

The invention relates to a brushless three-phase direct current motor with a permanent magnet arrangement and a three-phase winding, which are movable relative to one another, as well as with three position sensors fixed with respect to the winding and controlled by the permanent magnet arrangement for supplying sensor output signals, which are in each case at a first potential for 180° el and at a second potential during the following 180° el, the winding coils being energized with current as a function of the sensor output signals reciprocately displaced by 120° el in a cyclic sequence and in which as a result of the reciprocal movement of the permanent magnet arrangement and the winding coil voltages displaced by 120° el are induced in the individual winding coils and, accompanied by zero passages, are alternatively positive in a range of max. 180° el and negative in a range of max. 180° el and whose sum in each relative position between the magnet arrangement and the coil is equal to zero.

Direct current motors of this type are known in the form of rotary motors from DE-A-3 122 049 and in the form of linear motors from DE-A-3 123 441.

In the known motors the permanent magnet poles are formed by a permanent magnet ring with an approximately trapezoidal radial magnetization or a sequence of uniformly distributed, radially magnetized magnet segments and the poles of the slotted flux guidance part are cross-sectionally substantially T-shaped. The coils are free from overlap and are applied around in each case one pole of a slotted flux guidance part. The ratio of the coil pitch to the magnet pitch is 2:3. The slot openings between the pole shoes of the slotted flux guidance part are between 3° and 30° el wide, whilst the magnet pole width is between at least approximately 120° el and max. 180° el. Stepped voltages are induced in the individual winding coils, which are positive over approximately 120° el, approximately zero over approximately 60° el and negative over approximately 120° el. In the known motors the position sensors are oriented in such a way with respect to the winding coils, that their switchover point occurs substantially in the centre of the flank of the induced voltage on passing from the 60° zero voltage

range to the positive range. For this purpose the position sensors were either oriented towards the centre of the slot openings between the pole shoes of the slotted flux guidance part or to the axis of symmetry of the poles of the flux guidance part. Between the outputs of the position sensors and a final stage supplying current to the winding was connected a decoder, which ensured that two of the winding coils were in each case energized, whilst simultaneously voltage was induced in the particular coils in accordance with the 120° el ranges.

The known solution leads to high efficiency linked with simple winding construction. However, it is disadvantageous that in the commutating range the torque briefly drops to approximately 75% or less of the peak torque. Commutation errors, which are particularly significant in the case of small motors, can in practice lead to torque drops to 50 to 60% of the peak value, which is extremely undesirable in many applications.

In addition, a brushless d.c. motor is known (EP-A-40 484), whose stator carries in two slots two coils alternatively supplied with current for 180° by means of a commutator circuit and whose permanent magnetic rotor is equipped with two exciting magnets, which in each case have a peripheral extension of 150° . Commutation is controlled by means of the exciting magnets. In order to switchover the current supply to the two coils after in each case 180° , in addition to a Hall switch oriented towards the centre of one slot opening, a second Hall switch is positioned 30° upstream thereof, the two Hall switches being coupled together in such a way that at the common output of the Hall switch pair used for switching on and off the coil currents a logic signal level "1" only occurs if both Hall switches are at their positive voltage level, whereas at said output the logic signal level "0" appears if either one or both Hall switches are at their zero voltage level. Therefore the signal level at the output of the Hall switch pair changes after in each case 180° , although the exciting magnets controlling the Hall switches are only 150° wide.

In addition, a brushless synchronous drive is known (DE-A-3 151 257), whose speed is controllable by a drive frequency with the aid of a control switch, which has three winding coils in a Y-connection and in which current or control pulses are supplied to the winding coils whose size and direction results from a comparison of the rotor angular position determined by the sensors and a signal derived from the drive frequency.

The problem of the invention is to so further develop a motor of the aforementioned type, that it supplies a torque with a considerably improved constancy.

It has surprisingly been found that, according to the invention, this problem can be solved in that the position sensors are so arranged with respect to the winding coils that the changes in the sensor switching states substantially coincide with the zero passages of the associated induced coil voltages and that the winding coils are supplied by means of winding driver stages with driver voltages directly corresponding to the sensor output signals or derived from the sensor output signals.

The torque fluctuations are theoretically equal to zero in this motor construction. In practice, even with the small motors which are critical in this respect the torque fluctuation can be readily reduced to a value of approximately ± 5 to 7% of the maximum torque.

The winding coils can be Y-connected. In this case the winding driver stages can be directly coupled to the position sensors. The circuitry expenditure is particularly low, because there is no decoding between the outputs of the position sensors and the final stage provided for supplying current to the winding. As a result of the fact that the switching of the winding coils takes place in a range in which the particular coil substantially produces no torque, commutation noise is reduced.

However, the winding coils can also be delta-connected. A decoder is then connected between the position sensors and the winding driver stages and ensures that the driver voltages during in each case two successive 180° el half-periods or cycles of the sensor output signals are positive for 120° el and negative for 120° el and during the remaining 60° el ranges between successive 120° el ranges the winding connection terminal is disconnected, i.e. is potential-free.

The d.c. motor according to the invention can have a substantially cylindrical air gap and the permanent magnet arrangement can be part of an external rotor. However, the motor can also be designed as a linear motor with a substantially planar air gap. A particularly simple construction is obtained with a four-pole rotor.

According to a preferred construction according to the invention the individual winding coils are placed in overlap-free manner around in each case one pole of a slotted flux guidance part forming an air gap with the permanent magnet arrangement and each coil axis is perpendicular to the movement direction or to the tangent thereto, the ratio of the coil pitch to the magnet pitch being 2:3 and the individual induced coil voltages are three-stage, stepped voltages, which are in each case positive over approximately 120° el, equal to or almost equal to zero over approximately 60° el and negative over approximately 120° el, the position sensors being arranged in such a way that they modify their switching state substantially in the centre of the 60° el zero voltage range of the associated induced voltage.

The d.c. motor according to the invention is suitable for use wherever it is a question of a constant motor torque. A preferred use is for the driving of signal processing equipment, particularly disk memories. In a hard disk memory with a hub for receiving at least one e.g. magnetic hard storage disk the d.c. motor according to the invention is advantageously at least substantially housed within the hub. This leads to a particularly compact construction. It is made possible through the high torque constancy, because the motor can be designed

for a lower nominal torque than in the case of motors subject to considerable torque fluctuations.

As a result of its excellent torque constancy the aforementioned d.c. motor is also particularly suitable as a direct driving capstan and/or reel motors for magnetic tape units.

The invention is described in greater detail hereinafter relative to preferred embodiments and the attached drawings, wherein show:

Fig. 1 a section through a d.c. motor according to the invention along line I-I in fig. 2.

Fig. 2 a diagrammatic section along line II-II of fig. 1 when using the motor for driving a magnetic hard disk memory.

Fig. 3 a circuit diagram of a drive equipped with a motor according to figs. 1 and 2, in which the motor winding coils are Y-connected.

Fig. 4 a sequence of signals or voltages as occur in a motor according to figs. 1 to 3.

Fig. 5 a circuit diagram of a drive equipped with a motor according to figs. 1 and 2, in which the winding coils are delta-connected.

Fig. 6 a signal chart similar to fig. 4 for the motor according to figs. 1, 2 and 5.

In figs. 1 and 2 reference numeral 10 designates the stator plates of a three-phase, brushless direct current external rotor-type motor. The stator plates 10 are positioned radially symmetrically with respect to the centre axis 10A and has an annular central portion 10B. It forms six stator poles 11A to 11F, which are cross-sectionally substantially T-shaped and arranged with a reciprocal angular spacing of

60°. A sintered iron core can e.g. be provided in place of the stator plates. The pole shoes 12A to 12F of the stator poles determine together with a permanent magnet ring 13 a substantially cylindrical air gap 14. The permanent magnet ring is radially magnetized circumferentially in four-pole manner, i.e. it has four portions 13A to 13D and on the inside of the permanent magnet ring 13 facing the air gap 14 are provided in alternating order two magnetic north poles and two magnetic south poles 15,16 respectively. In the represented embodiment the poles 15,16 have a width of substantially 180° el (corresponding to 90° physical). Thus, in the circumferential direction of the air gap 14 an approximately rectangular or trapezoidal magnetization is obtained. The permanent magnet ring 13 is provided in an external rotor bell 17 forming the magnetic yoke, e.g. is bonded into said bell. The external rotor bell 17 forming the rotor casing has an end wall 17A and a cylindrical circumferential wall 17B. The permanent magnet ring 13 can in particular be a rubber magnet or a plastic-bound magnet. In place of a one-piece permanent magnet ring 13 it is also possible to bond in the bell 17 shell-shaped magnet segments or fix same in some other way. Particularly appropriate materials for the magnet ring or the magnet segments are a magnetic material in a synthetic binder, a mixture of hard ferrite and elastomeric material, ceramic magnetic material or samarium cobalt. Whereas in the represented embodiment each of the poles 15,16 extends over 180° el, it is also possible to work with narrower poles. In the interest of a high motor power the rotor pole width should be at least 120° el.

The stator poles 11A to 11F together define six stator slots 20A to 20F. A three-phase stator winding is placed in said slots. Each of the three phases comprises two 120° el-chorded coils 21,22; 23,24; and 25,26, whereof each is wound about one of the stator poles 11A to 11F. The two series-connected coils of each phase are diametrically facing one another. The coils are preferably wound in bifilar manner. As can be gathered from the diagrammatic representation of fig. 1, overlap is avoided between the coils 21 to 26. This leads to particularly short winding heads 27 (fig. 2). The slot openings 28A to 28F

can be between 3 and 30° el wide. In the represented construction of the stator windings the slots 20A to 20F can be ideally filled. There is generally no need for closures for the slot openings 28A to 28F.

The present motor construction makes it possible to obtain a relatively large internal opening 29 for the stator, because the depth of the stator slots 20A to 20F can be kept comparatively small. It is readily possible to obtain ratios between the diameter I of the internal opening 29 and the stator external diameter E in the vicinity of the pole shoes 12 of at least 0.35. Preferably the I/E value is in the range 0.4 to 0.7. The L/D ratio between the axial length L of the stator iron and the maximum diameter D of the air gap 14 is preferably equal to or smaller than 1. These dimensional conditions are particularly important with respect to a stable mounting of the rotor. Such a mounting is e.g. very important in the case of drives for disk memory systems. The total resistance of the stator winding is also kept particularly small.

For mounting the motor according to fig. 2 in the centre of the external rotor bell 17 is fixed a stub shaft 32. The latter is supported in a cylindrical sleeve 34 by means of axially spaced ball bearings 33, said sleeve carrying the stator plates 10 and is fixed to an assembly flange 35.

Onto the external rotor bell 17 is engaged an e.g. light metal hard disk memory hub 37. The hub 37 serves to receive one or more hard storage disks. In known manner it is stored in a very clean area of the memory. The assembly flange 35 carries a printed circuit board 38, which can carry the commutation electronics and optionally further circuit components, e.g. for a speed control. On the printed circuit board 38 are in particular located three position sensors 42, 43, 44, which in the represented embodiment are magnetic field sensors, e.g. Hall generators, field plates, magnetic diodes, etc. With particular advantage use is made of bistable-switching Hall-IC's. The use of

180° el wide rotor poles 15,16 makes it possible to use the main magnets, i.e. the permanent magnet ring 13 as control magnets for the position sensors 42,43,44, as indicated in the left-hand half of fig. 2. If desired, it is also possible to have a separate control magnet 45 for the position sensors, as shown in the right-hand half of fig. 2. In the embodiment according to fig. 2 the position sensors 42,43,44 axially face the controlling magnets 13 or 45. However, it is e.g. also possible to so arrange the position sensors in the manner shown in broken lines in fig. 2 that they radially face the controlling magnets, in this case the permanent magnet ring 13. In each case it is important to so position the position sensors 42,43,44 in the circumferential direction with respect to the coils 21,26 that changes to the sensor switching states coincide substantially with the zero passages of the associated induced coil voltages. In the embodiment of fig. 1 this is achieved in that the position sensors are displaced with respect to the centre of the slot openings 28A,28B and 28C by 15° mech.

According to fig. 3 the three winding phases 21,22; 23,24; and 25,26 are Y-connected. The outputs of the position sensors 42,43,44 are directly connected to the inputs of in each case one driver amplifier 46,47 or 48 of a final stage 49. The outputs of the driver amplifiers 46,47,48 are in turn connected to the ends of the coil pairs 21,22; 23,24; and 25,26 remote from the neutral point 50. The supply voltage is applied to the terminals VS or GND. An unblocking signal is supplied to the final stage 49 across a connection EN.

The position sensors 42,43,44 supply three sensor output signals in each case mode shifted by 180° el and which are reciprocally displaced by 120° el and which are designated S1,S2 and S3 in fig. 4. These signals are merely amplified by the driver amplifiers 46,47,48 of the final stage 49. The correspondingly amplified final stage voltages (with respect to the reference potential GND) are designated UE1, UE2 and UE3 in fig. 4. The permanent magnet ring 13 in each case induces a three-stage stepped voltage in the coil pairs 21,22; 23,24; and 25,26.

These voltages measured with respect to the neutral point 50 are designated U_{i1} , U_{i2} and U_{i3} in fig. 4. As illustrated, the induced voltages U_{i1} , U_{i2} , U_{i3} are positive over roughly 120° el and negative over roughly 120° el. Between these there is an approximately 60° el wide range within which the induced voltage has a significantly reduced value and in whose centre the induced voltage passes through zero. This 60° el wide range is referred to as the zero voltage range for short.

As can be gathered from fig. 4, the changes in the switching states of the position sensors 42,43,44, i.e. the jumps of the signals S_1, S_2, S_3 coincide with the zero passages of the associated induced coil voltages U_{i1} , U_{i2} and U_{i3} . Fig. 4 also shows that the induced coil voltages U_{i1} , U_{i2} and U_{i3} fulfil the condition that their sum in each relative position between the permanent magnet ring 13 and the winding formed by the coils 21 to 26 is equal to zero. However, the invention is not restricted to the illustrated form of the induced step voltages. For example, the induced voltages could also be sinusoidal.

In the modified embodiment according to figs. 5 and 6 the winding coils 21,22; 23,24; 25,26 are delta-connected. Between the outputs of the position sensors 42,43,44 and the inputs of the final stage 49 there is a decoder 51, which in per se known manner comprises AND circuits 52,53,54 and 55, NAND circuits 56,57 and inverters 58,59,60. From the sensor output signals applied to its three inputs 60,61,62 the decoder 51 derives six input signals for the final stage 64, which has three driver stages 65,66,67, which are in each case built up in the form of half-bridges with two output-side, series-connected semiconductor stages, e.g. final stage transistors or thyristors. The delta-connected winding coils 21,22; 23,24; 25,26 are connected to the winding terminals 68,69,70 of the final stage 64. The decoder 51 is designed in such a way that at the winding terminals 68,69,70, based on the potential GND, final stage voltages U_{E1} , U_{E2} and U_{E3} occur in the form illustrated in fig. 6. As shown in fig. 6 the final stage or driver voltages U_{E1} , U_{E2} and U_{E3} are once again reciprocally displaced by 120° el. During in each case two successive 180° el half-

periods of the sensor output signals S1, S2 and S3, the voltages are positive for 120° el and negative for 120° el. The 120° el ranges of the voltages UE1, UE2 and UE3 are in each case separated from one another by 60° el ranges, during which the winding terminal 68, 69, 70 is disconnected. Once again three-stage, stepped voltages are induced in the coil pairs 21, 22; 23, 24; 25, 26, which have the form illustrated at U11, U12 and U13 in fig. 6. The conditions are therefore the same as in the previously described embodiment.

It is pointed out that in figs. 4 and 6 the relative time positions of the different signals are represented true to scale.

According to fig. 2 the motor is housed in space-saving manner in the disk store hub 37. Due to the high constancy of the torque supplied by the motor the peak torque need only be sufficient to overcome the high frictional forces occurring on starting up the disk memory. However, as opposed to this, in the case of motors with pronounced torque drops, the minimum torque e.g. only representing 60% of this peak torque has to fulfil this condition. Therefore the peak torque must be chosen correspondingly higher. The presently achieved minimum torque fluctuations permit a particularly favourable dimensioning of the motor both during starting and at the nominal or rated speed.

The illustrated principle can be used not only in the case of rotary drives, but also in the case of linear drives. The linear motor can e.g. be constructed in the manner described in DE-OS 31 23 441.

CLAIMS

1. Brushless three-phase direct current motor with a permanent magnet arrangement (13) and a three-phase winding (21,22,23,24,25,26), which are movable relative to one another, as well as with three position sensors (42,43,44) fixed with respect to the winding and controlled by the permanent magnet arrangement for supplying sensor output signals (S1,S2,S3), which are in each case at a first potential for 180° el and at a second potential during the following 180° el, the winding coils being energized with current as a function of the sensor output signals reciprocately displaced by 120° el in a cyclic sequence and in which as a result of the reciprocal movement of the permanent magnet arrangement and the winding coil voltages (Ui1,Ui2,Ui3) displaced by 120° el are induced in the individual winding coils (21,22,23,24,25,26) and, accompanied by zero passages, are alternatively positive in a range of max. 180° el and negative in a range of max. 180° el and whose sum in each relative position between the magnet arrangement and the coil is equal to zero, characterized in that the position sensors (42,43,44) are so arranged with respect to the winding coils (21,22,23,24,25,26) that the changes in the sensor switching states substantially coincide with the zero passages of the associated induced coil voltages (Ui1,Ui2,Ui3) and that the winding coils are supplied by means of winding driver stages (46,47,48; 65,66,67) with driver voltages (UE1,UE2,UE3) directly corresponding to the sensor output signals (S1,S2,S3) or derived from the sensor output signals.
2. Direct current motor according to claim 1, characterized in that the winding coils are Y-connected and the winding driver stages are directly coupled to the position sensors.
3. Direct current motor according to claim 1, characterized in that the winding coils are delta-connected and a decoder is connected between the position sensors and the winding driver stages, so that the driver voltages are in each case positive for 120° el



and negative for 120° el during two successive 180° el half-periods of the sensor output signals and during the two 60° el ranges between the successive 120° el ranges the winding terminal is disconnected.

4. Direct current motor according to one of the preceding claims, characterized in that the motor has a substantially cylindrical air gap and the permanent magnet arrangement is part of an external rotor.
5. Direct current motor according to one of the claims 1 to 3, characterized in that the motor is designed as a linear motor with a substantially planar air gap.
6. Direct current motor according to claim 4, characterized in that the rotor is constructed in four-pole manner.
7. Direct current motor according to any one of the preceding claims, characterized in that the individual winding coils are placed in overlap-free manner around in each case one pole of a slotted flux guidance part forming an air gap with the permanent magnet arrangement and each coil axis is perpendicular to the movement direction or to the tangent thereto, the ratio of the coil pitch to the magnet pitch being 2:3 and the individual induced coil voltages are three-stage, stepped voltages, which are in each case positive over approximately 120° el, equal to or almost equal to zero over approximately 60° el and negative over approximately 120° el, the position sensors being arranged in such a way that they modify their switching state substantially in the centre of the 60° el zero voltage range of the associated induced voltage.
8. Use of the direct current motor according to one of the claims 4, 6 and 7 for driving signal-processing equipment, particularly disk memories.



9. Use according to claim 8 in a hard disk memory with a hub for receiving at least one hard storage plate, the d.c. motor at least substantially being housed within the hub.
10. Use of the direct current motor according to one of the claims 4,6 and 7 in a magnetic tape unit as a directly driving capstan and/or reel motor.

