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EP 1657808 A2 **US 4885519 A**

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(54) Title of the Invention: **Controller for electrical machines**
Abstract Title: **Controller for electrical machines**

(57) The present invention relates to control of electrical machines and in particular, though not exclusively, to control of synchronous machines such as hybrid stepping motors, flux switching machines and brushless permanent magnet motors and generators. A sensorless control system is provided for an electrical machine, the system comprising: detection means for monitoring the currents in the phase windings of the machine and for providing a real component along a real axis at a known angle in line with a rotating reference frame and an imaginary component orthogonal to the real component; calculating means for determining a value of the real component of the rotational emf along an axis at the known angle relative to the rotating reference frame and an imaginary component orthogonal to the real component; estimating means for estimating the angular difference between the current vector and the rotational emf vector, error means for determining an angular error signal indicative of the deviation of the angular difference from a desired magnitude, and means for controlling the machine such that the error signal tends towards zero.

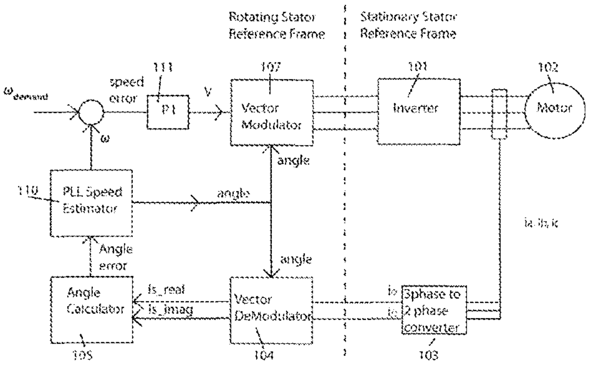

Figure 3

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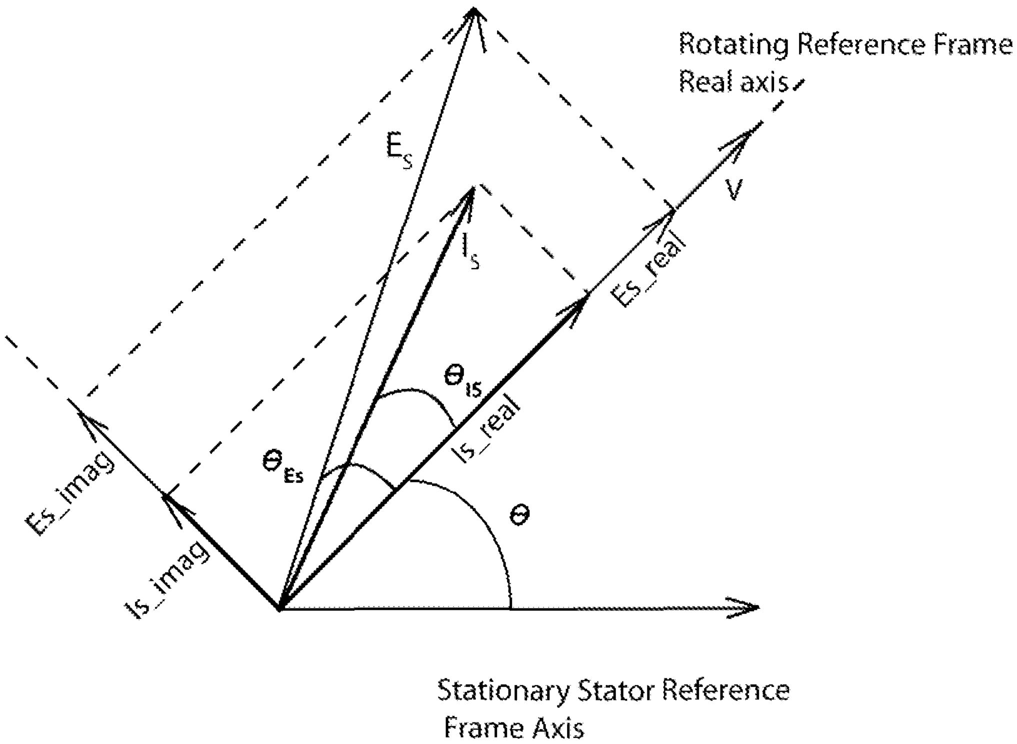
Rotating Reference Frame
Real axis
E_S
V
I_S
Es_real
θ_IS
Is_real
θ_Es
Es_imag
θ
Is_imag
Stationary Stator Reference Frame Axis

Figure 1

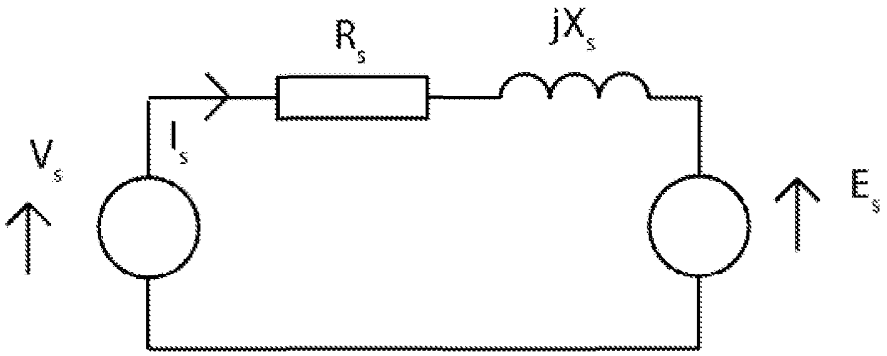

Figure 2

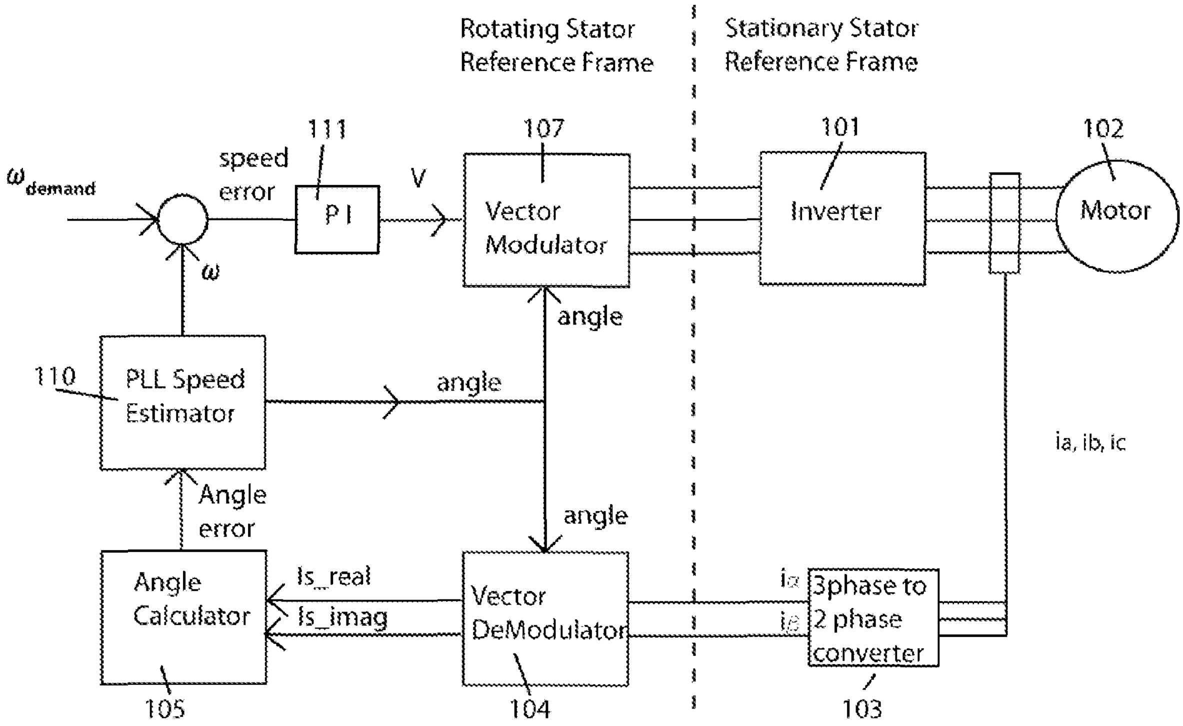

Figure 3

Controller for Electrical Machines

The present invention relates to control of electrical machines without position sensors or encoders and in particular, though not exclusively, to the control of synchronous machines such as hybrid stepping motors, flux switching machines and brushless permanent magnet motors and generators.

In all synchronous motors and generators, it will be appreciated that the excitation current applied to the phase windings must be in synchronism with the rotor position to achieve smooth rotation of the rotor within the stator. More particularly, the excitation current applied to a phase winding must alternate in synchronism with the emf induced in each phase winding.

Under normal running conditions, the terminal voltage, v_A, across a phase of an electrical machine is given by:

$$v_A = e_A + L_A \frac{di_A}{dt} + i_A R_A + M_{AB} \frac{di_B}{dt} + M_{AC} \frac{di_C}{dt} \ldots\ldots\ldots\ldots \qquad (1)$$

where the subscripts A, B and C denote the first, second and subsequent (if present) phase windings respectively, L_A is the self inductance of phase winding A, i_A, i_B and i_C are the currents in A, B and subsequent phase windings respectively, R_A is the resistance of phase winding A and M_{Ax} is the mutual inductance between the first and subsequent phase windings.

It is beneficial for the control of synchronous, flux switching and stepping motors to be achieved without position sensors. The rotor position information can be found if the rotational emf term in each phase winding (e_A) if it can be electronically separated from the other three terms in equation (1). In a practical sensorless estimator scheme, this process is complicated by the fact that the inductance L of a phase winding depends in a non-linear manner on the current i flowing through the phase winding and furthermore that the resistance R of the phase winding depends upon the temperature. Furthermore the resistance R can be changed dramatically if a motor is connected to a controller using a long cable or operates over a range of temperature. In most motors the mutual inductance, M, between phase windings, is negligible and can be ignored.

Previous sensorless estimator schemes have either ignored the dependence of phase inductance L on current i, resulting in significant errors, or have required the use of a machine-specific model which describes the non-linear characteristics of a motor core, resulting in a computationally intensive implementation and also a lengthy drive commissioning process.

In three phase permanent magnet synchronous motors it is common to estimate the position of the rotor by monitoring the rotational emf in one of the phase windings which is not carrying any current during part of the excitation cycle. This is not always possible over the whole operating range of a machine.

US 6910389 and its continuation US 7299708 uses a flux estimator to provide a first estimate of position and uses reactive power to provide a correcting second estimate of position. Such flux estimators involve accurate integration of voltage and require extremely accurate estimation of resistive voltage drops as any error is accumulated by the integrator.

US 5428283 uses Park Vectors to determine and control the reactive power and hence the power factor of the machine but the reactive power error is not used as part of a position estimation loop to control the motor without sensors.

US 5949204 describes a method for the control of the motor without sensors in which a phase winding without current is used to estimate the rotational emf of the motor as the input to the rotor position estimator. In many motors this is not possible because all the phase windings carry current simultaneously.

US 6301136 describes a floating frame controller method for control of quadrature current (i.e. imaginary current vector) to a pre-determined value (eg zero) by adjustment of the reference frame position (voltage vector position). This method maintains the current at a known angle relative to the voltage but does not control the position of the excitation relative to the rotor.

US 7075264 discloses an Instantaneous Power Floating Frame Controller for a synchronous machine. Calculation of real and reactive power gives a power factor angle. The motor is controlled to maintain the power factor angle close to zero. Application of this method is computationally complex. The estimated position is the result of two integral controllers delaying its response.

Application US2007/0040524 further describes a method for the control of the power factor of a synchronous machine to values other than unity using the synchronous and floating reference frame ideas.

None of these prior art documents describe a method for the control of a synchronous motor or generator without the use of sensors in which the method is not dependent on highly accurate measurements or accurate motor models.

Unlike the aforementioned prior art this invention describes a method to provide a sensorless control scheme which is not computationally intense, operates with high bandwidth and is more accurate than existing sensorless control schemes and can be operated over a wide speed range to control motors and generators of all types without being dependent on a detailed model of the machine's inductance, resistance and emf characteristics. The method according to this invention is particularly effective at elimination of small measurement errors making it suitable for implementation at lower cost.

According to a first aspect of the invention a control system for an electrical machine is provided comprising a rotor, a stator having one or more phase windings for generating a rotating stator magnetic field, the system comprising detection means for monitoring the currents in the phase windings providing a real component I_{s_real} along a real axis at a known angle in line with a rotating reference frame and an imaginary component I_{s_imag} orthogonal to the real component I_{s_real}, calculating means for determining a value of the real component E_{s_real} of the rotational emf along an axis at the known angle relative to the rotating reference frame and an imaginary component E_{s_imag} orthogonal to the real component E_{s_real}, estimating means for estimating the angular difference between the current vector and the rotational emf vector, error means for determining an angular error signal indicative of the deviation of the angular difference from a desired magnitude, and synchronising means for controlling the machine such that the error signal tends towards zero.

A further aspect of the invention may include a control system wherein the estimating means comprises a step of determining the ratio of the orthogonal components of the current.

A further aspect of the invention may include a control system wherein the estimating means comprises a step of determining the ratio of the orthogonal components of the rotational emf.

A further aspect of the invention may include a control system wherein the estimating means estimates a value representative of the angular difference between the angle of the current vector and the angle of the rotational emf vector by evaluating the difference between a function of the ratio of the orthogonal current vectors and a function of the ratio of the orthogonal emf vectors. The error means calculates the error between the value representative of the angular difference and a value representative of the required angular difference and uses this error in the synchronising means to control the position or magnitude of the voltage vector to minimise the error.

The invention will now be described with reference to the following diagrams in which :
Figure 1 shows a vector diagram in the stator rotating reference frame.
Figure 2 shows an equivalent circuit of a machine according to the invention in the stator rotating reference frame.
Figure 3 shows a block diagram of a machine controller according to the invention.

Application of the invention will be described with reference to motoring operation. However the method of the invention can be applied to a generator where the phase relationship between the current vector and the emf vector will be inverted.

As is common in the treatment of electrical machines it is common to analyse the machine totally in electrical cycles and electrical degrees. When this is done the analysis presented here is then identical for all synchronous machines of any type and pole numbers. In such analysis it is common to transform the statically orientated, time varying sinusoidal quantities of each stator winding into a single system of rotating vectors, rotating at the same speed as the average speed of the rotor.

Figure 1 shows the stator voltage vector, V, positioned at an angle, θ, to the stator's stationary reference frame. During normal rotation of the motor the stator voltage applied to the phase windings of the motor can be thought of as having a single component which acts at a variable angle, θ. In this example the stator voltage vector, V, will be considered as an anti-clockwise rotating vector such that the angle, θ, increases with time. The rate of increase of the angle, θ, determines the angular rotational velocity of the stator field. One revolution of the vector in the stator stationary reference frame corresponds to one electrical cycle of the machine. In a machine with p magnetic rotor poles there are p/2 electrical cycles per mechanical revolution of the stator.

In one embodiment of the invention, illustrated by the vector diagram in Figure 1, it is convenient to choose the position of the stator rotating reference frame to be coincident with the position of the stator voltage vector as this is a known and controlled parameter. The single voltage vector in the stator rotating reference frame is applied to the motor phase windings as variable voltage vectors through a multiphase inverter or power control means. The power control means uses pulse width modulation in the inverter switches to apply the desired voltage to each phase winding.

As a result of the application of the stator voltages by the power control means phase currents flow in the phase windings of the motor to and from the power control means. The time varying stator currents create a rotating stator current vector, $\overline{I_s}$. The components of this vector on a rotating stator reference frame can be calculated from time varying phase currents, for example, by the Park Transformation.

The rotational emf vector $\overline{E_s}$ is the combination of the rotational emf in the phase windings mapped onto the rotating stator reference frame. Figure 1 shows the relationship between the vector $\overline{E_s}$ and the stator current vector, $\overline{I_s}$.

The torque produced by the motor is given by

$$T = \frac{\overline{I_s} \cdot \overline{E_s} \cos(\gamma)}{\omega} \qquad (2)$$

where
γ is the angle between the rotational emf vector and the stator current;
ω is the rotational velocity of the rotor in mechanical radians per second.

Operation of the motor with maximum torque per ampere is achieved if $\gamma = 0$ and the $\overline{E_s}$ and $\overline{I_s}$ vectors are coincident. When, $\gamma = 0$, the rotational emf vector $\overline{E_s}$ is in phase with the stator current vector and the torque is again given by equation (2) which is now maximum and equal to

$$T_{max} = \frac{\overline{I_s} \cdot \overline{E_s}}{\omega} \qquad (3)$$

The angular position of the emf vector with respect to the stator current vector therefore determines the torque production of the motor.

Using the electrical quantities on the stator reference frame containing components of all the phase windings of the motor an equivalent circuit of the stator reference frame is shown in Figure 2. The stator voltage equation, in the stator reference frame, of each phase is given by :

$$\overline{V_s} = \overline{E_s} + j\overline{I_s}X_s + \overline{I_s}R_s \qquad (4)$$

Where $\overline{V_s}$, $\overline{E_s}$, $\overline{I_s}$ are the vector quantities of the stator voltage, rotational emf and stator current with respect to the rotating stator reference frame; X_s is the reactance of the stator phase winding and R_s is the resistance of the stator phase windings.

Control of a machine according to the invention can be achieved without using any magnetic flux estimation by simple calculation of a value indicative of the angular difference between the $\overline{E_s}$ and $\overline{I_s}$ vectors and using that value in a controller to determine an error signal indicative of the deviation of the angular difference from a desired magnitude, and controlling the modulation of the switches in the power control means to control the motor such that the error signal tends towards zero.

At any point in time the instantaneous phase currents in a motor can be measured. If it is a three phase motor, the three phase to two phase Clark transformation can be used before the two phase stationary currents are transformed into a rotating stator reference frame using, for example, the Park transformation. Two quadrature components of the stator current vector $\overline{I_s}$ in the rotating stator reference frame are, I_{s_real} and I_{s_imag}. The component I_{s_real} is the effective component of the stator current in line with the rotating stator reference frame, and I_{s_imag} is the effective component of the stator current at right angles (orthogonal) to the rotating stator reference frame. These quadrature vectors are shown in Figure 1.

The terms direct and quadrature axes are not used in this description to avoid confusion with rotor orientated controllers which require the stator currents to be mapped onto the direct and quadrature rotor axes.

Since $\overline{V_s}$, $\overline{E_s}$, $\overline{I_s}$ all have real and imaginary parts, equation (4) can be rewritten into a real part and an imaginary part :

$$V_{s\_real} = E_{s\_real} + (I_{s\_real} * R_s) - (I_{s\_imag} * X_s) \qquad (5)$$

and,

$$V_{s\_imag} = E_{s\_imag} + (I_{s\_imag} * R_s) + (I_{s\_real} * X_s) \qquad (6)$$

If, as shown in Figure 1, the rotating reference frame is chosen to be coincident with the stator voltage vector then the imaginary component of the stator voltage will be zero and equation (5) and (6) become

$$V_s = E_{s\_real} + (I_{s\_real} * R_s) - (I_{s\_imag} * X_s) \qquad (7)$$

$$0 = E_{s\_imag} + (I_{s\_imag} * R_s) + (I_{s\_real} * X_s) \qquad (8)$$

These equations can be rearranged to give equations for the real and imaginary components of the emf vector, $\overline{E_s}$,

$$E_{s\_real} = V_s - (I_{s\_real} * R_s) + (I_{s\_imag} * X_s) \qquad (7)$$

$$E_{s\_imag} = -(I_{s\_imag} * R_s) - (I_{s\_real} * X_s) \qquad (8)$$

Given suitable values for R_s and X_s these equations can be evaluated in real time during rotation of the motor to give the real and imaginary components of the rotational emf vector in the rotating reference frame.

The angle of the current vector relative to the stator reference frame can now be calculated and is given by

$$\theta_{Is} = \tan^{-1}\left(\frac{I_{s\_imag}}{I_{s\_real}}\right) \qquad (9).$$

The angle of the emf vector relative to the stator reference frame can also be calculated and is given by

$$\theta_{Es} = \tan^{-1}\left(\frac{E_{s\_imag}}{E_{s\_real}}\right) \qquad (10).$$

The angular difference, θ, between the current vector and the emf vector is therefore given by

$$\theta = \theta_{Is} - \theta_{Es} = \tan^{-1}\left(\frac{I_{s\_imag}}{I_{s\_real}}\right) - \tan^{-1}\left(\frac{E_{s\_imag}}{E_{s\_real}}\right) \qquad (11).$$

For small angles this can be approximated to

$$\theta_{Is} - \theta_{Es} \approx \left(\frac{I_{s\_imag}}{I_{s\_real}}\right) - \left(\frac{E_{s\_imag}}{E_{s\_real}}\right) \qquad (12).$$

Equation 12 is a simple calculation of a value indicative of the angular difference between the $\overline{I_s}$ and $\overline{E_s}$ vectors and can be implemented easily in a digital or analogue controller to operate in real time as the motor rotates.

The advantage of implementing the angular difference calculation in the form of equation 11 or 12 is that the ratio quantities provide cancellation of absolute values of the emfs and the currents. This makes the method completely independent of the variation in the magnitude of emf with speed and/or field current and avoids the need for the position controller to have detailed knowledge of the motor's emf characteristic.

Using the ratio terms in the equations (11) and (12) help to cancel out measurement and scaling errors in the current measurements since both the real and imaginary components will contain similar errors which are cancelled. This reduces the cost of the measurement system allowing the controller to be implemented at lower cost using simple electronic components.

One major advantage of this invention is that the implementation of equation (12) can be achieved with lower computational requirements than equation (11) with no significant penalty.

The angular error is the error between the measured angular difference calculated from Equation (12) or (11) and a particular desired value for the angular difference. For example, for maximum torque per ampere, it would be desired to have no angular difference between the current vector and the emf vector so that they were completely in phase. However, at high speeds it is common in electrical motor control to advance the voltage vector to pull the current vector ahead of the emf vector to achieve field weakening. In this case, under high speed conditions, it could be desirable to have a positive angular difference as calculated by equations (11) or (12) and so the desired value for the angular difference would be positive.

An angular error is therefore given by

$$Angular\_error = Angular\_demand - (\theta_{Is} - \theta_{Es}) \qquad (13).$$

Angular error calculated by equation (13) can be corrected by moving the voltage vector to a new position which tends to reduce the angular error. A positive angular error means that the position of the voltage vector needs to be moved further than the normal angular increment calculated from its average rotational velocity in order to correct the error. A negative angular error means that the position of the voltage vector needs to be moved by less than the normal angular increment calculated from its average rotational velocity in order to correct the error. A control scheme which achieves this could use a proportional plus integral controller on the angular error to deliver instantaneous control of the angular velocity of the voltage vector.

The invention can also be applied using a vector cross product of the $\overline{E_s}$ and $\overline{E_s}$ vectors to evaluate the sin of the angle between the vectors.

$$\overline{E_s} \times \overline{I_s} = |E_s||I_s| \sin\theta = \begin{vmatrix} i & j & k \\ E_{s\_real} & E_{s\_imag} & 0 \\ I_{s\_real} & I_{s\_imag} & 0 \end{vmatrix}$$

$$\sin\theta = \frac{E_{s\_real} I_{s\_imag} - E_{s\_imag} I_{s\_real}}{|E_s||I_s|} \quad (14)$$

which for small angles where I_{s_imag} and E_{s_imag} are small compared to I_{s_real} and E_{s_real} approximates to the same equation as (12). Since evaluation of Equation (14) involves calculation of the magnitude of the vectors, which involves a square root function, the use of equation (14) does not offer any advantage over Equation (12)

Control of a synchronous machine according to this invention is therefore most easily implemented by the Equation (12) and error equation (13). Whilst Equation (12) is an approximation to the actual mathematical equation for the angles it has been found to work surprisingly well even when the angles are large and the approximations are less accurate. This is because, whilst the approximation in equation (12) is a linear function representative of the inverse tan function it always represents the correct gradient and as a result the error calculated by Equation (13) always has the right sign. Since the controller involves the integration of this error, to produce the angular velocity of the voltage vector, the controller will always converge on the correct operating point. The speed of response can be controlled using the gains of the proportional and integral control loops. The gains of the control loop can also be non-linear to create a closer approximation to the inverse tan function, though practical experience has shown that this is not always necessary.

Maintaining equation (13) close to zero will hold the motor near to ideal operation at all times by allowing the angular velocity of the voltage vector to change instantaneously in each evaluation of the control loop. The average angular velocity of the voltage vector is directly related to the integral of the angular error. An outer control loop could monitor the average angular velocity of the voltage vector and increase or decrease the length of the voltage vector, increasing or decreasing the current in the motor, to increase or decrease the torque output to bring the rotational velocity of the voltage vector closer to a required angular velocity of the motor. This is illustrated in Figure 3.

Unlike other sensorless control methods which rely on estimating the emf in the motor accurately, the method according to this invention can be implemented without exact values for the motor parameters in Equation (7) and (8) i.e. *Rs* and *Xs,* since small errors are eliminated by the ratio of the two emf components. The error in the component values needs to be quite significant before it changes the sign of the error will occur, thus keeping the controller very stable despite the approximations used in its method.

One embodiment of the invention is illustrated by the block diagram in Figure 3 which uses the angular error calculated in each iteration of the control loop to set the instantaneous speed of rotation of the voltage vector up to the next calculation time. An outer control loop will determine the voltage vector magnitude. A power electronic inverter 101 and motor or generator 102 is controlled according to this aspect of the invention. The currents to/from the motor 102 are monitored at a pre-determined interval of time or rotor angle. Three phase currents can be transformed to two phase currents in the stationary stator reference frame by block 103. If the motor is a two phase motor such as a hybrid stepping motor this step 103 is not necessary.

A vector demodulation block 104 transforms the currents from the stationary stator reference frame to the rotating stator reference frame at a known angle to produce the real current vector I_{s_real} aligned with the rotating stator reference frame and the imaginary current vector I_{s_imag} orthogonal to the rotating stator reference frame. These currents are used by the Angle Calculator 105 which implements equation 13 to calculate an estimate of the angle over which the voltage vector needs to be moved to bring the current vector to the correct position with respect to the emf vector to deliver the required control angle at the next time step. The angular error term is passed to a controller 110 which may have proportional and integral controllers to generate an updated rotational speed and new angular position for the voltage vector modulator 107 which will tend to reduce the angular error for the present speed and load. The integration of an angular error to produce average speed with instantaneous correction of the next angular position is similar to a phase locked loop. The speed estimate from block 110 is compared to the speed required by the user demand to produce a speed error. The speed error may pass through a further PI controller 111 to recalculate the magnitude of the next voltage vector which is passed to the vector modulator 107. The voltage vector and its new angular position to the stationary stator reference frame to drive the inverter 101 and motor 102 during the next time step.

In this embodiment the speed control loop to set the voltage vector magnitude can be thought of as an outer control loop and would typically have a longer time constant than the angle control loop driven by the angular error according to the invention. In this way rapid resynchronisation of the stator voltage vector is possible in response to the angular error. This will result in minor fluctuations of the stator vector rotational speed (which is following the actual rotor speed) which are corrected by increasing or decreasing the voltage vector magnitude in the outer control loop.

The method of this invention is applicable to hybrid stepping motors which are commonly available with two, three and five phase windings are common.

Other brushless permanent magnet synchronous motors (both sinusoidal and trapezoidal types) can benefit from the method of the invention. Application of the invention to brushless permanent magnet synchronous motors has the following advantages over prior art sensorless control schemes for such motors. No knowledge of the motors rotational emf to speed characteristic is required and a reasonable estimate of the winding resistance is all that is required as the method is surprisingly tolerant to errors in this value. In brushless permanent magnet motors the reactance is usually smaller than the resistance and the method of the invention can be applied very successfully while completely ignoring the reactive voltage terms in Equations (7) and (8).

The flux switching machine is an electrical machine with a rotor with no magnets or windings and a stator carrying a field winding or permanent magnets and armature windings with any number of electrical armature phases, including one, two, three and five. As with all synchronous motors the armature rotational emf alternates at a frequency proportional to rotor speed. In flux switching machines with field windings in the stator, the magnitude of the rotational emf is dependent on both the speed of the rotor and the magnitude of the field current. Control of a flux switching motor according to this invention completely avoids the need to measure field current to establish the relationship between rotational emf and field current. The method according to this invention controls the armature current of each phase winding to be in phase with the emf in that phase winding without ever needing to know the magnitude of the emf. It does this by controlling the instantaneous angle of the voltage vector delivered to the machine to maintain the current in synchronism with the angle of the emf. The ratiometric calculations implemented in this invention therefore deliver a major breakthrough for the control of the flux switching motor without position sensors on the rotor.

The simple rotor construction of the flux switching motor makes them suitable for high speed operation. At higher rotational speeds the reactance of the armature windings may be significantly higher than the resistance. Under these conditions the resistive terms in Equation (7) and (8) may be ignored.

Controller for Electrical Machines

CLAIMS:

1. A control system for an electrical machine comprising a rotor, a stator having one or more phase windings for generating a rotating stator magnetic field, the system comprising detection means for monitoring the currents in the phase windings providing a real component (I_{s_real}) along a real axis at a known angle in line with a rotating reference frame and an imaginary component (I_{s_imag}) orthogonal to the real component (I_{s_real}), calculating means for determining a value of the real component (E_{s_real}) of the rotational emf along an axis at the known angle relative to the rotating reference frame and an imaginary component (E_{s_imag}) orthogonal to the real component (E_{s_real}), estimating means for estimating the angular difference between the current vector and the rotational emf vector, error means for determining an angular error signal indicative of the deviation of the angular difference from a desired magnitude, and synchronising means for controlling the machine such that the error signal tends towards zero.

2. A control system according to claim 1 wherein the estimating means comprises a step of determining the ratio of the orthogonal components of the current.

3. A control system according to claim 1 or 2 wherein the estimating means comprises a step of determining the ratio of the orthogonal components of the rotational emf.

4. A control system according to claim 2 and 3 wherein the estimating means estimates a value representative of the angular difference between the angle of the current vector and the angle of the rotational emf vector by evaluating the difference between a function of the ratio of the orthogonal current vectors and a function of the ratio of the orthogonal emf vectors.

5. A control system according to claim 4 wherein the error means estimates the error between the value representative of the angular difference and a value representative of the required angular difference.

6. A control system according to any preceding claim wherein the synchronising means comprises means for controlling the stator voltage angle dependent on the error signal.

7. A control system according to any preceding claim wherein the required representative value of the angular difference is approximately zero.

8. A control system according to any preceding claim wherein the desired value for the said estimated angular difference is varied according to operating speed or load at higher rotational speeds.

9. A control system according to any preceding claim wherein the estimating means comprises a step of determining the ratio of the orthogonal component of the current, *Is_imag*, to the real component of the current, *Is_real.*

10. A control system according to any preceding claim wherein the estimating means comprises a step of determining the ratio of the orthogonal component of the rotational emf, *Es_imag*, to the real component of the rotational emf, *Es_real.*

Application No:	GB0820895.1	**Examiner:**	Bill Riggs
Claims searched:	1 - 10	**Date of search:**	4 March 2009

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	EP 1657808 A2 (Vacon Oyj) see whole doc.
A	-	US 4885519 A (Siemens AG) see whole doc.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

H2J

Worldwide search of patent documents classified in the following areas of the IPC

H02P

The following online and other databases have been used in the preparation of this search report

Online databases: EPODOC, OPTICS, WPI

International Classification:

Subclass	Subgroup	Valid From
H02P	0021/00	01/01/2006