLAIMS:

What is claimed is:

1. A cooling tower comprising:

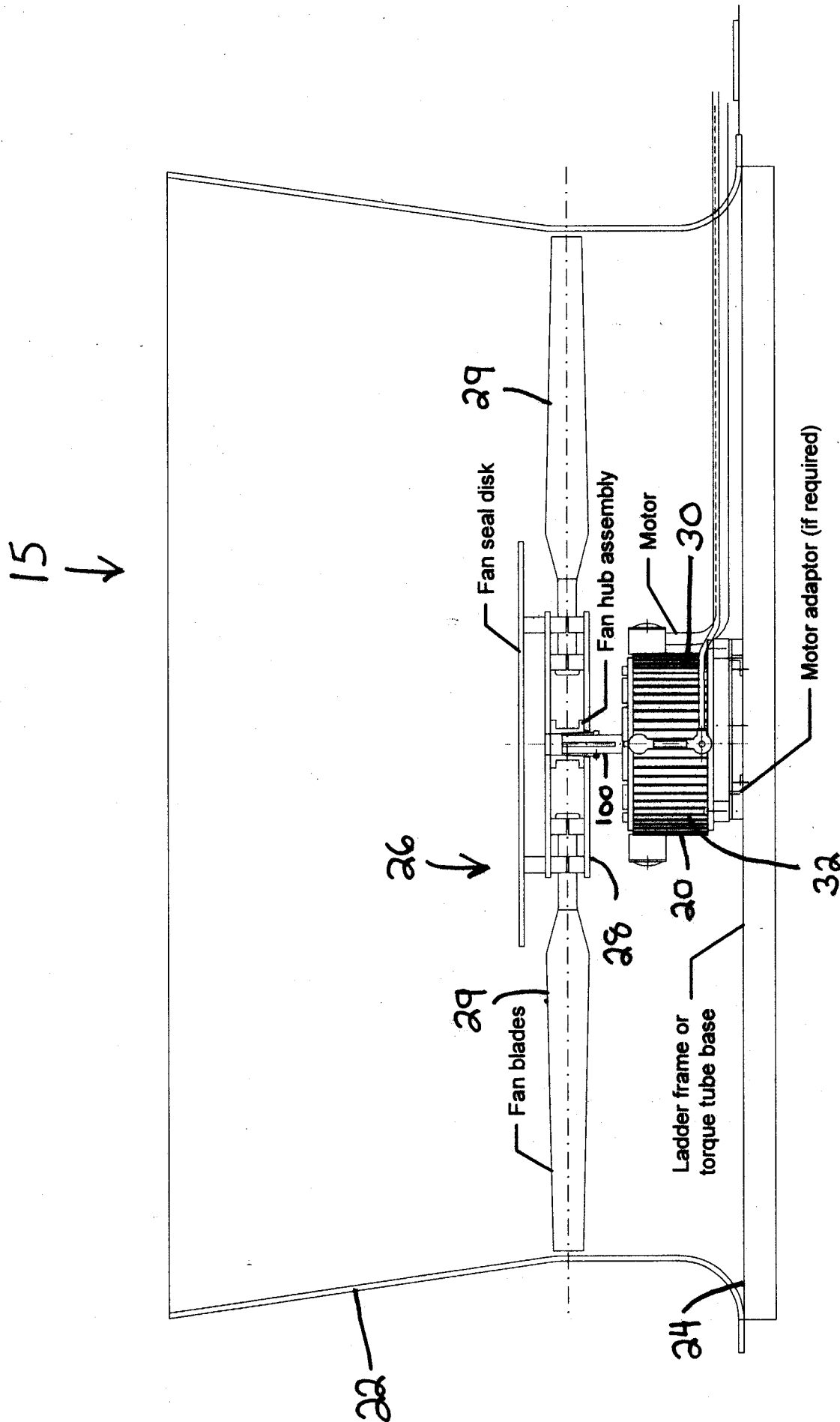
a cooling tower structure;

a motor supported by the cooling tower structure, the motor comprising a motor casing and a rotatable shaft;

a cooling tower fan comprising a fan hub and a plurality of fan blades attached to the rotatable shaft;

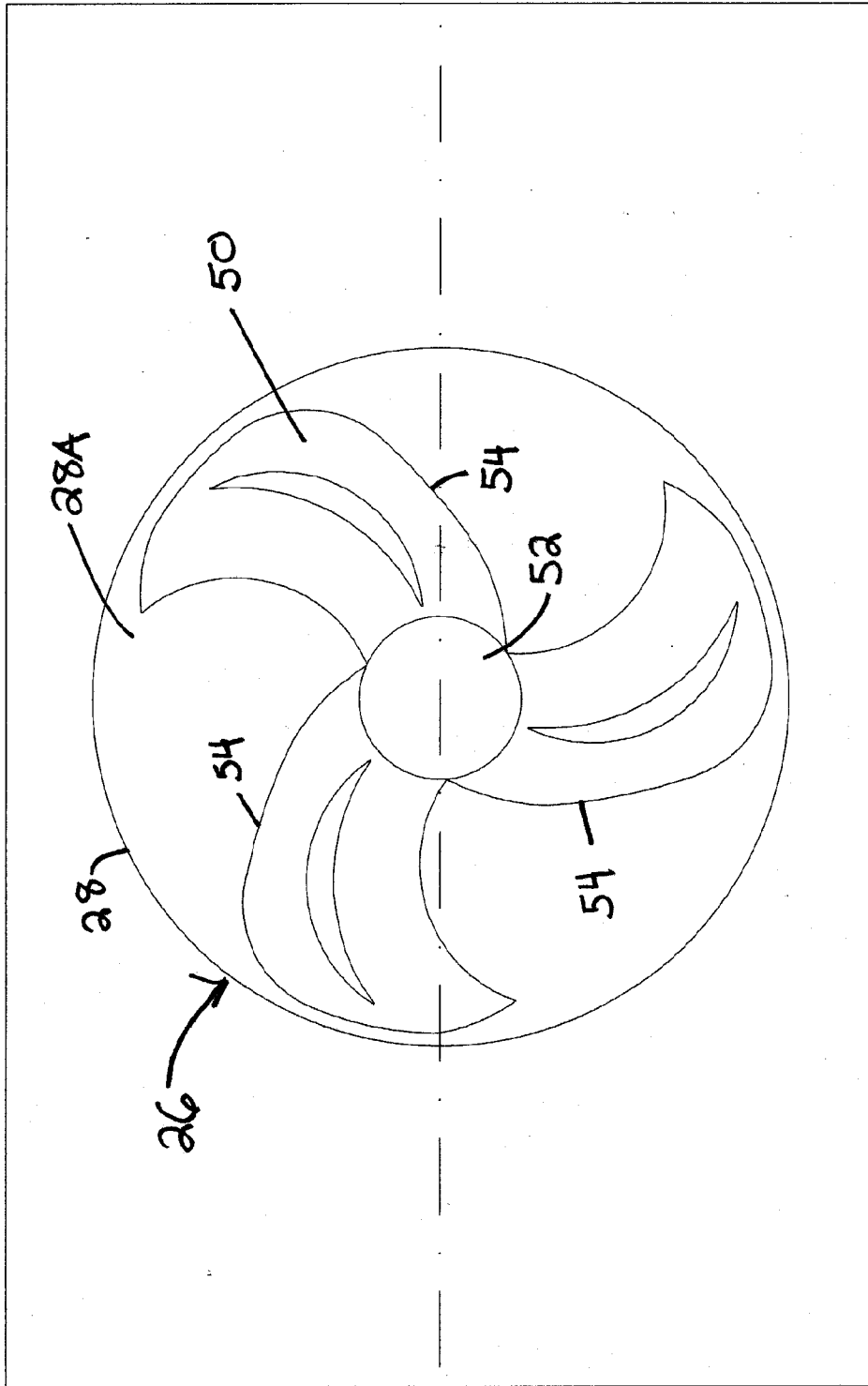
a supplemental fan attached to the fan hub such that the supplementary fan is between the fan hub and the motor;

whereby rotation of the cooling tower fan causes rotation of the supplemental fan which increases airflow around the casing of the motor.
2. The cooling tower according to claim 1 further comprising a fan pitch adjustment device to adjust the pitch of the supplemental fan.



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Fig. 2



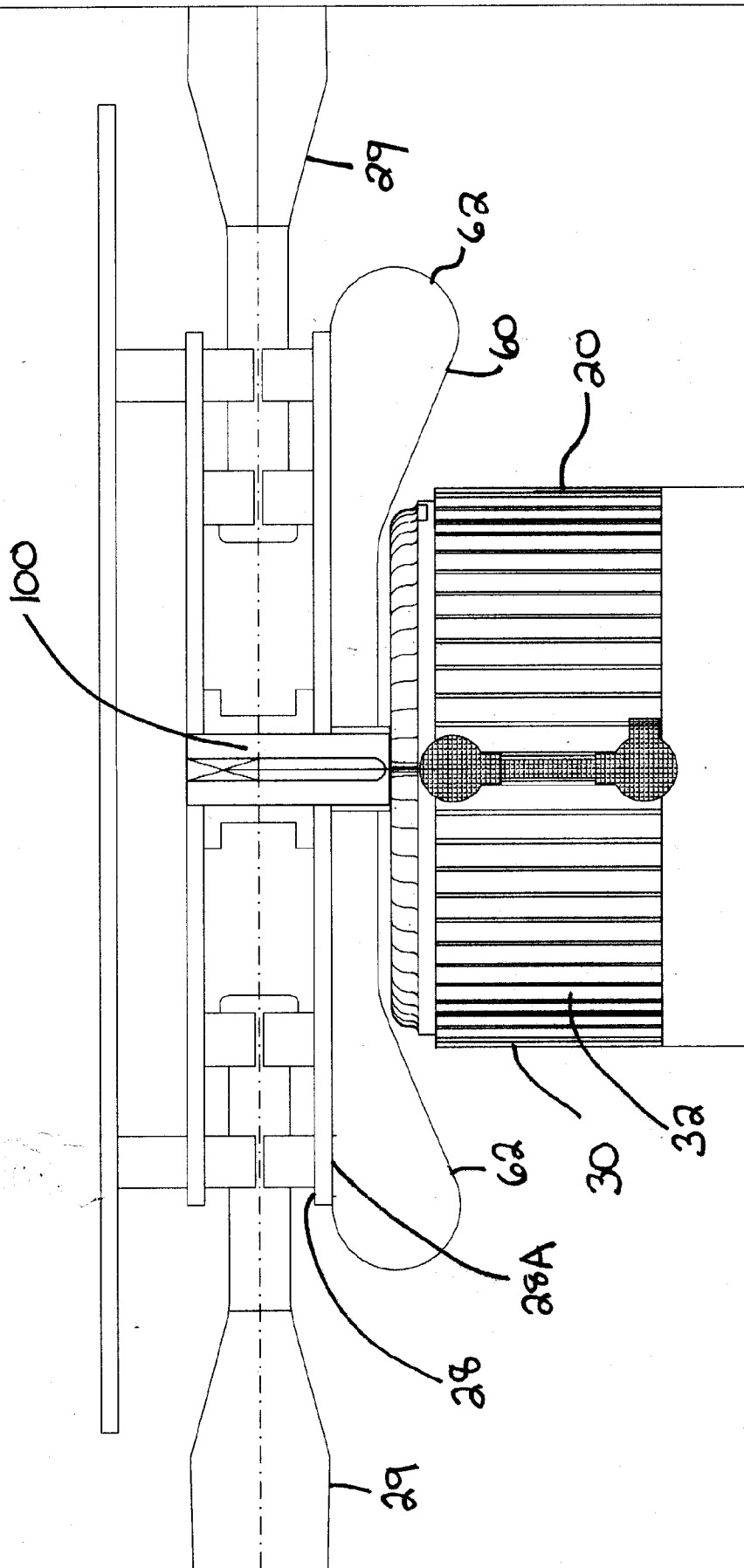
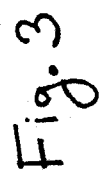


Fig. 4A

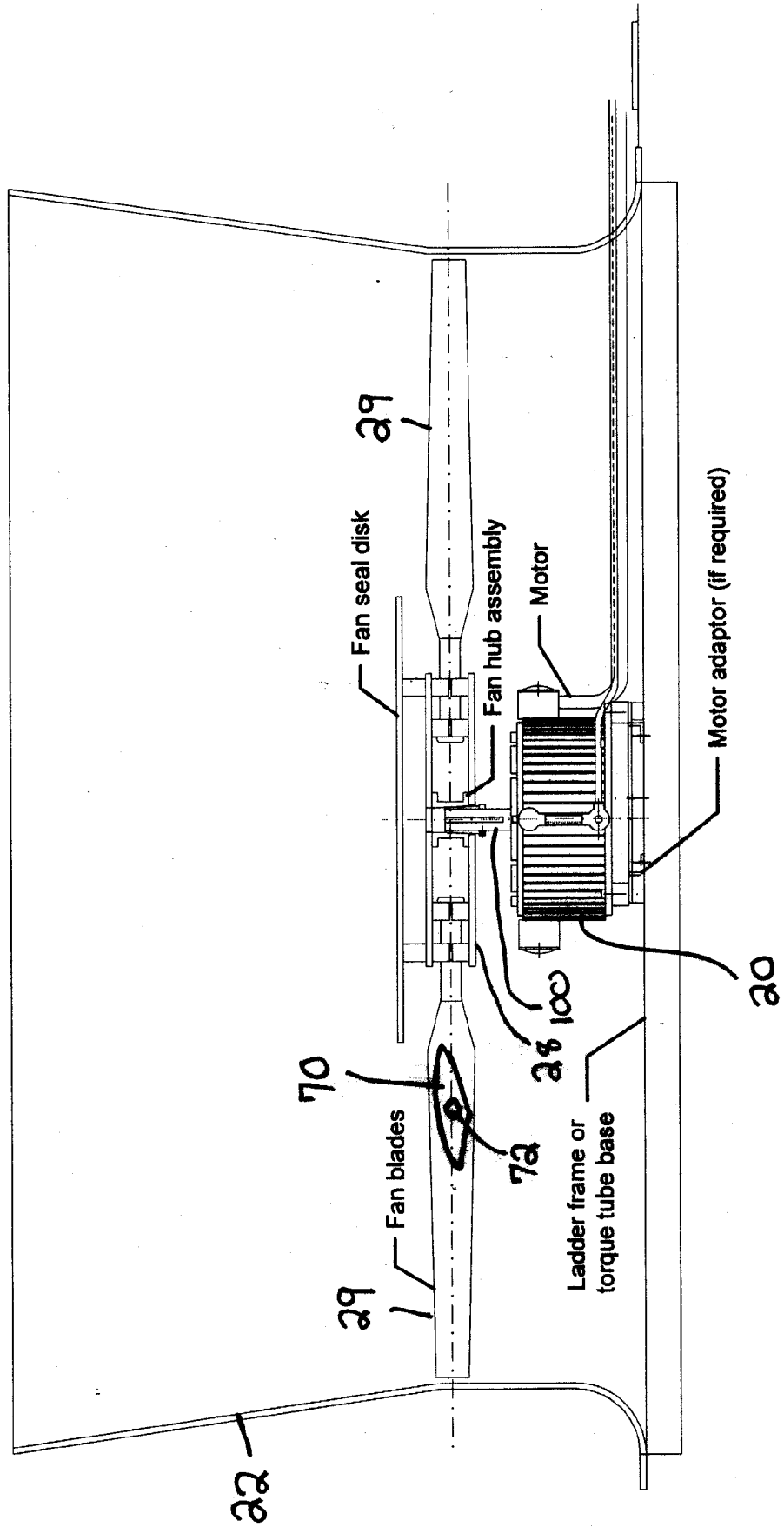


Fig. 4B

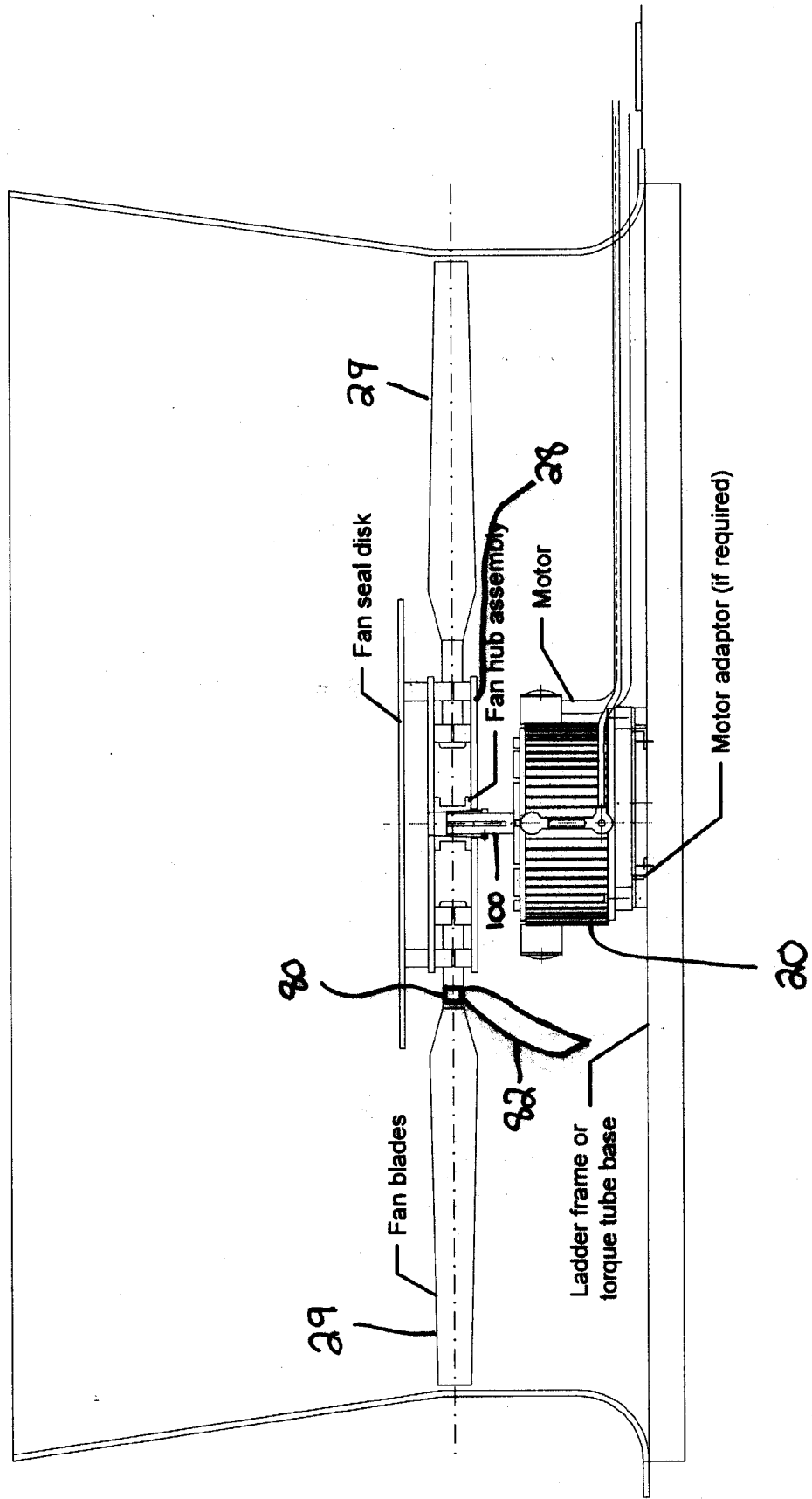
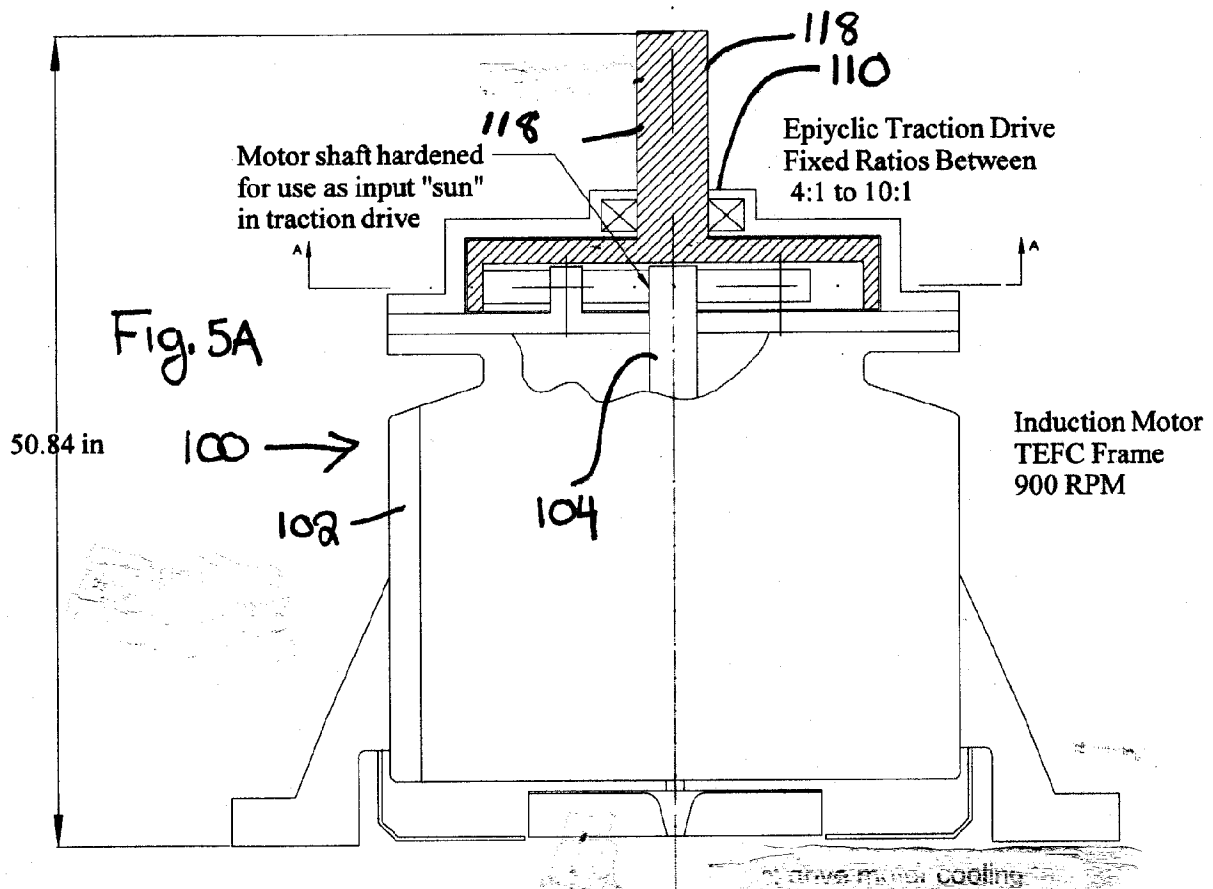
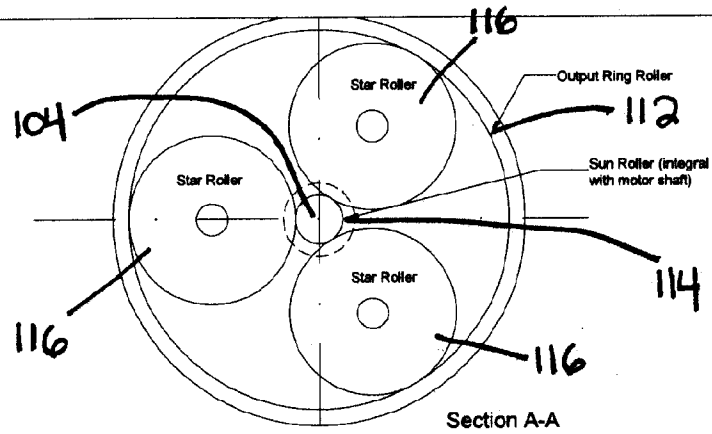
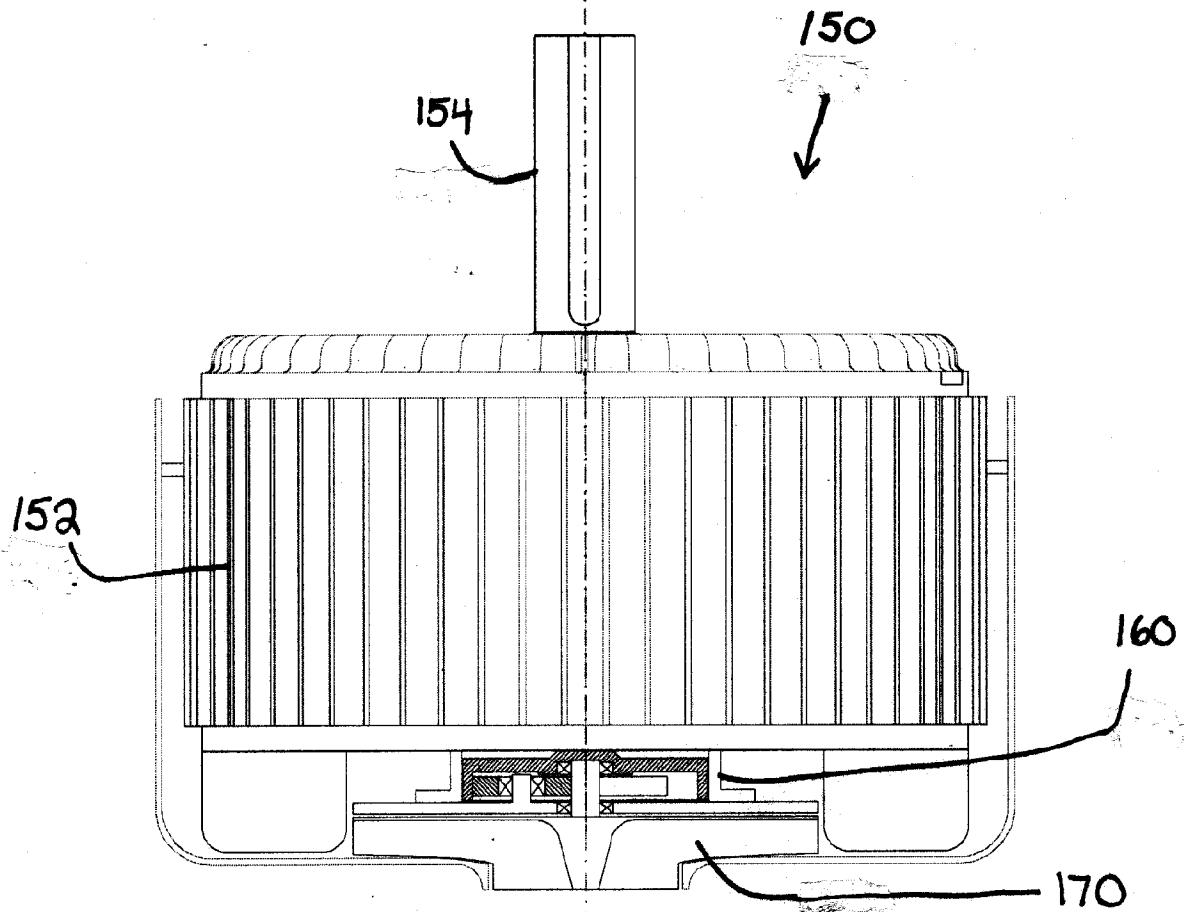


Fig. 5B

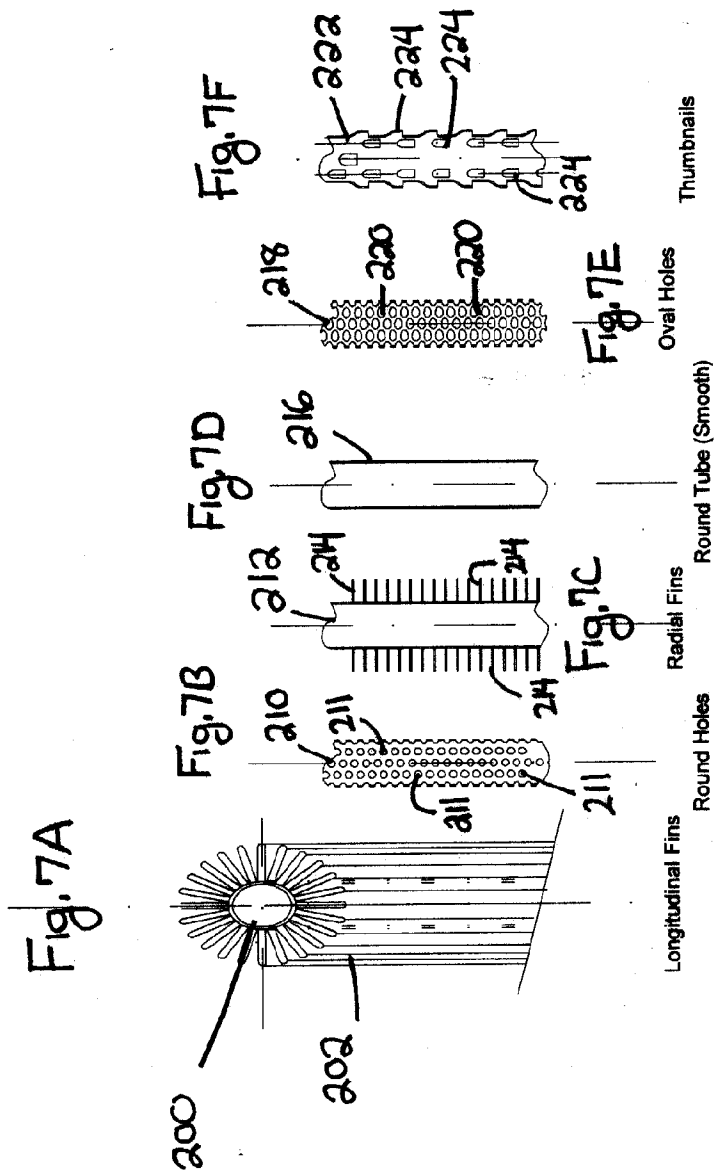


Traction Drive Cooling Tower Fan Drive System

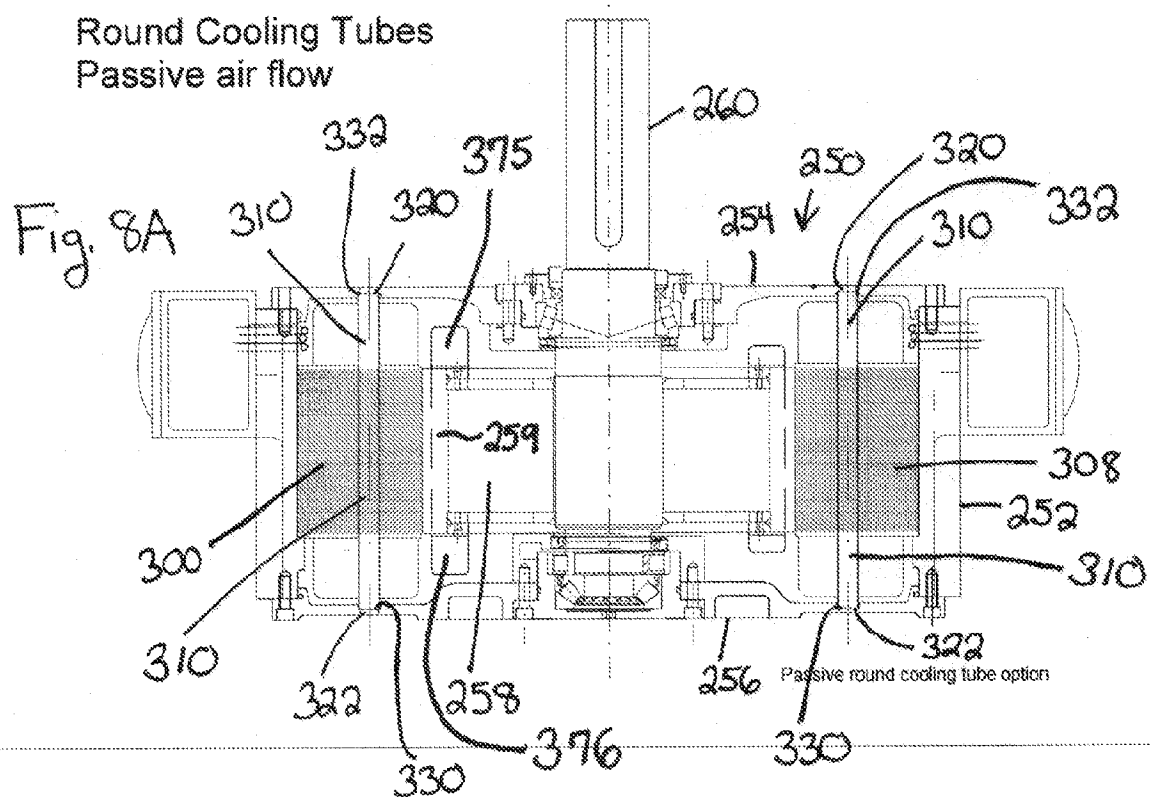
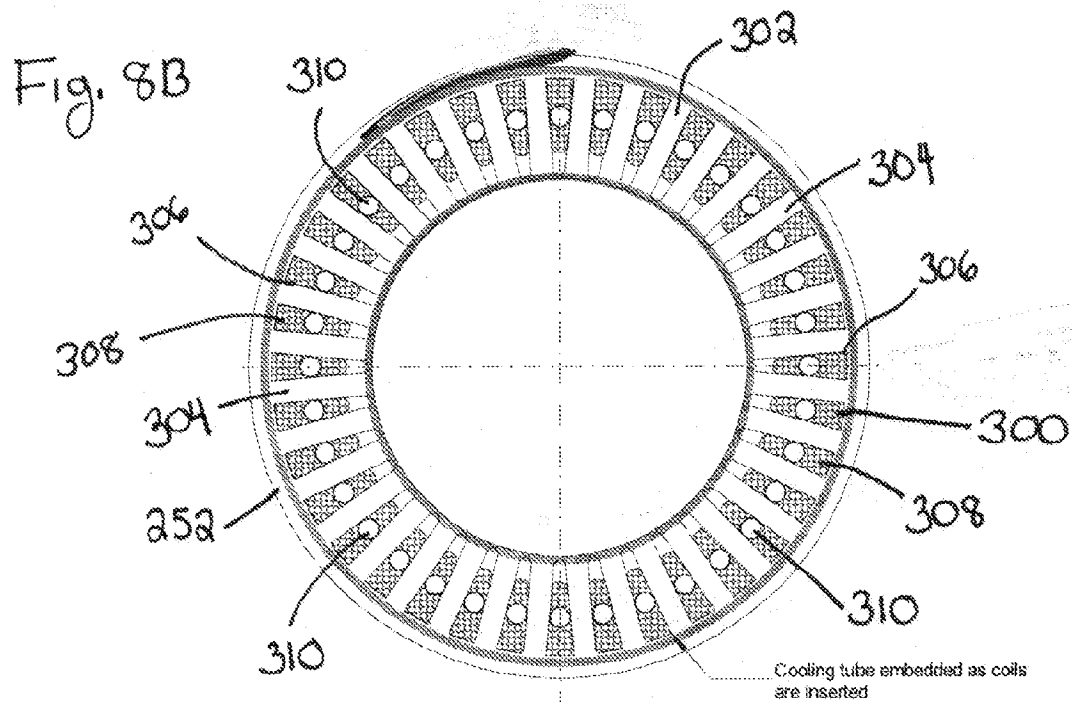
Fig. 6

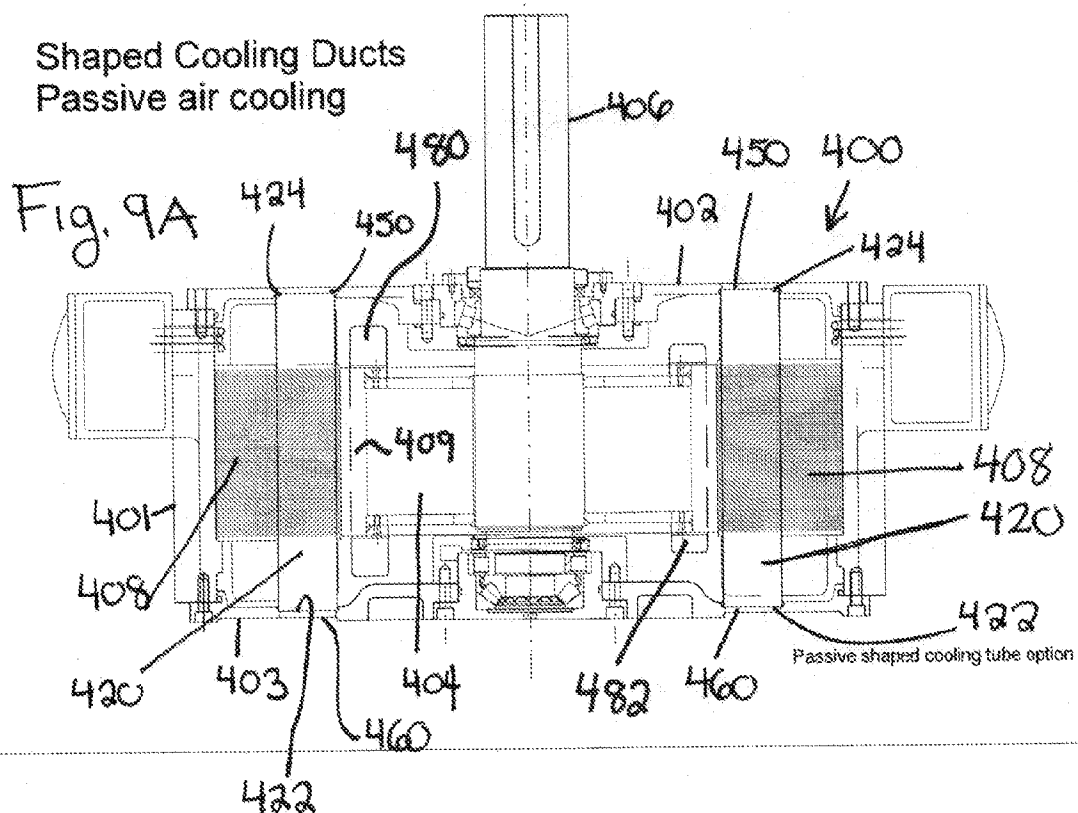
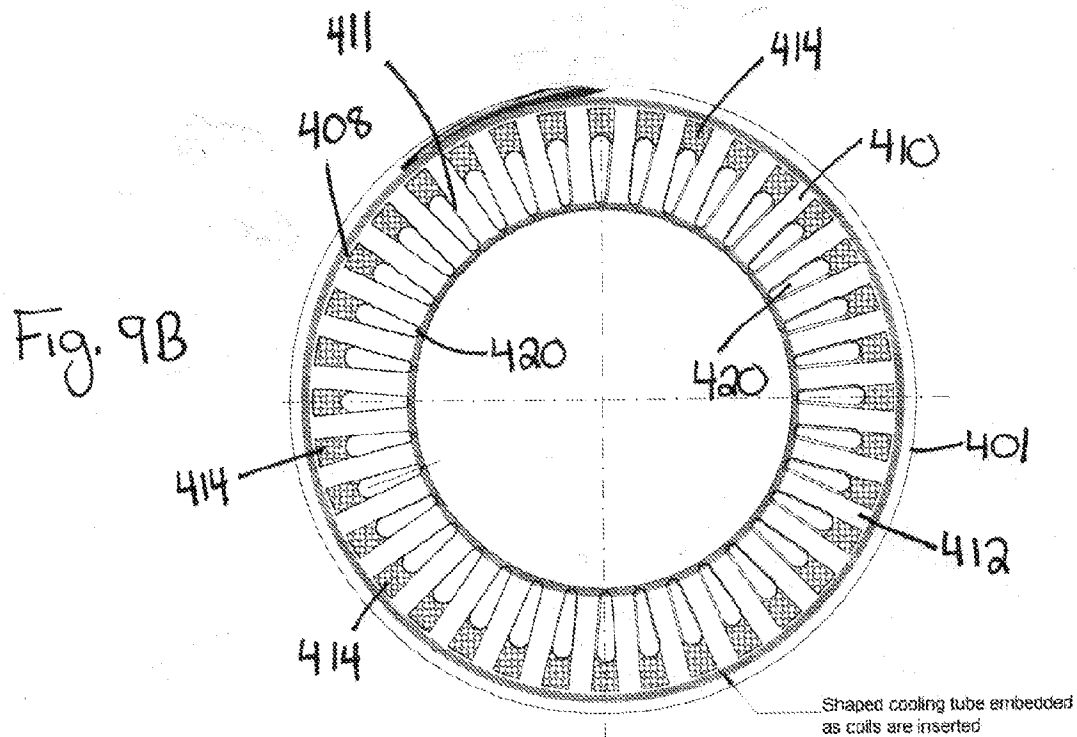


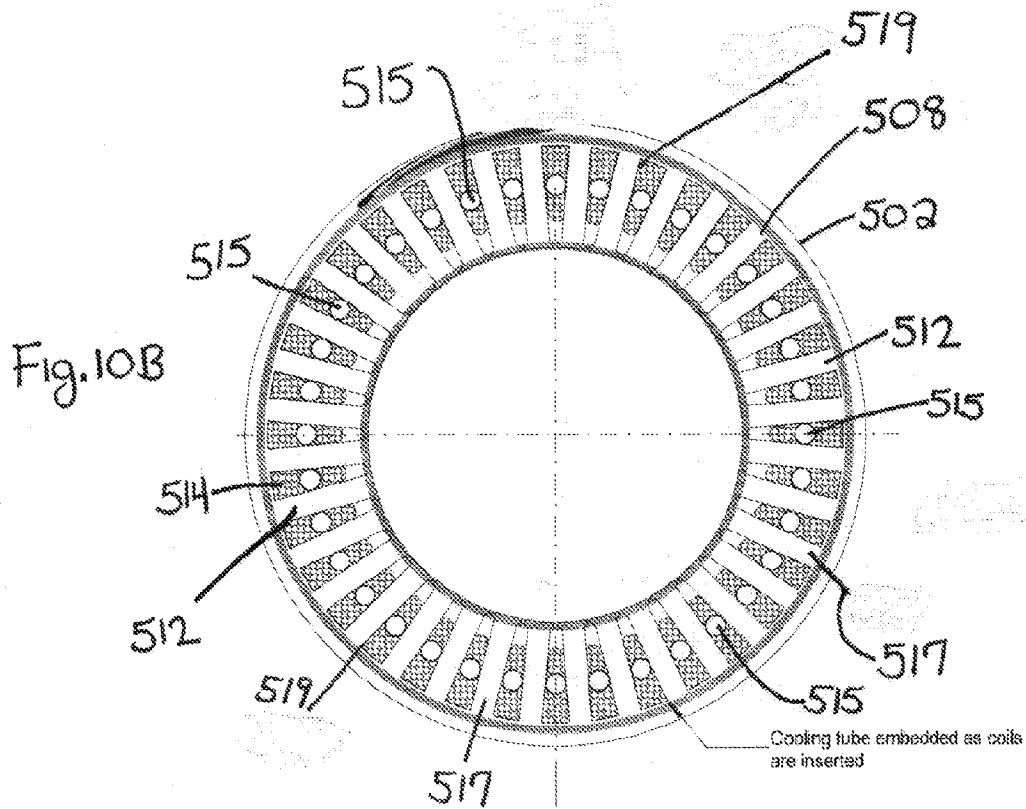
**Totally Enclosed Fan Cooled
With ETD fan**



Options For Cooling Tube Configuration







Round Cooling Tubes
Passive air flow

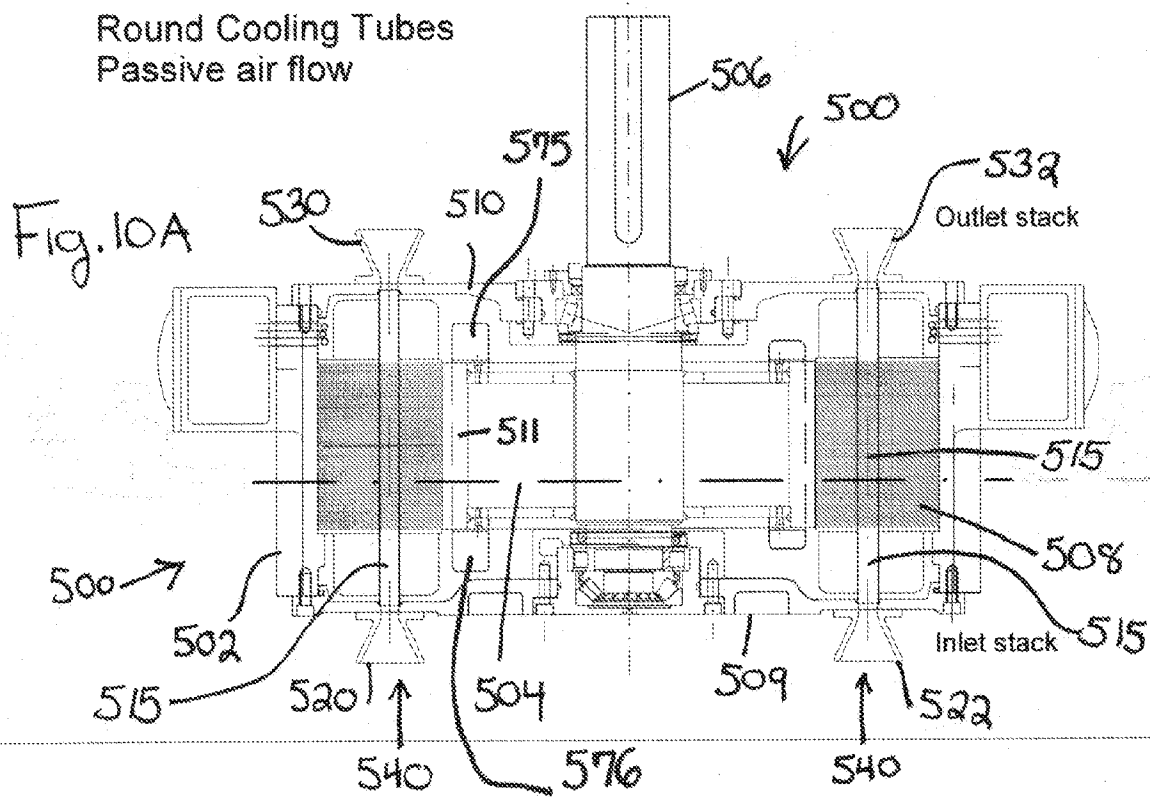


Fig. 11

Shaped Cooling Tubes
Passive air flow

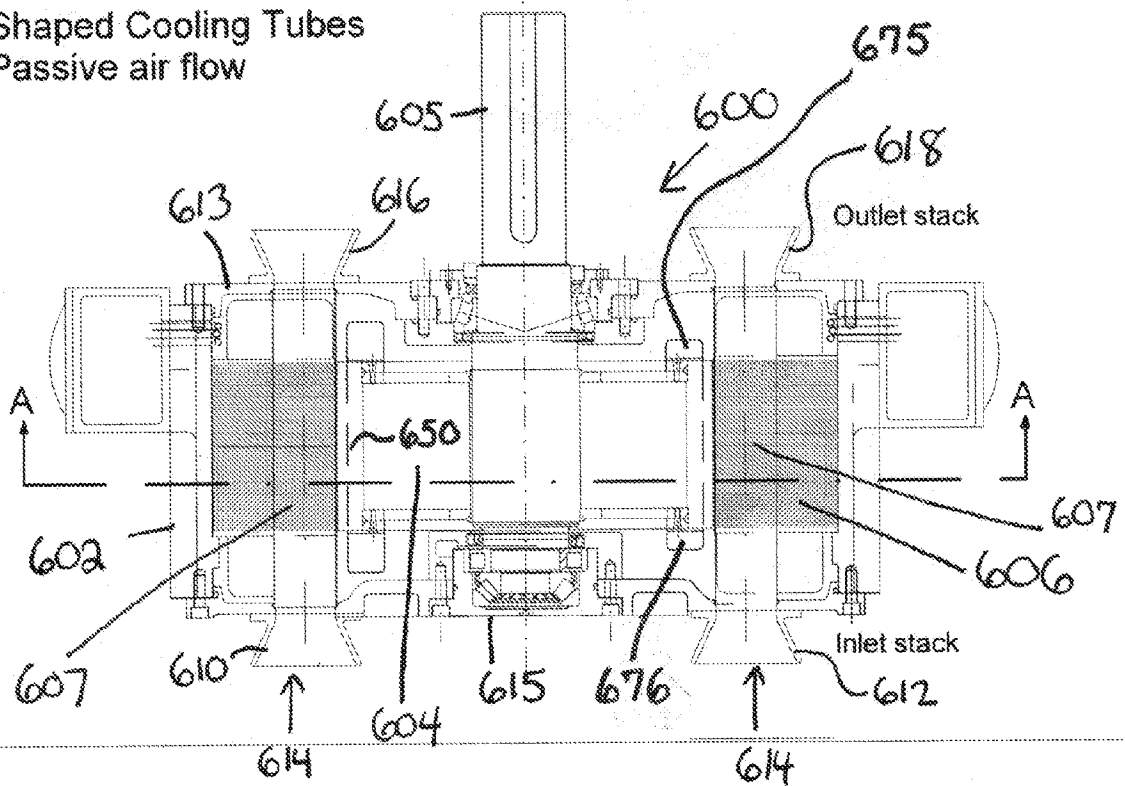


Fig. 12B

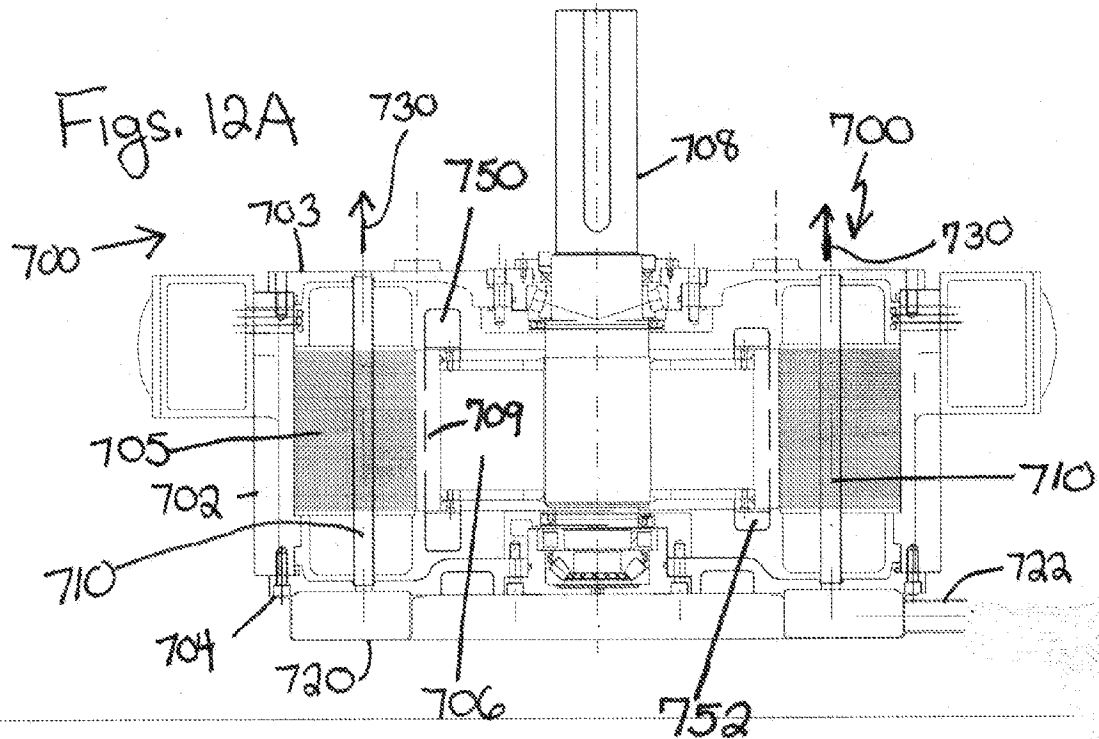
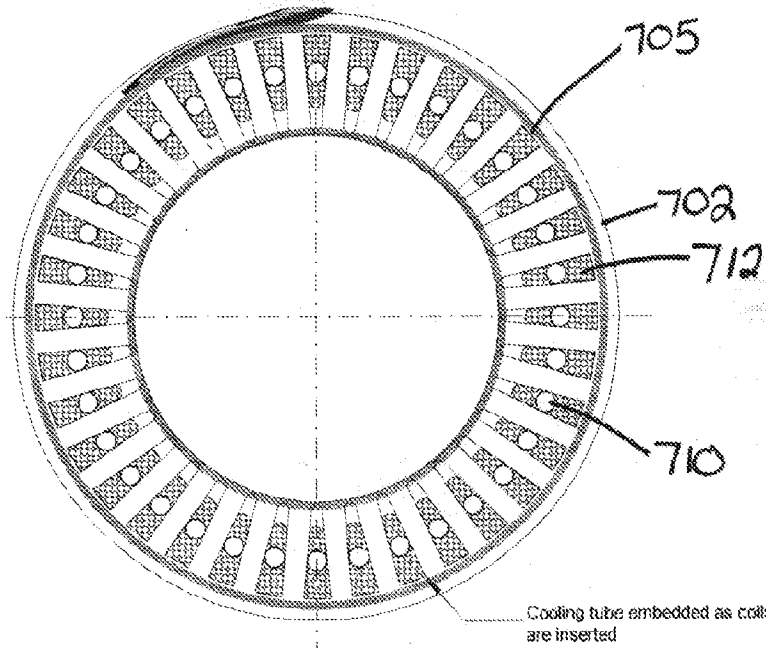
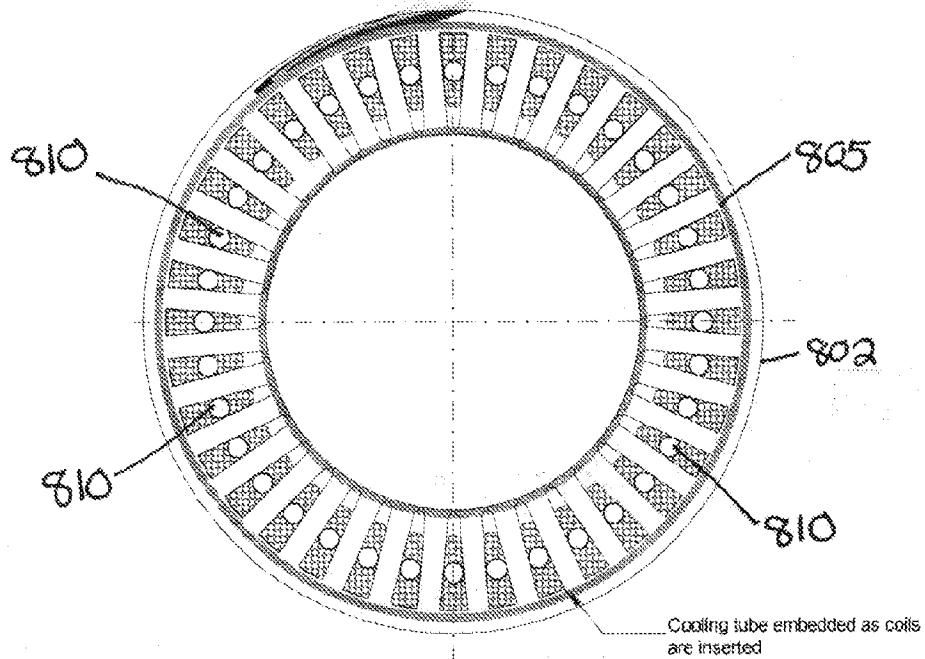


Fig. 13B



Round Cooling Tubes
Ducted forced air

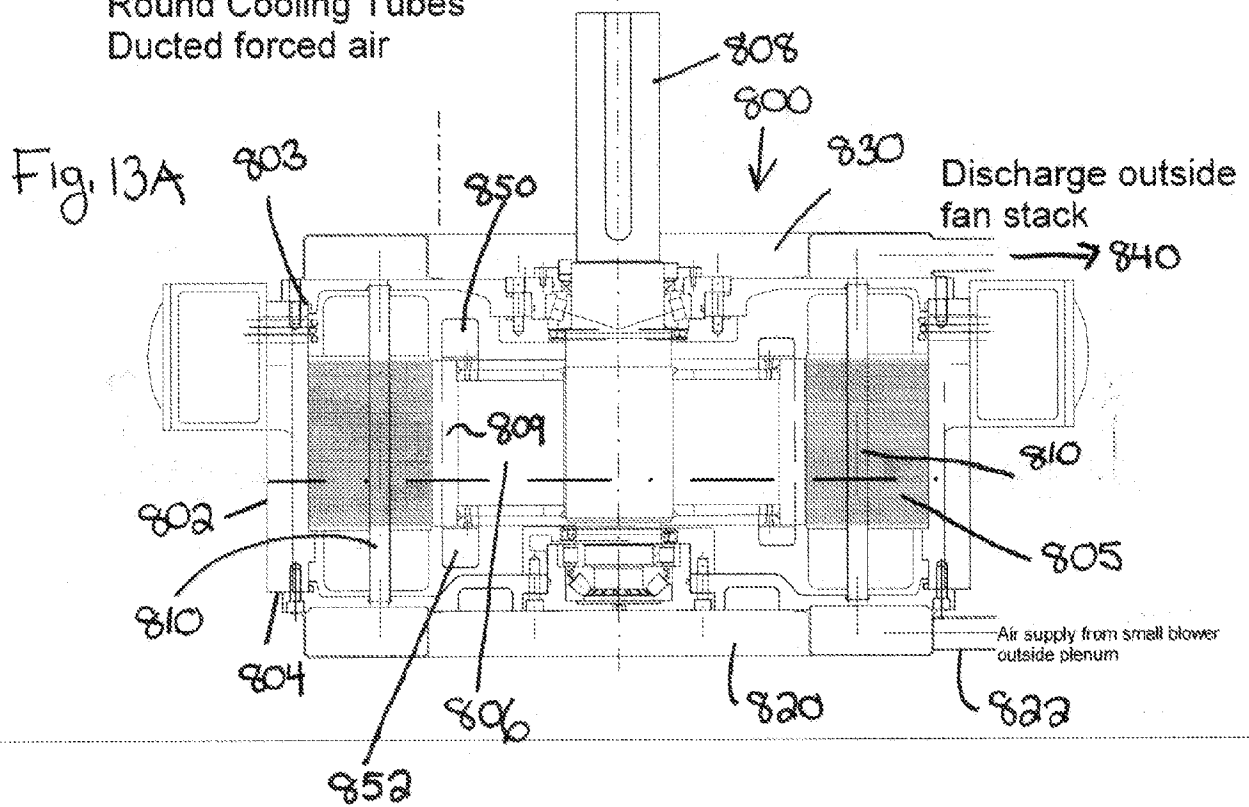
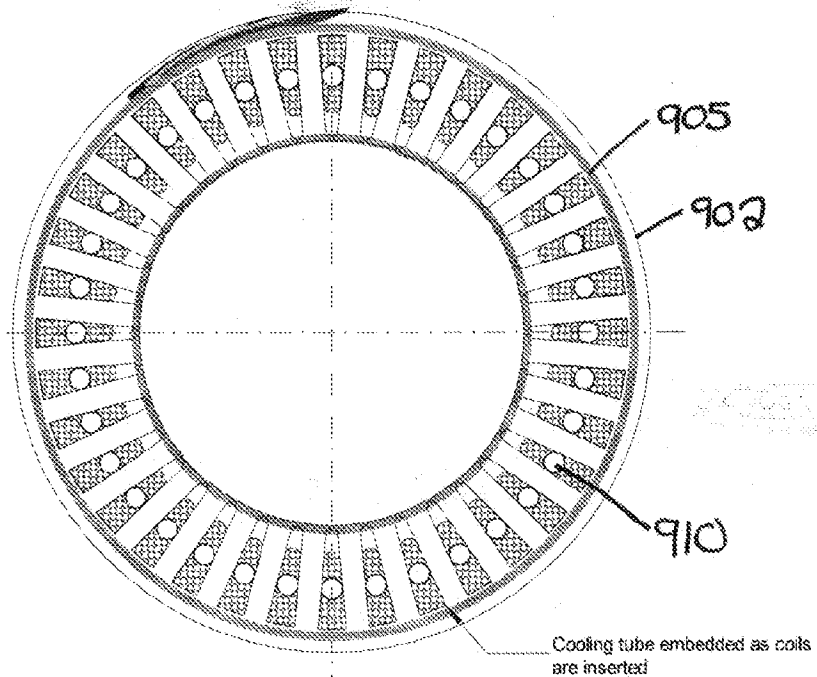
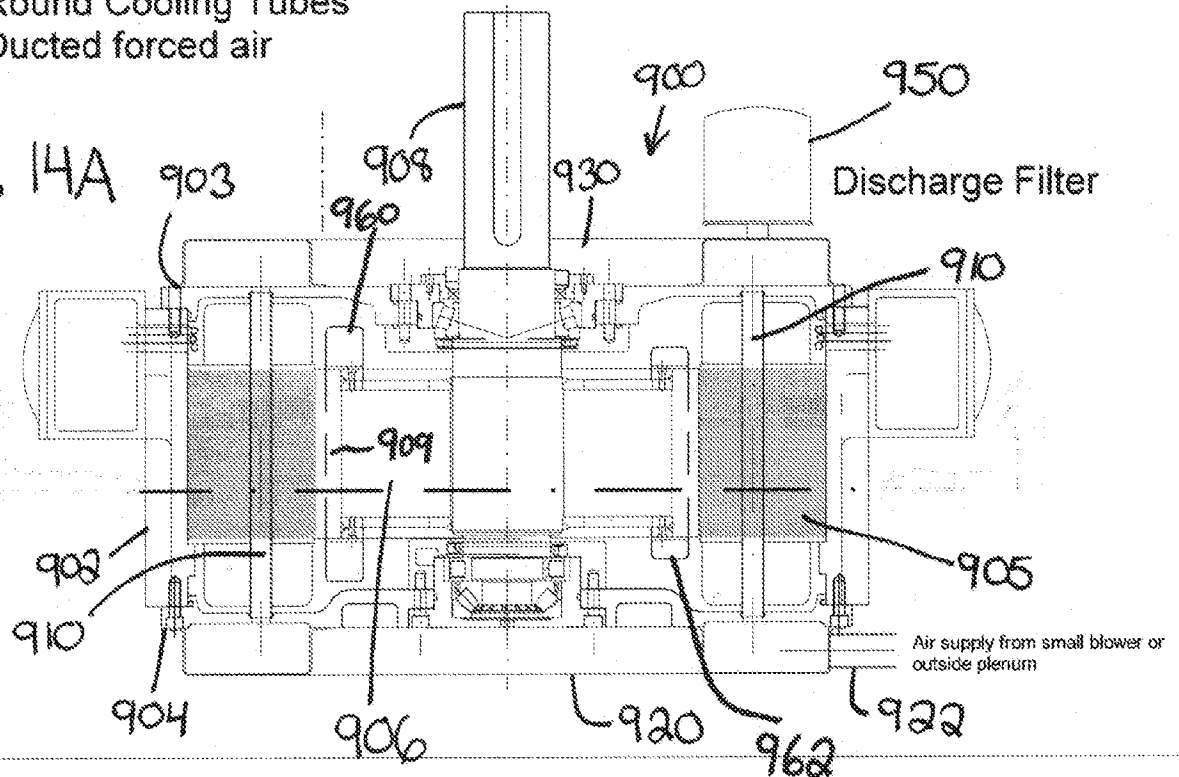


Fig. 14B



Round Cooling Tubes
Ducted forced air

Fig. 14A



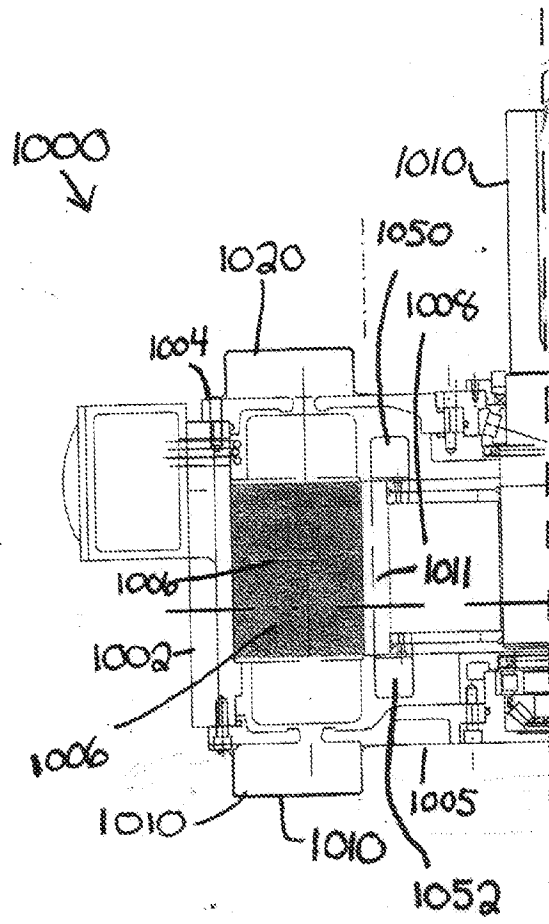


Fig. 15A

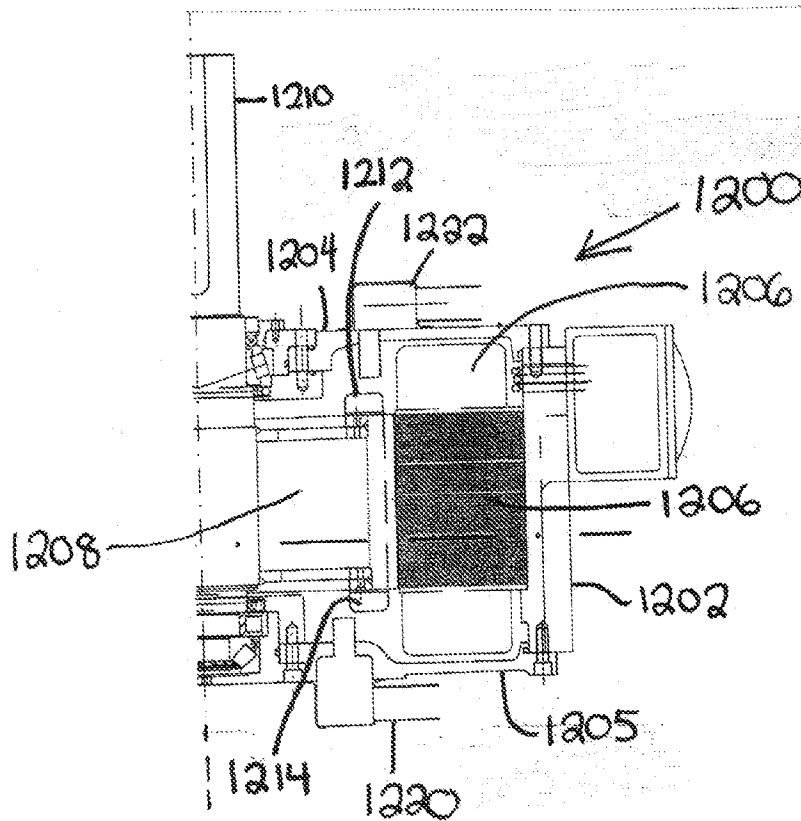


Fig. 15B

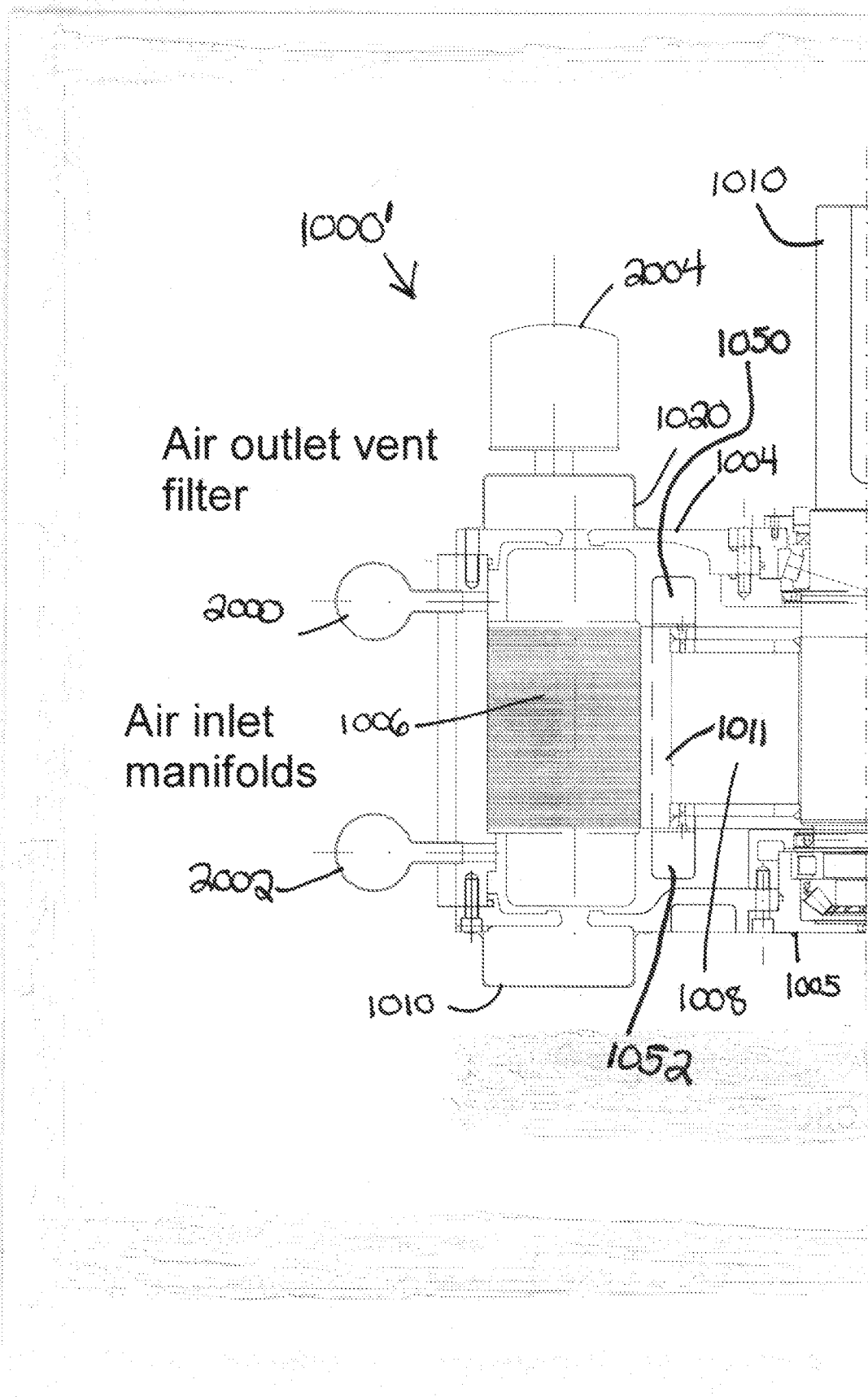


Fig. 16

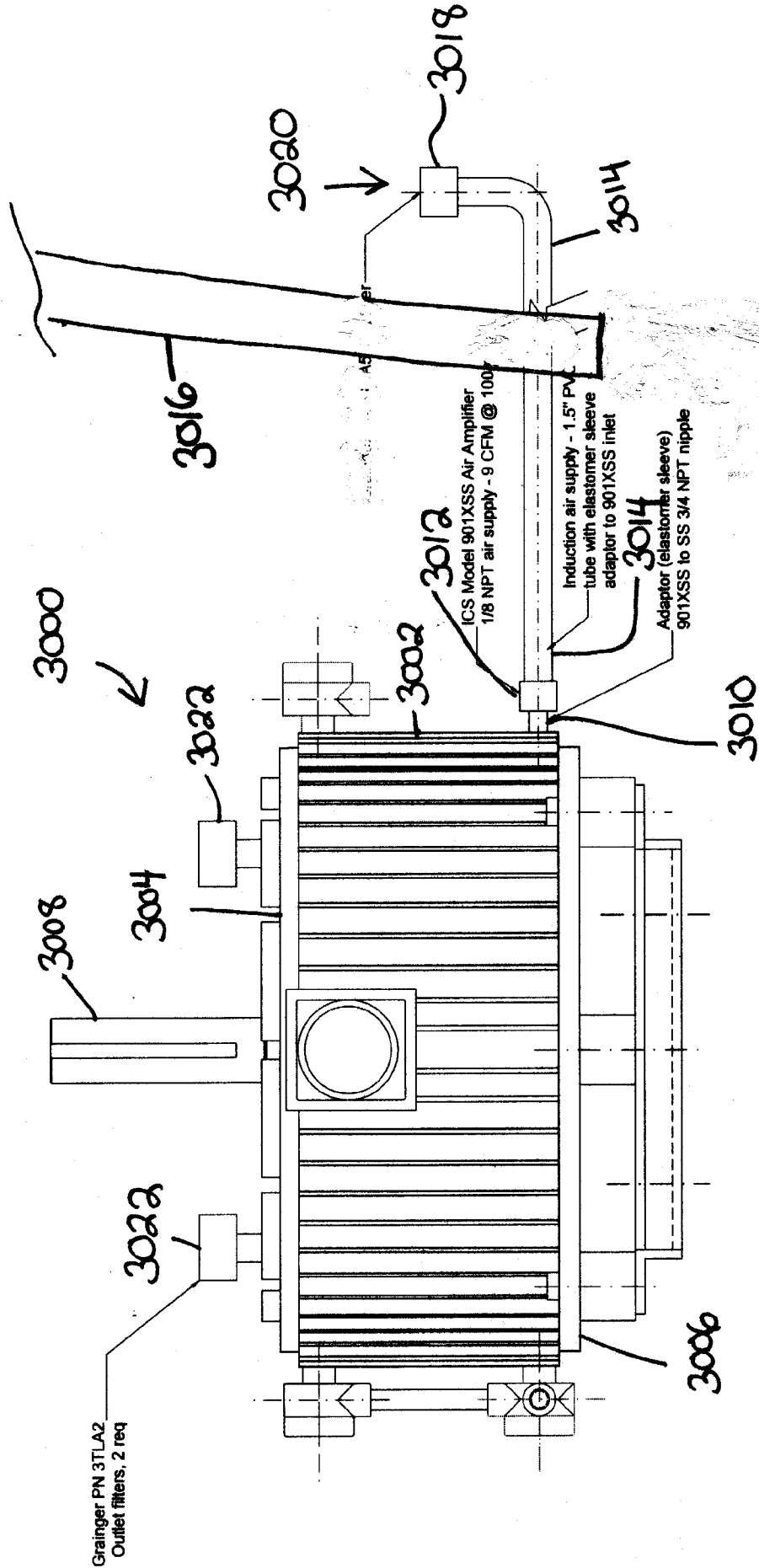


Fig.17

Top View Of Stator Winding

Fig. 18B

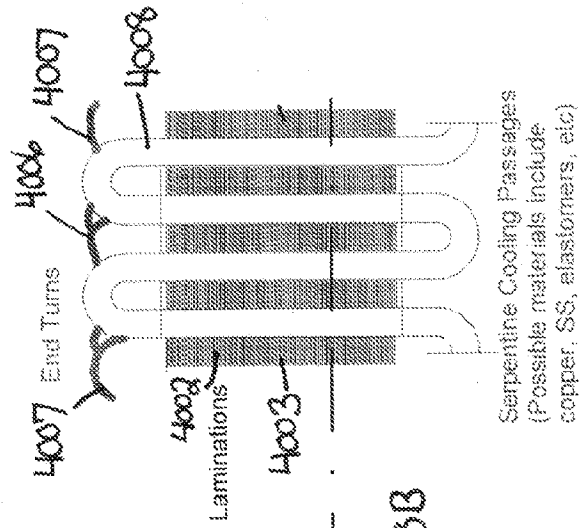


Fig. 18A

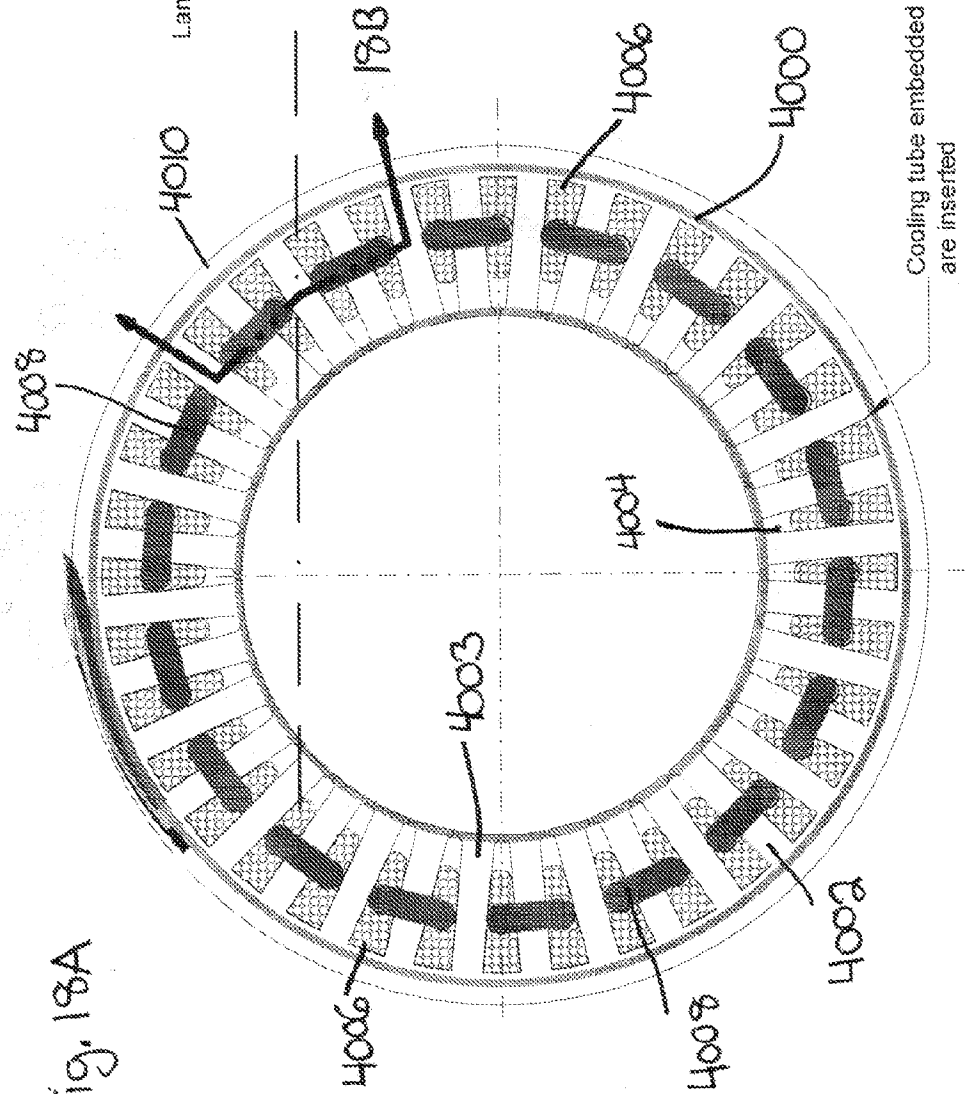
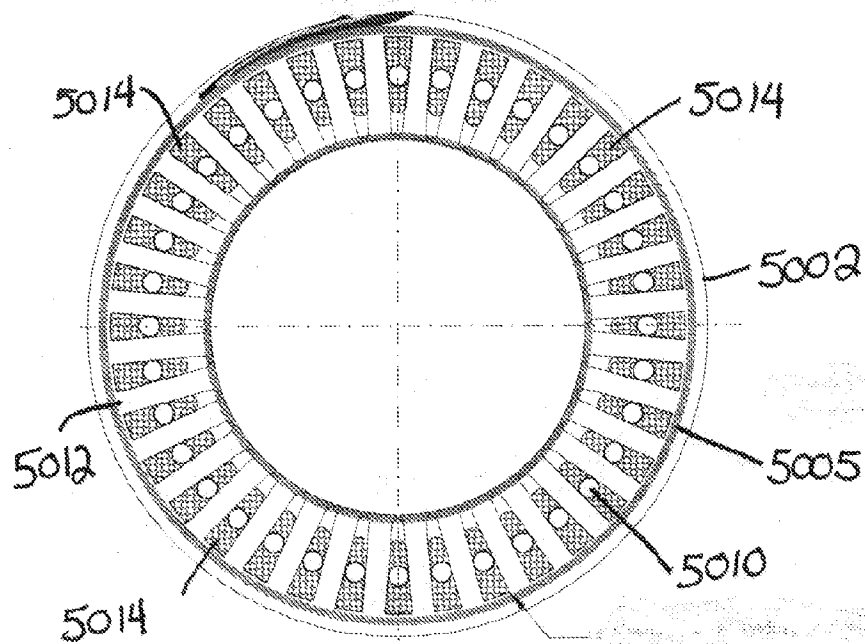
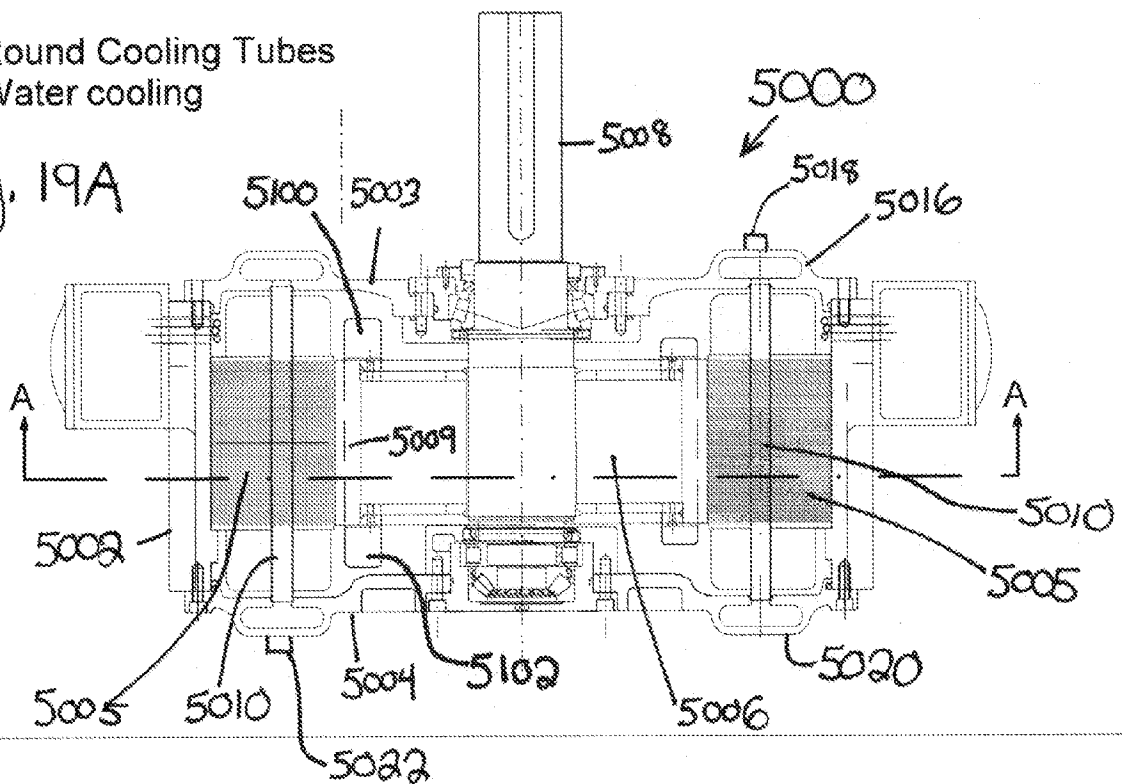


Fig. 19B



Round Cooling Tubes
Water cooling

Fig. 19A



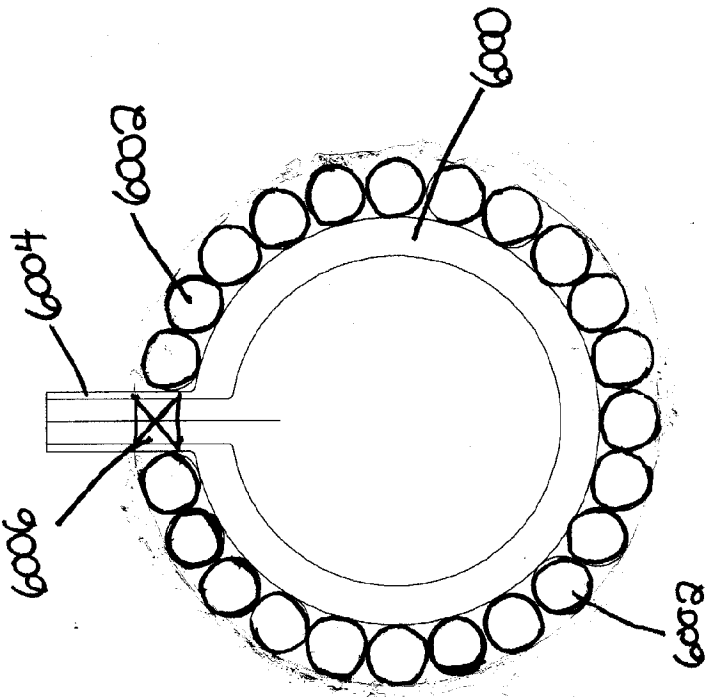


Fig. 20A

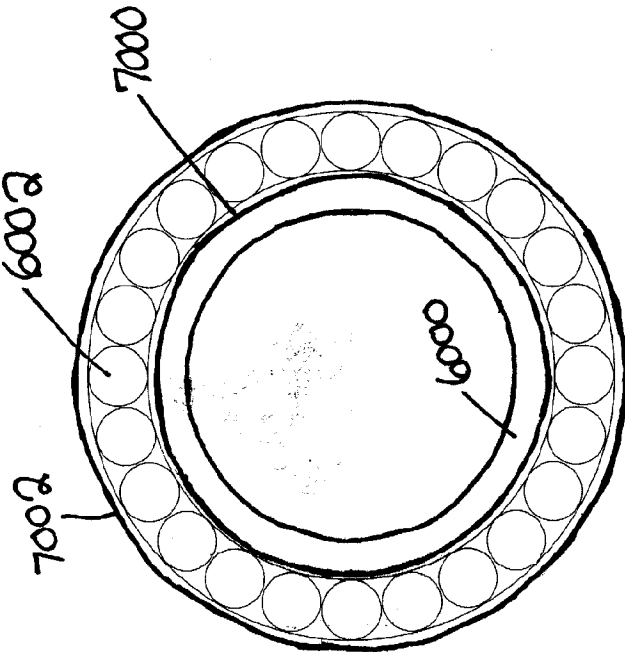


Fig. 20B

Fig. 21B

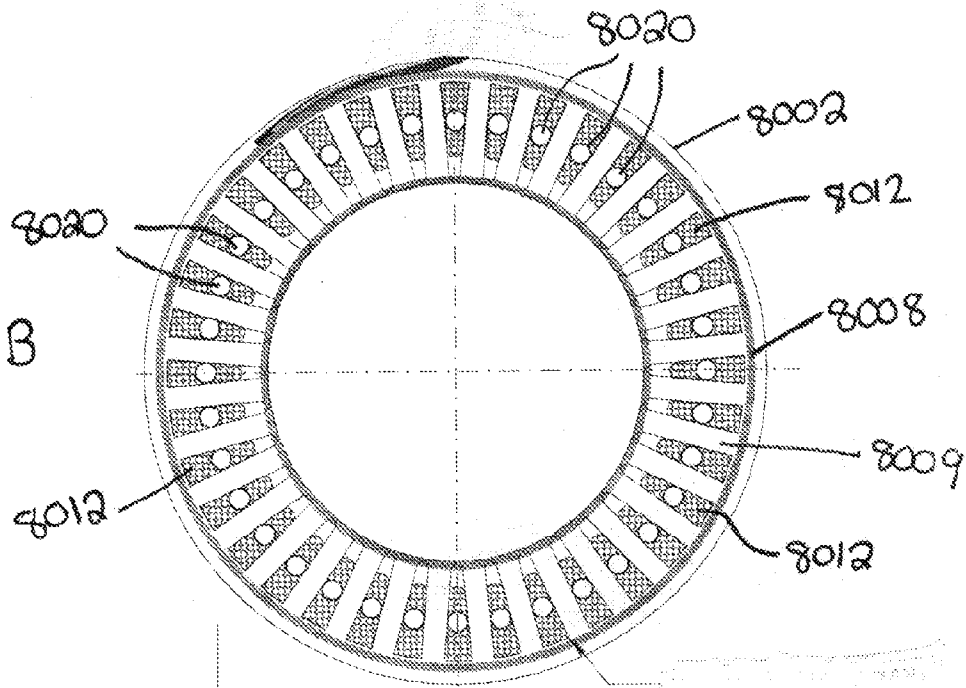


Fig. 21C

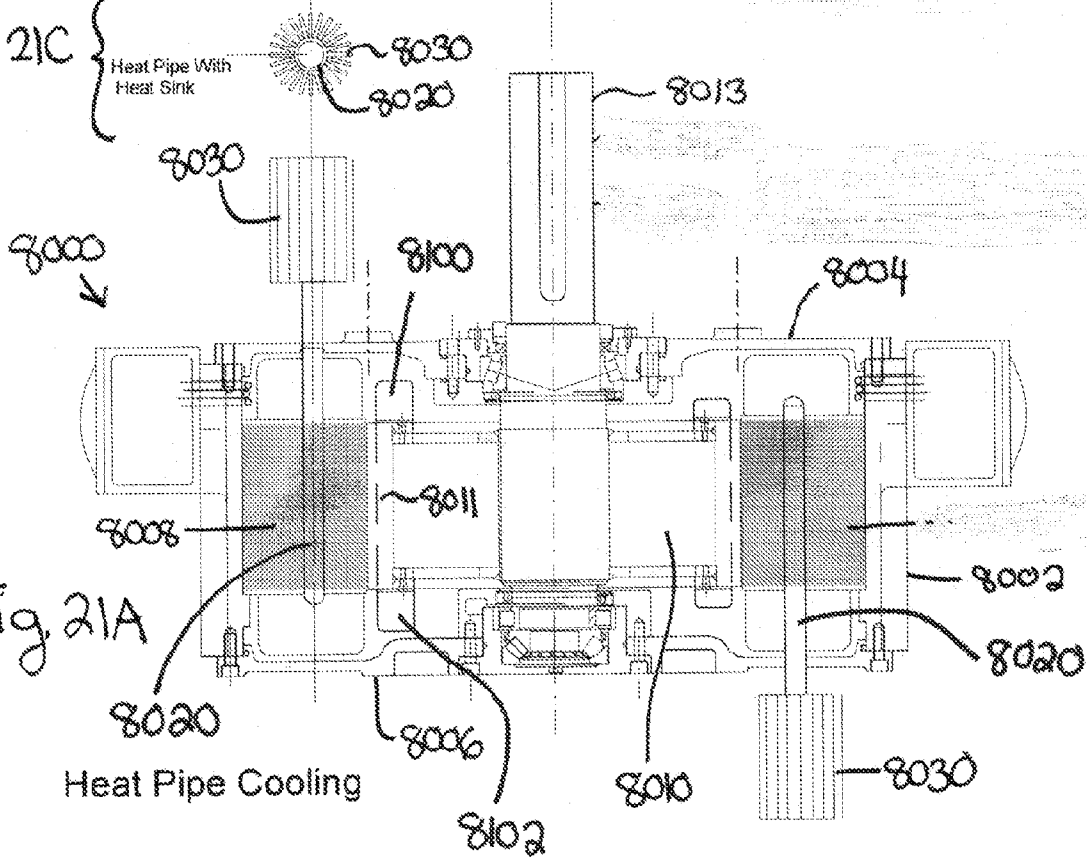


Fig. 21A

Heat Pipe Cooling

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 15/41422

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F28C 1/00 (2015.01)

CPC - F28C 1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8): F28C 1/* (2015.01)

CPC: F28C 1/*

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

IPC(8): F28C* (2015.01)

CPC: F28C*

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase, Google Patents, Google Web

Keywords: cooling, tower, auxiliary, secondary, supplemental, extra, plural, fan, fans, series, axial, blade, pitch, airflow, air flow, circulation, ventilation, motor, hub, coaxial, co-axial

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2,092,249 A (GYMNAITES) 07 September 1937 (07.09.1937), entire document	1
A	US 3,768,546 A (SHIPES) 30 October 1973 (30.10.1973), entire document	2
A	US 5,755,557 A (ALIZADEH) 26 May 1998 (26.05.1998), entire document	2
A	US 2006/0145367 A1 (GASPARINI et al.) 06 July 2006 (06.07.2006), entire document	1-2
A	US 3,637,195 A (BLAZER et al.) 25 January 1972 (25.01.1972), entire document	1-2
A	US 2,316,940 A (DEWEY et al.) 20 April 1943 (20.04.1943), entire document	1-2
A	US 1,844,313 A (DEAN et al.) 09 February 1932 (09.02.1932), entire document	1-2
A	US 2014/0131016 A1 (SANTORO) 15 May 2014 (15.05.2014), entire document	1-2

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

20 November 2015

Date of mailing of the international search report

30 DEC 2015

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