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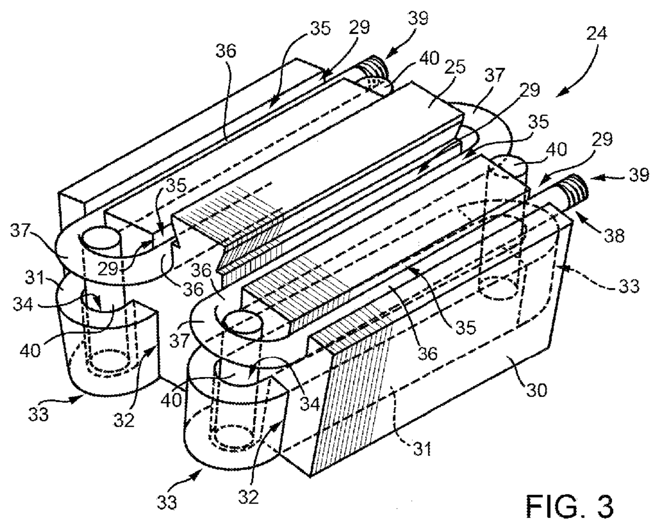

FIG. 3

(57) Abstract: An active segment (24) of a wind turbine rotary electric machine is selectively and prismatically connectable to a tubular support of a rotary electric machine, extends between two opposite ends to form, together with other active segments, an annular active part about an axis of rotation, and has a laminated pack (30); at least one active member (31) extending axially and fitted inside a seat (32) of the laminated pack (30); and at least one heat exchange member (40) located at one end to cool one end of the active member (31).

WO 2014/016802 A3

ACTIVE SEGMENT OF A WIND TURBINE ROTARY ELECTRIC MACHINE, ROTARY ELECTRIC MACHINE, AND WIND TURBINE

TECHNICAL FIELD

The present invention relates to an active segment of a wind turbine electric machine.

BACKGROUND ART

To produce electric energy using wind turbines, rotary electric machines are used to convert kinetic energy to electric energy. In this field, segmented rotary electric machines are also employed, i.e. in which the facing active parts moving with respect to one another are defined by axial active segments, which slide axially into and out of respective seats on respective supports of the rotary electric machine. A segmented rotary electric machine is described in the Applicant's Patents US 7,936,102 B1 and US 7,808,149 B2 and Patent Application US 2010/0123318 A1. This rotary electric machine design permits easy assembly of the active parts and easy replacement of the active segments when servicing the machine.

In a wind turbine, the rotary electric machine serves to convert kinetic energy to electric energy. Part of the kinetic energy converted by the rotary electric machine, however, is converted to heat, which must be removed to optimize efficiency of the machine.

In fact, as the temperature increases, the efficiency of the rotary electric machine decreases.

The electric energy produced is subsequently transformed in phase and frequency in static electric machines, which are also cooled to optimize performance.

For this purpose, the wind turbines described in US 7,057,305, US 7,161,260, US 6,676,122, US 7,594,800 and EP 2,136,077 comprise air cooling systems. More specifically, EP 2,136,077 describes a wind turbine comprising a rotary electric machine; a rotary assembly with a hub; blades fitted to the hub; a nacelle supporting the rotary electric machine; and a forced-air cooling system, which feeds air successively through the hub, the rotary electric machine and the nacelle. In other words, air flows in through a first opening in the hub, and out through a second opening in the rear of the nacelle.

Air cooling systems provide for fairly good performance of rotary electric machines on wind turbines installed in relatively mild or cold climates.

In hot climates, on the other hand, liquid cooling systems are required.

US 7,168,251 B1 describes a wind turbine comprising a preferably closed-circuit, preferably liquid cooling system.

Wind turbines must often be designed and built with a cooling system designed according to the climate of where the wind turbine is installed, i.e. to maximize power and efficiency of the electric machine according to the climate at the installation site.

Designing and building wind turbines according to the climate at the installation site, the scale economies made possible by mass production of the wind turbine component parts are greatly reduced.

In this respect, known cooling systems are not particularly versatile and perform poorly as regards cooling the electric generator.

To eliminate this drawback, the Applicant's Patent Application EP 2,354,542 proposes a rotor liquid cooling system with a tubular structure fitted with heat exchangers.

This system is highly effective and versatile, but the heat exchangers increase the weight of the rotor and are located on the opposite side to the active segments.

The active segments normally comprise a laminated pack; and an active member normally defined by a coil or a block of permanent magnets and housed inside a seat on the laminated pack.

One drawback observed by the Applicant is the failure of known cooling systems to maintain an even temperature along the active segment. In fact, the temperature varies widely between a maximum and minimum value.

DISCLOSURE OF INVENTION

It is an object of the present invention to provide an active segment of a wind turbine rotary electric machine, designed to eliminate the drawbacks of the known art.

According to the present invention, there is provided an active segment of a wind turbine rotary electric machine, wherein the active segment is selectively and prismatically connectable to a tubular structure of a rotary electric machine, extends between two opposite ends to form, together with other active segments, an annular active part about an axis of rotation, and comprises a laminated pack; at least one active member extending axially and fitted inside a seat of the laminated pack; and at least one heat exchange member located at one end to cool one end of the active member.

Tests by the Applicant show the temperature to be highest at the ends of the active member. So, providing a heat exchanger at one end of an active segment cools the hottest area of the active segment, provides for a more even temperature along the active segment, and improves performance of the rotary electric machine.

Each heat exchange member is preferably tubular for easy connection to a support.

Each heat exchange member is preferably straight for easy handling and installation.

In a preferred embodiment of the present invention, the heat exchange member extends in a direction crosswise to the axial direction, preferably radially with respect to the axis of rotation.

As a result, heat is removed crosswise to the axial direction along which the heat-generating active member extends.

Each heat exchange member is preferably a heat pipe designed to remove a large amount of heat per unit of time.

In a preferred embodiment of the present invention, the heat exchange member is positioned contacting the active member. As a result, part of the heat is transmitted by direct conduction between the end of the active member and the heat exchange member.

In a preferred embodiment of the present invention, the heat exchange member is fitted to the active member. The active member may advantageously support the heat exchange member, provided the heat exchange member is insulated electrically from the active member.

Preferably, the active member comprises two opposite ends projecting from the laminated pack; the active segment comprising at least one heat exchange member at each end of the active element. The temperature, in fact, is highest at both ends of the active member, and each heat exchange member provides for cooling a respective end.

In a preferred embodiment of the present invention, the laminated pack is designed to support a plurality of active members, each having two opposite ends projecting from opposite sides of the laminated pack; the active segment comprising at least one heat exchange member at each end of the active member.

As a result, the temperature peaks at each end of the active member are greatly reduced.

In other words, each active member comprises an electric coil having two U-shaped portions projecting from opposite sides of the laminated pack and defining said opposite ends of the active member; each heat exchange member being located partly inside a gap formed by the U-shaped portion and the laminated pack.

The coil portion forming the gap is actually the hottest area of the active segment, in which the temperature peaks occur.

Each heat exchange member preferably has one end located close to a cooling channel.

To optimize its efficiency, cooling channels are formed in the rotary electric machine. Locating one end of the heat exchange member close to a cooling channel improves cooling of the active part. The cooling channel may be traversed by liquid or gas. If the cooling channel is traversed by a liquid, the heat exchange member is positioned contacting the heat exchanger. If the cooling channel is traversed by a gas, the heat exchange member may easily be exposed to the gas flow along the cooling channel. For example, the air gap of the rotary electric machine may define an annular cooling channel when traversed by gas, preferably air. Moreover, the air gap is located close to the active member, so one end of the heat exchange member may easily be exposed to the gas flow.

Alternatively, the active segment comprises at least one cooling channel housed at least partly in the laminated pack. So, this cooling channel may also be used easily for the heat exchange member.

The active segment preferably comprises a pipe, which extends parallel to the active member, is housed in the laminated pack, and defines the cooling channel. As a result, the cooling channel is able to cool the whole of the active member, the laminated pack, and the ends of the active member. The pipe may be housed inside a groove on the laminated pack, or be fully enclosed in the laminated pack.

In a preferred embodiment of the present invention, the pipe has two opposite ends fitted with members for compressing the laminated pack.

The pipe defining the cooling channel thus also acts as a tie.

Each active segment preferably comprises a plurality of parallel cooling channels housed in the laminated pack. Distributing the cooling channels inside the laminated pack provides for distributing the 'cold' areas as required.

The active segment preferably comprises a plurality of pipes housed in the laminated pack and defining respective cooling channels.

These cooling channels may be connected to one another by bends located outside the laminated pack and therefore easily reached by the heat exchange member. The heat exchange member is also positioned contacting a bend to conduct heat.

It is a further object of the present invention to provide a rotary electric machine designed to eliminate the drawbacks of the known art.

According to the present invention, there is provided a segmented rotary electric machine for a wind turbine, comprising a rotor, and a stator which comprises a tubular structure extending about an axis of rotation, and a plurality of active segments selectively and prismatically connectable axially to the tubular structure to form an annular active part; and wherein each active segment is as claimed in any one of the foregoing Claims.

The temperature of the rotary electric machine can thus be reduced at opposite ends.

It is a further object of the present invention to provide a wind turbine, for producing electric energy, designed to eliminate the drawbacks of the known art.

According to the present invention, there is provided a wind turbine for producing electric energy, and comprising a rotary electric machine as described above; and a liquid cooling system comprising a stationary circuit connected to each active segment.

The liquid cooling system provides for greatly reducing the temperature, and so greatly improving the efficiency, of the rotary electric machine.

BRIEF DESCRIPTION OF THE DRAWINGS

A number of non-limiting embodiments of the present invention will be described by way of example with reference to the attached drawings, in which :

Figure 1 shows a view in perspective, with parts removed for clarity, of a wind turbine equipped with a segmented rotary electric machine featuring active segments in accordance with the present invention;

Figure 2 shows a partly schematic elevation, with parts removed for clarity, of the segmented rotary electric machine installed on the Figure 1 wind turbine;

Figure 3 shows a larger-scale view in perspective, with parts removed for clarity, of an active segment in accordance with the present invention;

Figure 4 shows a partly sectioned side view, with parts removed for clarity, of the active segment in Figure 3;

Figure 5 shows a partly sectioned side view, with parts removed for clarity, of a variation of the active segment in Figures 3 and 4;

Figure 6 shows a larger-scale view in perspective, with parts removed for clarity, of an active segment in accordance with an alternative embodiment of the present invention;

Figure 7 shows a larger-scale, partly sectioned side view, with parts removed for clarity, of the active segment in Figure 6.

BEST MODE FOR CARRYING OUT THE INVENTION

Number 1 in Figure 1 indicates as a whole a wind turbine for producing electric energy. Wind turbine 1 comprises a pylon 2; a nacelle 3 mounted to rotate on pylon 2; a rotary electric machine 4 fitted to nacelle 3; and a blade assembly 5 connected to rotary electric machine 4.

Wind turbine 1 also comprises a liquid cooling system 6, of which Figure 1 only shows two heat exchangers 7 fitted to the outside of nacelle 3.

In the example shown, rotary electric machine 4 comprises a stator 8 fixed to nacelle 3; and a rotor 9, which is supported to rotate with respect to stator 8, is located inside stator 8, and is connected rigidly to blade assembly 5 to define a direct-drive system. It is understood that the present invention also applies to configurations other than the one shown and described in detail, i.e. to configurations in which the rotor surrounds the stator, or in which a drive is interposed between the blade assembly and the rotor.

Rotary electric machine 4 is preferably a synchronous, permanent-magnet rotary electric machine.

As shown in Figure 2, rotary electric machine 4 is connected to the liquid cooling system. Rotary electric machine 4 is tubular about an axis of rotation A. In the example shown, stator 8 comprises a tubular structure 10; and an annular active part 11 fitted to tubular structure 10. Rotor 9 comprises a tubular structure 12; a hub 13; a radial structure 14 for connecting hub 13 to tubular structure 12; and an active part 15, which is fitted to tubular structure 12, faces active part 11, and is separated from the active part by an air gap T.

In the example shown, tubular structure 12 comprises a plurality of sectors 16 arranged about axis of rotation A and substantially adjacent to one another circumferentially. Each sector 16 is fitted to radial structure 14. Rotor 9 is connected to liquid cooling system 6, which comprises a rotary circuit portion 17 and a stationary circuit portion 18. Rotor 9 actually comprises rotary circuit portion 17 of liquid cooling system 6. Liquid cooling system 6 schematically comprises a rotary liquid distributor 19 to which rotary circuit portion 17 and stationary circuit portion 18 are connected; a liquid circulating pump 20 located along stationary circuit portion 18; and at least one of heat exchangers 7, which are also located along stationary circuit portion 18.

Liquid cooling system 6 generally comprises a plurality of rotary circuit portions 17, each associated with a respective sector 16. Each rotary circuit portion 17 comprises two, respectively liquid feed and liquid return, branches 21, which, in the example shown, extend radially at radial structure 14.

Tubular structure 12 comprises a plurality of cooling channels 22 formed in tubular structure 12 itself. In the example shown, each sector 16 has cooling channels 22 parallel to axis of rotation A. The cooling channels 22 formed in tubular structure 12 serve to conduct air, or, as in the example shown in the attached drawings, form an integral part of liquid cooling system 6. In other words, rotary circuit portion 17 is defined partly by the axially-extending cooling channels 22.

Each sector 16 is designed to support at least one active segment 23 and, in the example shown, supports five active segments 23, each extending parallel to axis of rotation A, and each of which is insertable axially into and removable axially from tubular structure 12. Each active segment 23 is defined by a magnetic guide, by substantially at least one laminated pack, and by an active member defined by permanent magnets not shown in the attached drawings.

Active part 11 is defined by a plurality of active segments 24 fitted to tubular structure 10. Each active segment 24 and tubular structure 10 are designed to form an axial prismatic coupling. In the example shown, each active segment 24 comprises a dovetail-shaped rib 25, and tubular structure 10 has a plurality of axial grooves 26 complementary in shape to rib 25.

Each active segment 24 is connected to cooling system 6, which comprises a stationary circuit 27 for circulating the cooling liquid, and along which one of heat exchangers 7 and a pump 28 are located. Each active segment 24 comprises cooling channels 29 connected to stationary circuit 27.

As shown in Figure 3, each active segment 24 comprises a laminated pack 30 fitted with an active member 31; and at least one cooling channel 29. Laminated pack 30 is prismatic in shape, and axial seats 32, preferably grooves, are formed in it to house the active members and define teeth substantially defining pole pieces of laminated pack 30.

In the example shown, each active member is an electric coil, which is wound about a tooth, i.e. about a pole piece, is housed in seats 32, and projects axially on opposite sides of laminated pack 30. More specifically, each coil has a U-shaped portion 33, which projects from one face of laminated pack 30 and defines a gap 34 between U-shaped portion 33 and laminated pack 30.

Laminated pack 30 comprises a plurality of grooves 35 formed on the opposite side to seats 32. Each groove 35 houses a cooling channel 29 substantially defined by a pipe 36, which is connected to the other pipes 36 defining the other cooling channels 29 by U-shaped bends 37 to form a coil 38, which terminates with attachments 39 for connection to stationary circuit 27.

Each active member 31 is connected at the end to a heat exchange member 40. That is, each U-shaped portion 33 of the electric coil is positioned contacting a heat exchange member 40. More specifically, heat exchange member 40 is located inside gap 34, and is preferably supported by the electric coil. Heat exchange member 40 is substantially cylindrical and is positioned substantially radially. Heat exchange member 40 is preferably a so-called 'heat pipe', i.e. a hollow pipe or cylinder of heat-conducting metal, closed at the ends and containing a small amount of cooling liquid; the rest of the pipe is filled with the cooling liquid vapour, so no other gases are present. A heat pipe serves to transfer heat from its hot end to its cold end by evaporation and condensation of the cooling liquid. The hot end, contacting a heat source, yields heat to the cooling liquid, which vaporizes and so increases the vapour pressure in the pipe. The latent vaporization heat absorbed by the cooling liquid reduces the temperature at the hot end of the pipe. The vapour pressure close to the hot end being higher than the balanced pressure at the cold end, vapour is transferred rapidly to the cold end, where the vapour in excess of equilibrium condenses, yielding heat to the cold end.

In the example shown, and with reference to Figure 4, heat exchange member 40 therefore has a 'hot' end contacting the electric coil or, more generally speaking, active member 31, and a 'cold' end located close to cooling channel 29 or contacting coil 38.

The area inside U-shaped portion 33 of the electric coil is particularly hot, so the heat exchange member 40 located in this area provides for rapid cooling.

In the Figure 5 variation, each U-shaped portion 33 of the electric coil is connected to two heat exchange members 41 and 42. Heat exchange member 41 extends from

U-shaped portion 33 to a cooling channel 29. Heat exchange member 42 extends in the same direction as member 41 but on the opposite side, and more specifically from U-shaped portion 33 to air gap T, which, when traversed by air or gas in general, acts as a cooling channel for cooling heat exchange member 42.

Number 43 in the Figure 6 embodiment indicates an active segment comprising a laminated pack 44 supporting two active members 45.

Like segment 24 in Figure 3, laminated pack 44 has seats 46 for housing active members 45 and which, in the example shown, are defined by electric coils. Each electric coil forms a U-shaped portion 47, which projects from one face of laminated pack 44 and defines a gap 48 between U-shaped portion 47 and laminated pack 44, as shown more clearly in Figure 7.

Laminated pack 44 has a rib 49 designed to form an axial prismatic coupling with tubular structure 10.

As shown in Figure 7, laminated pack 44 also comprises a plurality of axial through openings 50. Active segment 43 differs from active segment 24 by comprising openings 50, each of which houses a cooling channel 51 connected to the other cooling channels 51 by U-shaped bends 52 to form a coil 53 terminating with attachments 54 for connection to stationary circuit 27 (Figure 2).

Active member 45 is connected at the end to a heat exchange member 55. That is, each U-shaped portion 47 of the electric coil is positioned contacting a heat exchange member 55. More specifically, heat exchange member 55 is located inside gap 48, and is supported by the electric coil.

In the example shown, and with reference to Figure 7, heat exchange member 55 therefore has a 'hot' end contacting the electric coil or, more generally speaking, active member 45, and a 'cold' end located close to cooling channel 51 or contacting coil 53.

Each cooling channel is substantially defined by a pipe 56 housed inside a respective axial opening 50. In the example shown, each pipe 56 has two opposite ends 57, which project from the laminated pack to connect to the other pipes 56 and stationary circuit 27 (Figure 2).

The projecting ends 57 of each pipe 56 are preferably threaded and engaged respectively by two ring nuts 58, which serve to compress laminated pack 44. In fact, in this case, pipes 56 may act as ties normally used to produce laminated packs.

Clearly, changes may be made to the active segment according to the present invention without, however, departing from the scope of the accompanying Claims.

CLAIMS

1) An active segment of a wind turbine rotary electric machine, wherein the active segment (24; 43) is selectively and prismatically connectable to a tubular structure (10) of a rotary electric machine (4), extends between two opposite ends to form, together with other active segments (24; 43), an annular active part (11) about an axis of rotation (A), and comprises a laminated pack (30; 44); at least one active member (31; 45) extending axially and fitted inside a seat of the laminated pack (30; 44); and at least one heat exchange member (40; 41; 42; 55) located at one end to cool one end of the active member (31; 45).

2) An active segment as claimed in Claim 1, wherein each heat exchange member (40; 41; 42; 55) is tubular.

3) An active segment as claimed in Claim 1 or 2, wherein each heat exchange member (40; 41; 42; 55) is straight.

4) An active segment as claimed in any one of the foregoing Claims, wherein the heat exchange member (40; 41; 42; 55) extends in a direction crosswise to the axial direction, preferably radially with respect to the axis of rotation.

5) An active segment as claimed in any one of the foregoing Claims, wherein each heat exchange member (40; 41; 42; 55) is a heat pipe.

6) An active segment as claimed in any one of the foregoing Claims, wherein the heat exchange member (40; 41; 42; 55) is positioned contacting the active member (31; 45).

7) An active segment as claimed in any one of the foregoing Claims, wherein the heat exchange member (40; 41; 42; 55) is fitted to the active member (31; 45).

8) An active segment as claimed in any one of the foregoing Claims, wherein the active member (31; 45) comprises two opposite ends projecting from the laminated pack (30; 44); the active segment comprising at least one heat exchange member (40; 41; 42; 55) at each end of the active member (31; 45).

9) An active segment as claimed in any one of the foregoing Claims, wherein the laminated pack (30; 44) is designed to support a plurality of active members (31; 45), each having two opposite ends projecting from opposite sides of the laminated pack (30; 44); the active segment (24; 43) comprising at least one heat exchange member (40; 41; 42; 55) at each end of the active member (31; 45).

10) An active segment as claimed in any one of the foregoing Claims, wherein each active member (31; 45) comprises an electric coil having two U-shaped portions (33; 47) projecting from opposite sides of the laminated pack (30; 44) and defining said opposite ends of the

active member (31; 45); each heat exchange member (40; 41; 42; 55) being located partly inside a gap (34; 48) formed by the U-shaped portion (33; 47) and the laminated pack (30; 44).

11) An active segment as claimed in any one of the foregoing Claims, wherein each heat exchange member (40; 41; 42; 55) has one end located close to a cooling channel (29; T; 51).

12) An active segment as claimed in any one of the foregoing Claims, and comprising at least one cooling channel (29; 51) housed at least partly in the laminated pack (30; 44).

13) An active segment as claimed in Claim 12, and comprising a pipe (36; 56), which extends parallel to the active member (31; 45), is housed in the laminated pack (30; 44), and defines the cooling channel (29; 51).

14) An active segment as claimed in Claim 13, wherein the pipe (56) is fully enclosed in the laminated pack (44).

15) An active segment as claimed in Claim 13 or 14, wherein the pipe (56) has two opposite ends (57) fitted with members for compressing the laminated pack (44).

16) An active segment as claimed in any one of Claims 12 to 15, and comprising a <u>plurality</u> of parallel cooling channels (29; 51) housed in the laminated pack (30; 44).

17) An active segment as claimed in Claim 16, and comprising a plurality of pipes (36; 56) housed in the laminated pack (30; 44) and defining respective cooling channels (29; 51).

18) An active segment as claimed in Claim 16 or 17, and comprising a bend (37; 52) connecting the cooling channels (29; 51) and located outside the laminated pack (30; 44).

19) A segmented rotary electric machine for a wind turbine, comprising a rotor (9), and a stator (8) which comprises a tubular structure (10) extending about an axis of rotation (A), and a plurality of active segments (24; 43) selectively and prismatically connectable axially to the tubular structure (10) to form an annular active part (11); and wherein each active segment (24; 43) is as claimed in any one of the foregoing Claims.

20) A wind turbine for producing electric energy, and comprising a rotary electric machine (4) as claimed in Claim 19; and a liquid cooling system (6) comprising a stationary circuit (27) connected to each active segment (24; 43).

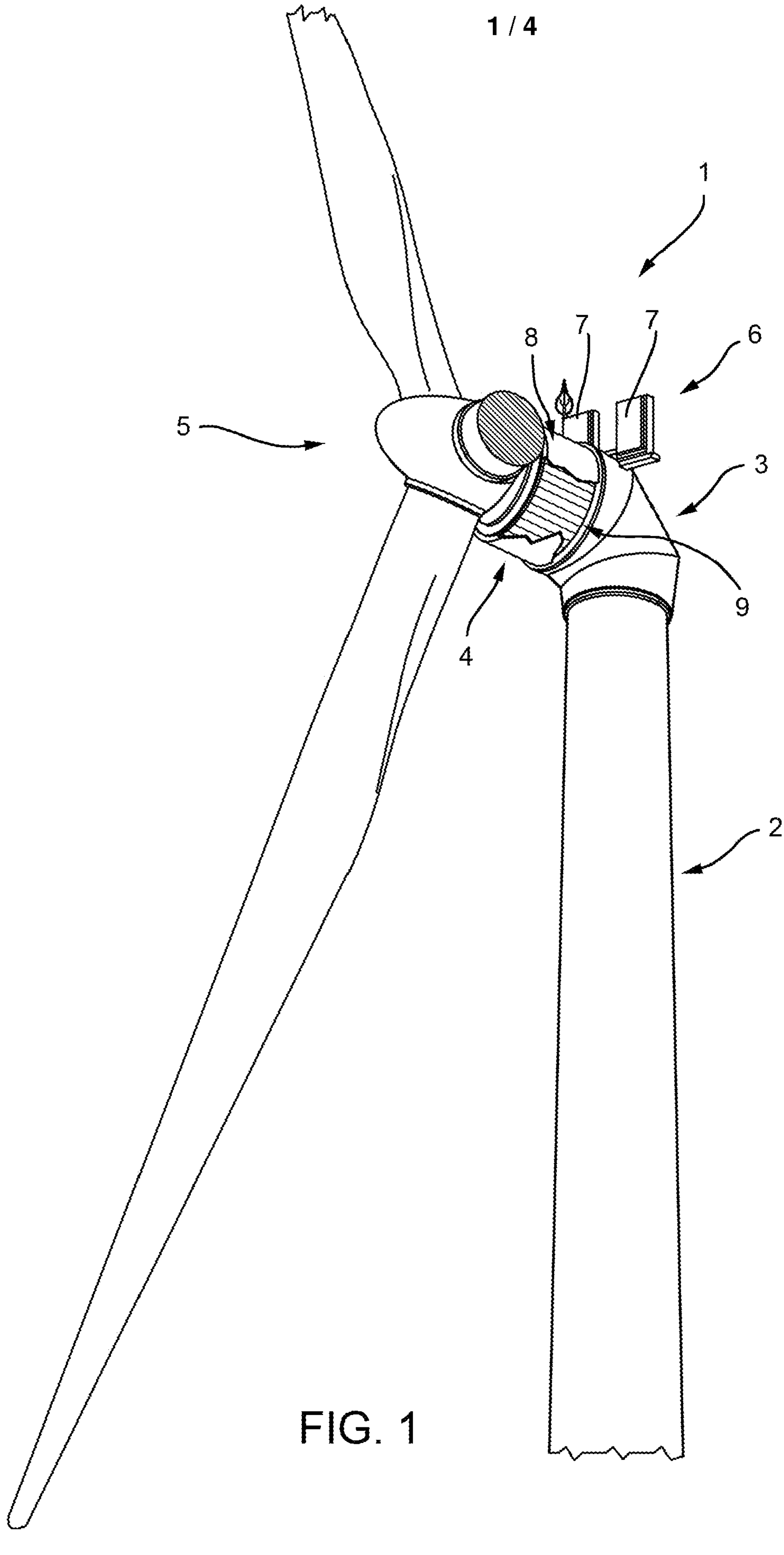

FIG. 1

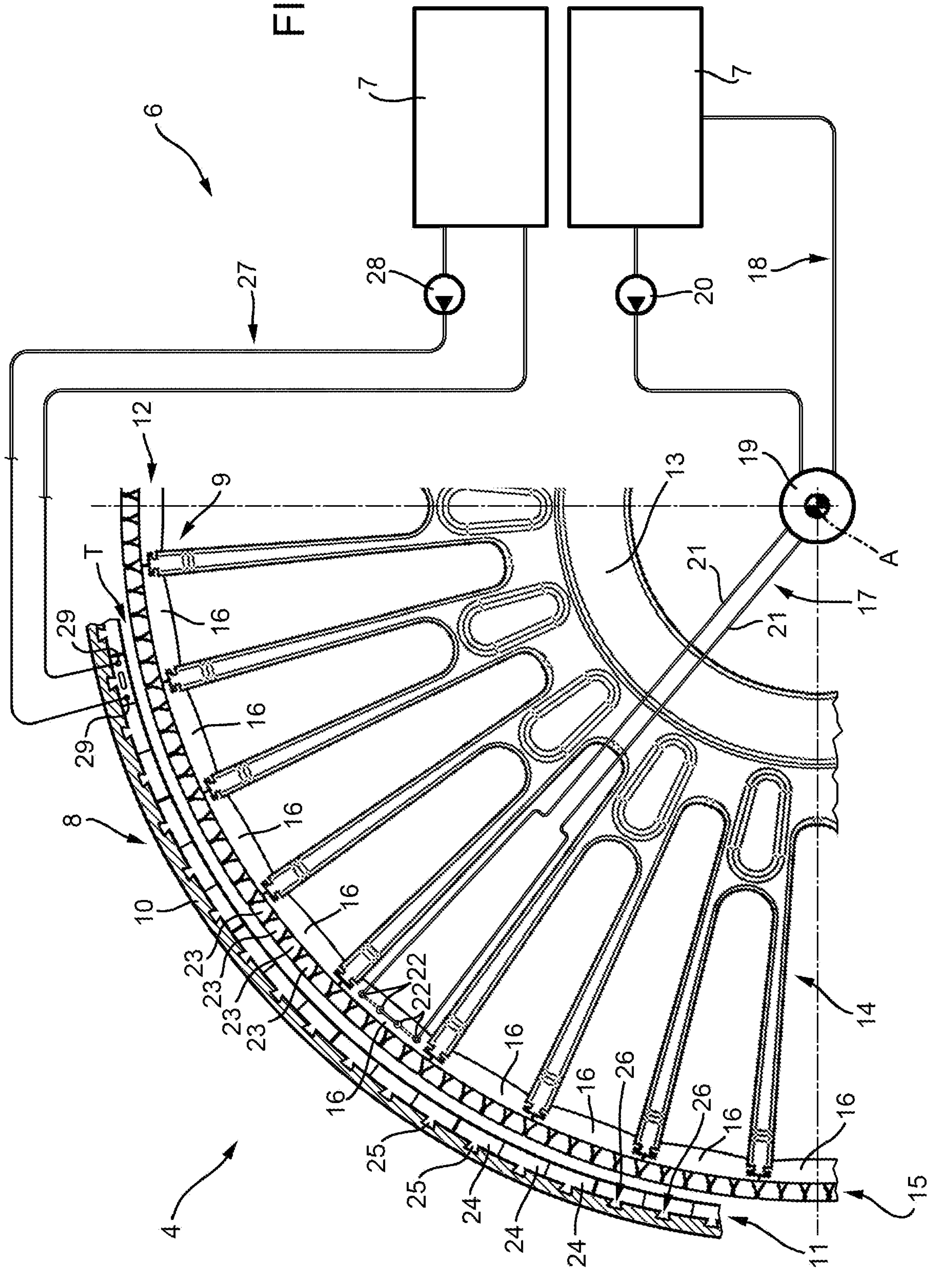
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FIG. 2

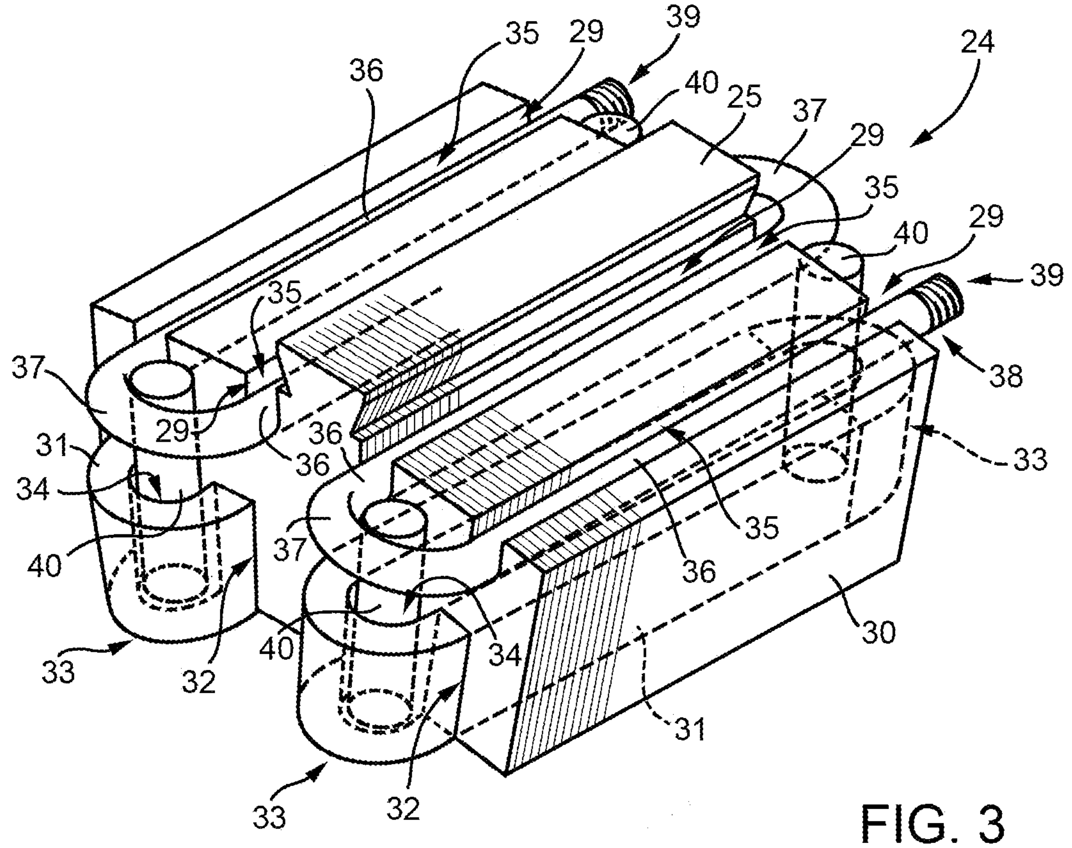

FIG. 3

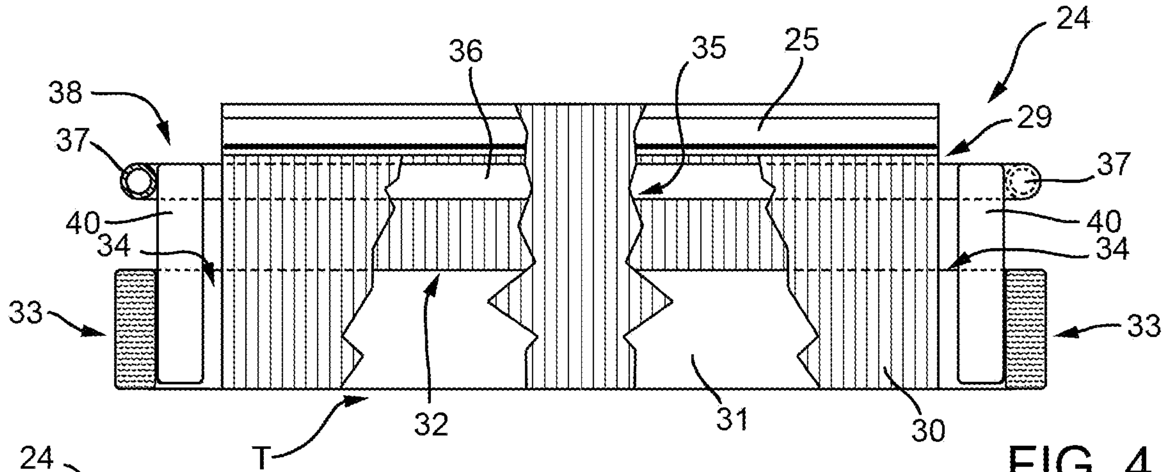

FIG. 4

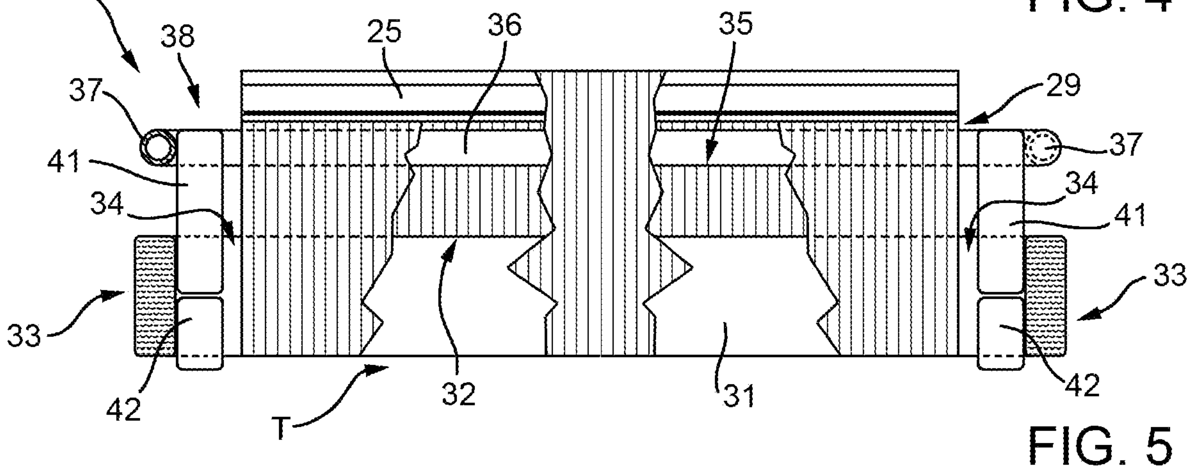

FIG. 5

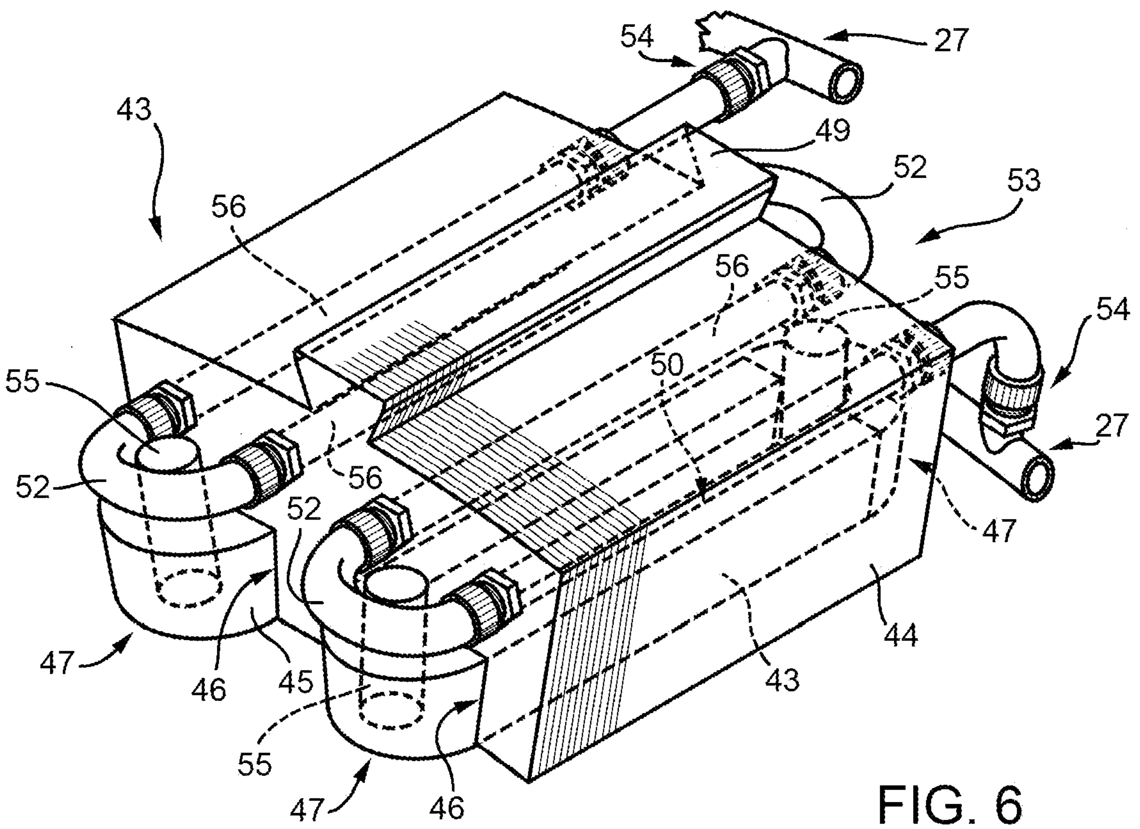
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FIG. 6

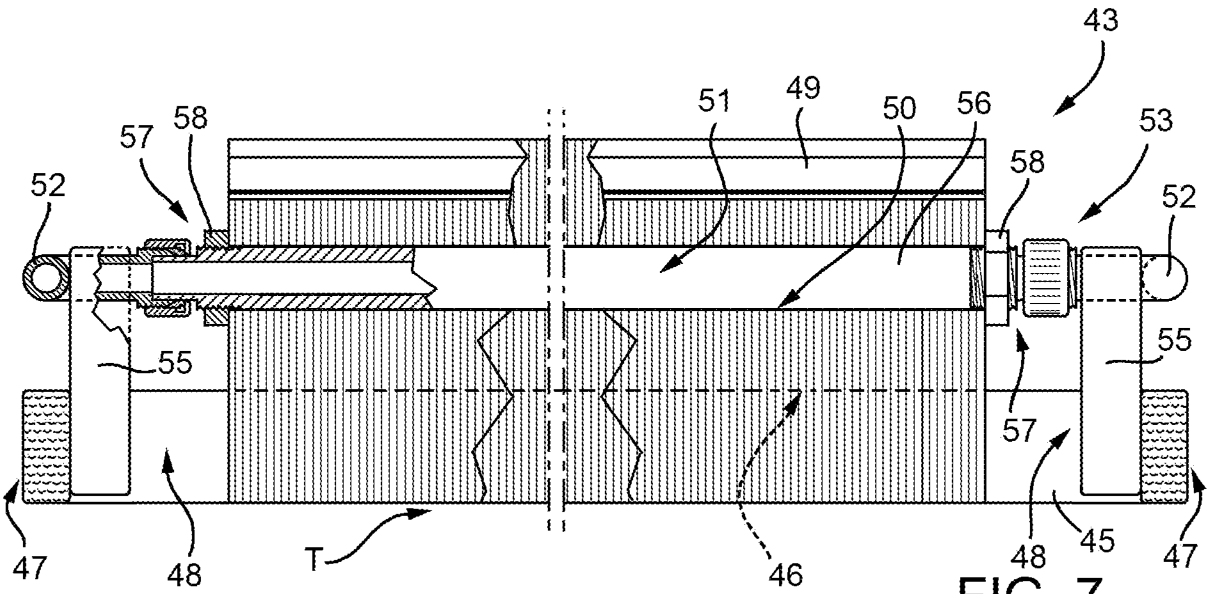
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FIG. 7