

The invention relates to an electric machine comprising a permanent-magnetic excitation part and an induction part equipped with current conductors, said parts being movable relative to each other and said machine being in particular an electric machine commutated by means of electronic components.

Such electric machines, which are known, can be envisaged most easily with the aid of the comparative picture of a mechanically or electronically commutated d.c. motor with permanent-magnetic excitation, although the machine according to the invention by no means has to completely or largely correspond to this comparative picture. Conventional machines of this type have an M-n-characteristic (M meaning torque and n meaning speed of rotation) which, at least starting from a specific rotational speed range, decreases in pronounced manner as the rotational speed increases. The main cause thereof is that, as the rotational speed increases, the electromotive force (e.m.f.) induced in the machine increases and, consequently, only a lower current can still be "pressed" into the machine against this e.m.f. The fundamental correlation outlined holds also for electronically commutated machines in which the electronic commutation indeed can be controlled such that the current flowing through the machine is held approx. at the same level until a specific rotational speed range is reached;

however, above this rotational speed range the machine current then decreases rapidly.

It is the object of the invention to make available an electric machine providing controllability of the amount of torque output, which is at least to a large extent independent of the conventional dependency on the rotational speed.

The invention provides several solutions for this object.

Subject matter of a first solution (claim 1) is an electric machine comprising a movable member including a permanent-magnetic excitation part of the machine, and a stator including an induction part of the machine equipped with current conductors, in which the movable member is movable relative to the stator and, for purposefully changing the voltage induced in the induction part during operation of the machine, by adjustment of the phase position of the voltages induced in two partial regions of the induction part, a first partial region of the induction part equipped with current conductors is physically adjustable relative to a second partial region of the induction part equipped with current conductors, in the direction of relative movement of the movable member and the stator, characterized in that the machine is an electric machine commutated by means of electronic components, with a sensor for detecting the instantaneous relative position of the movable member and the stator being associated with the second, stationary partial region of the induction part.

In comparison herewith, document US-A-4 371 801 discloses an electric machine which indeed has partial

regions of the induction part that are rotatable relative to each other, but which is no electronically commutated machine provided with a sensor for detecting the rotational position of the movable member. The documents DE-A-33 17 553 and US-A-4 110 649 show electric machines in which partial regions of the permanent-magnetic excitation part are adjustable relative to each other.

Subject matter of a second solution (claim 3) is an electric machine comprising a permanent-magnetic excitation part and an induction part equipped with current conductors, said parts being movable relative to each other, characterized in that, for purposefully changing the voltage induced in the induction part during operation of the machine, by adjustment of the phase position of the voltages induced in two partial regions of the induction part, an electric phase shifter is interposed between the two partial regions of the induction part (Fig. 2).

In comparison herewith, document DE-A-34 27 103 discloses an electric machine in which the rotating excitation part is axially extended and cooperates there with a stationary additional winding associated with the machine housing. Part of the permanent-magnetic flux is branched off thereby, and the current induced in the additional winding is switched to an L.C. member. This does not result in a different phase position of two voltages induced in two partial regions of the induction part.

Subject matter of a third solution (claim 5) is an electric machine comprising a permanent-magnetic excitation part and an induction part equipped with current conductors, said parts being movable relative to

each other in a direction of relative movement, characterized in that, for purposefully changing the voltage induced in the induction part during operation of the machine, by adjustment of the magnitude of the effective permanent-magnetic flux in the machine, a pole head constituent portion of the induction part facing the excitation part is physically rotatable relative to the remainder of the induction part or - in case of linear machines - is adjustable in said direction of relative movement (Fig. 4).

In comparison therewith, document US-A-4 578 609 discloses a rotary electric machine in which iron parts in the magnetic return path on the side of the induction part facing away from the excitation part are adjustable in axial direction, but there is no adjustability of a pole head constituent portion of the induction part facing the excitation part in the direction of relative movement of induction part and excitation part.

Subject matter of a fourth solution (claim 7) is an electric machine comprising a permanent-magnetic excitation part and an induction part equipped with current conductors, said parts being movable relative to each other, characterized in that, for purposefully changing the voltage induced in the induction part during operation of the machine, by adjustment of the magnitude of the effective permanent-magnetic flux in the machine, there are provided auxiliary windings on the excitation part which are associated with the flux path between adjacent permanent magnets, for superimposing an electrically induced magnetic flux in order to reduce and/or increase the permanent-magnetic flux in the excitation part (Fig. 5).

In comparison herewith, document DE-A-34 27 103 discloses an electric machine in which the rotating excitation part is axially extended and cooperates there with a stationary additional winding associated with the machine housing. Part of the permanent-magnetic flux is branched off thereby, and the current induced in the additional winding is supplied to circuit members. The additional winding is not provided on the excitation part in the flux path between adjacent permanent magnets. - The reduction and increase of permanent-magnetic fluxes in electric machines by means of auxiliary windings is known in principle from the document DE-A-23 19 184.

Subject matter of a fifth solution (claim 8) is an electric machine comprising a permanent-magnetic excitation part and an induction part equipped with current conductors, said parts being movable relative to each other, characterized in that, for purposefully changing the voltage induced in the induction part during operation of the machine, by adjustment of the magnitude of the effective permanent-magnetic flux in the machine, there is provided a means for increasing and/or decreasing the permanent-magnetic magnetization of the permanent magnets of the excitation part, with said means comprising current conductors, electromagnets or temperature changing means for further magnetizing or, possibly partially, demagnetizing the permanent magnets of the excitation part (Fig. 6).

In comparison therewith, document JP-A-61-231 857 discloses an electric machine in which an additional winding is provided on the core of the induction part for bringing the core to magnetic saturation. The document DE-A-34 27 103 discloses an electric machine in which the rotating excitation part is axially ex-

tended and cooperates there with a stationary additional winding associated with the machine housing. Part of the permanent-magnetic flux is branched off thereby, and the current induced in the additional winding is supplied to circuit members. In case of both of these known machines, there is no change of the permanent magnetization of the permanent magnets.

In the machines according to the invention, the effect achievable in particular, if desired, is that the power $P = M \times n$ of the machine - at least from a specific range of the rotational speed - remains constant with respect to the rotational speed at least in essence. Furthermore, it is possible in particular to achieve the effect that the torque decreases greatly only at a higher speed of rotation, so that higher speeds of rotation can be utilized.

Thus, in case of said first and second solutions, the magnitude of the e.m.f. induced during operation of the machine is influenced, and in particular a reduction of the e.m.f. is adjusted at increasing rotational speed, so that a higher current can be commutated in this machine than without this measure. The third, fourth and fifth solutions have in analogous manner the effect of an adjustment of the induced e.m.f., since the magnitude of the induced e.m.f. is directly dependent on the magnetic flux flowing due to the permanent magnets; a higher permanent-magnetic flux means - provided that the rotational speed remains the same - higher e.m.f. and vice versa. The adjective "effective" was added in order to point out that those magnetic fluxes originating from the permanent magnets are of importance which are each prevailing in the region of the current conductors or coils; as regards individual locations of the magnetic circuits, for in-

stance on the permanent magnets themselves, there may be greater magnetic fluxes present.

It is pointed out that the electric machine according to the invention need not necessarily be a motor consuming electrical power and outputting mechanical power, but may also be a generator consuming mechanical power and outputting electrical power. In case of a generator, it is possible to control the mechanical power consumed by the generator at a specific rotational speed by control of the electrical power output.

Furthermore, it is pointed out that the electric machine according to the invention need not be a rotary machine, but may also be a linear machine. The more concrete possible embodiments of the invention described hereinafter can be realized both with rotary motors or generators, respectively, and in analogous manner also with linear motors or generators, respectively. Finally, it is pointed out that in the electric machine according to the invention optionally either the induction part can be associated with the stator and the excitation part can be associated with the rotor, or vice versa. A further feasible possibility is that both the induction part and the excitation part are moving, however at a relative speed. However, in most cases it will be more expedient to associate the induction part equipped with current conductors with the stator of the machine, since in that case the current supply and respectively - in case of a generator - the current removal can be effected in simpler manner. The rotor of the machine may be a so-called internal rotor which is annularly surrounded by the stator. However, the rotor may also be a so-called external rotor which is of annular configuration and surround the stator radially on the

outside thereof. Finally, it is possible that the rotor is disposed axially beside the stator, i.e. such that the so-called active area of the machine is located in a plane extending at right angles to the axis of rotation and is not of cylindrical configuration as in case of the constructional types described before.

It is apparent that the excitation part and the induction part are located opposite each other with an air gap being left free therebetween.

Preferably, highly coercive permanent magnets, for instance on the basis of rare earths with cobalt or iron, such as Sm-Co-magnets or Fe-Nd-magnets, are utilized.

Most preferred are embodiments of the electric machine according to the invention as rotary motors, preferably with external rotor and/or with electronic commutation.

In case of the first solution mentioned hereinbefore, the partial regions of the induction part are preferably arranged beside one another transversely to the direction of relative movement. In case of rotary machines, this results in a rotatability of the two partial regions relative to each other about the axis of rotation of the machine. There is an adjustable phase difference between the two parts of the total e.m.f. A sign-considering addition of the two partial e.m.f. values results at all times in a total e.m.f. which - except for non-shifted induction parts - is lower than the e.m.f. without the outlined subdivision of the induction part, since the peak values of the partial e.m.f. do not coincide in terms of time.

In case of the third solution mentioned hereinbefore, the rotation or adjustment of the pole head constituent portion of the induction part has the effect that the flux conditions for the magnetic fluxes originating from the permanent magnets are either improved or deteriorated in that an optimum flux path through magnetically conductive material is offered either to the entire or to a larger or smaller part of the magnetic flux, while considerably deteriorated or virtually interrupted flux conditions are present for the remainder of the magnetic flux. However, it is also possible to provide short circuit paths for the magnetic flux, with the result that a lower magnetic flux flows through the current conductor or coil regions. The resulting reduction in the effective permanent-magnetic flux, which has its effect in the region of the current conductors or current coils, leads to a reduction of the e.m.f. induced in the machine.

A further preferred possibility of reducing and/or increasing the effective magnetic flux in the excitation part consists in providing auxiliary windings in the excitation part by means of which the magnetic flux originating from the permanent magnets can be reduced or increased.

In case of the fifth solution mentioned hereinbefore, current conductors or electromagnets of sufficient field strength, or temperature changing means are provided which are adapted to increasingly magnetize or partially demagnetize part of the permanent magnets or all of the permanent magnets of the excitation part.

As regards the statement made hereinbefore that a first and a second partial region of the induction part are rotatable relative to each other, this is to

be understood in the sense that the machine on the whole may also have more than two partial regions, for instance two non-adjustable partial regions and a central adjustable partial region. If desired, the afore-described adjustments or flux changes, respectively, can also be effected automatically, as a function of the rotational speed of the machine, with concrete reference in this respect being made to the possibility of an automatic adjustment due to centrifugal force. However, in most cases it will be preferred to effect these adjustments or changes by purposeful control acts and not in purely automatic manner. Furthermore, it is pointed out that a number of embodiments of the invention permit an adjustment of the torque and the total e.m.f., respectively, to zero. This can be envisaged in particularly clear manner in embodiments of rotary machines in which a first and a second partial region of the induction part are rotatable relative to each other. When the second partial region is rotated with respect to the first partial region by one permanent-magnet pole center-to-center spacing, an e.m.f. is induced in a first direction in one part of the machine, and an e.m.f. of the same magnitude is induced in the opposite direction in another part of the machine, provided that the machine parts have the same size.

In part of the embodiments of the invention, in particular in those employing a relative adjustment of the first and second partial regions of the induction part, the design is most expediently chosen such that mutually associated coil pairs in the induction part are connected in series, so that the electromotive forces induced in these coils add up in sign-considering manner. Furthermore, care should expediently be taken that the moments of time of the current commu-

tation in the current conductors of the induction part are matched with the adjustment situation, since the zero passage of the total e.m.f., because of the addition, is located at a different moment of time than prior to the adjustment.

Electric motors with electronic commutation are known per se, so that further details in this respect need not be described specifically. As an example hereof, reference is made to EP-PS 94 978.

The machine according to the invention preferably is in the form of a multiple construction. This means that the machine, especially with respect to the coils of the induction part and/or with respect to the converters for the electronic commutation and/or with respect to the sensors for the electronic commutation, is of modular construction with a plurality of mutually alike large-series parts. A multiple construction can also be realized in that self-supporting partial combinations of coils, converters and sensors are operable per se, i.e. that the machine so-to-speak is composed of a plurality of self-supporting partial machines. Failure of individual partial machines then does not entail the failure of the machine as a whole.

The invention and further developments of the invention will be elucidated in more detail hereinafter by way of preferred embodiments schematically shown in the drawings in which

Fig. 1 shows a perspective view of the induction part of a rotary machine, which consists of two partial regions;

Fig. 2 shows a basic presentation of the electric phase shift between two coils of the induction part of a machine;

Fig. 3 shows a cross-sectional view of the induction part of a rotary machine, comprising two partial regions;

Fig. 4 shows a cross-sectional view of the induction part of a rotary machine, comprising a rotatable pole head ring;

Fig. 5 shows a fragmentary perspective view of the excitation part of a rotary machine, comprising an auxiliary winding for influencing the permanent-magnetic flux;

Fig. 6 shows a fragmentary perspective view of the excitation part of a rotary machine, comprising an auxiliary winding for changing the magnetization of the permanent magnets.

The substantially cylindrical induction part 2, shown in Fig. 1, of an electric machine (motor or generator) consists of two axially adjacent partial regions 4, 6. Each partial region 4, 6 comprises in circumferentially distributed manner twenty poles 8 each provided with a coil 10. The two partial regions 4, 6 are at least essentially of like structure.

Disposed concentrically around the illustrated induction part is a hollow cylindrical excitation part which is not shown in the drawing and is provided on its inner circumference with circumferentially distributed permanent

magnets of alternating polarization. The excitation part is not subdivided into two mutually rotatable partial regions. The excitation part is supported so as to be rotatable about the longitudinal central axis 12 of the induction part 2.

The, with respect to Fig. 1, rear partial region 6 of the induction part 2 is rotatable relative to the other partial region 4 in one or both directions by mechanical, hydraulic, pneumatic or electric means, as indicated by arrow 14, in an extent corresponding to the circumferential length of one pole 8. In each case those two coils 10 which are axially aligned with each other in the zero position of the partial region 6, i.e. when the partial region 6 is not rotated with respect to the stationary partial region 4, are electrically connected in series with each other.

16 designates an electronic commutation means. The commutation means 16 constantly receives, via a sensor 18 arranged on the induction part, information on the instantaneous rotational relative position of excitation part and induction part 4. Due to this information the coils 10 of the induction part 4 are each commutated or reversed in their polarity at the time appropriate for the torque generation. The commutation means 16 may switch individual ones, several ones or also all coils 10 of the machine. When the illustrated commutation means 16 does not switch all coils 10, several commutation means 16 must be provided.

When the two partial regions 4, 6 are rotated with respect to each other, corresponding to the condition shown in the drawing, the e.m.f. induced in partial region 6 is offset in time with respect to the e.m.f. induced in partial region 4. Due to the series connection of coils 10 that are axially associated with each other, a sign-considering addition

of the two partial electromotive forces takes place at all times. The peak values of the total e.m.f. are lower than the sum of the e.m.f. of the two partial regions 4, 6 in the zero condition.

When the partial region 6 is rotated by one full pole length on the circumference in one direction, no torque and no e.m.f. will be produced.

Fig. 2 illustrates the possibility of replacing the mechanical rotation of the partial regions 4, 6 by a purely electrical, adjustable phase shifting operation. Mutually axially associated coils 10 of the induction part 2 are connected to each other by an adjustable L.C. member.

The embodiment according to Fig. 3 differs from the embodiment according to Fig. 1 in that the induction part is not subdivided into two axially adjacent partial regions 4, 6 but - in circumferentially alternating manner - into stationary partial regions 4 and partial regions 6 which are shown in dotted manner and are rotatable relative to the latter about the axis 12, cf. arrow 14. The coil(s) 10 of the particular rotatable partial region 6 is(are) connected in series with the coil or coils, respectively, of an associated stationary partial region 4 which, when the partial regions 6 are not rotated, has an analogous relative position with respect to the rotary excitation part 22, not shown, which concentrically surrounds the latter. The effects of the rotation are in principle analogous with those outlined hereinbefore.

In the embodiment according to Fig. 4, the illustrated induction part 2 comprises a pole head ring 32 rotatable relative to the remainder of the induction part 2 coaxially about the axis 12. The induction part 2 illustrates iron cores 34 of the coils 10, however, the coils 10 proper have been omitted for reasons of clarity. The pole head ring 32 is composed - in circumferentially alternating manner - of iron regions 36, shown in dotted manner, and of magnetically non-conducting regions 38, for instance of fiber-reinforced plastics material. Fig. 4 illustrates the zero position in which at each pole 8, an iron region 36 is disposed radially outside on a coil core 34 in symmetrical manner. Upon rotation of the pole head ring 32 from the illustrated zero position, the flux conditions for the permanent-magnetic flux in the coil cores 34 deteriorate, said flux flowing from magnetic flux circuits from the concentrically surrounding excitation part 22, not shown, through two coil cores 34 and back to the excitation part 22. The flux conditions deteriorate particularly greatly when the face areas of the coil cores 34 are no longer covered completely by iron regions 36 or when these face portions even are still covered only by the magnetically non-conducting regions 38.

In the embodiment of Fig. 5, an auxiliary winding coil 48 is associated with the particular return path extending through the return path ring 42 between two respective circumferentially adjacent permanent magnets 30 shown in dotted manner. By means of the particular auxiliary winding coil 48, the magnetic flux in the particular magnetic circuit can be reduced or increased, depending on whether a positive or a negative electromagnetic flux is superimposed on the flux originating from the permanent magnets 30.

The embodiment according to Fig. 6 comprises current conductors 50 in the distance spaces between the circumferentially spaced permanent magnets 30 shown in dotted manner. The current conductors 50 can be acted upon impulsively with such high currents that the permanent magnets 30 are magnetized to a stronger extent or are partly demagnetized.

It is to be understood that the embodiments described can be composed in alternative manner with a stationary excitation part and a rotatable induction part. It is to be understood, furthermore, that the excitation part shown and described as being located radially outside, may in alternative manner also be arranged radially inside and surrounded by a radially outer induction part. Corresponding linear motors or generators are easily conceivable when the illustrated rotary embodiments are depicted in a developed view.

In the illustrated and described embodiments, the magnetic flux conditions were influenced in substantially uniform manner throughout the machine. However, it is possible to build variants in which such influencing is carried out only in part of the magnetic circuits.



Patent Claims

1. An electric machine comprising a movable member including a permanent-magnetic excitation part (22) of the machine, and a stator including an induction part (2) of the machine equipped with current conductors (10), in which the movable member is movable relative to the stator and, for purposefully changing the voltage induced in the induction part during operation of the machine, by adjustment of the phase position of the voltages induced in two partial regions (4, 6) of the induction part (2), a first partial region (6) of the induction part (2) equipped with current conductors (10) is physically adjustable relative to a second partial region (4) of the induction part (2) equipped with current conductors (10), in the direction of relative movement of the movable member and the stator, characterized in that the machine is an electric machine commutated by means of electronic components, with a sensor (18) for detecting the instantaneous relative position of the movable member and the stator being associated with the second, stationary partial region (4) of the induction part (2) (Fig. 1).

2. A machine according to claim 1, characterized in that the two partial regions (4, 6) of the induction part (2) are arranged beside one another transversely to the direction of relative movement of the movable member and the stator.



3. An electric machine comprising a permanent-magnetic excitation part (22) and an induction part (2) equipped with current conductors (10), said parts being movable relative to each other, characterized in that, for purposefully changing the voltage induced in the induction part (2) during operation of the machine, by adjustment of the phase position of the voltages induced in two partial regions (4, 6) of the induction part (2), an electric phase shifter is interposed between the two partial regions (4, 6) of the induction part (2) (Fig. 2).

4. A machine according to claim 3, characterized in that mutually axially associated coils (10) of the one partial region (4) and of the other partial region (6) of the induction part (2) are connected in series with each other via an adjustable L.C. member.

5. An electric machine comprising a permanent-magnetic excitation part (22) and an induction part (2) equipped with current conductors (10), said parts being movable relative to each other in a direction of relative movement, characterized in that, for purposefully changing the voltage induced in the induction part (2) during operation of the machine, by adjustment of the magnitude of the effective permanent-magnetic flux in the machine, a pole head constituent portion (32) of the induction part (2) facing the excitation part (22) is physically rotatable relative to the remainder of the induction part or - in case of linear machines - is adjustable in said direction of relative movement (Fig. 4).



6. An electric machine according to claim 5, characterized in that the pole head constituent portion (32) of the induction part (2) is rotatable or adjustable, respectively, to such an extent that the face areas of the remainder of the induction part are covered by magnetically non-conducting regions (38).

7. An electric machine comprising a permanent-magnetic excitation part (22) and an induction part (2) equipped with current conductors (10), said parts being movable relative to each other, characterized in that, for purposefully changing the voltage induced in the induction part (2) during operation of the machine, by adjustment of the magnitude of the effective permanent-magnetic flux in the machine, there are provided auxiliary windings (48) on the excitation part (22) which are associated with the flux path between adjacent permanent magnets (30), for superimposing an electrically induced magnetic flux in order to reduce and/or increase the permanent-magnetic flux in the excitation part (22) (Fig. 5).

8. An electric machine comprising a permanent-magnetic excitation part (22) and an induction part (2) equipped with current conductors (10), said parts being movable relative to each other, characterized in that, for purposefully changing the voltage induced in the induction part (2) during operation of the machine, by adjustment of the magnitude of the effective permanent-magnetic flux in the machine, there is provided a means for increasing and/or decreasing the permanent-magnetic magnetization of the permanent magnets (30) of the excitation part (2), with said means comprising current conductors (50), electromagnets or temperature changing means for further magnetizing or, possibly partially, demagne-



- 20 -

tizing the permanent magnets (30) of the excitation part (22) (Fig. 6).

9. A machine according to any one of claims 3 to 8, characterized in that it is an electric machine commutated by means of electronic components.

10. A machine according to any one of claims 1 to 9, characterized in that the excitation part (22) is composed with highly coercive permanent magnets (30).

11. A machine according to any one of claims 1 to 10, characterized in that the excitation part (22) and the induction part (2) are located opposite each other with a cylindrical air gap being left free therebetween.

12. A machine according to any one of claims 1 to 11, characterized in that it is an electric motor.