

The invention relates to an electric machine comprising:

- a) a stator part having stator poles and a current conductor winding;
- b) an armature (movable) part disposed opposite the stator part so as to leave an air gap therebetween and being in magnetic correlation with the stator part;
- c) the stator part and the armature part being movable relative to each other in a direction corresponding at least in essence to that direction in which the stator poles are arranged in succession;
- d) a stator support to which the stator poles are attached along with the winding thereof and which - as seen in a sectional view transversely to the afore-mentioned direction of arrangement of the stator poles - has a substantially U-shaped configuration including a base wall and two sidewalls and having a closing cover on its air gap side;
- e) a first flow space for cooling fluid between the stator poles and the first sidewall of the stator support as well as a second flow space for cooling

fluid between the stator poles and the second side-wall of the stator support, the two flow spaces extending along the series of the stator poles, such that the cooling fluid can flow at least across partial regions of the stator pole winding;

- f) a first flow passage for cooling fluid extending substantially in the direction of arrangement of the stator poles and provided in the base wall of the stator support or in the stator material; and
- g) interior, second flow passages for cooling fluid extending at least through some of the stator poles and being in communication with the flow spaces and the first flow passage.

An electric machine of this type, in concrete terms a rotary electric motor, is known from the document FR-A-517949, embodiment according to Figs. 8 to 10. With this electric motor, the cooling fluid flows from a lower, axially central supply opening in circumferential direction both along the two face sides of the stator and in slots of the stator material. These three circumferential flows are collected again at a diametrically opposed, upper axially central discharge opening.

It is an object of the invention to provide an electric machine comprising a fluid cooling for the stator part, which renders possible cooling in a particularly effective manner while having a constructionally favorable structure.

For meeting this object, the electric machine according to the invention is characterized in

- h) that, at least at some locations, spaces between the stator pole winding and the cover of the stator support are provided as connecting passages for cooling fluid, which communicate with the flow spaces as well as with associated, second flow passages;
- i) and that the cooling fluid flow path as a whole is designed such that the cooling fluid at first flows in the first and second flow spaces along the series of stator poles and then flows through the connecting passages and the second flow passages in the stator poles into the discharge-collecting first flow passage, or vice versa.

The document FR-A-1276717 discloses an electric machine, in concrete terms a rotary electric motor, in which the cooling fluid flows from a lower supply opening on one axial side of the motor to a diametrically opposed upper discharge opening on the other axial side of the motor and, in doing so, flows along the two face sides of the stator. The cooling fluid flows from the one face side of the stator to the other face side of the stator through axially extending connecting passages located between the stator pole winding and a stator cover. The stator poles do not have interior flow passages.

The document FR-A-517949, embodiment according to Figs. 6 and 7, reveals an electric machine, in concrete terms a rotary electric motor, having axially and radially extending, interior flow passages in the stator. The cooling fluid flows to the two face sides of the stator through an outer annular channel each, in radial direction from an outer location inwardly, and from there flows in axial direction into the interior flow passages. The cooling fluid discharged

in radially outward direction is collected in a discharge space extending in circumferential direction, to which cooling fluid flows also from the two face sides of the stator.

The document DE-C-337561 discloses an electric machine, in concrete terms a rotary generator, in which the cooling fluid flows through a lower supply opening on one axial side of the machine and is discharged through a circumferentially extending, outer discharge space having an axially central, upper discharge opening. The cooling fluid flows from one axial side of the machine to the other axial side thereof through axially extending flow paths located between the stator pole winding and the walls of the stator grooves. In the embodiment according to Fig. 1, the cooling fluid flows from the other axial side of the machine into slots between stator sections located in planes extending at right angles to the axis of the machine. Instead of this, the embodiment according to Fig. 2 provides axially extending, interior flow passages in the stator, through which cooling fluid flows parallel to the flow paths associated with the stator grooves; by way of axial transfer openings, the cooling fluid can flow from the other axial side of the machine into the discharge space.

As is known, dissipated heat is created in electric machines primarily in the winding (often expressed by the catchword-like term "copper losses") and in the ferromagnetic stator (often expressed by the catchword-like term "iron losses"). In the electric machine according to the invention, cooling fluid is passed in canalized form along the stator pole winding such that at least partial regions of the stator pole winding are cooled directly by cooling fluid flowing thereacross, whereby the heat is discharged from the

winding in particularly effective manner. Even though the cooling fluid may not flow directly across all parts of the stator winding, the cooling effect nevertheless is very effective since the winding usually consists of a material having good current-conducting and, thus, also good heat-conducting properties, so that the heat in the winding easily flows to the fluid-cooled heat discharge regions. Furthermore, since the stator winding is mounted on the ferromagnetic stator, the dissipated heat from the stator material proper can also flow via the winding material to the fluid-cooled heat discharge sites. The so-called winding heads projecting on both sides from groove-like portions between respective adjacent stator teeth are cooled directly by cooling fluid. The heat conduction paths from the interior of the groove-like portions to the winding heads are short. However, it is indeed possible as well to have sufficient free space for the passage of cooling fluid also in the groove-like portions between the coils of adjacent stator poles, so that cooling fluid flows directly across the stator winding as a whole.

The connecting passages provided between the stator pole winding and the cover of the stator support, which extend as a rule transversely of the direction of extension of the two flow spaces, may be provided either at all locations between adjacent stator poles or only at a part of these locations. The interior flow passages provided in at least some, and preferably all, stator poles provide direct interior cooling of the stator material. The interior flow passages in the respective stator poles extend from the connecting passages to the stator basis.

The term "electric machine" was chosen in order to cover primarily both electric motors and current

generators. The use of the term "stator part" and "armature or movable part" is not necessarily to be understood to the effect that the stator part is stationary and the armature part is movable relative to the stator part, although this configuration is the more usual and preferred one; an inverse configuration, i.e. stationary armature part and stator part moving relative to the armature part, is possible as well. The electric machine may be - to cite the two most important cases - either a rotary machine in which armature part and stator part move relative to each other in rotational manner, or a linear machine in which armature part and stator part move relative to each other in rectilinear manner. A fluid suitable for cooling may be a liquid or a gas, with liquid being preferred because of the greater heat discharge capacity. Suitable cooling liquids are known, for instance from the field of transformer construction.

When an extremely high cooling intensity is desired, the stator winding may be provided such that, at least at those locations of the particular coil of the particular stator poles which have cooling fluid directly flowing thereacross, free spaces exist between conductor wires for allowing the cooling fluid to flow therethrough. In the most extreme embodiment, the coils of the individual stator poles are not wound "closely adjacent against each other" - as is usual - and filled with casting compound therebetween, but rather the conductor wires - for instance by using spacer-like elements - are wound in mutually spaced manner such that the cooling fluid can flow around the separate conductor wires. It is of course possible to have intermediate configurations in which conductor wire groups are wound in closely adjacent manner and in which the free spaces mentioned are present between conductor wire groups.

The cooling according to the invention is provided preferably with electric machines having the constructional features mentioned hereinafter either separately or in combination:

Electronic commutation as it is known per se and thus need not be described herein in more detail.

Armature part having permanent magnets. Preferable in this respect are highly-coercive permanent magnets or permanent magnets of a material having a high energy product. Such permanent magnets are known per se and consist in particular of a material on the basis of one or more rare earth elements with cobalt or on the basis of iron neodymium material.

Construction of the armature or movable part in accordance with the flux concentration principle, as will be described in more detail further below and as known from the document EP-A-0331180.

The stator pole windings are each associated with one stator pole only and do not cross with coils of other stator poles. This leads to optimally small winding heads which are well suited for being cooled.

Construction of the machine in accordance with the multiple principle in which several analogous sub-units of the machine are each operable per se in independent manner. An example hereof is: A specific number of x stator pole coils is connected to a common electronic inverter means and to a common sensor for sensing the relative position of armature part and stator part for activating and deactivating or switching over of the separate coils in correct manner as regards time and sign. There are provided in total several of such sub-units so that, even in case of a failure of one of these sub-units, the machine remains operable, although with somewhat reduced power.

In most cases the direction of arrangement of the stator poles coincides exactly with the direction of relative movement of armature part and stator part. However, embodiments differing therefrom are possible as well.

The invention and developments of the invention will now be elucidated in more detail on the basis of embodiments. Only the embodiment according to Fig. 4 realizes the invention defined in claim 1. However, the embodiments according to Figs. 1/2 and Fig. 3 are useful for the understanding of the construction of the machine. In the drawings

Fig. 1 shows a machine in a sectional view transversely to the direction of arrangement of the stator poles;

Fig. 2 shows the machine of Fig. 1 in a sectional view at right angles to the sectional view of Fig. 1, i.e. in a sectional view in the direction of arrangement of the stator poles;

Fig. 3 shows a modified machine in a sectional view as in Fig. 1, with the armature part of the machine being omitted; and

Fig. 4 shows a further modified machine realizing the invention, illustrated in a sectional view as in Fig. 1, with the armature part of the machine being omitted.

The embodiment according to Figs. 1 and 2 illustrates, at the bottom, the stator part 4 and, at the top, the movable or armature part 6 of the electric machine 2. The

stator part 4 consists in essence of a stator support or carrier 8, the stator poles 10 and the coils 12 which are separately provided on each of the stator poles 10. As seen in the sectional view of Fig. 1, the stator support has a U-shaped configuration including a base wall 14, two sidewalls 16 and a cover 18 closing the open side of the "U" in fluid-tight manner. The sectional view of Fig. 2 reveals that a row of stator poles 10 is provided which are adjacent each other from the left to the right. Each individual coil 12 is, as seen in plan view (from the top in Fig. 1), of rectangular configuration with rounded corners. The individual stator poles 10 or stator teeth, on their side facing away from the cover 18, are in communication with each other via a magnetic flux path in that the material of the stator poles 10 at the bottom is passed around in U-shaped manner to the respectively adjacent stator poles 10. Each coil 12 reaches at the bottom the magnetic flux path, but at the top thereof it does not reach the cover 18.

In the armature part 6, there are trapezoidal permanent magnets 19 alternating with triangular flux conduction members 20. It is also possible that the permanent magnets 19 are triangular and the flux conduction members 20 of trapezoidal configuration. The permanent magnets 19 are magnetized, as seen in Fig. 2, from the left to the right. In the flux conduction members 20, the magnetic flux exiting from the permanent magnets 19 is deflected by 90° and passed via an air gap 22 into the upwardly directed stator pole areas 24. It is possible to see that, in plan view (from the top in Figs. 1 and 2), the magnetic flux exit areas 26 of the flux conduction members 20 are smaller than the sum of the cross-sectional areas - visible in Fig. 1 - of the two permanent magnets 19 adjoining the particular

flux conduction member 20. The result hereof is a flux concentration at the particular magnetic flux exit area 26 of the particular flux conduction member 20. Machines operating in accordance with the flux concentration principle, as exemplified hereinbefore, often have a particularly high power density and, thus, heat generation in a narrow space. The specific effective cooling according to the invention is particularly advantageous in this respect.

It can be seen from Fig. 1 that between the individual coil 12 of the particular stator pole 10 and the two sidewalls 16 of the stator support 4 there are formed a first flow space 30 on the left-hand side and a second flow space 32 on the right-hand side for cooling fluid 34. Both flow spaces 30 and 32 extend along the row of stator poles 10 and the individual coils 12 associated therewith. It is perceivable that the cooling fluid 34 flowing in these flow spaces 30 and 32 flows across all individual coils 12 in those portions which (in Fig. 1) on the left-hand side and the right-hand side extend out of the stator grooves between adjacent stator poles 10. These portions are usually referred to as winding heads. The cooling fluid 34 also flows across the upper surfaces of the winding heads facing the cover 18 as well as the lateral areas of the stator material which are free from winding.

It is possible to see, furthermore, that connecting passages 36 are formed between the individual coils 12 and the cover 18, which in Fig. 1 extend from left to right and in Fig. 2 at right angles to the drawing plane, between the first flow space 30 and the second flow space 32. By way of the connecting passages 36, the cooling fluid flows across the surfaces of the coils 12

located there and facing the cover 18 as well as across the stator pole portions 12 located there.

The cover 18 consists of a material which is magnetically and electrically not or only hardly conductive, such as for instance plastics material.

Fig. 2 is conceivable as being part of a linear motor in which the armature part 6 is movable relative to the stationary stator part 4 from right to left, in accordance with the arrow 28. However, Fig. 2 is also conceivable as illustrating a partial region of a rotary motor with external armature part, which is bent open so as to present a straight configuration. Fig. 2 would then be a cross-sectional view at right angles to the rotational axis of the motor located underneath Fig. 2; Fig. 1 would then be an axial section through the upper half of the motor.

The main difference between the afore-described embodiment according to Figs. 1 and 2 and the embodiment according to Fig. 3 consists in that the stator poles 10 each have inner flow passages 38 which extend in the direction of arrangement of the stator pole series and connect the groove-like portion on the one side of the particular stator pole 10 and the groove-like portion on the other side of the particular stator pole 10 with each other and which are adapted to have the cooling fluid 34 flowing therethrough. In the sectional view of Fig. 3, the flow passages 38 have the configuration of a very narrow, upstanding rectangle with an inside width of less than 1 mm as measured horizontally in Fig. 3. Entrance and exit of the cooling fluid 34 are effected from the connecting passages 36.

The embodiment according to Fig. 4 differs from the embodiment according to Fig. 3 in that the base wall 14 of the stator support 8 is provided on its inside with a recess 40 constituting a flow passage 40 extending in the direction of arrangement of the row of stator poles 10. This flow passage 40 communicates with the inner flow passages 38 of the respective stator poles 10. The flow passage 40 may also be located at a lower level in the base wall 14 and may be connected to the flow passages 38 via passageways.

The hydraulic design of this embodiment is such that the cooling fluid is supplied from one location to the two flow spaces 30 and 32 and flows along the flow spaces 30 and 32 across a longer or shorter distance, then flows through connecting passage sections and flow passages 38 away from the cover 18 to the foot of the particular stator pole 10 and then is collected in the flow passage 40 and is discharged from the stator support 8 at a suitable location.

It should be remarked in general that as a rule there is provided a closed cooling fluid circuit comprising a circulating pump and an external heat exchanger so that the cooling fluid 34 can be pumped properly through the flow spaces 30 and 32, optionally through connecting passages 36, optionally through flow passages 38 as well as optionally through the flow passage 40.

Furthermore, it should also be remarked in general that a feasible material for the stator poles 10 is first of all stacked ferromagnetic sheet material or the manufacture from pulverized ferromagnetic material that is bonded by means of plastics material. It is to be understood that the cover 18 closes the channel-shaped interior space of the stator support in fluid-tight manner.

The total of the individual coils 12 of the stator poles 12 is referred to as stator winding in the introductory part of the specification.

Measures of per se known nature may be provided in addition for enhancing the heat transition from the stator material and/or the stator winding to the cooling fluid, in particular for a high cooling fluid flow velocity and/or purposeful turbulence increase.



P A T E N T C L A I M S

1. An electric machine (2) comprising:
 - a) a stator part (4) having stator poles (10) and a current conductor winding (12);
 - b) an armature (movable) part (6) disposed opposite the stator part (4) so as to leave an air gap (22) therebetween and being in magnetic correlation with the stator part (4);
 - c) the stator part (4) and the armature part (6) being movable relative to each other in a direction (28) corresponding at least in essence to that direction in which the stator poles (10) are arranged in succession;
 - d) a stator support (8) to which the stator poles (10) are attached along with the winding (12) thereof and which - as seen in a sectional view transversely to the afore-mentioned direction (28) of arrangement of the stator poles - has a substantially U-shaped configuration including a base wall (14) and two sidewalls (16) and having a closing cover (18) on its air gap side;
 - e) a first flow space (30) for cooling fluid (34) between the stator poles (10) and the first side-wall (16) of the stator support (8) as well as a



second flow space (32) for cooling fluid (34) between the stator poles (10) and the second side-wall (16) of the stator support (8), the two flow spaces (30; 32) extending along the series of the stator poles (10), such that the cooling fluid (34) can flow at least across partial regions of the stator pole winding;

- f) a first flow passage (40) for cooling fluid (34) extending substantially in the direction (28) of arrangement of the stator poles and provided in the base wall (14) of the stator support (8) or in the stator material; and
- g) interior, second flow passages (38) for cooling fluid (34) extending at least through some of the stator poles (10) and being in communication with the flow spaces (30; 32) and the first flow passage (40),

characterized in

- h) that, at least at some locations, spaces between the stator pole winding (12) and the cover (18) of the stator support (8) are provided as connecting passages (36) for cooling fluid (34), which communicate with the flow spaces (30; 32) as well as with associated, second flow passages (38);
- i) and that the cooling fluid flow path as a whole is designed such that the cooling fluid (34) at first flows in the first and second flow spaces (30; 32) along the series of stator poles (10) and then flows through the connecting passages (36) and the second flow passages (38) in the stator poles (10) into the discharge-collecting first flow passage (40), or vice versa.



2. An electric machine (2) according to claim 1, characterized in that at least part of the stator poles (10) is provided with a coil (12) each which has free spaces between conductor wires for allowing the cooling fluid (34) to flow therethrough.

3. An electric machine (2) according to any one of claims 1 and 2, characterized in that it is constructed as an electronically commutated electric motor.

4. An electric machine (2) according to any one of claims 1 to 3, characterized in that the armature part (6) is designed as exciter part of the machine (2) that is equipped with permanent magnets (13).

5. An electric machine (2) according to claim 4, characterized in that highly coercive permanent magnets (19) are provided.

6. An electric machine (2) according to claim 4 or 5, characterized in that the armature part (6) is constructed in accordance with the flux concentration principle, wherein - when progressing in the direction of the series of the permanent magnets (19) - permanent magnets (19) magnetized in this direction and magnetic flux conduction members (20) alternate with each other, and the magnetic^{flux}/conduction members (20) - as seen in a projection onto the air gap area (22) - each having a magnetic flux exit area that is less than twice as large as the area of a permanent magnet (19) - as seen in a projection in the direction of the permanent magnet series.

7. An electric machine (2) according to any one of claims 1 to 6, characterized in that the stator pole



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coils (12) each are associated with one stator pole
(10) only.