

DESCRIPTION

The invention relates to a brushless direct current motor according to the preamble of claim 1.

Such a motor is known from fig. 7 of US-A-4 374 347, where both semiconductor control means have a switching delay. In that case the two semiconductor control means are complimentary Darlington transistors, which are in each case provided with a Miller capacitor (between the collector and the base), in order to avoid HF oscillations. Such a Miller capacitor brings about generally undesired delays both on switching the transistor on and off. It has been found that the switching off delay can be greater than the switching on delay. If there is a certain inductive coupling between the two capacitors of a pair of capacitors, which is almost necessarily the case with an electric motor as a result of the magnetic circuit, then the delayed switching off of one transistor and a rapid switching on of the other leads to a marked rise in the current in the winding conductor which has just been switched off and prior to the final switching off of said current. However, such current peaks or spikes lead to high frequency interference, undesired motor noise and bring about increased loading of the semiconductor control means which is being switched off.

DE-A-3 247 359 discloses a circuit for a brushless direct current motor enabling a switching interval to be produced between two successive stator current pulses, as is required in particular in full bridge circuits. For this purpose the bases of two power transistors of the same conductivity type are coupled by a capacitor. During commutation this capacitor initially brings about a blocking of the power transistor to be switched on. Only if the capacitor is recharged across a relatively high value resistor, can said power transistor switch on. However, such a circuit presupposes the presence of control signals in phase opposition and is consequently relatively complicated and is only used in practice for the control of full bridge circuits.

It is therefore a problem of the invention, in the case of the aforementioned brushless direct current motor, to improve the commutation

process using simple means.

In the case of a brushless direct current motor of the aforementioned type, this problem is solved by the measures given in the characterizing part of claim 1. As a result of the alternating current coupling of the control outputs of said network, the potential changes at its two outputs have substantially the same configuration, i.e. it is not possible for one potential to rise or fall much faster than the other. Thus, there is a forced synchronization of the switching processes at the two semiconductor control means and it is possible to avoid undesired current spikes in the winding conductors shortly prior to their switching off. It is also possible with such an arrangement and in the case of a suitable design for the inductive energy stored in the conductor being switched off to be safely converted into heat in the respective semiconductor control means, so that there is no need for a separate storage capacitor in the motor. Such storage capacitors, such as are e.g. described in the aforementioned US-A-4 374 347, must have relatively high capacitance values and must therefore be constructed as electrolytic capacitors, which only have a limited life. In the case of simple, inexpensive types, this can be shorter than the expected mechanical life of the motor in which said capacitors are located. In addition, such capacitors require a relatively large amount of space in the motor. However, in the case of the inventive alternating current coupling of the control electrodes of both semiconductor control means only a small capacitor is required, which can be constructed as a ceramic capacitor and which therefore has a very long life, which is regularly in excess of the mechanical life of the motor, so that as a result of the invention the motor life is increased to the value predetermined by its mechanical life. In addition, the circuit for an inventive motor can be made extremely small, because it only has a few components, which are in any case largely in the form of resistors, which makes it possible to construct extremely compact motors. Such a circuit can e.g. be in the form of a printed circuit on a circular ring disk with an external diameter of 43 mm and an internal diameter of 22 mm. When mounted said ring has a maximum thickness of 4 mm and over it only project by a few millimetres the Hall IC and possibly a PTC resistor.

This is particularly important for small fans, whose construction with integrated electronics is made possible through the present invention.

Further details and advantageous further developments of the invention can be gathered from the hereinafter described, non-limitative embodiment, the subclaims and the attached drawings, wherein show:

- Figs. 1a and 1b Schematically depict a two-pole, two-conductor brushless direct current motor of known construction, such as can be used in the case of the invention.
- Fig. 2 Depicts the construction of a prior art circuit for controlling the commutation of the motor of fig. 1.
- Fig. 3 Presents explanatory diagrams for explaining the manner of operation of the motor of fig. 2.
- Fig. 4 Depicts the construction of the inventive circuit for controlling the commutation of a two-conductor motor, e.g. the motor of fig. 1.
- Fig. 5 Presents explanatory diagrams for explaining the manner of operation of the circuit of fig. 4.

Fig. 1 depicts an external rotor motor 10 of known construction with an external two-pole rotor 11, designed as a continuous magnet ring, whose magnetization is designed nearly trapezoidal, namely with a practically constant induction in the region of the poles, and with narrow pole gaps.

In fig. 1 the locations with practically constant induction for the north pole are symbolically indicated by hatching, and for the south pole with grey shading. The rotor 11 is designed as a radially magnetized permanent magnet member, e.g. made of barium ferrite or a "rubber magnet". The two pole gaps are likewise symbolically indicated and denoted with 12 and 13. Fig. 1 shows the rotor 11 in one of its two stable rest positions, which it can assume in the currentless state of the motor. These rest

positions are determined by the shape of the air gap and the shape of the magnetization. In operation the rotor 11 turns in the direction of the arrow 14. A fan blade is denoted by 9 and is directly secured on the rotor 11.

The stator 15 of the motor 10 is configured as a double T-anchor with an upper pole 16 and a lower pole 17, both of which have approximately the outline of an umbrella, i.e. each one extending circumferentially for almost the whole of the pole arc, and including between themselves two slots 18 and 19 in which are arranged the two conductors 20 and 21 of a two-conductor, one-phase stator winding. The terminals of the conductor 20 are denoted by a1 and e1, those of the conductor 21 by a2 and e2. The conductors 20 and 21 have equal numbers of turns and the same winding sense, i.e. when a direct current flows from a1 to e1 there results identically the same magnetization of the stator 15 as when the same direct current flows from a2 to e2. In this case there results the dot representation according to fig. 1b, i.e. the wound conductor 20 has the dot at terminal a1, the wound conductor 21 at the terminal a2. This representation is employed in the same way in the subsequent figures. The conductors 20 and 21 can in preferred manner, in accordance with the teaching of DE-A-22 39 167, be wound bifilar, in order to obtain a close inductive coupling between them.

Rotor position dependent sensing means, here a Hall IC 25, are arranged on the stator 15 at an angular position substantially corresponding to the opening of the slot 18 or being some degrees offset relative to this opening opposite the rotation direction 14, namely counterclockwise. The Hall IC 25 is here controlled by the magnetic field of the permanent magnet rotor 11 and, in dependence upon rotor position, generates a signal which is either high or low, i.e. constituting upon rotation of the rotor 11 practically a rectangular signal whose high and low intervals are each about 180°el long.

The air gap 26 above the stator pole 16 and the air gap 27 above the stator pole 17 are designed in a special way. Beginning from the slot 18 the air gap 26 monotonically increases, measured in the rotation direction

14, for about 10 to 15 degrees up to a first location 30 at which it reaches its maximum. From there on, the air gap 26 monotonically decreases for about 170 degrees electrical until about the opening of the slot 19 where as illustrated it reaches its minimum value d1. As illustrated the air gap 27 has an identical variation. This air gap shape, in cooperation with the described type of magnetization of the rotor 11, effects during operation the development of a reluctance torque of predetermined shape, such as described in detail in DE-B-2 346 380, to which reference is made for the sake of brevity. Naturally, instead of a motor of the type depicted in fig. 1, also a flat motor with ironless stator can be employed e.g. in accordance with DE-A-2 239 167, or e.g. an internal rotor motor, or a motor which a higher number of poles such as shown e.g. by DE-A-28 35 210 in figs. 2 or 9. Thus the invention is in no way limited to the embodiment of fig. 1 and the latter instead serves only to make the invention understandable with reference to a concrete example.

Fig. 2 depicts a circuit for the motor of fig. 1, such as known from e.g. fig. 7 of the already mentioned US-A-4 374 347. A plus line 33 is connected via a diode 47 to a positive operating voltage U_B , e.g. of a battery, and a minus line 35 can be connected to e.g. the minus pole of this battery (e.g. 12, 24 or 48 V). The Hall IC 25 is connected with one terminal to the minus line 35 and with its other terminal is connected via a resistor 48 to the plus line 33. Connected parallel to it is a zener diode 49 which regulates the voltage on the Hall IC 25 to e.g. 5 V. The output 50 of the Hall IC 25 is connected to a resistor network 53 with three resistors 54, 55, 56. The resistor 54 leads from the output 50 to the base of a pnp Darlington transistor 57; the resistor 55 from the output 50 to the plus line 33; and the resistor 56 leads from the output 50 to the base of an npn transistor 58 which is of conductivity type complementary to the transistor 57. The emitter of the transistor 57 is connected with the plus line 33, its collector with the terminal al of the wound conductor 20, and antiparallel to it is connected a diode 57'. The terminal el of the wound conductor 20 is connected to the minus line 35.

The emitter of the transistor 58 is connected to the minus line 35; its

collector is connected to the terminal a2 of the wound conductor 21, whose other terminal e2 is connected to the plus line 33. A diode 58' is connected antiparallel to the transistor 58. A storage capacitor 45 is connected between the lines 33 and 35. The wound conductors 20 and 21 are, by virtue of bifilar winding, closely coupled. With regard to the terminals a1, e1 and a2, e2, reference is made to the representation according to figs. 1a and 1b. The transistor 57 is provided with a Miller capacitor 59 connected between its collector and base. Likewise the transistor 58 is provided with a Miller capacitor 60 connected between its collector and base. These Miller capacitors, which e.g. have a capacitance value of 150 pF, effect a negative feedback coupling from the collector to the base and slow the switching on and switching off of the transistors 57 and 58, in this way reducing inductive switching spikes, and reducing high frequency oscillations.

If during operation of the motor e.g. the transistor 57 switches on, a current flows from a1 to e1, and the stator pole 16 becomes a south pole, the stator pole 17 in contrast a north pole. In contrast, if the transistor 58 switches on, a current flows from e2 to a2, i.e. the stator pole 16 becomes a north pole and the stator pole 17 a south pole. In the position shown in fig. 1, in which the Hall IC 25 faces a north pole of the rotor 11, the transistor 57 and, together with it, the wound conductor 20 are accordingly switched on, and in the opposite case (south pole of the rotor 11 at the Hall IC 25) the wound conductor 21, in order that the rotation direction 14 be established. When a north pole faces the Hall IC 25, its output 50 becomes low, thus having approximately the potential of the minus line 35, and therefore the transistor 58 blocks and the transistor 57 becomes conductive. If on the other hand a south pole faces the Hall IC 25, then the output 50 becomes high, namely positive, the transistor 58 becomes conductive and the transistor 57 blocks. Thus one can, with the one output signal at the output 50, activate the two transistors 57 and 58 in phase-opposed manner via the network 53 made up of passive elements.

As noted the Miller capacitors 59 and 60 reduce the speed of the switching operations. However in practice it has been shown that this reduction

is less strongly effective for the switching on operation than for the switching off operation and that, as a result of this, problems can develop in a surprising manner.

In this connection reference is made to fig. 3. The latter shows at A) the Hall voltage u_{Hall} at the terminal 50. If the motor of fig. 2 is operated with e.g. 12 V, then this Hall voltage jumps between approximately 12 V and 0 V, depending upon the position of the rotor 11. For example at the points in time t_1 and t_3 it jumps from 12 V to 0 V, and at the point in time t_2 from 0 V to 12 V. The points in time t_0 , t_1 , t_2 , t_3 each have equal intervals of 180° el, with reference to the rotation of the rotor 11.

Fig. 3B depicts the base emitter voltages u_{BE} of the transistors 57 and 58. As can be recognized, between the points in time t_0 and t_1 the transistor 58 is conductive, inasmuch as its base emitter voltage amounts to 1.4 V, because the Hall voltage u_{Hall} has a high value. Simultaneously, the transistor 57 is non-conductive. At the point in time t_1 u_{Hall} jumps to zero, and the voltage u_{BE58} goes to zero with a delay effected by the Miller capacitor 60. When this voltage has reached 10% of its previous value, the point in time t_{aus} is reached, at which the transistor 58 is switched off.

On the other hand, at the point in time t_1 the base emitter voltage of the transistor 57 begins to become more negative, and indeed rather quickly, so that already after a short time t_{ein} it has reached 90% of its full value, upon which the transistor 57 becomes switched on.

The point in time t_{ein} thus occurs before time t_{aus} , i.e. the slope du/dt of the switch on curve u_{BE57} is steeper than that of the switch off curve u_{BE58} at time t_1 , and thereafter the two transistors 57 and 58 are briefly simultaneously conductive.

Inasmuch as the two wound conductors 20 and 21 are inductively coupled with each other, the switching on of the conductor 20 at time t_{ein} effects a reduction of the magnetic flux in the stator 15 and, inasmuch as this

flux endeavours to stay constant, this reduction effects a corresponding rise of the current i_{58} through the transistor 58 and the conductor 21, in order to counteract this effect. As a result of this, there are produced high current spikes 62, 63 upon performance of the switching off operation, as shown in fig. 3C, and these current spikes can achieve values up to twice the start-up current, i.e. the current that is limited by means of the ohmic resistance of the respective wound conductor. These current spikes can, among other things, produce radio interference and are therefore extremely undesirable.

The invention eliminates these current spikes with a very simple technique.

Fig. 4 depicts a circuit of an inventive motor. Elements which are the same as in fig. 2 or functionally equivalent are denoted with the same reference characters as there and are generally not described again.

Instead of the diode 47 of fig. 2 (or in addition to it), there is provided in fig. 4 a PTC resistor 64 whose purpose is to render the motor currentless upon stalling of the rotor 11. The Hall IC 25 of the circuit of fig. 4 has a built-in voltage-stabilizing circuit, so that the zener diode 49 of fig. 2 can be dispensed with.

The network 53, made up of passive elements, has an output 65 which leads to the control electrode of the Darlington transistor 57, which serves as a semiconductor control element. The network 53 furthermore has an output 66 which leads to the control electrode of the Darlington transistor 58, which likewise serves as a semiconductor control element.

Between these outputs is provided a coupling capacitance 70 whose purpose is to effect a.c. coupling of these outputs and to make the potential variations at the outputs 65 and 66 (and thus at the control electrodes of the two transistors 57 and 58) as similar to each other as possible. These potential variations at the two outputs 65, 66 are both the result of the changes in value of the Hall signal u_{Hall} at the output 50 and therefore tend to correspond to each other; however, because the resistors 54 and 56 are of relatively high resistance, the potential variations

at the bases of transistors 57 and 58 do not correspond to each other perfectly. Tests have shown that coupling capacitance 70 can have values in the range of several hundred pF up to 1 μ F, thus within a range of magnitude of at least 1:1000, without essential change of function. According to present knowledge values in the nF order of magnitude are optimal, i.e. for example 3 - 5 nF. Such values can be realized by means of ceramic capacitors, whose lifetime is very long. Too high capacitance values lead, by virtue of the charging operation occurring upon switching on, to the two transistors 57 and 58 becoming for a while simultaneously conductive, which, in some circumstances, can lead to difficulties upon start-up. Also, in the event of fluctuations of the operating voltage U_B , corresponding charging or discharging processes can appear in the coupling capacitance 70, which in the event of too high capacitance values for capacitor 70 likewise tend to produce malfunction. The Miller capacitors 59 and 60 preferably have values in the range of about 100 to about 220 pF. Below 100 pF one scarcely any more obtains the desired delay in the switching, and in the event of high capacitance values (from approximately 500 pF) the danger of current spikes is substantially greater.

Fig. 5 sets forth the manner of operation of the coupling capacitance 70. Fig. 5A depicts - like fig. 3A, the Hall voltage at the output 50 of the Hall IC 25. The latter jumps at time t_1 e.g. from plus 12 V to 0 V. As a result the base emitter voltage u_{BE58} of the hitherto conductive transistor 58 drops and, in particular, delayed by the Miller capacitor 60. Simultaneously the base emitter voltage u_{BE57} of the transistor 57 becomes more negative, likewise delayed by means of the Miller capacitor 59.

By means of the coupling capacitance 70 there is produced now a substantially parallel variation of the decreasing branch 71 of u_{BE58} and of the rising, i.e. increasingly more negative, branch 72 of u_{BE57} . Expressed in another way, at any point in time the branches 71 and 72 have approximately the same du/dt , and they differ from each other practically only to the extent of a d.c. voltage, namely the voltage across the coupling capacitance 70, which during this short time interval cannot

substantially change. This applies in the same way to the branches 73 and 74 upon the switching off of the transistor 57 and the switching on of the transistor 58 at time t_2 .

By virtue of this parallelism of the base voltage variation, the currents i_{57} and i_{58} are prevented from having noteworthy current spikes upon switching off, as fig. 5C shows. By means of this simple expedient one manages to very substantially reduce interference voltages, because the two transistors 57 and 58 cannot any more be for a while simultaneously conductive upon commutation. When e.g. the voltage u_{BE58} has dropped from 1.4 V to 1 V, so that the transistor 58 blocks, the voltage u_{BE57} has in accordance with fig. 5B only just reached -0.4 V, i.e. the transistor 57 is at this point in time still not conductive. There accordingly develops a, very desirable, current gap at the commutation time. At the point in time at which the voltage u_{Hall} changes, also the current in the conductive transistor begins to drop, as fig. 5C shows.

Furthermore with the circuit of fig. 4 one can omit the storage capacitor 45, which is necessary in the circuit of fig. 2 and which, there, can in practice possibly limit the lifetime of the motor, as was set forth further above. With fig. 4, by virtue of the relatively slow switching off operations of the transistors 57 and 58, it is achieved that upon switching off, liberated inductive energy of the conductors 20, 21 is converted into heat in the transistors while they are switching off, and from the latter is dissipated in conventional manner via cooling bodies, or the like. Specifically, inasmuch as the current's rate of change di/dt during the switching off is relatively small, the induced voltage is also small, so that e.g. the voltage of the free-wheeling diode in the respective transistor is not even reached. (cf. the free-wheeling diodes 57' and 58' shown in fig. 2). Accordingly these diodes are not needed. The energy to be dissipated is converted into heat during the relatively slowly occurring switching off operation of the respective transistor - heat is developed during this operation in any event. This occurs without undesirable breakdown in the respective transistor, i.e. without detrimental effect upon lifetime, and without zener effects and their highly disturbing current pulses which could produce high frequency interference.

For an operating voltage U_B of 24 V there results for fig. 4 the following values:

resistor 5: PTC resistor

Hall IC 25: Sprague UGN 3016

resistor 48: 750 ohms

resistor 55: 1.6 kohms

resistors 54, 56: 27 kohms

capacitors 59, 60: 150 pF

capacitor 70: 4.7 nF

transistor 57: BD 680

transistor 58: BD 679

The motor in this embodiment is a four-pole motor with a bifilar winding corresponding to fig. 2 of DE-A-28 35 210, speed 3000 r.p.m., power consumption ca. 5 W.

The circuit of fig. 4 can be constructed extraordinarily small. For example the resistors can be constructed as flat thick-layer resistors and the circuit elements can be arranged on a circular annular carrier with an outer diameter of 43 mm and an inner diameter of 22 mm. Including the Darlington transistors 57 and 58, such a carrier then has a thickness of only 4 mm, only the Hall IC 25 and the PTC resistor 64 projecting beyond the latter a couple of mm. This makes possible the construction of extraordinarily compact motors with a very long lifetime, inasmuch as the ceramic capacitors 59, 60 and 70 have a long lifetime even at the high operating temperatures of a motor.

In many cases even one of the capacitors 59 and 60 can be omitted, inasmuch as e.g. via the relatively large coupling capacitance 70 e.g. the capacitor 59 is effective also for the transistor 58, and by virtue of the coupling capacitance 70 the potentials at the outputs 65 and 66 are anyway clamped. The conductors 20 and 21 can in accordance with the invention be inductively coupled more or less strongly. Instead of the Hall IC 25 one can employ any equivalent sensor, namely any rotor positional signal generator having a high output-voltage variation, e.g. at the output of an intermediately connected transistor which amplifies a

rotor-position signal of low voltage variation and thus furnishes a signal with a high voltage variation. Self-evidently, the invention is suitable in the same way for two-phase, four-conductor motors or three-phase six-conductor motors, the circuit then needing to be doubled or tripled, as is familiar to the skilled person. However, the preferred application is one-phase, two-conductor motors, such as shown in the exemplary embodiment. Instead of the Miller capacitors 59 and 60 one can alternatively employ delay capacitors 75, 76 connected between base and emitter of the transistors 57 or 58. However, the solution with at least one Miller capacitor 59 or 60 is preferred, inasmuch as one requires smaller capacitors for it. Alternatively, the switching delay can be implemented by inserting a delay capacitor in fig. 4, between the point 50 and the minus line 35, it then being advantageous to insert a resistor between the point 50 and the output of the Hall IC 25 in order to make the delay approximately equally great for the positive and the negative flanks of the Hall signal. What seems important is that there be present, somewhere, a switching delay which then, by means of the coupling capacitance 70, is made to be effective in the same way for both transistors 57 and 58.

Despite its extremely simple construction and small volume, the inventive circuit fulfils all the requirements of a high quality commutation arrangement. Furthermore, a motor having this circuit can be regulated in a very simple way, e.g. in the case of a fan by means of a series-connected NTC resistor in order to obtain at lower temperatures a lower speed for the fan whereas with increasing temperature the fan's speed increases.