A sensorless scheme which mitigates the above-mentioned disadvantages has previously been proposed in PCT patent application WO2013/132249. Whilst this scheme may go some way toward mitigating the above-mentioned disadvantages, the scheme disclosed therein utilises a complex hardware arrangement which may add to the overall cost of the control system of the motor.

SUMMARY

In a first aspect, the present disclosure refers to a method of determining a position of a rotor of a brushless permanent magnet motor, the method comprising measuring phase current flowing through a phase winding of the motor during excitation of the phase winding, measuring voltage applied to the phase winding of the motor during excitation of the phase winding, calculating a phase of back EMF induced in the phase winding using the measured phase current and the measured voltage, determining a zero-crossing point of the back EMF induced in the phase winding using the calculated phase of back EMF induced in the phase winding, and determining an aligned position of the rotor of the brushless permanent magnet motor when the back EMF induced in the phase winding is at the zero-crossing point.

The method according to the first aspect of the present disclosure may be advantageous principally as the method comprises calculating a phase of back EMF induced in the phase winding using the measured phase current and the measured voltage, determining a zero-crossing point of the back EMF induced in the phase winding using the calculated phase of back EMF induced in the phase winding, and determining an aligned position of the rotor of the brushless permanent magnet motor when the back EMF induced in the phase winding is at the zero-crossing point.

In particular, it is known that the back EMF of a brushless permanent magnet motor may have a substantially sinusoidal form, and it may be possible to obtain an amplitude and a frequency of back EMF induced in the phase winding from past measurement or simulation, or from real-time calculation. By calculating a phase of back EMF induced in the phase winding using the measured instantaneous phase current and the measured voltage, this information can then be used in conjunction with the known amplitude and frequency to provide a relatively accurate representation of a waveform of the back EMF induced in the phase winding. The representation of a waveform of the back EMF induced in the phase winding may then be used to determine a zero-crossing point of the back EMF induced in the phase winding, and hence to determine an aligned position of the rotor when the back EMF induced in the phase winding is at the zero-crossing point.

The method according to the first aspect of the present disclosure may also be advantageous as the method may enable zero-crossing points to be determined where they lie outside of periods of excitation of the phase winding. In particular, by utilising a representation of the back EMF induced in the phase winding in the manner described above, zero-crossing points can be determined irrespective of whether or not they lie within a period of excitation of the phase winding. This may enable efficient operation over a wider range of powers relative to, for example an arrangement where the rotor position is determined by hardware. In particular, a motor in which zero-crossing points can only be determined during periods of excitation may have a lower operating efficiency for a given power relative to a motor which is controlled in accordance with the method according to the first aspect of the present disclosure, as zero-crossing points which lie outside periods of excitation cannot be determined with any accuracy, leading to inefficient commutation.

The method may be carried out using software, for example rather than using hardware. Hence component number and/or overall cost of a control system to implement the method according to the first aspect of the present disclosure may be reduced, for example relative to a scheme where zero-crossings of back EMF are predicted or calculated using hardware.

By a zero-crossing point of back EMF induced in the phase winding is meant a point at which the value of the back EMF hits zero during a transition between a positive polarity back EMF value and a negative polarity back EMF value, or vice versa.

A phase of back EMF induced in the phase winding may be calculated using the equation $E = L\frac{dI}{dt} + IR - V_{PH}$, where E is the back EMF induced in the phase winding, L is the inductance of the phase winding, I is the phase current flowing through the phase winding, R is the resistance of the phase winding, and V_{PH} is the voltage across the phase winding.

The method may comprise measuring phase current over a plurality of excitation pulses applied to the phase winding, for example over each excitation pulse applied to the phase winding, or over every other excitation pulse applied to the phase winding. Measuring phase current over each excitation pulse applied to the phase winding may be beneficial as it may improve the accuracy of the determined zero-crossing point. The method may comprise measuring phase current at the beginning of each excitation pulse applied to the phase winding, and at the end of each excitation pulse applied to the phase winding. The method may comprise measuring phase current for substantially the full duration of each excitation pulse applied to the phase winding.

Measuring current flowing through the phase winding of the motor may comprise measuring average phase current flowing through the phase winding of the motor

least one instantaneous back EMF value using the measured instantaneous phase current may comprise calculating instantaneous back EMF values at the beginning of each excitation pulse applied to the phase winding, and at the end of each excitation pulse applied to the phase winding.

Calculating a phase of back EMF induced in the phase winding may comprise integrating calculated instantaneous back EMF values, for example integrating calculated instantaneous back EMF values between boundaries set by the phase angle at the beginning and end of an excitation pulse applied to the phase winding. This may be beneficial as it may enable calculation of the phase of the back EMF induced in the winding, whilst also filtering any noise that may be introduced during calculation of the instantaneous back EMF values using the measured instantaneous phase current, for example noise introduced via differentiation.

The method may comprise normalising integrated calculated instantaneous back EMF values.

In a second aspect, the present disclosure refers to a brushless permanent magnet motor comprising a controller configured to measure instantaneous phase current flowing through a phase winding of the motor during excitation of the phase winding, measure voltage applied to the phase winding of the motor during excitation of the phase winding, calculate a phase of back EMF induced in the phase winding using the measured instantaneous phase current and the measured voltage, determine a zero-crossing point of the back EMF induced in the phase winding using the calculated phase of back EMF induced in the phase winding, and determine an aligned position of the rotor of the brushless permanent magnet motor when the back EMF induced in the phase winding is at the zero-crossing point.

In a third aspect, the present disclosure refers to a data carrier comprising machine readable instructions for the operation of a controller of a brushless permanent magnet motor to measure instantaneous phase current flowing through a phase winding of the motor during excitation of the phase winding, measure voltage applied to the phase winding of the motor during excitation of the phase winding, calculate a phase of back EMF induced in the phase winding using the measured instantaneous phase current and the measured voltage, determine a zero-crossing point of the back EMF induced in the phase winding using the calculated phase of back EMF induced in the phase winding, and determine an aligned position of the rotor of the brushless permanent magnet motor when the back EMF induced in the phase winding is at the zero-crossing point.

Preferential features of aspects of the present disclosure may be equally applied to other aspects of the present disclosure, where appropriate.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the present invention, and to show more clearly how the invention may be put into effect, the invention will now be described, by way of example, with reference to the following drawings:

Figure 1 is a block diagram of a motor system in accordance with the present invention;

Figure 2 is a schematic diagram of the motor system of Figure 1;

Figure 3 details allowed states of an inverter of the motor system of Figure 1 in response to control signals issued by a controller of the motor system;

CLAIMS

1. A method of determining a position of a rotor of a brushless permanent magnet motor, the method comprising measuring phase current flowing through a phase winding of the motor during excitation of the phase winding, measuring voltage applied to the phase winding of the motor during excitation of the phase winding, calculating a phase of back EMF induced in the phase winding using the measured phase current and the measured voltage, determining a zero-crossing point of the back EMF induced in the phase winding using the calculated phase of back EMF induced in the phase winding, and determining an aligned position of the rotor of the brushless permanent magnet motor when the back EMF induced in the phase winding is at the zero-crossing point.

2. A method as claimed in Claim 1, wherein the phase of back EMF induced in the phase winding is calculated using the equation $E = L\frac{dI}{dt} + IR - V_{PH}$, where E is the back EMF induced in the phase winding, L is the inductance of the phase winding, I is the phase current flowing through the phase winding, R is the resistance of the phase winding, and V_{PH} is the voltage across the phase winding.

3. A method as claimed in Claim 1 or Claim 2, wherein the method comprises measuring phase current over a plurality of excitation pulses applied to the phase winding.

4. A method as claimed in Claim 3, wherein the method comprises measuring phase current over each excitation pulse applied to the phase winding.

5. A method as claimed in any preceding claim, wherein measuring current flowing through the phase winding of the motor comprises measuring average phase current flowing through the phase winding of the motor and/or measuring instantaneous phase current flowing through the phase winding of the motor.

6. A method as claimed in any preceding claim, wherein measuring voltage applied to the phase winding of the motor during excitation of the phase winding comprises measuring average DC voltage and/or measuring instantaneous DC voltage applied to the phase winding of the motor during excitation of the phase winding.

7. A method as claimed in any preceding claim, wherein the method comprises commutating the phase winding relative to the determined zero-crossing point of back EMF induced in the phase winding.

8. A method as claimed in any preceding claim, wherein determining a zero-crossing point of the back EMF induced in the phase winding may comprise utilising any or any combination of an amplitude representative of the amplitude of back EMF induced in the phase winding, and a frequency representative of the frequency of back EMF induced in the phase winding.

9. A method as claimed in any preceding claim, wherein calculating a phase of back EMF induced in the phase winding comprises integrating the equation $E = L\frac{dI}{dt} + IR - V_{PH}$ to obtain a relationship representative of integrated back EMF.

10. A method as claimed in Claim 9, wherein calculating a phase of back EMF induced in the phase winding comprises equating integrated back EMF to an integral of a sinusoidal waveform representative of back EMF induced in the phase winding.

11. A method as claimed in Claim 10, wherein calculating a phase of back EMF induced in the phase winding comprises equating a relationship

representative of integrated back EMF with an integral of a sinusoidal waveform representative of back EMF induced in the phase winding.

12. A method as claimed in any of Claims 1 to 8, wherein calculating a phase of back EMF induced in the phase winding comprises calculating at least one instantaneous back EMF value using the measured instantaneous phase current and the measured voltage.

13. A method as claimed in Claim 12, wherein instantaneous back EMF values are calculated using the equation $E = L\frac{dI}{dt} + IR - V_{PH}$.

14. A method as claimed in Claim 12 or Claim 13, wherein calculating a phase of back EMF induced in the phase winding comprises integrating calculated instantaneous back EMF values.

15. A brushless permanent magnet motor comprising a controller configured to measure instantaneous phase current flowing through a phase winding of the motor during excitation of the phase winding, measure voltage applied to the phase winding of the motor during excitation of the phase winding, calculate a phase of back EMF induced in the phase winding using the measured instantaneous phase current and the measured voltage, determine a zero-crossing point of the back EMF induced in the phase winding using the calculated phase of back EMF induced in the phase winding, and determine an aligned position of the rotor of the brushless permanent magnet motor when the back EMF induced in the phase winding is at the zero-crossing point.

16. A data carrier comprising machine readable instructions for the operation of a controller of a brushless permanent magnet motor to measure instantaneous phase current flowing through a phase winding of the motor during excitation of the phase winding, measure voltage applied to the phase winding of the motor

during excitation of the phase winding, calculate a phase of back EMF induced in the phase winding using the measured instantaneous phase current and the measured voltage, determine a zero-crossing point of the back EMF induced in the phase winding using the calculated phase of back EMF induced in the phase winding, and determine an aligned position of the rotor of the brushless permanent magnet motor when the back EMF induced in the phase winding is at the zero-crossing point.