

The invention relates to a brushless direct current motor, with a stator winding which has at least one phase, with a permanent magnet rotor, with a rotor-position sensing arrangement, and with a semiconductor arrangement serving for the control of the current in the stator winding, said semiconductor arrangement having at least two switching elements which, in dependence upon the position of the rotor, are commutated in order to power the at least one phase in dependence upon the rotor position, a current interruption being produced between each two successive current impulses, and with driver stages, associated with the switching elements.

A motor of this kind is known from DE-A-3 044 056 of the patentee. In this motor, the stator winding of which is supplied with power via a full bridge circuit, rotation of the rotor generates synchronous temporally spaced first pulse sequences with steep flanks and second pulse sequences with less steep flanks guided via delay elements. These pulse sequences are logically connected together so that the two conducting power transistors of one bridge diagonal can be blocked before the two power transistors of the other bridge diagonal become conductive. This known circuit arrangement works very well, but requires a relatively large number of components.

A drive circuit for one phase of a brushless motor is known from GB-A-2 071 939. This drive circuit is controlled via a square wave signal. In order to reduce the generation of electromagnetic noise in this phase, the ascending and descending flanks of the pulse of the square wave signal are smoothed with the aid of CR-networks. However, in an arrangement of this kind, smoothing of the descending flanks

leads to pulse lengthening, which, in many cases, and in particular in the control of full bridge circuits, is undesirable, as it increases the risk of all bridge branches being conductively controlled at the same time.

Furthermore, EP-A-40 484 discloses a two-phase, two-pulse brushless direct current motor which is controlled by means of a square wave output voltage from two Hall-IC's. In this case, the pulse smoothing measures known from GB-A-2 071 939 are used, in order to delay the actuation and disconnection of the power transistors of this motor. This results in the fact that after the instant of commutation a current flows periodically into both phases of the motor. As the first phase then slows down the motor, the noise level of the motor is actually reduced by this measure, but at the expense of efficiency, as part of the electrical energy supplied is then used not to drive the motor but to slow it down.

Therefore, the object of the invention is to propose a motor, in which the commutation process can be advantageously controlled in the required manner without adversely affecting the efficiency of the motor.

This problem is solved according to the invention in that the driver stages each have an electronic semiconductor switch which in its conducting state essentially short-circuits the input of the associated switching element and thereby blocks the latter, that the driver stages are further associated with respective sources of substantially constant current, preferably of the order of a few milliamps, from which an actuating current flows to the associated switching element when the electronic semiconductor switch of the respective

driver stage is non-conducting, and that a capacitance is connected to the output of at least one driver stage in order to delay the actuation of the associated switching element. By virtue of the fact that the semiconductor switch of one driver stage essentially short-circuits the input of the associated switching element, the latter is blocked virtually immediately upon disconnection. As, on the other hand, the source of substantially constant current requires time to charge the capacitance, the actuation process is delayed, so that there is a time interval between disconnection and actuation. Smooth actuation is thus simultaneously obtained, this reducing the generation of noise in the motor. By virtue of the fact that the source of essentially constant current can only supply one specific current, it is furthermore possible to provide for another additional signal at the output of a driver stage, e.g. a regulating signal, a temperature-dependent signal, etc.

One particularly advantageous embodiment of the invention is clear from the features of claim 2, as in this case two driver stages require only one individual common capacitance. As this capacitance can, in addition, be very small, e.g. of the order of 100 pF, this results in a circuit with extremely reliable operation and few components.

An additional possibility for controlling the motor is clear from the measures according to claim 3, wherein, in this manner, e.g. the rotational speed of the motor can be made dependent on the temperature, as stated in claim 4.

Thus, the embodiment according to claim 5 is particularly advantageous as in this case only small actuating currents are necessary and consequently, the sources of substantially

constant current can be adapted for low currents, wherein simply resistors with relatively high resistance values are often sufficient, as described in one part of the example.

One particularly preferred embodiment of the motor is characterised in claim 8, as it is precisely in the case of square wave pulse signals of this kind from a Hall-IC that the advantages of the invention become particularly apparent.

Further details and advantageous embodiments of the invention will be clear from the subclaims and from the examples, which by no means limit the invention, and are described hereinafter with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a two-pulse brushless direct current motor having an auxiliary reluctance torque, serving for the direct drive of a fan; this motor is known per se,

Figure 2 shows a first embodiment of the motor according to the invention, with a full bridge circuit,

Figure 3 is a diagram illustrating Figure 2,

Figure 4 shows a second embodiment of the invention, analogous to Figure 2,

Figure 5 shows a third embodiment of the invention,

Figure 6 shows a fourth embodiment of the invention, with an integrated commutation unit according to the invention,

Figure 7 shows a variant embodiment of the commutation unit illustrated in Figure 6,

Figure 8 is a diagram illustrating Figure 6,

Figure 9 shows a fifth embodiment of the invention, in this case, a motor with a full bridge circuit of the type illustrated in Figure 2,

Figure 10 shows a sixth embodiment of the invention, in this case, what is known as a single-phase, single-pulse motor and

Figure 11 shows a seventh embodiment of the invention.

In the following description, identical components or components with identical operation have been given the same reference numerals and in general are described only once.

Figure 1 shows a schematic representation of a two-pulse brushless direct current motor 10, in this case, a single-phase, two-pole motor, as known from US-A-4 030 005.

Definition of terms:

Two-pulse: The number of current impulses supplied to the stator winding per rotation of the rotor about 360° el. E.g. in the course of one complete revolution, the motor illustrated in Figure 1 will receive only two current impulses of substantially the same length and the same strength, one flowing through the stator winding 25 in one direction and the other in the opposite direction.

Single-phase: The motor has only a single winding phase for the drive. A motor of this kind may also be referred to as a single-strand motor.

Two-pole: The rotor has two poles.

It should be noted in particular that this invention is equally suitable for motors with a higher number of poles, e.g. for four-pole, six-pole, etc. motors, and that it is also suitable for four-pulse or six-pulse motors, wherein, e.g. for a four-pulse motor, the circuit according to Figure 2, 4, 5, 6 or 8 must be duplicated and the two Hall-IC's must be placed on the stator at a suitable distance from each other, e.g. spaced by 90° el.

The motor 10 illustrated in Figure 1 is an external rotor motor having a two-pole external rotor 11, its radial magnetization being indicated in the usual manner by N and S. This magnetization is trapezoidal, with narrow gaps 14, 15 (e.g. approximately $5 - 10^\circ$ el.) between the poles. This trapezoidal magnetization results in substantially constant induction (magnetic flux density) over approximately $170 - 175^\circ$ el. and thereafter a monotonic decrease in magnetization, c.f. DE-C-2 346 380 where this is described in more detail.

The rotor 11 has a peripheral portion 12, e.g. a pot-shaped cover made of deep-drawn steel, the base of which (not shown) is coupled to the shaft (not shown) of the rotor. The magnet 13 itself, usually a rubber-type magnet, is secured within this pot-shaped cover 12. The pot-shaped cover 12 has fan vanes 17 of the fan welded thereon, this fan 17 being driven by the motor 10. Only one single vane 17 is shown. In Figure 1, the

points having substantially constant induction are indicated, for the north pole, by hatching, and, for the south pole, by stippling. The direction of rotation is indicated by the arrow 16.

The stator 18 has two salient poles, an upper pole 19 and a lower pole 20 separated by slots 23 and 24, in which the winding 25 is disposed, the terminals of which are indicated by 27, 28 and 29. A rotor-position sensor 32 is disposed at the opening of the slot 24. The rotor-position sensor 32 is in this case formed as a Hall-IC, delivering only one output signal. Other types of sensors can of course also be used, e.g. an optical sensor.

The air gap 33 above the stator pole 19 and the air gap 34 of corresponding shape above the pole 20 are formed as shown in US-A-4 030 005. E.g. starting from the slot 23, the air gap 33 increases in the direction of rotation to a maximum 30, and from then on decreases monotonically back down to a minimum d_1 , thus producing the required reluctance torque, c.f. DE-C-2 346 380. Of course, a motor according to the invention can equally be designed as an internal rotor motor. The shape of the air gap depends on the shape of the required reluctance torque and on the type of magnetization of the rotor 11. The pole slots 14 and 15 are advantageously sloping. The motor according to Figure 1 is only shown by way of example in order to facilitate understanding of the subsequent circuit. Of course, it is equally possible to use other motors, e.g. internal rotor motors, motors with a level air gap, etc.

As illustrated, alternately within the winding 25, a direct current impulse will flow from the terminal 28 to the terminal

29 and then from the terminal 29 to the terminal 28. There must be a current interruption between each two successive impulses, firstly in order to maintain high efficiency of the motor and secondly, when using a bridge circuit, in order to prevent short circuits via the power semiconductors of the bridge circuit.

To the right of the line A-A in Figure 2 there is a full bridge circuit 40 with four power semiconductor switches and two driver stages, and to the left of the line A-A is a circuit 41 for the control of the bridge circuit 40. The circuit 41 is often referred to as a control circuit, a commutation circuit or a current flow selection circuit. A meltable resistor 42 and a diode 43 preventing reverse polarity lead from the positive pole of a direct current source (e.g. 24, 48 or 60 V) to a positive lead 44. A filter capacitance 46, e.g. of between 20 and 100 μF , is disposed between the positive lead 44 and the negative lead 45. The resistor 42 melts in the event of overload of the motor, thus serving as a protector.

The Hall-IC 32 serving as a rotor-position sensor is connected to the emitter 47 of a transistor 48, the collector and base of which are connected via resistors 49 and 50 to the positive lead 44, and from the base of which a Zener diode 53 leads to the negative lead 45, so that a constant voltage of, e.g. 5.6 V is obtained at the emitter 47, to which other low-power devices (not shown) may also be connected, e.g. a speed control circuit or a current limiting circuit. One advantage of this circuit, however, is the fact that it can operate up to a relatively high motor power output without a current limiting circuit.

The Hall-IC 32, which is connected via its other terminal to

the negative lead 45, includes at its output an npn-transistor 54 with an open collector, this collector, as illustrated, forming the output 55 of the Hall-IC 32. A first operating resistor 56 for the Hall-IC 32 leads from this output 55 to the constant voltage at the emitter 47, and a further resistor 57 leads to the base of a phase-inverting npn-transistor 58, the emitter of which is connected to the negative lead 45, and the collector of which is connected via a high resistance resistor 59 to the positive lead 44, the voltage of which in operation, as shown, is substantially higher than that of the emitter 47.

The cathode of a diode 62 is further connected to the output 55, and its anode is connected via a high resistance resistor 63, serving as a second operating resistor for the Hall-IC 32, to the positive lead 44, via a delay capacitance 64 to the negative lead 45 and via a junction J1 to the base of an npn-transistor 65 serving as a driver stage.

The collector of the phase-inverting transistor 58 is also connected via a delay capacitance 66 to the negative lead 45 and via a junction J2 to the base of an npn-transistor 67 serving as a driver stage.

The full bridge circuit 40 has four Darlington transistors. The upper branches include two pnp-transistors 70, 71, and the lower branches include two npn-transistors 72, 73. The emitters of the transistors 70, 71 are connected to the positive lead 44 and the emitters of the transistors 72, 73 are connected to the negative lead 45. The collectors of the transistors 70 and 72 are connected together and to the terminal 28 of the stator winding 25. The collectors of the transistors 71 and 73 are also connected together and, via a

PTC resistor 74, to the terminal 29 of the stator winding 25. The base of the transistor 70 is connected via a resistor 75 to the collector of the driver transistor 65, the emitter of which is connected directly to the base of the transistor 73. The base of the transistor 71 is connected via a resistor 76 to the collector of the driver transistor 67, the emitter of which is connected directly to the base of the transistor 72.

Thus, when the driver transistor 67 is conductive, the bridge transistors 71 and 72 are conductive and a current will flow from the positive lead 44 via the transistor 71, the PTC resistor 74, the stator winding 25 and the bridge transistor 72 to the negative lead 45. If, on the other hand, the driver transistor 65 is conductive, the bridge transistors 70 and 73 become conductive and a current will flow from the positive lead 44 via the transistor 70, the stator winding 25, the PTC resistor 74 and the transistor 73 to the negative lead 45. Thus, the current in the stator winding 25 will flow from terminal 29 to 28, and, then, from terminal 28 to 29. The PTC resistor 74 prevents the motor current from increasing to an excess value in the case of a blocked rotor 11, as its resistance value will then be greatly increased as a result of heating and the current in the winding 25 will be reduced to safe levels.

If both driver transistors 65 and 67 were to be rendered conductive simultaneously, all the bridge transistors 70 - 73 would become conductive simultaneously, resulting in a short-circuit connection between the positive lead 44 and the negative lead 45, leading to immediate destruction of these transistors. This situation, thus, must never be allowed to arise, i.e. the control signals for the driver transistors 65

and 67 must be spaced in time. Special measures are provided to this end according to the invention.

The Hall-IC 32 provides square wave pulses 80 at its output (c.f. Figure 3A). These are high for 180° el. (transistor 54 blocked) and then low for 180° el. (transistor 54 conductive).

When the output 55 becomes high, the transistor 58 will be rendered conductive via the relatively high resistance resistor 57, the delay capacitance 66 thus discharging very rapidly, e.g. within one microsecond. The transistor 58 thus acts as a discharge element for the capacitor 66, and blocks the driver transistor 67, and with it the bridge transistors 71 and 72. This is shown in Figures 3B and 3C. Figure 3B shows the voltage u_{66} at the capacitance 66 and Figure 3C, in the hatched portion, shows the actuation of the transistors 71 and 72.

When the output 55 becomes high, the diode 62 simultaneously blocks, so that a charge current can flow via the high resistance resistor 63 to the delay capacitance 64 and charges the latter substantially linearly, as illustrated in Figure 3D (u_{64}). If the voltage at the capacitance 64 reaches a threshold value u_{th} of approximately 2 V (approximately the combined base-emitter threshold voltages of three transistors!), the driver transistor 65 becomes conductive, thus causing conduction of the transistors 70 and 73.

After rotation of the rotor about 180° el., the voltage at the output of the Hall-IC 32 becomes low, i.e. the transistor 54 becomes conductive. The delay capacitance 64 can then discharge very rapidly, e.g. within one microsecond, via the diode 62 and the transistor 54, used here as a discharge

element, so that the previously conductive driver transistor 65 is very rapidly blocked, thus also blocking the transistors 70 and 73 it controls.

The phase reversal transistor 58 is blocked simultaneously via the relatively high resistance resistor 57, so that, according to Figure 3B, the delay capacitance 66 can be charged via the relatively high resistance resistor 59 with an effectively constant current, i.e. substantially linearly. When the threshold voltage u_{th} (here, e.g. of approximately 2 V) is exceeded, the driver transistor 67 will become conductive, causing the transistors 71 and 72 to become conductive.

Therefore, as can be clearly seen from Figure 3, time gaps 82 will occur between the sections at which, on the one hand, the bridge transistors 70 and 73 and, on the other hand, the bridge transistors 71 and 72 are conductive. In the case of a four-pole motor operating at 3000 rpm, e.g. 180° el. corresponds to a time of 5 ms. The duration of the gaps 82, in this case, will preferably be selected to fall between approximately 0.1 and 0.5 ms, i.e. substantially longer than the discharge time of the capacitances 64, 66, which need be only a few microseconds.

The high resistance resistors 59 and 63 at the relatively high operating voltage, e.g. of 24 or 48 V, form, for all practical purposes, a constant current source, and thus provide for essentially linear charge of the delay capacitances 64 and 66. This results in more precise actuation delay than charging in accordance with an exponential function, which would be the result if the connection were to be made to the emitter 47. Moreover, the transistor 48 is thus less loaded, so that a

smaller transistor can be used.

The internal transistor 54 of the Hall-IC 32 is utilised in this circuit as a discharge element for the delay capacitance 64. This is a particularly advantageous and hence preferred solution. Although a separate transistor could of course also be used to this end, this would introduce additional costs. A decoupling element in the form of the resistor 57 and the diode 62 is required in the circuit as shown in order to ensure that when the transistor 54 blocks, on the one hand, the transistor 58 immediately becomes conductive and the capacitance 66 can immediately discharge, while, on the other hand, the capacitance 64 can charge slowly via the resistor 63. Without these two components, the voltage at the capacitance 64 would be limited to the base-emitter threshold voltage of the transistor 58. Freewheeling diodes 70' to 73' are connected in an antiparallel manner with the bridge transistors 70 - 73.

The following are typical values for some of the components, where $k = k \text{ Ohms}$:

- operating voltage: 48 V =
- a four-pole, single-phase motor of 15 W
- voltage at the point 47: 5.6 V
- Hall-IC 32: TL 170
- resistor 56: 2.2 k
- resistors 57, 59, 63: 100 k
- resistors 75, 76: 22 k
- capacitances 64, 66: 10 nF.

Figure 4 shows a further simplified embodiment of the motor according to the invention, in which operation can be greatly improved while using fewer components, this being of particular

importance when it is applied to fans, as in this case the space available is extremely limited. As in the the case of the preceding figures, identical components or components having identical operation have been given the same reference numerals and in general have not been described again.

The full bridge circuit 40' essentially has the same construction as the full bridge circuit 40 according to Figure 2, i.e. four Darlington transistors 70-73 with freewheeling diodes 70' - 73' and base-emitter resistors 70" - 73" are provided. The stator winding 25 and the PTC resistor 74 lead from the bridge terminal 28 to the bridge terminal 30.

The upper bridge transistors 70 and 71 are controlled differently from the control circuit according to Figure 2. A resistor 85 leads from the terminal 28 to the base of the transistor 71 and, conversely, a resistor 86 leads from the terminal 30 to the base of the transistor 70.

Furthermore, a capacitance 87 is provided between the bases of the transistors 72 and 73, although this may be dispensed with if the transistors 72 and 73 have high inherent capacitances.

The control circuit 41' likewise uses a Hall-IC 32, although any other type of sensor, e.g. a light barrier, may also be used. It is particularly preferred, according to the invention, to use sensors having digital output signals 80 (Figure 3), i.e. signals which are not representative of the analog value of the magnetic field controlling the sensors (or any other physical parameters).

A Zener diode 53 with a Zener voltage of, e.g. 5 V, is

connected in parallel with the Hall-IC 32. The Hall-IC 32 has one terminal connected directly to the negative lead 45, while its other terminal is connected via the resistor 49 to the positive lead 44. The internal construction of the Hall-IC 32 was described in connection with Figure 2.

The output 55 of the Hall-IC 32 is connected via a resistor 88 to the positive lead 44, and directly to the cathode of a diode 89, the anode of which is connected via the junction J1 to the base of the bridge transistor 73 and to which a resistor 90 is connected in parallel.

Furthermore, a resistor 93 leads from the output 55 to the base of an npn-transistor 94, the emitter of which is directly connected to the negative lead 45, and the collector of which is connected via the junction J2 to the base of the bridge transistor 72, and via a resistor 95 to the positive lead 44. The transistor 94 serves as a phase inversion stage and is utilised as a controllable element to block the control input of the transistor 72, while the internal transistor 54 of the Hall-IC 32 serves as a controllable element to block the control input of the bridge transistor 73.

The arrangement according to Figure 4 has the following advantages:

- a) The PTC resistor 74 protects the motor and the bridge circuit 40' against overloading.
- b) When overloading is eliminated, i.e. when the rotor 11 is no longer blocked, the overload protector automatically reverts to the normal state, so that the motor can operate

normally once again.

- c) Even in the event of overloading of the bridge circuit 40', the control circuit 41' remains operative.
- d) In spite of the use of "digital" signals 80, the bridge circuit 40' is controlled in such a manner that there is a relatively long time gap, e.g. of the order of 1/100 to 1/10 of the duration of the switching cycle, between the disconnection of one transistor pair and the actuation of the subsequent transistor pair.
- e) Furthermore, the arrangement according to Figure 4 is protected against failure of the bridge circuit 40' by the meltable resistor 42.

The capacitance 46 serves to receive the energy released upon commutation of the motor current in the stator winding 25, thereby preventing voltage peaks.

During operation the bridge transistor 72 is controlled by the phase inversion stage 93, 94, 95, while the bridge transistor 73 is directly controlled by the Hall-IC 32 with no phase inversion. E.g. if the transistor 94 is blocked, i.e. the bridge transistor 72 is conductive, the voltage at the point 28 corresponds approximately to that of the negative lead 45. Consequently, the base of the bridge transistor 71 will receive an actuating current via the resistor 85, so that this transistor becomes conductive. Thus, the voltage of its collector (point 30) will correspond approximately to that of the positive lead 44, and a current can flow from the positive lead 44 via the transistor 71, the PTC resistor 74, the stator

winding 25 and the transistor 72 to the negative lead 45.

In the reverse case, if the transistor 73 is conductive and the transistor 72 is blocked, a base current will flow via the resistor 86 to the transistor 70, so that it becomes conductive, and the motor current will flow in the reverse direction, i.e. from the lead 44 via the transistor 70, the stator winding 25, the resistor 74 and the transistor 73 to the negative lead 45.

For reliable operation of bridge circuits of this type, it is of great importance that the transistors, which have their collectors connected together and are of respectively different conductivity types, should never be conductive at the same time, as the current then would not be limited, i.e. there would be a short circuit between the positive lead 44 and the negative lead 45. The loss of power in the transistors in such cases can reach dangerous levels.

According to one feature of the invention, these short-circuit currents are prevented by disconnecting the transistors 72 and 73 relatively rapidly via conductively switched semiconductor paths with relatively low differential internal resistance. Thus, the time constant, which is formed by these internal resistances with the base-emitter and the base-collector capacitances of the transistors 72 and 73, will be comparatively low. The conductive semiconductor path for the transistor 73 is formed by the diode 89 and the conductively switched internal transistor 54 of the Hall-IC 32. The conductive transistor 94 forms the semiconductor path for the transistor 72.

In contrast to disconnection, actuation is effected by base currents produced by relatively high resistance resistors, and which thus cause a relatively slow increase in the base voltage. E.g. if the transistor 94 is switched off, a base current will flow via the resistor 95 into the base of the bridge transistor 72. The base of the bridge transistor 72, however, just in advance of this instant, was approximately at the voltage of the emitter, so that the base current must first overcome the storage effect of the base-emitter and above all the base-collector capacitances before the transistor 72 can become conductive.

Similarly, the transistor 73 is actuated with delay when the internal transistor 54 of the Hall-IC 32 is blocked. Just previously, the base of the transistor 73 was at the voltage of the emitter and the base current flowing via the resistors 88 and 90 to the base of the transistor 73 must first overcome the inherent storage effect before the transistor 73 can become conductive.

As the inherent capacitance values of modern transistors are relatively small, this delay effect described in respect of the actuation operation, as opposed to the blocking operation, is not specifically apparent. It is, however, generally sufficient in order to prevent direct short-circuit currents via the transistors 70 and 72 or 71 and 73. Nevertheless, this effect can be easily destroyed by other effects that cannot always be suppressed, e.g. capacitances between the leads, resistances in connecting lines and tolerance variations within the individual transistors being used.

However, the effect described can be enhanced in a very simple

manner according to one extremely advantageous development of the invention by connecting the capacitance 87 between the bases of the transistors 72 and 73. The value of such a capacitance may be 100 pF or more.

The capacitance 87 operates as follows: let it be assumed that the internal transistor 54 of the Hall-IC 32 is conductive, the transistors 94 and 73 are thus non-conductive, and the transistor 72 is conductive. If the Hall-IC 32 then switches its switching state at a given instant, i.e. becomes non-conductive, the transistor 94 will become conductive almost simultaneously and will essentially short-circuit the base-emitter path of the bridge transistor 72. This causes the base-emitter voltage U_{BE} at the transistor 72 to drop very rapidly to approximately 0.1 to 0.3 V, from a previous level of approximately 1.2 to 1.4 V. This rapid change of voltage at the base of the transistor 72 is transferred via the capacitance 87 to the base of the transistor 73, so that its base voltage at the transistor 73 will drop below that of the negative lead 45, keeping the transistor 73 initially securely blocked, even although an actuating current flows via the resistors 88 and 90 to the base of the transistor ~~73~~. This current must first recharge the capacitance 87 by a voltage difference of $2 \times U_{BE}$ before the transistor 73 can become conductive. Thus, for a relatively long period of time, both transistors 72 and 73, and hence also the transistors 70 and 71, are securely blocked.

Conversely, when the internal transistor 54 of the Hall-IC 32 changes over from the blocked to the conductive state, the capacitance 87 first must recharge in a completely analogous manner, but now in the reverse direction. The base-emitter

voltage U_{BE} of the previously conductive transistor 73, which, up to then, was between approximately 1.2 and 1.4 V, is reduced by the internal transistor 54 of the Hall-IC 32 via the diode 89 to approximately 0.8 V within a very short space of time, causing rapid blocking of the transistor 73. The resistor 90 further reduces the base-emitter voltage, more slowly, to approximately 0.1 to 0.3 V. This rapid change in voltage is transferred by the capacitance 87 from the base of the transistor 73 to the base of the transistor 72, so that, in spite of the base current then flowing via the resistor 95, the transistor 72 remains blocked. The capacitance 87 again must be recharged by a voltage of approximately $2 \times U_{BE}$ via the resistor 95 before the bridge transistor 72 can become conductive. The capacitance 87 thus has a dual function, being used for two switching operations and delaying both of them, i.e. delaying actuation of the bridge transistor 72 and actuation of the bridge transistor 73.

The resistor 93 serves to decouple the output voltage of the Hall-IC 32 (necessarily relatively high) at its output 55 from the low base-emitter voltage of the transistor 94.

The resistors 88, 90 and 93 are particularly advantageously so dimensioned that they provide approximately the same current at the base of the transistor 73 as the resistor 95 provides at the base of the transistor 72. The delay periods upon actuation of the transistors 72 and 73 will then be essentially the same.

In particular, as a result of the fact that the bases of the two bridge transistors 72 and 73 are connected together by the capacitance 87, the required relatively long time interval of

the order of between 1/100 and 1/10 of the duration of the switching cycle can be obtained between disconnection of one transistor pair and actuation of the subsequent transistor pair. The duration of this interval can be varied by appropriate selection of the value of the capacitance 87 and/or of the resistors 88, 95. This pause also reduces the thermal loading of the transistors of the bridge circuit 40', resulting in high efficiency and a long service life of the motor.

The cross connections of the bases of the transistors 70, 71 with the collectors of the transistors 72, 73 provide for direct control, so that the driver transistors 65 and 67 according to Figure 2 can be dispensed with, thereby considerably simplifying the circuit.

The following are some typical values for Figure 4, where k = k Ohms:

operating voltage: 48 V (40 to 60 V)

a 10 W motor operating at 3000 rpm

Hall-IC 32: TL 170

resistors 85, 86: 47 k each

capacitance 46: 47 μ F

capacitance 87: 3300 pF

resistor 49: 4.7 k

transistors 70, 71: BD680

resistor 88: 33 k

transistors 72, 73: BD679

resistor 90: 12 k

resistor 93: 27 k

diode 89: 1N4148

resistor 95: 68 k

transistor 94: BC546

Figure 5 shows a simple modification of Figure 4. The control circuit 41' of Figure 5 is absolutely identical to the control circuit 41' according to Figure 4 and so has not been described again. The semiconductor arrangement 40" of Figure 5 comprises only two Darlington transistors 72 and 73, the circuit arrangement and connection of which also correspond exactly to Figure 4, and so have not been described again. In addition, a capacitance 87 of approximately equal value to that of Figure 4 is provided between their bases. The typical values indicated for Figure 4 apply similarly to Figure 5.

The motor 10 in this case is a two-phase motor, i.e. according to Figure 1, its winding 25 has a centre tap 27 which is connected via a PTC resistor 74 to the positive lead 44. One terminal 28 of the winding (c.f. Figure 1) is connected to the collector of the transistor 72, and the other terminal 29 of the winding is connected to the collector of the transistor 73. Thus, when the transistor 72 conducts, current flows in one direction through the upper half of the winding 25 in Figure 1, representing one phase, and when the transistor 73 conducts, current flows in the opposite direction through the lower half of the winding 25 in Figure 1, this representing the second phase.

As is immediately clear, it is pointless for both transistors 72 and 73 to conduct at the same time as the magnetic fields of the upper and lower halves of the winding 25 will cancel each other out so that the winding 25 will be heated to no avail and the efficiency of the motor will be reduced.

Therefore, also in the case of the two-phase arrangement according to Figure 5, it is useful to produce a conduction

gap, during which, for a brief period (pause 82 in Figure 2), neither of the transistors 72 or 73 will be conducting.

The method of operation has already been described in detail with reference to Figure 4. E.g. if the phase reversal transistor 94 becomes conductive, it blocks the transistor 72 and causes the base-emitter voltage to drop to between 0.1 and 0.3 V from a previous level of 1.2 - 1.4 V. This rapid change in voltage is transferred via the capacitance 87 to the base of the transistor 73, so that its base voltage will rapidly drop below that of the negative lead 45, keeping the transistor 73 securely blocked. This current, which flows via the resistors 88 and 90 to the transistor 73 must first alter the charge at the capacitance 87 by a voltage difference of $2 \times U_{BE}$ before the transistor 73 can become conductive. Thus, both transistors 72 and 73 are blocked simultaneously during this recharging process and the required current interruption is obtained at the instant of commutation.

Conversely, if the transistor 73 is blocked during commutation, the opposite situation obtains, as explicitly described in connection with Figure 4.

If the rotor 11 is blocked, there is a large increase in the motor current. This current heats the PTC resistor 74 to such an extent that it reaches a high resistance value and thus protects the motor 10 against overload. When the rotor 11 is no longer blocked, the resistor 74 can cool down and the motor 10 can be re-started.

Figure 6 shows a fourth embodiment of the invention, which, like Figure 5, shows a two-phase motor, e.g. 4 W motor, which

can have an operating voltage of between 8 and 30 V. (Higher capacities and operating voltages are of course also possible). The commutation circuit is in this case formed as a commutation unit 100, advantageously an IC, this being particularly advantageous in the case of fans for reasons of space. This unit 100 has particularly advantageous intersection points between the sections of the circuit respectively low and high in energy, so that the loss of power in the circuit itself is low, resulting, inter alia, in high efficiency of the motor.

In this case, a PTC resistor 101 is provided in the positive supply lead to ensure secure blocking. One phase of the motor 10 is connected via its terminal 27 to the positive lead 44 and via its terminal 28 to the collector of an npn-Darlington transistor 102, the emitter of which is connected to the negative lead 45 via a low resistance resistor 103 (e.g. between 0.1 and 0.3 Ohms) providing for negative current feedback. This emitter is also connected to the emitter of a second npn-Darlington transistor 104, the collector of which is connected to the terminal 29 of the winding 25, the terminal 27 of which is located, as illustrated, at the positive lead 44. As illustrated, the transistors 102 and 104 have base-emitter resistors 102', 102'', 104', 104'' and freewheeling diodes 102''', 104'''. E.g. transistors of the BD 679 type can be used for these. If one of the transistors 102 and 104 is conducting, there is a drop in voltage at the resistor 103, this causing a reduction of the control voltage of the relevant transistor and thus providing for negative feedback. This prevents these transistors resulting in different currents, e.g. when they are heated to differing degrees. These transistors display high power amplification, of the order of 1000 to 1500, this being very advantageous within the context of the invention, as will

be described in more detail hereinafter.

The unit 100 is connected via its terminal 105, via a resistor 106 or a diode 107, or both in series, to the positive lead 44 and it is connected via its terminal 108 to the negative lead 45. The terminal 105 leads to a voltage regulator 110 with an output voltage of, e.g. 3 - 5 V, which is also connected to the terminal 108. Its controlled output is indicated by 111.

The unit 100 comprises a Hall effect element 112 with one current input at the output 111 and the other current input at the terminal 108. Its left output is directly connected to the negative input of a comparator 114, and its right output 115 is connected via a resistor 116 to the positive input of the comparator, which is connected via a positive feedback resistor 117 to the output 118 of the comparator 114.

The output 115 is directly connected, in an absolutely symmetrical manner, to the negative input of a comparator 120 and the output 113 is connected via a resistor 121 to the positive input of the comparator 120, which is itself connected via a positive feedback resistor 122 to the output 123 of this comparator. As illustrated, the comparators 114 and 120 are connected to the controlled output 111 and the terminal 108.

Two npn-transistors 126 and 127 serve as outputs of the unit 100, i.e. as driver stages. The base of the driver transistor 126 is connected to the output 118, and its emitter to the terminal 108. Its collector is connected to the terminal 128 and it is either connected via an integrated constant current element 129 to the controlled output 111, as illustrated, or is connected via a high resistance resistor 130 to the positive

lead 44. During operation, a low current, e.g. of a few milliamps (1 - 5 mA), flows via the constant current element 129 or the resistor 130 to the collector of the transistor 126, to which the anode of a diode 133 serving as a current control element, the cathode of which leads to a terminal 134 of the unit 100, via which a low-energy control value, e.g. a control value specific to a fan, can be supplied to the unit 100 in order to increase or decrease the rotational speed of the motor.

In an absolutely symmetrical manner, the base of the driver transistor 127 is connected to the output 123 and its emitter is connected to the terminal 108. Its collector is connected via a constant current element 135 to the controlled output 111, or via a high resistance resistor 136 to the positive lead 44. Here too, a constant current of a few milliamps flows to the collector of the transistor 127. The lower this current, the smaller the loss of power in the unit 100, the higher the efficiency of the motor and the easier it is to control the power of the motor 10 within wide limits by means of a small signal at the terminal 134. The collector of the driver transistor 127 is connected to a terminal 137 of the unit 100 and to the anode of a diode 138, the cathode of which is connected to the terminal 134, which is connected to a junction 141, from which a fixed resistor 142 leads to the positive lead 44 and a PTC resistor 143 leads to the negative lead 45. The resistor 143 can, e.g. be disposed in the air flow of the fan driven by the motor 10. If this air becomes warmer, the voltage at the junction 141 increases, more power is supplied to the motor 10, its rotational speed increases and more air is supplied, so that the temperature decreases again.

Alternatively, an NTC-resistor 144 can lead from the junction 141 to the positive lead 44 and a fixed resistor 145 can lead to the negative lead 45. The operation is then essentially the same. The variation with the PTC resistor 143 is preferred, as in the event of failure of the resistor 143 full motor power is automatically actuated.

The base of the transistor 102 is connected to the output 128, and the base of the transistor 104 to the output 137. Therefore, here once again there are very few components, i.e. the two power transistors 102 and 104, the capacitance 46 of, e.g. 22 μF , the unit 100, the resistor 106 and, if required, the resistors 142 and 143. (The terminal 134, e.g. can also be at a fixed voltage).

Operation of the circuit according to Figure 6.

The unit 100 with the Hall effect element 112 is disposed, e.g. in the case of the motor according to Figure 1, in place of the Hall-IC 32, so that it is controlled by the rotor magnet 13. If the rotor 11 rotates, a voltage according to Figure 8A is produced between the outputs 113 and 115 of the Hall element 112, this being representative of the magnetization of the rotor magnet 13. This voltage is fed, e.g. to the comparator 114 and is converted at its output into the square wave voltage u_{114} , illustrated in Figure 8B. This controls the driver transistor 126, at the collector of which the voltage u_{126} is obtained, illustrated in Figure 8C. This voltage is blocked by the diode 133, i.e. if the voltage at the junction 141 is high, the diode 133 remains blocked and the curve a indicated by the continuous line is obtained, corresponding to a high temperature of the PTC resistor 143 and thus the maximum motor

power. The voltage a corresponds approximately to the voltage u_{111} at the output 111. If the resistor 143, which, e.g. can be disposed in the air flow of a fan, has a lower temperature, the voltage at the junction 141 is lower and the curve b indicated by the dotted line in Figure 8C is obtained, i.e. lower motor power.

If the resistor 143 has a very low temperature, the curve c indicated by the dash-dotted line in Figure 8C is obtained, i.e. the motor 10 receives even less power and operates even more slowly. It is thus possible, in the case of very low currents of a few mA, to regulate or control the rotational speed of the motor by limiting the voltage increase of the driver stages 126, 127 to the required value by a common signal at the terminal 134.

In order to delay actuation, it is possible, in addition, to connect a capacitance 148 between the emitter and the base of the transistor 102 and a capacitance 149 between the emitter and the base of the transistor 104. These can have typical values of between 1 and 10 nF. The method of operation of these capacitances is identical to that of the capacitances 64 and 66 of Figure 2. E.g. the capacitance 148 will discharge very rapidly when the transistor 126 becomes conductive, so that the transistor 102 blocks very rapidly. Conversely, if the transistor 126 blocks, the capacitance 148 (or even only the inherent capacitance of the Darlington transistor 102), must first be charged via the constant current element, thereby providing for a time delay in respect of actuation. By virtue of the symmetry of the circuit, the same process applies in the case of the transistor 104, when it becomes conductive. In most cases, the capacitances 148 and 149 can be dispensed with

as the inherent capacitances of the transistors 102 and 104 are already sufficient and as, in the case of two-phase motors, one brief current interruption is sufficient.

Of course, the voltage at the terminal 134 can be influenced in a plurality of ways, e.g. by the pressure or air humidity to be regulated, the rotational speed, etc. If the power transistors 102 and 104 used are transistors having high power amplification, a low base current of the order of a few milliamps is sufficient for the control thereof. The voltage divider 142, 143 (or 144, 145) can then be designed accordingly with high resistance, so that a motor with correspondingly high efficiency is obtained. Therefore, the unit 100 is particularly suitable for use in connection with Darlington transistors with high power amplification or with equivalent transistor arrangements. However, with a unit of this kind it is also possible to effect control by means of thyristors.

Figure 7 shows a unit 100' which is suitable for relatively high output currents. This unit corresponds with only a few differences to the unit 100 according to Figure 6. Identical components or components having identical operation have therefore been given the same reference numerals in both figures and have not been described again in the case of Figure 7.

Instead of the diodes 133, 138 of Figure 6, in Figure 7, pnp-transistors 155, 156 (or equivalents that can be designed as an IC) are provided. The emitter of the transistor 155 is connected to the terminal 128, its collector is connected to the terminal 108 and its base is connected to the terminal 134. Similarly, the emitter of the transistor 156 is connected to

the terminal 137, its collector is connected to the terminal 108 and its base is connected to the terminal 134. Therefore, when the constant current sources 129 and 135 are adapted for relatively high currents, the current can be controlled by means of a small signal at the terminal 134, this current being shunted from the outputs 128 and 137 via these transistors 155 and 156, and here too the motor power can thus be controlled by means of a very small control signal.

Figure 9 shows a motor with a bridge circuit, of identical design to the bridge circuit 40' according to Figure 4, and so the same reference numerals have again been used. The freewheeling diodes 70' to 73' are not shown in Figure 9.

In Figure 9, the emitters of the bridge transistors 72 and 73 are connected together and are connected via a low resistance resistor 160 of, e.g. 0.1 - 3 Ohms to the negative lead 45. The base of the transistor 72 is connected to the terminal 137 of the unit 100, and the base of the transistor 73 is connected to the terminal 128. The capacitance 87, typically of 0.1 - 2 nF, which in many cases can be dispensed with completely, is in this case located directly between the terminals 128 and 137, while in Figure 6, the two capacitances 148 and 149 are located, connected in series, between these two terminals. Consequently, the capacitance 87 can be smaller than the capacitances 148 and 149. The terminal 105 of the unit 100 is connected via the diode 107 to the positive lead 44, and its terminal 108 is connected to the negative lead 45. As in the case of Figure 6, the junction 141 of the resistor 142 and the PTC resistor 143 connected in series is connected to the terminal 135.

The method of operation according to Figure 9 is identical to that of Figure 4. E.g. if the previously conductive transistor 73 is blocked, the voltage of its base is reduced very rapidly by the driver transistor 126 (Figure 6). This change in voltage is transferred via the capacitance 87 to the base of the transistor 72, keeping it blocked initially. An essentially constant current then flows via the constant current source 135 (or alternatively via the resistor 136) to the capacitance 37 and recharges the latter, the transistor 72, and with it the transistor 71, then becoming conductive after a short space of time. In the case of commutation in the reverse direction, this process obtains in reverse, as can be clearly deduced from the symmetry of the arrangement.

Figure 10 shows the use of a unit 100 for the operation of a single-phase, single-pulse motor 162 with one single phase 163 and a rotor 164. Motors of this kind are described, e.g. in DE-A-22 60 069. In this case, only one half of the unit is used, and the output 128 that is not used is ~~thus connected~~ via a resistor (not shown) to the negative lead 45. Its output 137 is connected to the base of an npn-Darlington transistor 165, its collector is connected via the phase 163 to the positive lead 44 and its emitter is connected via a low resistance resistor 166 to the negative lead 45 and via a shunting resistor 167 to the base. The unit 100 is disposed in the magnetic field of the rotor 164 and is controlled by the latter. A high resistance potentiometer 168 is located between the positive lead 44 and the negative lead 45, its pick-up 169 being electrically connected to the terminal 134 of the unit 100 and being mechanically actuated by bellows 170, evacuated in the usual manner. If the ambient pressure increases, the pick-up 169 is pushed upwards and the rotational speed of the

motor 162 increases, so that, e.g. more air is supplied if this motor is driving a fan. Similarly, e.g. it is possible to detect a differential pressure, or in the event of an increase in the air humidity, the rotational speed of the fan can be increased by means of a hygrometer. There are many possible applications in this connection.

The method of operation of the PTC resistor 101 in the supply lead is the same as that described in more detail with reference to Figure 5, i.e. when the rotor is blocked, the resistor 101 reaches a high value, thereby reducing the motor current to a low value. Reverse polarity is provided for by the diode 107, i.e. in the event of reverse polarity of the motor, the unit 100 receives no power and so cannot be destroyed.

Figure 11 shows a variant non-symmetrical design of the integrated commutation unit, here indicated by 100". The operation is the same as that of the units 100 (Figure 6) and 100' (Figure 7). The construction is also substantially the same. The voltage regulator 110 with its output 111 of, e.g. 3 - 5 V, the Hall element 112 with its outputs 113, 115, the comparator 114 and the first driver stage (constant current source 129 with a current of, e.g. 1 - 5 mA and the npn-driver transistor 126) are identical to the left hand portion of the circuit of the unit 100 according to Figure 6. The diode 133 of the current control element is also connected to the output 128 in an identical manner. The resistor 116 is preferably here, as in the preceding embodiments, much smaller than the positive feedback resistor 117, e.g. in the ratio 100:1 - 10:1. (This applies similarly to the resistors 121 and 122 in Figures 6 and 7).

The other driver stage (constant current element 135 for, e.g. 1 - 5 mA and the npn-transistor 127) also corresponds to Figure 6, as does the current shunting diode 138. The external terminals of the unit 100" are also indicated by the same numerals as the unit 100 of Figure 6, or the unit 100' of Figure 7, as the behaviour of these units (electrical characteristics, signals, operating voltages, etc.) is essentially the same.

In the embodiment according to Figure 11, however, in comparison with the embodiment of Figure 6, the second comparator 120 can be dispensed with and replaced by a phase inversion stage 175, illustrated in this case as an operational amplifier, connected for the voltage supply to the controlled voltage 111 and to the terminal 108. Its negative input is connected via a resistor 176 to the junction 118, i.e. the output of the comparator 114, and it is connected via a resistor 177 to its output 178.

The resistors 176 and 177 are preferably of approximately identical size in order to obtain an amplification factor of approximately 1. The output 178 is connected to the base of the driver transistor 127 and controls the latter. The inversion stage 175 thus provides for phase inversion of the essentially square wave signal u_{114} (junction 118), indicated by 180 in Figure 11. According to Figure 11, by this means, out of phase signals are obtained at the outputs 128 and 137, and also at the outputs 128 and 137 of the unit 100 of Figure 6. Thus, although the circuit of the unit 100" of Figure 11 has a non-symmetrical construction, its operation is the same as that of the circuit 100 according to Figure 6 or 100' according to Figure 7. The version used depends on various

criteria, inter alia, which circuit can be integrated more easily.

However, one essential advantage of the circuits according to Figures 6 and 7 is that in this case two different signals are delivered by the Hall element 112, which are then processed into different signal lines, whereas in the case of Figure 11, the Hall element 112 only delivers one single signal, which is sometimes used directly and sometimes after phase inversion.

If two different signals are used and are fed to two different comparators 114 and 120, as shown in Figure 6 or 7, these comparators can be adjusted in such a way that the output signals are spaced at a small time interval from one another, or are directly adjacent to one another or overlap one another. The first possibility (time interval) is of course the preferred solution for many motor designs, as it improves efficiency. This applies particularly in the case of ~~two-pulse~~ motors.

Figure 6 shows an example of this variation. To this end, the positive input of the comparator 114 is connected via a high resistance resistor 185 to the controlled positive output 111 of the voltage regulator 110, and the positive input of the comparator 120 is likewise connected via a high resistance resistor 186 to the output 111. E.g. in Figure 6, the resistor 117 is approximately 10 - 100 times larger than the resistor 116 and the resistor 185 is approximately 200 times larger than the resistor 116. The same thing applies to the other side of the circuit by virtue of the symmetry. Therefore, the comparator 114 does not commutate until the Hall output 115 becomes more negative than would be necessary without the

resistor 185. Conversely, the comparator 120 does not commutate until the Hall output 113 becomes more negative than would be necessary without the resistor 186. The required time interval between the signals at the outputs 128 and 137 is thus obtained in a very simple manner. The same effect can of course also be achieved by controlling the reference voltage at the other comparator input in a corresponding manner.

Therefore, whilst having an extremely simple construction, the invention provides excellent efficiency and operational reliability, and, by virtue of the small number of components, is particularly suitable for use with fans of the apparatus fan type, frequently having an overall length of only approximately 38 mm, so that only minimum space is available for the circuit components. The invention can also be used for what are known as half bridge circuits.

CLAIMS

1. Brushless direct current motor, with a stator winding which has at least one phase (25), with a permanent magnet rotor (11), with a rotor-position sensing arrangement (32; 100; 100'; 100"), and with a semiconductor arrangement (40; 40'; 102, 104; 165) serving for the control of the current in the stator winding, said semiconductor arrangement having at least two switching elements (72, 73; 102, 104) which, in dependence upon the position of the rotor, are commutated in order to power the at least one phase (25) in dependence upon the rotor position, a current interruption (32) being produced between each two successive current impulses, and with driver stages (54, 58; 54, 94; 126, 127), associated with the switching elements (72, 73; 102, 104), characterised in that the driver stages each have an electronic semiconductor switch which in its conducting state essentially short-circuits the input of the associated switching element (72, 73; 102, 104) and thereby blocks the latter, that the driver stages are further associated with respective sources (59, 63; 88, 90, 95; 129, 135) of substantially constant current, preferably of the order of a few milliamps, from which an actuating current flows to the associated switching element (72, 73; 102, 104) when the electronic semiconductor switch of the respective driver stage is non-conducting, and that a capacitance (64, 66; 87; 148, 149) is connected to the output (J1, J2; 128, 137) of at least one driver stage (54, 58; 54, 94; 126, 127) in order to delay the actuation of the associated switching element (72, 73; 102, 104).



2. Motor according to claim 1, characterised in that a common capacitance (87) is provided for two driver stages (54, 94), the capacitance being connected between the outputs (J1, J2) of these two driver stages (54, 94) in order to delay the actuation of the switching element (72, 73) about to be actuated and associated with one of these driver stages (54, 94) (Figures 4 and 5).
3. Motor according to claim 1 or 2, characterised in that the voltage increase at the output of at least one driver stage (126, 127) is adapted to be limited by an additional signal (at the input 134).
4. Motor according to claim 3, characterised in that, for the production of the additional signal, a temperature-dependent sensor (143; 144') is provided in order to control the rotational speed of the motor in dependence upon the temperature (Figures 6, 9).
5. Motor according to one or more of the preceding claims, characterised in that the switching elements serving for energizing the at least one phase (25) are formed as transistor devices (102, 104) with high current amplification.
6. Motor according to claim 5, characterised in that the transistor devices comprise a common, preferably low resistance emitter resistance (103, 160) connecting them to a current supply lead (45).
7. Motor according to one or more of the preceding claims, in which the rotor-position sensing arrangement comprises a



Hall effect sensor (112), characterised in that the Hall effect sensor (112) and the driver stages (126, 127) are connected together in an integrated circuit.

8. Motor according to one or more of the preceding claims, characterised in that the rotor-position sensing arrangement comprises a Hall-IC (112) which is controllable by the magnetic field of the rotor magnet (13) and which produces a square wave signal (80) at its output (55) on passage of a magnetic pole of the rotor.
9. Motor according to one or more of the preceding claims, characterised in that two transistors (72, 73) of a full bridge circuit (40') are connected to the outputs (J1, J2) of the driver stages, and that the two other transistors (70, 71) of this full bridge circuit (40') are controllable by the outputs of said first-mentioned transistors (72, 73).
10. Use of a motor according to one or more of the preceding claims for driving a fan (17), particularly an apparatus fan of axially short construction.