

The invention relates to a motor or position indicator (position sensor) according to the preamble to Claim 1. In this case, the term 'motor' will also for example embrace a linear motor of which it is desired to detect the position.

Both a rotary motor and also a linear motor comprise a rotor as their moving part.

Various types of position sensors are known. These are used for example for detecting the position of motor elements. In most cases, there is an associated linear acting principle for a rotary acting principle. The most important classes of such position transmitters or position indicators are based on the following devices:

Position sensors with direct contact with the movable element:

- a) Mechanical contacts.

Position sensors with means which operate without contact:

- a) Optoelectronic position sensors:
Light barriers, differential photosensors, optical interference sensors
- b) Magneto-electronic (galvanomagnetic) position sensors:
Hall effect sensors (based on Hall generators), Wiegand effect sensors, magnetostrictive sensors, magnetoresistive sensors,
- c) Electromagnetic position sensors:
Resolvers, eddy current sensors, differential transformers
- d) Electrical position sensors:
Capacitatively acting position sensors, microwave distance measuring instruments.

This list represents only the most important classes and constitutes only a small selection of the sensors for rotary or linear measurement problems which are in practical use. The position detection methods will be explained hereinafter in so far as they are used in electric motors which operate on a linear or rotary basis.

Hereinafter, reference will be made to the electrical angular position. This is measured in electrical degrees, e.g. 20° el. In the case of a two-pole motor, in which the pole number $p = 1$, the electrical degrees of the rotor position correspond to the mechanical degrees. In the case of a motor with four poles ($p = 2$), the rotor, when it rotates through 360° mech, passes through a total $p \times 360^\circ$ el, in other words 720° el, etc.

The described measuring methods according to the invention respectively agree within a range of 360° el, i.e. they determine the electrical angular position of the rotor. For example, in the case of a four-pole motor ($p = 2$), the measured electrical angular position 90° el may denote a rotor position of 90° el or of $(90 + 360)^\circ$ el, which is however unimportant for commutation control.

In addition to the methods which detect a position in motors by means of external sensors (for example with Hall effect sensors, with light barriers, with magnetoresistive sensors), there are methods which are intended to detect the position of a motor by means of components within the motor. These methods can be substantially subdivided into two categories.

A first category uses generator properties of motor coils. A position is determined dynamically. As a function of the extent or of the integral of the generated voltage as a function of time, so it becomes possible to deduce the

position of the rotor.

This class is characterised by different areas of application and the most widely diverse constructions. As an example of the relevant state of the art, the following patent literature may be cited:

US 4 495 450
EP-B 0171635
DE-OS 27 52 880
DE-PS 30 13 550
*EP-A 0316077

In this respect, it is immaterial whether the magnetic field of the rotor is generated by permanent magnets or by electromagnets. Therefore, here or hereinafter, where mention is made of permanent magnets, such reference will always include electromagnets unless anything to the contrary is stated.

In the same way, it is possible functionally to interchange rotating and stationary parts of the electric motor, i.e. the invention is equally suitable for internal rotor-type motors, in which the permanent magnet rotor rotates and the winding of the rotor remains stationary or conversely motors in which the winding of the motor rotates and is supplied with current for example via slip rings and the permanent magnetic part remains stationary and other constructions of motor, as illustrated hereinafter in detail with reference to examples.

In a second category, the position recognition methods are based on the fact that the motors in question are not ideal, i.e. that despite constant and imprinted electrical quantities, usually variable position or angular

dependences of the mechanical quantities can be established.

In this case, therefore, those physical effects are of interest which are based on the position-dependent variation in electrical or electromagnetic parameters of the motor and which can be experienced by being checked with solely electrical means. Such a check or measurement of interesting parameters can be carried out for example in that one or a plurality of suitable additional measuring coils is or are provided at one or at a plurality of locations within the motor.

As bipolar units, the coils have complex resistors which are characterised by ohmic resistances and inductance values. These complex resistors are usually also frequency-dependent.

When choosing a suitable location within the motor, one or a plurality of the said quantities will be dependent upon whichever is the assumed position of the rotor, in the case of either a linear or a rotary motor.

For example, by extremely precise determination of the inductance of the measuring coils, it is possible to deduce the position of the rotor, at least its electrical angular position, as explained at the outset. A disadvantage in this respect is that instead of an externally mounted sensor, a sensor has to be provided in the form of at least one additional measuring coil inside the motor.

Where a plurality of such measuring coils are provided, then in addition to the complex input resistance and the complex output resistance, also the coupling ratio of two coils must be used as a measured quantity. Then, there are various possibilities for combined measurement of

the position-dependent quantities. In addition, also different frequencies or mixtures of frequencies may be used.

A method of this type is described for example in German Patent Specification 26 16 552. It is advantageous that in this respect the inductances of the coils can be so designed that also higher-frequency test signals can be used without difficulty.

In the case of a technically improved procedure, there is no additional fitting of measuring coils inside the motor. Instead, the inductance values of the motor's own inductances, in other words the strands (phases) or coils of the motor are also used for the process of measurement which is to be performed.

Since in the case of the last-mentioned category of sensors, in addition to the necessary sensor electronics, no additional structural complication is necessary, all members of this category enjoy a potentially substantial cost advantage while at the same time the reliability of the motor is improved.

Examples of such arrangements are disclosed in EP-A 251785 or EP-A 171635. In the case of the arrangement according to EP-A 251785, essentially only the additional power stages are needed to control the motor phases, as well as some special components as electronics for operating the motor. However, the circuitry has the drawback that a range of 360° el which has to be measured is divided into two indistinguishable ranges of 180° el each. This is based on the fact that symmetrically with the angle of 0° el or 180° el, in the subsequent range of 180° el to 360° el, function values are found which are of equal magnitude. This means that no-one knows whether a

basic value of 0° el or one of 180° el has to be added to the calculated rotor position (Fig. 22A). In addition, the accuracy of precision detection is limited to about $\pm 60^\circ$ el.

An arrangement for and a method of circumventing this problem are indicated in a work by Watanabe, Isii and Fuji (IECON 87, pp. 228 - 234). The solution in this case is based on the fact that according to the pole position of the permanent magnet of the rotor, through the permanent magnet pre-magnetisation, an individual stator coil has a current passed through it either more rapidly or more slowly in the case of a reverse pole position or current application direction.

This is based on the non-linear magnetisation characteristic of the participating soft magnetic coil cores or magnetic circuit and the resulting inductance variation in the coil through which current flows. This circuit gives a position determination of the rotor within a range of 360° el without ambiguity.

Certainly, here, too, the accuracy of position determination still leaves much to be desired. The typically attainable accuracy is limited to $\pm 15^\circ$ el. Nevertheless, this precision is sufficient for one to be able to rotate a suitable motor in a controlled manner. Above a certain angular velocity, then, the voltages induced in the coils become so great that they can only be used for "dynamic" determination of the commutation times and an acceleration to higher angular velocities is possible.

This rotary speed-controlled change between position recognition by a static method to a dynamic method is likewise described in the aforementioned EP-A 251785 and

the above-mentioned citation of Watanabe, Isii and Fuji.

Further methods: by position-dependent variation in the coil inductances, it is also possible under suitable conditions to use the transformer coupling ratio between two coils in order to determine the position of the rotor.

In addition to analysing the amplitude behaviour, it is also possible to analyse the time behaviour. The last-mentioned method is referred to in JP-PS 60-207489 and in Ishii and Watanabe, Mem. Fac. Eng., Osaka City University, Volume 26, pp. 57 - 65 (1985).

In order to be carried out, all the methods referred to usually require the use of comprehensive electronic aids.

Methods of this type are particularly used in commutator-less direct current electric motors. By virtue of their simple construction and the resulting advantages in terms of reliability and efficiency, these have enjoyed widespread use.

Essential components of such commutatorless motors are: magnets, coils (with or without an iron core), position sensors, controlling and power electronics. Under normal circumstances, these motors are controlled by galvanomagnetically operating position sensors, e.g. Hall generators, whereby, as controlling magnets for these position sensors, also the working magnets of the motor may be used, in other words their rotor magnets. In this case, the reliability of such an arrangement is however limited by the reliability of the sensor components, their feed line and by the operating temperature of sensors and control magnets.

Therefore, in order to improve the reliability of such devices, it is advantageous entirely to dispense with external position sensors. In order to determine position by using the motor's own components, therefore, it is necessary to use the motor coils jointly as the system's own sensor elements, in parallel with their functioning to drive the motor. An advantage which is achieved at the same time must be regarded in the fact that by dispensing with external sensor elements, e.g. the Hall generators, structural volume is saved and smaller overall sizes are made possible. For operating the motor without external position sensors, the motor is expediently moved alternately into the state of a sensor and then into the state of a motor (actuator), and then back into the condition of a sensor etc.

However, it proves to be relatively difficult to detect the position when the motor is stationary. In particular, the difficulties reside in generating sufficiently accurate position data from a minimum of measured data within the absolutely shortest measuring time and signal processing time. In a simple case, it is sufficient to use a reduced accuracy to establish only commutation times for which it is necessary to change the current flow conditions of the motor. According to the motor operation requirements, so it is possible for the position of the rotor to be determined within an accuracy of $\pm 10^\circ$ el. In another case, it may for example be necessary, for the purpose of controlling the motor, to obtain extremely accurate measured values within a very short measuring time so that it is possible to achieve a desired speed correction or position check. This problem imposes increased demands on the performance of the associated electronics and on the software used. In the case of the known methods, a further difficulty resides in reliably excluding the possibility of generically typical

phase errors of $\pm 180^\circ$ el when determining the position of the rotor. Such errors mean that when the rotor is rotated on through 180° el, 360° el etc., the typical position data is in each case substantially unaltered in comparison with the original position.

Therefore, one object of the invention is to provide accurate and nevertheless inexpensive and insensitive sensors for rotary movements or linear movements. A further problem on which the invention is based resides in providing reliable motor operation by reliable commutation processes.* A further object of the invention is to bring about a secured starting direction of such motors.

In accordance with the invention, these problems are resolved by the measures indicated in Claims 1 and 37. The invention also makes it possible to enhance the useful range of speeds compared with the state of the art. According to the invention, it is possible to improve accuracy when determining position by employing microelectronics and the software used so that the relative errors are restricted.

Further details and advantageous further developments of the invention will emerge from the examples of embodiment described hereinafter and shown in the accompanying drawings and referred to in the sub-claims. In the drawings:

Fig. 1 shows the basic structure of the control electronics for a motor,

Fig. 2 shows the basic structure of a commutating processor,

Fig. 3 shows the non-linear behaviour for

ferro-magnetic core materials for coils and relative permeabilities or inductances,

Fig. 4 shows the field pattern for a DC motor when it is in no-load operation,

Fig. 5 shows the field pattern for a DC motor when current is being applied to it,

Fig. 6 shows the diagrammatic construction of a reluctance motor with six coils and a rotor with quad symmetry,

Fig. 7 shows a 3-T armature motor with three coils and two magnetic poles,

Fig. 8 shows a stator of an external rotor-type motor with stator plates and stator phases,

Fig. 9 shows the field pattern of an internal rotor type motor with four poles and six stator phases,

Fig. 10 shows the motor according to Fig. 9 by way of explaining the magnetic flux in different stator elements,

Fig. 11A shows a further flux pattern for a non-symmetrical rotor position of the motor according to Fig. 9,

Fig. 11B shows the construction of the rotor for a flat motor with a different construction of individual rotor poles,

Fig. 11C shows the construction of a rotor similar to Figs. 8 to 11A with a differing magnetisation of individual rotor poles,

Fig. 11D shows a motor construction with a different construction of air gap between individual stator poles,

Fig. 11E diagrammatically shows various alternative ways of generating saturation in the stator iron,

Fig. 12 shows the current application pattern for obtaining measured values,

Fig. 13 shows the derivation of a mean from a plurality of measurements,

Fig. 14 shows the linear disposition of a plurality of position-dependent mean values,

Fig. 15 shows the comparison of positions of two phase-displaced curves,

Figs. 16A to 16C show different ways of conducting position comparison between two phase-displaced curves,

Figs. 17A and 17B are a spatial representation of a measured result consisting of three individual measurements and its evaluation,

Fig. 18 shows the two-dimensionally orientated view of a measured result with three individual measurements, and their evaluation,

Fig. 19A is a diagram showing the application of current to three coils by means of six switches,

Fig. 19B shows the resulting flow of current in the coils in Figs. 19A for in each case two closed switches,

Fig. 19C shows a simple sequence of current

application and six associated current patterns,

Fig. 19D shows a diagram for ascertaining the fundamental wave of a function, in fact graphically with six values M1 to M6 (corresponding to a motor with three or with six phases L1 to L6, as is shown for example in Fig. 9),

Fig. 20 is a view of a vector sum, calculated according to the above calculating specification according to Fig. 19D,

Fig. 21 shows a flow diagram for phase and amplitude determination of the first harmonic of a function which is determined by six supporting values,

Fig. 21A shows the approximated and periodically continued curved pattern by six supporting values M1 to M6 as well as the phase position of the associated first harmonic,

Figs. 22A, 22B and 22C are a representation of inductance-dependent values compared with the electrical angle,

Fig. 23 shows the pattern of a correcting function for the correlation of an actual value with a characteristic value of the rotor position,

Fig. 24 shows a flow diagram for the application of current to a motor or position sensor,

Fig. 25 shows a diagram illustrating various possible ways of controlling starting and

Fig. 26 shows a flow diagram indicating the pattern of

measurement of the rotor position alternating with the application of current in the case of a motor.

The thought according to the invention as a way of resolving the problem posed comprises the following parts:

- a) A microprocessor is used. The novel type of current application required for measuring purposes is monitored by a microprocessor.
- b) Measurement and novel evaluation of the measured values are likewise carried out by the microprocessor with associated interface circuits.

However, in this respect, it must be borne in mind that inexpensive microprocessors only have a low computation speed and in most cases they are incapable of handling the problem which has to be resolved. In accordance with the invention, it is possible in order to resolve this particular problem to have the performing, controlling and measuring processes carried out at least in part by a specially prepared auxiliary processor.

The basic structure of such an apparatus according to the invention is shown in Fig. 1. In addition to the actual motor 10, it consists of an associated current applying and output stage unit 26, a commutating processor 100 and also the controlling or regulating microprocessor 23. Hereinafter, instead of the term microprocessor, also the term processor is used as a simple and brief term. As shown in Fig. 1 for example, the motor 10 may be a three-phase brushless DC motor. However, the invention is not confined to such motors but, as shown in later illustrations, it may also be advantageously used with other motor constructions. In addition, it is an object of

the invention when required to dispense completely with motorised drive and to use the motor solely in sensor mode in order to determine positions.

Where the output stage unit 26 is concerned, this is essentially a switching unit for applying current to the individual motor phases.

It is expediently constructed in conventional technology and an arrangement of for example three transistor half-bridges. Such circuits are known for example from DE-OS 31 06 856. Other constructions, for example with thyristor elements or SCR elements, are likewise conceivable. The output stage unit 26 comprises a plurality of control inputs (261 to 266) for actuating the electronic switches contained in it but not shown in the drawings. These switches apply current to the motor 10 via the individual phases in accordance with the attached signal combination of the switch inputs 261 to 266.

The resulting overall motor current is measured via any desired current sensor, e.g. the measuring resistor 1011 in Fig. 2 and fed via the current sensor output 267 to the input 101 of the commutating processor 100 as a measured signal.

Further elements which are not shown in the drawings may for example consist of a control unit which ensures that a predetermined current strength and of a pre-defined magnitude is fed to the individual phases of the motor 10. Such an imprinting of pre-defined currents can be achieved for example by using conventional lineally acting control stages. However, it may also reside in the fact that conventional switching controllers are used for this purpose.

Substantially, the problem for the commutating processor 100 is to receive current sensor signals 267 and voltage signals 111, 112 and 113 from the three motor phases L1, L2, L3 (Fig. 2) and to use them for calculating commutating signals. In addition, the commutating processor 100 has analogue and digital control and communications 102 to 110 to the superior processor 23. The commutating processor 100 can by itself, i.e. without the microprocessor 23, but also in conjunction with the output stage unit 26, provide for orderly operation of the motor 10.

However, it is additionally possible in a processor-controlled mode, to carry out controlled movement patterns of the motor and to carry out only one position recognition while dispensing with motorised drive. For this purpose, the interaction of processor 23, commutating processor 100 and output stage unit 26 are needed. One problem for the processor 23 is to use sample and hold- signalling conductors 105 to establish points in time at which current sensor signals 267 are to be ascertained. These current sensor signals are fed to the processor 23 via the power line 102. When needed, the commutating processor 100 can also ask the microprocessor 23 via the conductor 104, to receive a current measured value or to carry out other processor activities. The object on which the processor 23 is substantially based is to use current sensor data acquired in this way to calculate the correct position of the rotor of the motor 10. The data thus calculated can be shown for example on a display unit. However, such data may also be communicated to a superior computer system for further processing. This position data can via the position conductors 108 to 110, be made known to the commutating processor 100 which will in turn carry out a correct commutation of the motor 10 on the basis of this data.

As can be seen in Fig. 2, the commutating processor 100 consists substantially of the following units:

Central component of the commutating processor 100 is the commutating logic 1002. From externally predetermined position data fed in through the line 108 - 110 or from coil voltages measured via lines 111 - 113, this calculates initially the point in time, i.e. the next point in time, at which commutation of the motors is to take place.

For this purpose, a commutation switching signal or actuating signal is generated which is communicated to the output stage unit 26 via signal line 261 to 266. Instead of direct transmission of switching signals, it is also possible, naturally, to transmit such signals in coded form.

Furthermore, the commutating logic 1002 is influenced by a commutating control unit 1005 which can react to different external signals.

Such signals may for instance be the start mode signal 107 or the microprocessor present signal 106. Exception signals C1 to C4 can likewise influence the control unit 1005. In the same way, the control unit 1005 is influenced by signal voltages which are derived from the motor 10 coil voltages present at the inputs 111 to 113.

In order to assess such coil voltages, it is possible to use either coil voltages from idling mode or to examine coil voltages from current-carrying mode. For this purpose, an attenuating member 1008 is provided as well as a voltage comparison unit 1007 and a signal delay unit 1006.

The signals from the windings L1 to L3 therefore pass

first to the attenuating member 108, from there to the voltage comparison unit 1007 and finally from there to the signal delay unit 1006 from which they are passed on to the commutating logic 1002 and to the commutation control unit 1005. In this way, when a sufficiently high induced voltage (EMF) is attained in the windings L1 to L3, the induced voltage produces a switchover to commutation.

A further device in the commutating processor 100 is the current detection unit 1009. The purpose of this is to detect, amplify and process current sensor signals 267.

This happens in that the current sensor signals 267 are amplified and stored at given points in time. In this way, it is also possible to a certain extent to freeze rapidly variable current patterns and feed them to the microprocessor 23 via the current output or current signal line 102 for further processing. The processor 23 then has sufficient time to evaluate these current signals since the stored signals do not initially undergo further change. In addition to the internal switching means, the commutating processor 100 usually has external switching means such as resistors and capacitors. These are not shown in Figs. 1 and 2.

Further details of the commutating processor 100 are a starting oscillator 1004 and a counter 1003 for the optional generation of preset times or preset commutating patterns. As mentioned, the independent functioning of the commutating processor 100 without an associated microprocessor 23 is based on evaluation of the induced voltages (EMF) at the motor phases L1 to L3, such as are generated for example under no-load conditions.

However, this operating mode is only viable if the rotor of the motor is already in motion. Furthermore, a

positioning measuring process utilising these signals requires a moving rotor for correct operation while using these signals.

In the event of the motor stopping, either a non-directional starting movement has to be initiated or, by a special application of current to the motor phases L1 to L3 and measuring the individual phase currents, it will be necessary to obtain the necessary measurement data.

Examination of this pattern of phase currents can vary widely in form. The simplest possibility resides in evaluating the time pattern of the total motor current.

In addition, it may according to the invention be advantageous to apply current to a plurality of stator phases for measurement purposes and to record the current intensities at different times. According to the output strength of the processors used for this purpose, i.e. microprocessor 23 and/or commutating processor 100, so therefore either one or more current values, particularly maximum current values, just at selected points in time may be recorded or only the points of time associated with specific threshold current values will be recorded or one or a plurality of current patterns may be recorded in terms of time and intensity and with reference in each case to a plurality of measurement points. The values recorded in such a way implicitly represent numerical values for the sought and rotor position-dependent inductances or mutual inductances of the motor phases.

Under certain conditions, they may also be numerical values representing transformer coupling ratios.

As Fig. 3 shows, position data can be obtained successfully by an appropriate application of current to

stator phases in that by applying various levels of current, the iron components of a magnetic circuit to which the coils of this phase belong are brought close to saturation or actually to a saturated condition. Correspondingly, the total inductance of a participating coil will alter, since for otherwise constant conditions, the coil formula $L = n^2 \mu \mu_0 F/d$, it is generally only the μ which alters and so any change in relative permeability results in a proportional variation in inductance L . As is the case with iron, the non-linear relationship between field strength H and magnetic flux density (induction) B can be used in order to establish current-dependent effective inductances in the participating stator coils.

However, the inductance of the stator coils is not influenced solely by the level of the coil current but also by the polarity of permanent magnets of a rotor, said permanent magnets being opposite these stator coils.

This is based on the fact that the permanent magnets produce a pre-magnetisation of the coil cores so that according to the polarity of the coil current, so saturation of the coil core takes place either more rapidly or more slowly than in a neutral situation, i.e. without permanent-magnetic pre-magnetisation. With the conventional design of the magnetic circuits of motors of the generic or general type, the endeavour in most cases is to keep the magnetic flux density in the iron components far below saturation point in order to minimise stray flux components.

Since the fluctuation in the stator coil inductances caused by movement of the rotor and nominal application of current usually amounts to just a few percent, for trouble-free measure data acquisition in order to establish a position, it is important to adopt additional measures to

achieve the greatest possible variation in inductance over a motor motion range of 360° el.

For this purpose, for example the magnetic circuit of the motor can be modified. Optimisation with a view to a substantial variation in coil inductances as a function of the rotor position may possibly result in a reduction in maximum motor efficiency.

Therefore, in accordance with the thoughts underlying the invention, it is advantageous to apply current not only to one coil but also to more than one.

Similarly, it is advantageous to apply a relatively high current compared with the norm for a short period, i.e. in the range of a few dozen microseconds (e.g. from 10-2000 microseconds).

Correspondingly, it is according to the invention advantageous to apply current to a combination of coils in a manner not normally used for driving purposes. If such an application of current is time-limited, then there is no need to fear any significant losses in motor efficiency during motor operation.

For example, in the case of one embodiment of the invention, it is possible for a very high level of current to be applied to two stator coils of a three-phase motor for a short time, a high and short current pulse of current being applied to the third stator coil in the meantime. The current-time data obtained in this way is usually more enlightening than comparable data obtained by conventional means and methods according to the state of the art.

In order to arrive at the said differences in inductance, it is useful therefore, as stated hereinabove,

to apply current to some of the existing coils in such a way that their ferromagnetic cores are as far as possible close to or in the saturation range.

An additional pre-magnetisation by permanent magnets within the magnetic circuit or circuits can, as already stated, be of assistance but is not necessarily a prerequisite.

In the case of a motor, Fig. 22A shows the pattern of coil inductance over the angle of rotation of the rotor.

According to the motor design, so fluctuations in inductance occur over a range from a few to several percent. As Fig. 22A shows, in the case of this type of motor, this function is periodic, with a cycle of 180° el.

When permanent magnetic pre-magnetisation is present, this curve becomes asymmetric (Fig. 22B) and then has a period of 360° el, so that unequivocal measurements are possible in this angular range (360° el). The pattern of the curve in Fig. 22B depends upon the intensity of pre-magnetisation (by a permanent magnet) and can be further enhanced by the application of current to additional coils. In this case, the coils to which current is applied are to a certain extent in saturation.

Fig. 22C shows the same situation as in Fig. 22B, in other words the inductance plotted on the polar coordinates and as a function of the angle of rotation of the motor.

This pattern is similar for each of the motor coils. Compared with a neighbouring phase, however, a corresponding phase offset of 360° el. : n will be noted, where n denotes the number of motor phases. However, this denotes the following connection, found as a result of the

invention: if a motor comprises for example six phases and if inductance measurements are carried out on all six phases one after another but almost simultaneously, then the measured values obtained likewise define a curve which can for example also be drawn in polar coordinates (Fig. 22C).

Regardless of the rotor position, all the curves obtained in this way have the same basic form. However, they are rotated through a phase angle in comparison with a standard representation, i.e. showing the curve associated with a basic position. This phase angle is surprisingly also a measure of the mechanical rotor position. It is evident that the dependency of the inductance of one phase upon the position of the rotor should be as great as possible in order to be able to perform a precise and unequivocal measurement.

In accordance with the invention, an additional possible way of bringing this dependency about resides in so designing permanent magnets of the rotor that an irregularly high effective field strength in these permanent magnets is achieved.

For example, this can happen if during magnetisation of the rotor an unevenly high level of magnetisation is achieved or if after magnetisation is completed, there is a controlled demagnetisation of individual magnetic poles.

Another possibility resides in following a combination of equally strong north and south rotor magnetic poles by a similar arrangement of which however the effective field strength has been reduced by a constant amount.

These relationships are explained in greater detail with reference to Figs. 11B and 11C. In Fig. 11C, for

example, the rotor magnetic pole 501 and 502 are more intensely magnetised than the rotor magnetic pole 503 and 504.

Instead of differently intensely magnetised permanent magnets of the rotor, it is possible alternatively or additionally to use an arrangement comprising differently sized air gaps 1121, 1122. This is shown in Fig. 11D.

The same effect is achieved by using an arrangement of magnetic partial resistors of different sizes. This can for example be set up in that the ferromagnetic coil cores are of different sizes or in that yoke elements of the magnetic circuits are given a different magnetic resistance, either by varying the length or cross-section or by the introduction of air gaps. The embodiment shown in the drawings, Fig. 11E, diagrammatically illustrates a linear motor which, as its rotor element, has a permanent magnet with north poles 1101 and south poles 1102. Opposite the magnetic poles is the stator unit 1103 with stator pole shoes 1104. Specially shaped stator webs of elongated form (1105) or short form (1106) connect the stator pole shoes to the return plates 1008.

The stator webs themselves are wound with corresponding coils 1107. Compared with the normal cross-section, the return plates 1103 may have a reduced cross-section 1109 or an increased cross-section 1110. Even the incorporation of an air gap 1111 may be expedient. The advantage of these arrangements resides in the fact that as a result of the different levels of magnetisation within the magnetic circuit, an additional location-dependent datum (coding) is incorporated into the motor or position sensor. Consequently, it is possible to achieve a more precise and also a geometrically farther reaching determination of position which makes it possible

to determine an absolute position within the full angle of rotation of 360° el. The procedure according to the invention whereby the application of high level and pulse-like current can bring some ferro-magnetic parts of the magnetic circuit to saturation or close to magnetic saturation naturally presupposes the use of magnetic circuits which are equipped with permanent magnets of a sufficiently high coercive field strength since the application of current for position measuring purposes must not result in any demagnetisation of the magnets. Correspondingly, when alnico magnets are used, this point requires particular attention. When using modern magnetic materials such as for example rare earth cobalt materials or neodymium-iron-boron materials, no problems arise in this respect.

Prior to calculating a current position of the rotor, it is necessary first to acquire a sufficiently large number of measured values. It is expedient to separate the acquisition of measured values from the relevant evaluation, so that measured values are acquired in the shortest possible time. The faster the rotor of the motor is already moving, the more care and attention must be paid to this requirement.

Otherwise, a mixing of measured values from various positions must be anticipated so that an unequivocal reconstruction is possible only with difficulty or perhaps remains altogether impossible. In the evaluation phase, time limitations of this type are no longer so critical. Nevertheless, it is a good idea to limit the evaluation phases to a time-related minimum in order to obtain the most comprehensive possible measured data based on the largest possible number of measured values per unit of time.

For acquisition of the measured values, the following procedures are the most suitable, although others are possible:

- Application of current to a predetermined stator winding with the object of achieving high magnetisation of its ferromagnetic core.
- Recording of the current in this stator winding at several points in time. This current pattern is, for example in Fig. 12, designated by the pulse sequence 1 as I_1 . For example, along with continuous current registration, it is possible also to observe just one single measurement point M_1 . For this, for example after a given time differential $t_1 - t_0$, the associated current value is determined. Alternatively, at a predetermined current value, e.g. half the maximum current value, it is possible to ascertain the time required for the current to rise from 0 to this value.

(The current I_1 is switched on at t_0 and measured at t_1).

This process is repeated in parallel or with a minimal time offset, i.e. in a range from about 10-1000 microseconds, in a further stator coil without the first stator coil being switched off.

Fig. 12 shows this time-related connection for the application of current to a selected number of three coils whose current is designated I_1 , I_2 and I_3 . If further coils exist, then for a more extensive acquisition of data, so one or a plurality of additional processes of the same type may be applied to a fourth or further stator coils. Once current has been applied to all stator coils in question, then either they are all completely and

simultaneously shut down or, as shown in Fig. 12 for the pulse sequences 1, 2 and 3, one clearly defined shut-down procedure is performed. Also in both these cases, it is possible likewise to perform time and/or amplitude measurements, e.g. the amplitudes M4, M5, M6 at points in time t4, t5 and t6 respectively.

Thus, it is for example possible to switch the coils in a currentless manner in reverse order compared with the connection frequency. In this way, in a first pulse sequence 1, there is a first set of measured values which in the simplest case consists of one single measured value. If two measured values are obtained per coil, as is shown in Fig. 12, then for a motor with three coils, already six measured values M1 to M6 are available.

In addition, it is naturally possible to obtain from rising and falling flanks additional measurement points and to have them to influence further calculations.

Generally, the endeavour will be to crystallise from a plurality of such measured values just a few which are representative.

However, generally it is as yet impossible to determine a position on the basis of a single first pulse sequence. For this purpose, further sets of measured values must be acquired. The associated procedure is outlined in Fig. 12 with the power application curves pulse sequence 2 and pulse sequence 3. This process is equivalent to that concerned with the said pulse sequence 1, the application of power starting however with a stator coil disposed in the vicinity of the coil 1.

For a motor with three coils, it is possible for example to start by applying current to coil 2 whereupon,

briefly afterwards, current is applied to coil 3 and then coil 1. Logically with the process of applying current during pulse sequence 1, then at given times the application of current to the individual coils will be broken off even in the case of pulse sequence 2. In a pulse sequence 3, the cycle resumes but commencing with coil 3 followed by coil 1 and subsequently coil 2. If there are more than three coils, then complicated current application sequences may be performed. The current application requirement for virtually simultaneous application of current to further spools will always relate correspondingly to coils which are at comparable distances from the initially energised coil. Accordingly, then, since a start has been made by applying current to one coil, for example an immediately adjacent coil may likewise have current applied to it.

However, the second current application process may also relate to a coil which is at some distance from the initially energised stator coil. The most efficient coil energising sequence is individual and depends upon the motor type. For the purpose of complete data acquisition, the process is repeated several times. The application of power then commences with a different stator coil each time. Data acquisition is complete when, of all the stator coils in the motor, a set of measured values is present which has been generated cyclically by the same pattern.

However, it is also possible to carry out a simpler determination of position with reduced accuracy. For this, a smaller quantity of data is adequate, consisting only of sets of measured values emanating from fewer stator coils than corresponds to the number of stator coils actually present in the motor or rotary transmitter.

For three-phase motors with for example six stator

coils, it is sufficient for instance to analyse just three sets of measured values. In this case, it is advantageous if the sets of measured values are acquired from every second coil.

Once a predetermined number of sets of measured values have been acquired, evaluation is undertaken (according to the efficiency of the evaluating unit, naturally evaluation can be carried out also while the sets of measured values are being acquired). On a basis of the necessary speed at which even simply structured sets of data have to be evaluated,* so for analysing measured values, preferably a special microprocessor or controller 23 is used the programme of which is tailored to the position recognition problem which is to be resolved but which can also be used at the same time for standard motor operation.

For this purpose, it is possible for example to use a standard processor 23 with associated externally disposed expansion circuit or commutating processor 100.

A further possibility is to combine the units 23 and 100 so that on one and the same silicon surface there is a standard processor unit which is supplemented by customer-specific accessory function units.

Mean value formation:

The measured values ascertained in a pulse sequence, e.g. pulse sequence 1 in Fig. 12, are expediently combined into a single representative measured value. Since the measurement precision of the individual measured values, shown there as M1 to M6, will vary, it is logical to carry out a weighting when it becomes necessary to form a mean value. This may for example reside in calculating from the measured values M1 to M6 a mean value m1, using the

following or some similar calculation process (Fig. 13), the weighting factors having to be determined individually, e.g. :

$$m1 = (0.8*M1 + 0.3*M2 + 0.1*M3 + 0.7*M4 + 0.3*M5 + 0.1*M6) / 6$$

A logical mean value formation with the same coefficients can be used for pulse sequence 2, being applied to the measured values M21-M26 shown there, producing a mean value m2.

The same applies to the likewise shown pulse sequence 3, in which, then, the measured values M31-M36 logically have to be multiplied by the same coefficient, producing a mean value m3. The mean values m1-m3 then implicitly contain the required position data which must still be explicitly calculated from this data. Fig. 14 and Fig. 15 (bottom half) shows in a linear arrangement the amplitudes of the calculated mean values m1-m3. In a special case, it is also possible for $m1 = M1$, $m2 = M21$, $m3 = M31$ etc.

If further pulse sequences are present, e.g. pulse sequences 4, 5, 6 etc. which are not shown in the drawings, then the associated mean values m4, m5, m6 etc. have to be ascertained by comparable methods.

As the evaluation of values ascertained in this way has surprisingly shown, any measured value multiplet found in this way can be used to plot a substantially identical periodic curve K, as shown for example in Fig. 14 or as identified by reference numeral 161 and 163 in Fig. 15, the phase location of which must however have varied sufficiently long for the measured values, in this case for example m1-m3, to come to rest on the curve (Fig. 15, Fig. 16A). The measure of periodicity for this curve is identified by reference numeral 144 in Fig. 14.

The measure of the aforesaid phase displacement is already a characteristic of the actual position of the motor rotor.

Figs. 19A and 19B show a way of acquiring six values m_1 to m_6 . Three motor coils L_1 , L_2 and L_3 with terminals R, S and T have current applied to them via a switch set SW1 - SW6 (reference numerals 178 to 183). In each case one of the switches SW1 - SW3 and one of the switches SW4 - SW6 is closed simultaneously. In this way, there is a flow of current from the supply conductor 175 through the coils and the current sensor 177 to the earth potential conductor 176, the level of current being capable of detection via sensor conductor 184. The resulting current flows are shown in greater detail in Fig. 19B. At the intersections of lines and columns, the associated current flow is in each case shown for two switches. In this way, six switching possibilities are available. An application of current to ascertain the rotor position then passes for example as illustrated in Fig. 19C.

Firstly, the current flow i_1 is created by SW1 and SW5 and it increases in accordance with a rising flank 190, the intensity of which is measured after time lapse 193 and it delivers a value m_1 . Once a predetermined current application time has been reached, the current is switched off by opening the switches, and the result is a shut-down flank 191. This process with relatively rapid switch-on and disconnection times is, in accordance with the other switch combinations shown in Fig. 19B, repeated for a further five current applications i_2 - i_6 , whereby in each case after time lapse 193, the associated value m_2 , m_3 ,, m_6 is detected and is stored on an intermediate basis for further evaluation. Although this method is somewhat more expensive than the acquisition of just three values m_1 , m_2 , m_3 , the accuracy of rotor position determination is

however enhanced. As already mentioned, the object of measured values obtained in such a way is to plot an already known curve, the phase being however so displaced that the measured values lie on or as close as possible to the curve.

There are various ways of arithmetically calculating this phase displacement. For example, one of these possibilities lies in firstly determining a curve K which provides an optimum connection of the measured values to one another.

This procedure has the advantage that when comparing a found curve with a reference curve, then not only a few but any desired number of points can be compared with one another (Fig. 14).

In this way, the individual points on a found curve can then be displaced in fine steps until such time as both curves which are to be compared occupy an almost coincident position.

In order, then, from a set of measured values comprising for example three or six or further mean value points, to generate the smoothest possible curve, various prior art calculating procedures may be employed.

One of these calculating procedures resides in using obtained mean values m_1 - m_n as input values for a Fourier analysis.

In this case, these mean values are multiplied by suitable complex coefficients, e.g. the n^{th} cube roots of unity and are subjected to a complex summation. In per se known manner, the method is carried out individually for all spectral components. These spectral components are

already sine or cosine terms by means of which it is possible to construct a relatively smooth connecting function through the measurement points. The exact functional representation of the connecting curve is however obtained in known manner by a so-called inverse transformation.

According to the invention, however, it is extremely useful according to relevant prior art calculating instructions, to show a so-called spline function which constitutes an optimised continuous connection between all points of the set of measured values. Essentially, the generation of such functions differs from the first-mentioned method in that the ascertained spectrum is modified in a controlled manner or in that the functions are approximated, for example by third degree polynomials. In this way, a limited number of points $n_1 \dots n_m$ of a set of mean values are converted to a desired number of points of the matching spline function.

In order to determine the characteristic value for the position, the reference curve 161 and the actual curve 163 defined by current measured values have to be compared with each other (Fig. 15).

This is carried out as follows:

Both curves, hereinafter referred to as the measurement function and the reference function, are periodically supplemented outside the periodicity range 144, by others having the length of the periodicity range 144.

Both curves are tested for correlation, i.e. conformity or similarity, by means of a conventional calculation process.

According to the invention, this is carried out most expediently by applying the method of least squares (Fig. 16B), where the measurement curve is designated 163 and the reference curve as 161, the maxima 165 and 166 respectively being spaced apart by the distance d , 167.

For an agreed number of function values of measurement and reference function, the difference between any two associated function values is ascertained and squared (curve 164). The result is added to an overall total, i.e. the curve 164 is integrated between 0 and x_1 .

Once this calculation has been carried out for each pair of function values, the similarity is recognised from the total sum.

If the sum found in this way, in other words the integral of the curve 164, amounts in fact to nil, then identical functions are present and their phase difference is likewise nil.

Consequently, small totals denote considerable similarity of functions while large totals on the other hand show that the similarity of functions is small.

It is understood that at the aforesaid summation, it is necessary over a standard interval to total 0 to x_1 or to arrive at an integral total which is at least as long as that defined for example by the reference function.

Position-characteristic determination is now carried out in such a way that after a first summation process, further processes ensue. However, one of the two functions including their supplements, on both sides, are in each case successively further offset, in each case by a phase angle α 114 (Fig. 16C).

For that phase displacement which has a minimum summation result, the correlation is at its maximum and correspondingly a measure of phase displacement which is found in this way can be used as a rotor position characteristic.

For example, in Fig. 16C, it is possible with the phase differential ξ_4 already to establish a virtually complete agreement between curves 161 and 163.

A further method lies in displacing reference and comparison functions in respect of each other until such time as the sum of the absolute amounts of the differences in a number of function values of reference and comparison functions is as small as possible. This method is shown in Fig. 16A. The two functions to be compared each have a maximum 165 or 166. The phase offset is in each case identified by d . The differences in the function generate surfaces, the resulting total surface is likewise a measure of the congruence of both functions.

As in the present case, too, the smallest possible comparison amount, namely the integral of the function 168 between 0 and 360° el, denotes a ready conformity between the curves. When conformity is complete, the differential surface dimension amounts to 0. The figures for rotor position obtained in this way are obviously substantially more accurate than gained by ascertaining a maximum value of various supporting values of the function, as described in EU-A 251 785. However, the calculating cost required to achieve this improved accuracy is greater since on the one hand firstly the function values of the spline function have to be ascertained from interpolation nodes and secondly the optimum curve location must be determined by iterative curve comparison operations.

Both processes can be combined to constitute a possible solution to a pattern recognition problem. However, according to the invention, there are further solutions to the problem indicated:

A further such process is based on the method of centroid analysis. For this purpose, the values m_1 , m_2 etc. are represented in graphic form so that a surface is generated which takes the form of a regular or irregular polygon. In a particularly simple case, a position characteristic can be calculated from just three values, i.e. mean values m_1 , m_2 and m_3 .

The associated process according to the invention for calculating a value characteristic of a position does for this situation reside in plotting the three measured values m_1 , m_2 and m_3 as axial portions in one three-dimensional cartesian coordinates system. Such a system of coordinates which is spanned by the three unit vectors i (801), j (802) and k (803) is shown in Fig. 17A. this illustration also shows the spatial diagonal 804, which passes through the neutral point and the point with coordinates i , j , k , i.e. the spatial diagonal is defined by the origin of the coordinates system with the associated unit vectors i , j and k (801, 802, 803) and the vector sum $i + j + k$.

A first, second and third measured value m_1 , m_2 , m_3 of a trio of values are in each case plotted in the direction i , j and k .

In this way, a triangle 81 is defined of which the (surface) centroid S , 82, is variously located according to the underlying trio of measured values, since with different locations of rotor to be evaluated, so different trios of measured values have to be assessed.

The said surface centroid S can be ascertained graphically or in a practical situation by calculation and lies on a curve 810 (Fig. 17B) which passes substantially in cycloid fashion around the spatial diagonal 804 and which is shown on an enlarged scale in Fig. 17B. The spatial diagonal 804 passes through the centre Z, reference numeral 83, of the triangle 81.

Together with the centroid 82 which varies as a function of the measured values, the centre 83 defines on the triangle 81 a straight line 805 which, in relation to a straight line 806 between centre 83 and a corner point, e.g. m1 of the triangle 81, encloses a clearly defined angle 807 in the plane of the triangle. This angle 807 is used as a position characteristic for the rotor position and is further processed.

Instead of the three-dimensional form, the said three measured values can also be evaluated in a two-dimensionally orientated representation (Fig. 18). For this, the three axes of space are projected onto three straight lines which emerge from the origin of a x - y-system of coordinates and have an angular difference of 120° . Starting from the origin, paths are plotted in the direction of these axes and which are proportional to the mean values m1, m2, m3. In this way, a triangle is spanned, the centroid S of which does not necessarily coincide with the origin 1802 of the three straight lines. In known manner, this centroid can be constructed by drawing or by calculation. According to the form and location of the generated triangle, so a straight line between centroid S and the origin of the three axes will acquire a varying angle 1801 in respect of these three axes. This angle is then used directly for determining the position of the rotor of an electric motor. The distance from the centroid to the origin plays only a minor role and

may possibly be used for the purposes of correcting rotor position determination. The position of the centroid can in known manner be determined by constructing the median or alternatively by using the centroid formula, which must in this case be applied for example to three equal-weight elements m_1 , m_2 and m_3 . In accordance with this rule of calculation, the portions in the X- and Y-direction (Fig. 18) can be calculated separately.

A closer examination of this method shows its arithmetical identity with a further process.

Since in Fig. 18 only the angular location 1801 of the centroid S in respect of a straight line 1803 emanating from the origin 1802 is sought, upon arithmetical establishment of the centroid, the otherwise necessary division, in this case a division by three, can be omitted, so that it is sufficient simply to add the X-values of the corner points of this triangle in order to ascertain an X component of the centroid direction. The same applies to the Y-values of the triangle. In another formulation, this means that the vectors m_1 , m_2 and m_3 which emerge from the centre 1802 to the corners of the triangle, have to be added together and that the resulting vector of the vector sum already points in a direction which substantially coincides with the electrical rotor position which is being sought.

Furthermore, the method of centroid analysis which has just been explained can be taken as a special case for all methods based on Fourier analysis or transformations.

Also, in the case of such analyses or transformations, an appropriate vector summation is performed for the values in respect of amplitude and phase of the so-called first harmonic of a function defined by a plurality of

interpolation nodes.

Together with Fig. 20, Fig. 19D shows a corresponding example of the evaluation of for example three or six stator coils for which six values m_1 to m_6 have been ascertained by procedures which are shown in Figs. 12 and 13. As already explained, $m_1=M_1$, $m_2=M_{21}$, $m_3=M_{31}$ etc.

Fig. 19D shows the "complex plane", the x-axis corresponding to the real part while the y-axis corresponds to the imaginary part. Fig. 20 can likewise be regarded as a complex plane.

In addition to the coordinates of the complex plane, Fig. 19D shows all six vectors v_1 to v_6 of the sixth unit cubes, the term 'unit cube' meaning as usual a solution x which satisfies the problem x raised to the power of $n = 1$.

The first harmonic, i.e. the sinusoidal fundamental wave, which is associated with a given number of measured values of a periodic function, is calculated in amplitude and phase by adding associated complex numbers. This addition can be likened to the adding together of vectors and is shown for example in Fig. 20 for a so-called six-point DFT (discrete Fourier transformation). If fewer or more measured values (measurement points) are present, then correspondingly modified procedures apply, such as are known from the theory of Fourier transformations.

In a first stage in this calculation procedure, firstly the measured values, which are generally present as real values, e.g. as measured current values, have to be converted into the correct complex numbers.

This is shown in Fig. 19D:

If for example the six values m_1 to m_6 are present, then firstly the six so-called sixth unit roots $v_1, v_2, v_3, v_4, v_5, v_6$ for which the equation $(v_k)^6 = 1$ is satisfied are plotted on the unit circle in the complex plane, where $k = 1, 2, 3, 4, 5, 6$. The angle ϕ_0 shown in Fig. 19D amounts to 60° , so that the said unit cubes can also be shown by the formula $\exp(k * i * \phi_0)$, k being a value from 1 to 6. In a further stage, then, for the six values m_1 to m_6 , a linear extension of the unit cubes is performed in successive sequence, in fact in each case by the relevant factor $m_1 \dots m_6$, so that the points m_1 to m_6 in Fig. 19D are obtained in the complex plane. The vectors emerging from the origin of the coordinates and extending to these points m_1 to m_6 are also shown in Fig. 20 but in a different form.

The term "extending the unit cubes" must be understood to mean that they are multiplied by the respective value m_1 to m_6 .

For example, in Fig. 19D, the value m_1 is greater than 1 and therefore the respective vector m_1 (based on its amount) is greater than 1. On the other hand, if m_3 is less than 1, therefore the respective vector m_3 will be less than 1.

The vectors $m_1, m_2, m_3, m_4, m_5, m_6$ are identified by reference numerals 201 to 206 in Fig. 20. Furthermore, they are shown in a chain-like juxtaposition in order to illustrate their vector sum.

To illustrate the associated calculating rule for arithmetical summation of these vectors, their x- and y-portions are shown and are identified as x_1, x_2, y_2, x_3, y_3 etc. The x-component at the resulting vector is designated x_7 and is composed of the x-portions shown,

while the y-component is composed of the y-portions and is designated y_7 . This resulting vector has the end point Z O, which can in turn be regarded as a complex number with the real part x_7 and the imaginary part y_7 . The amount R and the phase ϕ of this complex number can be ascertained by known calculating rules from the real part and imaginary part, for example if the amount of R equals the square root, then from the sum of the squares of real part and imaginary part, in other words $\sqrt{(x_7^2 + y_7^2)}$.

An associated rule of calculation for processing the values m_1 to m_6 by a digital computer, for example a microprocessor, is shown as a flow chart in Fig. 21. As is normal with such methods, many other analogous procedures are possible.

In a first step S40, the already known values m_1 to m_6 ascertained by another programme part are stored in a memory, e.g. a stack memory.

In the following steps S41 and S42, various quantities are given initial values, in particular the memory cells with allocation addresses SUM_R and SUM_I are set at zero and constitute the memories for real part and imaginary part. In the subsequent steps S43 to S58, substantially values are added to or subtracted from these memories, said values being derived from the values m_1 to m_6 .

Thus, in step S43 and S44, firstly the value m_1 is retrieved from stack memory and then added to the contents of the memory SUM_R which subsequently assumes the value m_1 .

In step S45, then, the value m_2 is retrieved from the stack memory and divided by two. This result is on the one hand added to the contents of the memory SUM_R while on the

other it is again multiplied by the factor $\sqrt{3}$ and then added to the contents of the memory SUM_I. This method is continued in a similar manner in the subsequent steps whereby in steps S51 and S52, the division by the factor 2 is left out and a similar procedure adopted as in steps S43 and S44, whereby certainly m4 has to be subtracted from the contents of the memory SUM_R. In the other cases, it is in each case necessary first to divide by two in order to obtain intermediate results which are added to or subtracted from the memory SUM_R or, after being multiplied by the factor $\sqrt{3}$ to the memory SUM_I. This totalling of the memories SUM_R and SUM_I up and/or down is then concluded by step S58.

The values present in the memories SUM_R and SUM_I thus represent on the one hand the x-component x_7 of the vector R in Fig. 20 and on the other the y-component y_7 of the same vector.

Accordingly, the further calculation steps according to Fig. 21 are intended to determine the angle of this vector in relation to the x-axis and in addition also its amount. In accordance with steps S59 to S64 in Fig. 1, for ascertaining their amount, firstly the contents of the memories SUM_R and SUM_I are individually squared and then a total is formed from the squares. From this total, then, the square root is obtained, which value already represents the desired amount of the vector and for this reason it is stored in the BETRAG/amount memory cell. In order to calculate the phase angle ϕ in relation to the x-axis, then, in steps S65 to S68, firstly the contents of the memories SUM_R and SUM_I are accessed and the relative signs of these values are noted. In accordance with known trigonometric procedures, the desired main angle value ϕ_0 can be calculated from the quotient of SUM_I/SUM_R and the arc tan function applied thereto. The final angular

value is then, in accordance with known transformations, determined on a basis of the stored sign values within a range from 0° to 360°.

The situation described here can likewise be described in abbreviated form by the summation formula

$$Z_0 = \epsilon m_k * \exp(i*k*\phi_0)$$

and the sum Z_0 therefore indicates by its real part and its imaginary part likewise amount and phase of the first harmonic or fundamental wave, in other words the fundamental wave of a periodic function defined by the measured values m_1 to m_6 .

This last-described method can be compared with calculation procedures and processes of discrete Fourier transformation (DFT).

This is explained with reference to Fig. 21A, where the values m_1 to m_6 are shown at A) as 6 interpolation nodes of a periodic function 230 which is then repeated. Comparison shows that the last-described method can be regarded as DFT for determining amounts R and phase ϕ_0 of the first harmonic of this function 230, which is likewise defined by equidistant interpolation nodes and which is repeated periodically outside the interpolation nodes, i.e. is continued in the same form.

Then, at B), Fig. 21A shows the ascertained first harmonic with its amplitude R and its phase angle ϕ_0 which essentially indicates the rotor position and which for example is calculated according to the flow chart in Fig. 21.

As already mentioned, essentially the angle or phase

phi of this first harmonic which is shown graphically in Fig. 20 and 21A and which can be calculated according to Fig. 1 is of interest and already represents the desired position characteristic for position of the motor rotor.

It is understood that instead of the embodiment performed, it is also possible to use similar calculation procedures such as are known from the theory of Fourier transformations and generally integral transformations. In particular, with a relatively large number of interpolated nodes, it is possible also and naturally to use an allied algorithm which is known by the name fast Fourier transformation (FFT) and which is suitable for saving on further calculation costs. According to the methods, so restrictive conditions may need to be observed which are however normal for any man skilled in this field.

If the methods of determining the desired phase location of a function which have been described are compared, it becomes evident that the methods based on integral transformations or based on centroid analyses are characterised by a considerable saving on calculation time.

For a simple determination of the position of a rotor, the amount of R (Fig. 20 or S64, Fig. 21) is not required.

Monitoring of this value to see whether it exceeds previously established upper and lower limit values can however serve as a check on whether there is a generally plausible calculation result for determining the angle phi or whether there is cause to presume the influence of an error of any kind. If no error need be feared, then the amount can also be used for correction purposes when determining the position of the rotor, as explained hereinafter.

For precisely determining the position of the rotor with relative errors within a percentage range, it is necessary to have a substantially linear relationship between actual angle or rotor position and the calculated angle or position value. Since measurement, on the basis of its principle, is based on non-linear physical effects, the initially attainable results are normally non-linear and can at the outset only be described as position characteristics. In accordance with the thought underlying the invention, it is advantageous to evaluate correcting values in an experiment on certain Tables. These values can also be plotted in a chart as Fig. 23 shows.

This shows in detail the cartesian coordinates "actual position" and "position characteristic". The functional correlation between actual and characteristic values is provided by the association curve 72, as is illustrated by the example of the abscissa and ordinates value of function value 71.

The association curve 72 will not generally have any rectilinear pattern and so it differs from a straight line 73 which most resembles the function values. The deviations of some interpolation nodes of function 72, shown with regard to the example of the paths 71 - 76, can be kept in a Table of Corrections. According to a known mathematical procedure, one or more matching straight lines can be implied through a number of interpolation nodes.

In order to define a matching straight line 73 which need not necessarily be characterised by a best match of the interpolation nodes, it is, as is well known, sufficient to have coordinate intersections 74 and 75.

For each position value which has been ascertained according to one of the already mentioned methods, it is

possible then, by using such a Table of Corrections and normal interpolation methods, to calculate an actual position value. For various types of motor, then, instead of a correction table, it is also possible to indicate a correction formula which is defined by one or more sine terms and possibly associated phase terms.

In practice, maximum correction values in the range of a few to a few dozen degrees (el.) may arise. A typical value is a sinusoidally varying deviation which has a maximum of about 20° el and which can be reduced by the said correction by about a factor 10.

In a further refinement of the corrective measures, it is naturally also possible to include other parameters in the calculations such as for example the temperatures of the motor coils or magnets.

Additional correcting data can be ascertained from the higher harmonic of the basic measured value sequences which are not considered in greater detail hereinabove where an appropriate number of measurement points are available.

Similarly, it is possible from the amplitude of the first harmonic to derive a further correction function of this type. For this procedure, an additional correction function or chart is required and the desired rotor position is then calculated from the angle ϕ (Fig. 20) and an additive or multiplicative correction value which depends directly upon the amount (amplitude) of the first harmonic. Correction functions or charts have to be established by experimentation as is carried out beforehand.

Commutating stratagem for sensorless motors:

The decision sequence as to when the motor needs to be switched is illustrated by the flow chart in Fig. 24. On the one hand, it must first be established whether a start-up is acceptable as a stepping motor or not since starting up in a basic position can possibly be performed by a non-acceptable direction of rotation (Fig. 24, S1). If stepping motor mode is acceptable, then for example a stepping pulse is performed (Fig. 24, S2) which increments the counter 1003 (Fig. 2). In step S3, the commutating logic 1002 generates a new commutating pattern which is fed to the output stage unit 26 which in a step S4 provides for energising of the motor. In the subsequent step S5, then, EMF observation establishes whether the direction of correction is right. If this is the case, then in step S6, the direction of rotation can be retained as otherwise it is necessary to provide for commutating sequences which produce a change in the direction of rotation. This sequence is initially repeated until such time as a first limit speed is reached.

Alternatively, if it is necessary for the motor to start up immediately in the correct direction of rotation, then steps S7 to S9 are performed. In fact, as a result of the rotor position ascertained in step S7, as is likewise the case with the normal operation of a commutatorless direct current motor, then in a step S8, the necessary commutating pattern is at the same time generated and emitted, to cause the motor to turn in the correct direction during step S9. In step S10, a decision is taken as to whether this method is to be repeated or whether a limit speed has been reached.

Once this first speed limit has been reached, steps S11 to S14 provide for a farther-reaching acceleration of the motor.

This is achieved in that after recognising the zero passages of the motor counter EMF at an appropriate point in time and in accordance with a freshly calculated commutation pattern, power is supplied to the motor.

In this way, the motor is run up to a maximum attainable speed.

Regulation and control of motor speed or position by methods according to the invention:

The precise determination of the position of a rotor using the method according to the invention can in practice be carried out with a sufficiently high repetition frequency, e.g. 100 times per second, in order to register deviations from a desired position of the motor rotor and in order to minimise them by taking an active counteraction (regulating principle).

Since the position values can only be determined at discrete points in time, then where this type of control is concerned, it can only be a scanning control. In this field, numerous independent publications are known.

For scanning controls, it is well known that the attainable quality of control is influenced by the scanning time and also by the various system-time constants as well as by the control algorithm applied.

Therefore, a further object of the invention is to use determination of the position of the rotor in keeping with one of the said methods in order to carry out a control of either the speed or position of the rotor. In this respect, it is possible preferably to use a control structure with a PID algorithm or even with a status control algorithm.

Instead of regulation, it is naturally also possible to carry out control. In this case, by a programme or an external presetting, the pattern of the speed or sequence of positions which the motor rotor is to assume as a function of the time can be predetermined.

A further method according to the invention and relating to the control of speed resides in performing only one measurement of the rotor position and subsequently performing only power application stages.

The duration of the power application stages will generally depend upon when the next motor commutation is to take place and will shorten constantly as the motor is accelerated.

In accordance with the thought underlying the invention, an advantageous method, when calculating the necessary pulse shortening, is to take into account the number of current application cycles already applied. As a rule, the pulses will be shortened with increasing rotor speed.

Instead of the pulse shortening being dependent upon a number of current application pulses as an implicit measure of the time, the said dependency may also be lineally and explicitly dependent upon time.

According to Fig. 25, another possibility according to the invention resides in making the current application-period duration lineally dependent upon the attained overall angle of the position reached, for example (commencing with a relatively large starting value for the current application time) and in keeping with the already achieved position, reducing the current application time continuously and lineally (131) until for example a minimal

value is reached, below which no further drop will take place.

Similarly, it is possible to perform the said procedures in a non-linear manner. This can be achieved particularly in the form of a logarithmic or hyperbolic dependency (132) and if necessary, more complicated functional dependencies can be employed.

According to the motor type and the coupled load, particularly in the case of a resiliently coupled load, it may be advantageous to reduce the current application time (τ) in accordance with a tabulated dependency (Fig. 25, 133), i.e. the necessary current application times are no longer calculated on the basis of a mathematical expression but are instead filed in tabular form, for example in a memory component. With increasing rotor angle or with increasing time, in each case new current application duration data will be acquired from the memory component. This method is likewise carried out until such time as the minimum current application time is reached which is maintained constant so that access to the memory component becomes unnecessary (Fig. 25, value 134). The method described hereinabove is shown in Fig. 26 in the form of a structogram.

Commencing with a starting step S20 in which there is in particular an initial allocation of initial values to variable memory values, then subsequently in step S21 a time counter is set at zero and then periodically increments its count automatically and in a quasi-continuous manner, i.e. with a predetermined short cycle time.

By means of the methods described hereinabove, in the subsequent step S22 and without the aid of external

sensors, at least the electrical position is determined. The subsequent steps relate to the running-up phase, during which the kinetic energy of the motor increases constantly. As a function of the already ascertained position value, in step S23, a suitable commutation signal is generated which in step S24 is used to apply current to the motor so that an acceleration of the motor takes place in the desired direction. The current however is not at first interrupted. Immediately thereafter, in step S25, the current actual time t is ascertained on a basis of which in the next step S26, the envisaged current application time τ is ascertained according to a predetermined calculation rule or in accordance with a predetermined table stored in the processor. In the next step S27, one waits until the current application time ascertained in S26 has elapsed so that then the motor current can be switched off initially in step S28. Since the acceleration phase lasts only a certain time, there is in step S29 a check as to whether the envisaged acceleration time t_{LIM} is already exceeded or not. If this is not the case, then step S23 is resumed etc. However, if the time t_{LIM} has been exceeded, then the programme branches into the constant velocity phase and in step S30 it provides a further commutating signal. This step is followed by a step S31 which on a basis of the generated commutation signal provides the associated correct application of power to the motor.

In the subsequent step S32, there is a waiting period as in step S27, when the motor current is to be temporarily switched off again, which is the case after a time corresponding to τ_0 time units, the constant variable τ_0 being known to the processor.

Temporary shut-down then takes place in step S33. In the subsequent step S34, there is a check to see whether a stop signal was generated by any condition.

If this is not the case, then at step S30 there is a branch into which a new commutation signal is fed etc.

In the other case, in the presence of a stop signal, however, there is a branch at the programme end, step S35. No further motor current is supplied and the motor comes to a standstill.

In the case of speed control, it is also possible necessarily to change the type of position determination from static, i.e. at low speeds and by ascertaining the phase location of a fundamental wave, to dynamic by means of counter-emf, or vice versa.

According to the invention, this change can take place directly after a specific number of current application cycles. Naturally, it is a prerequisite of this last-mentioned mode of operation that sufficiently known and reproducible friction conditions and moments of inertia of the motor and of the appliances driven by it are present so that a premature change cannot take place and the dynamic position determination method can work without error.

Further fields of application:

The application of the invention is not confined to standard commutatorless direct current motors such as are used for example with 4 or 8 magnetic poles and with for example 6 or 12 coils (Fig. 8, Fig. 9, Fig. 10).

Instead, the embodiments according to the invention can also extend to any motors of which the inductance varies according to the position, e.g. simple motors with so-called three-T-armatures (Figs. 4, 5 and 7), and in particular and naturally all kinds of reluctance motors with or without permanent magnets (Fig. 6).

The magnetic conditions are shown particularly in Figs. 4 and 5. Fig. 4 firstly shows a conventional so-called three-T-armature 44 which is in the magnetic field of a pair of magnetic poles with a north pole 40 and south pole 41 and about which the centre 46 is mounted to rotate. Already in a currentless situation (Fig. 4), the arm 42 which is closer to the north pole 40 than the arm 43 and 44 are to the south pole 41, is exposed to a higher magnetic flow density (10 drawn flow lines) than the other two arms (approximately 5 drawn flow lines). It is evident that a coil 47 such as is shown in Fig. 5, intensifies magnetisation of the arm 42 when the application of current is appropriate and can cause an iron part of this arm to come to saturation with a minimal current than if there were still no pre-magnetisation by the permanent magnet 40, 41 or if such pre-magnetisation were only weak, as in the case with arm 43 in Fig. 5. Correspondingly, however, a higher application of current to such a coil 47 is needed in order to achieve a magnetic saturation of this arm 42 in the opposite direction. Since current application processes of this type are by virtue of the initial inductance which is in each case present are encumbered by a first time constant, the time required for magnetisation to the point of saturation will vary with a desired polarity.

Similar considerations apply to a case where a series circuit of coil 47 and coil 48 has current applied to it. According to the polarity of the current, in particular arm 42 will be either quickly or slowly brought to saturation which is likewise expressed in a change in the effective inductance of this coil. It is obvious that these effects will show up differently according to the angular position of the armature 44 but that according to the rotation symmetry of the armature, they will be repeated for the next coil after a rotation of 120° mech.

A simple spatial disposition of such a three-T-armature motor is shown in Fig. 7. Contacting of the coils 47 and 48 can be undertaken directly with the rotor 44 fixed and magnets 40, 41 rotating. For fixed magnets and rotating armature, the coils expediently have a current applied to them through slip rings (not shown in Fig. 7).

A similar effect can be achieved with the arrangement shown in Fig. 6 (reluctance motor). A stator 60 of dynamo iron with 6 marked stator poles 62 acts on a movable rotor 61 which may likewise consist entirely of iron.

On the stator pole 62 there are associated coils L1 to L6 which may be individually wired with a direct current voltage of any desired polarity. Since the rotor 61 is initially non-magnetic, it is possible to establish situations comparable with those shown in Fig. 4 in that the coils L1 and L4 are so connected that the south poles of the rotor 61 shown in the drawings are accessed. The simultaneously created north poles of the rotor are then opposite the south poles of those stator poles created by the same magnetisation process, on which the coils L2 and L3 or L5 and L6 are located.

Therefore, the iron cores of these coils are also pre-magnetised and so influence the current pattern through these coils when for the purpose of measuring position by these short test pulses, they are required. Such test pulses can naturally and particularly be of differing electrical polarity and it is also possible to have coil combinations as pre-magnetisation means, particularly in serial and parallel connection.

A similar configuration as in Fig. 7 is shown in Fig. 8 in which the fixed armature 44' has however twice the number of stator poles which are provided with associated

coils L1 to L6.

Also the number of permanent magnet poles of the rotor 55 is doubled in Fig. 8 and the permanent magnet poles of the magnet 50 are adjacent one another, without interruption.

This magnet is held by an iron yoke 51 which at the same time serves to improve the magnetic circuit.

A comparable arrangement with rotating but internal magnets (inner rotors) is shown in Figs. 9 and 10. In addition, these drawings show the magnetic conditions when the motor is idling. The stator 915 likewise has six marked poles with in each case associated coils L1 to L6. The magnets 912 of the rotor are on an iron yoke 913 and are able to rotate about the centre 914.

The stator poles with the coils L1, L2, L4 and L5 detect the full magnetic flux of the permanent magnets 912. Accordingly, by the additional application of current to these coils, they can more easily be brought to saturation than is possible when applying current to the coil L3 or to the coil L6 in the illustrated position of the rotor.

This is illustrated by section lines 910 and 911 in Fig. 10. As can be seen, the magnetic flux ϕ_1 is represented by a larger number of magnetic flux lines which cross the section line 910 while there is no notable magnetic flux (ϕ_2) present at the intersection line 911. Naturally, also these conditions are dependent upon the angular position of the rotor, which is shown in Fig. 11A, where the rotor is shown as having been rotated on by a few degrees in a clockwise direction in comparison with Fig. 10.

While the flux through section line 910 has not changed to any notable degree, the flux through section line 909 has already been considerably reduced. The associated coil L2 (Fig. 9) must therefore have a higher level of current passed through it in order to achieve magnetic saturation in this stator pole.

Fig. 11C shows a corresponding embodiment of a rotor with four magnetic poles 501 to 504.

Poles 501 and 502 are more intensely magnetised than poles 503 and 504. Those stator poles which are opposite the magnetic poles 501 and 502 correspondingly receive a higher degree of pre-magnetisation and can therefore be more easily brought to a state of magnetic saturation, i.e. with less current.

However, if the aforementioned pre-magnetisation has to be overcome by a corresponding application of current, then naturally more current has to be applied than in the case of those stator poles which are situated opposite the permanent magnet poles 503 and 504.

As a result of this asymmetry in magnetisation, which has a periodicity of above 360° , therefore, it is possible unequivocally to deduce the rotor position over the entire mechanical complete angle of 360° .

A surface structure of the rotating permanent magnet, such as is shown in Fig. 11B, has at one or more poles, e.g. north pole 117, a retracted surface 116.

As a result of this geometric asymmetry, there is likewise an asymmetry in the magnetic flux so that by virtue of this asymmetry, there is a marked determination of the rotor position in relation to the entire mechanical

complete angle. A similar situation is shown in Fig. 11D.

The permanent magnet with north pole 1123 and south pole 1124 is mounted to rotate about the centre 1127 and is situated opposite the stator poles 1126 of the stator 1125. Air gap 1122 is greater than air gap 1121 and further air gaps not shown. In the same way as in the previously described case, there is generated in this way a mechanical/magnetic asymmetry which makes it possible unequivocally to determine the rotor position in relation to the entire mechanical solid angle.

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Patent Claims

1. A motor or position indicator, particularly a brushless direct current motor comprising a magnetic circuit provided with at least one winding and with a rotor the rotated position of which is continuously ascertained, the rotated position of the rotor being progressively determined by means of computing operations from rotary position dependent or position dependent electrical motor values, characterised in that the motor or position indicator contains means for at least approximately determining the rotary position of the rotor by vectorial computing operations and/or by computing operations for complex-value magnitudes and/or by an integral transformation and/or by a computing method for determining very small square sums or very small absolute amounts and/or by a computing method for determining centre of gravity coordinates.
2. A motor or position indicator according to Claim 1, characterised in that a Fourier transformation or Fourier analysis is used as the integral transformation.
3. A motor or position indicator according to Claim 1 or 2, characterised in that the inductance or counter-inductance of one or more motor windings is used as the position-dependent electric motor value.
4. A motor or position indicator according to Claim 3, characterised in that the position-dependent inductance or counter-inductance of at least one motor winding or position indicator winding is used, of which the magnetic circuit, during the course of a 360° rotation of the rotor, at least temporarily



enters a state of saturation or is at least temporarily within the saturation range.

5. A motor or position indicator according to one or more of the preceding Claims, characterised in that the active faces of existing permanent magnets have differing levels of, or unevenly distributed, magnetisation.
6. A motor or position indicator according to one or more of the preceding Claims, characterised in that at least one magnetic flux path of the motor is converted to the unsaturated or less saturated condition by suitable current in at least one inductance.
7. A motor or position indicator according to one or more of the preceding Claims, characterised in that pre-conduction currents are applied to one or more inductances in order to create pre-magnetisation conditions.
8. A motor or position indicator according to one or more of the preceding Claims, characterised in that the current path through at least one inductance of the motor is ascertained at least at one point in time and in that the inductance value of this at least one inductance is ascertained therefrom.
9. A motor or position indicator according to one or more of the preceding Claims, characterised in that the inductance values of at least two inductances are ascertained as functions of the rotor angle of the rotor and are combined to form one averaged-out inductance function and in that the ascertained inductance function is then stored in a storage means in the form of a reference table.



10. A motor or position indicator according to one or more of the preceding Claims, characterised in that interpolated intermediate values either of the measured inductance pattern or of the averaged out inductance pattern are also stored in the storage means.
11. A motor or position indicator according to Claim 10, characterised in that intermediate values which are to be interpolated are ascertained by means of a spline interpolation.
12. A motor or position indicator according to Claim 10, characterised in that intermediate values to be interpolated are ascertained based on a sin-cos series expansion.
13. A motor or position indicator according to one or more of the preceding Claims, characterised in that the rotor position to be found is ascertained by seeking the greatest similarity of functions which are based on the measured current pulses on the one hand and on the values stored in the storage means on the other.
14. A motor or position indicator according to Claim 13, characterised in that the greatest similarity of functions is established by the method of the very small squares or the method of very small absolute amounts.
15. A motor or position indicator according to one or more of the preceding Claims, characterised in that the rotor position is ascertained by multiplying the individual measured current values by estimated or predetermined directional components associated with them and subsequent direction-orientated addition of



the products.

16. A motor or position indicator according to Claim 15, characterised in that the predetermined direction components are determined by integral angles which are defined by $360^\circ / n$, in which $n = 1, 2, 3, \dots$
17. A motor or position indicator according to Claim 15, characterised in that the directional orientated addition is carried out by vector addition.
18. A motor or position indicator according to Claim 15, characterised in that the directional orientation addition is carried out by the separate addition of the parts of individual and entirely independent components (x_n, y_n) (Fig. 20).
19. A motor or position indicator according to Claim 15, characterised in that in order to ascertain the rotor position by the directional orientated addition of the products the ascertained directional value (R) is subject to determination of an angle by trigonometric functions, e.g. the inverse tangent function or inverse sine function.
20. A motor or position indicator according to Claim 15, characterised in that the directional components are ascertained by controlled movement of the rotor and are stored in a storage means.
21. A motor or position indicator according to one or more of the preceding Claims, characterised in that current is applied to it according to a discovered deviation of rotor position or rotor speed from a desired position or desired speed, according to a proportional-integral-derivative control algorithm or



a condition control algorithm.

22. A motor or position indicator according to one or more of the preceding Claims, characterised in that during run-up of the motor, the cycle duration of the energising pulses is shortened as a function of the number of energising pulses, particularly in accordance with a lineally extending function.
23. A motor or position indicator according to one or more of Claims 1 to 21, characterised in that during run-up of the motor, the cycle duration is shortened as a function of the number of energising pulses, in particular according to a tabulated function.
24. A motor or position indicator according to one or more of the preceding Claims, characterised in that during run-up of the motor, after a specified number of energising pulses, there is a switch-over to a type of commutation which is based on the evaluation of voltages induced in phase windings of the motor.
25. A motor or position indicator according to one or more of the preceding Claims, characterised in that a current signal measured at the motor or position indicator is boosted by an amplifier, particularly one with a high upper limit frequency, the amplified value being fed to an analogue storage circuit.
26. A motor or position indicator according to one or more of the preceding Claims, characterised in that one or more processors are provided for the necessary computations and energising sequences.
27. A motor or position indicator according to one or more of the preceding Claims, characterised in that in



order to ascertain the rotor position, a phase determination is used for the first harmonic (fundamental oscillation) of a function, which function is represented by a plurality of sample values, which sample values are obtained from measurements of current, voltage or inductance.

28. A motor or position indicator according to Claim 27, characterised in that the result of phase determination constitutes a direct or indirect measurement for the rotor position which is to be found.
29. A motor or position indicator according to Claim 27, characterised in that for phase determination for the first harmonic, a sum is formed from at least partially multi-component summands, the phase position being calculated from the components of the sum (Fig. 21).
30. A motor or position indicator according to Claim 29, characterised in that trigonometric or arithmetic functions are used to ascertain the phase position, the components of the sum being used to compute trigonometric function values, the arc-tangent function in particular being used as the trigonometric function.
31. A motor or position indicator according to one or more of the preceding Claims, characterised in that the amount (R) of the first harmonic (fundamental oscillation) of a function represented by sample values is used for monitoring the measuring process.
32. A motor or position indicator according to one or more of the preceding Claims, characterised in that the



amount (R) and direction (ϕ) of the first harmonic (fundamental oscillation) of a function represented by sample values are ascertained by determining the centre of gravity. (Figs. 17a, 17b, 18).

33. A motor or position indicator according to one or more of the preceding Claims, characterised in that a value is ascertained for the rotor position and in that the value thus ascertained is corrected on the basis of a motor-typical or motor-individual correction table in order to obtain a corrected and better value for the rotor position.
34. A motor or position indicator according to one of Claims 1 to 33, characterised in that a commutating processor (100) is provided in order to receive current sensor signals (267) and voltage signals (111, 112 and 113) from phases (L1, L2, L3) of the motor or position indicator and use them to calculate commutating signals, the commutating processor (100) being connected on the output side to an output stage unit (26) for application of current to the individual phases of the motor (10) or position indicator.
35. A motor or position indicator according to Claim 34, characterised in that a further processor (23) is provided which is superior to the commutating processor (100) and in that the commutating processor (100) is connected to the superior processor (23) via control and communication connections (102-110).
36. A motor or position indicator according to Claim 34 or 35, characterised in that the commutating processor (100) has the following features:
 - a commutating logic (1002) in order to calculate from externally predetermined position data or coil



- voltages of the motor (10) or position indicator fed in through lines (108-113) the point in time at which commutation of the motor currents is to take place;
- output terminals on the commutation logic (1002) which are connected to the output stage unit (26) and at which it is possible to access commutation switching signals (261, 262, 263);
 - input terminals (111-113) connected to the coils of the motor (10) or position indicator for the application of coil voltages;
 - connected to these input terminals (111-113), a series circuit of an attenuating member (1008) of a voltage comparison unit (1007) and a signal delay unit (1006), this latter having its output side connected to the commutating logic (1002);
 - a commutating control unit (1005) which is adapted to respond to different external signals and to which the commutating logic (1002) is connected and
 - a current detection unit (1009) for detecting, amplifying and preparing a current sensor signal of the motor (10) or position indicator.
37. An arrangement for actuating a motor with motor windings according to one of Claims 1 to 36, characterised by the features:
- an output stage unit (26) with a plurality of switching elements and output terminals (261-266) in order to supply power to the motor windings (L1, L2, L3) of the motor (10) which is to be controlled,
 - coupled with the output stage unit (26), a control arrangement (100) for applying control signals to the output stage unit (26) in order to actuate the switching elements selectively, power being selectively applied to the motor via the switching elements, the control arrangement (100) being provided for receiving measured value signals (108, 109, 110)



of a constituent part of the power fed to the motor (10), the control arrangement (100) further comprising a means (1002) for determining parameters of a function which is dependent upon the variable inductance in the motor and established by the sequence of measured values, including an arrangement (23) for carrying out vector addition or an addition of complex numbers, whereby the parameter-determining arrangement (1002) determines position-dependent and/or inductance-dependent electrical motor values from the parameters.

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