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Research article

Sensorless control for switched reluctance motor based on special position detection

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ABSTRACT

This paper proposes a new sensorless control approach for switched reluctance motor (SRM) in the single pulse control mode in high speed operation. The sensorless method uses the cross point position of transformer electromotive force (EMF) and motional back electromotive force (BEMF) to estimate the rotor position. The cross point position can be derived from the inductance model of SRM, and it is regarded as reference position. The rotor position can be calculated by detecting the special position for each electrical cycle. The proposed position estimation method is not affected by the magnetic saturation of SRM. Importantly, no additional hardware and no complicated computation or memory storage are required with the proposed method. Finally, the simulation and experimental results on a three-phase 12/8-pole SRM demonstrate the validity of the proposed sensorless scheme.

1. Introduction

Switched reluctance motor (SRM) has received considerable attention for industry applications due to its high fault-tolerant capability, rugged structure and large torque output over wide speed range. SRM drives have been investigated for use in aerospace, variable speed and servo-type applications, electric vehicles and household appliances [1]. Accurate and continuous rotor position information is essential for SRM drive operating in variable speed drive applications. Conventionally, the SRM driver obtains accurate rotor position information via optical encoders or Hall sensors. However, the use of position sensors not only increases system complexity and cost, but also reduces the reliability of the drive system. Therefore, developing the high reliability, low cost and high precision sensorless control technology for SRM drive is quite necessary [2–4].

Over the past three decades, a wide variety of sensorless control methods for SRM drives have been reported in the literature [5–25]. The pulse injection method is the most effective sensorless methods for the low speed operation and standstill condition [5–8]. The method which presented in [5] is based on the current pulse injection and sectors is determined by comparing phase currents in an idle phase with two thresholds. The pulse injection method is only valid for sensorless control of SRM at start-up and low speeds operation. At high speed, the conduction phase occupies a large part of the electrical cycle of one phase, and the time for pulse injection becomes small, which leads to significant errors of the method [6]. Aiming at the medium-high speed regions, methods such as flux current method [9], inductance model method [10–12], neural networks [13,14] and fuzzy logic method [15–17], and sliding mode observer (SMO) method [18,19] have been deeply investigated. In traditional flux-linkage method, the flux linkage of SRM under different phase current and different rotor position is measured off-line [9]. Thereafter, the three-dimensional table was established to store the three detected parameters in the digital controller. The rotor position can be obtained by looking up a table of pre-stored current and flux linkage values. Although the method was simple for implementation purposes, it did require extensive characterization of the machine and large amounts of memory. In [10], a rotor position estimation scheme based on phase inductance vector was proposed. The pulse was injected to get the inductance of inactive phases and full cycle inductance was obtained. In [11], two methods to eliminate the mutual flux effect on rotor position estimation were presented, which did not require a priori knowledge of mutual flux linkage profiles of SRM. Over the past decade, the use of computation intensive methods such as state observer based estimation, and fuzzy logic or neural network estimation methods had been investigated for indirect position sensing in SRM drives at high speeds. Refs. [18,19] used the SMO for position

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estimation in SRM drives at high speeds. The method has the advantage of strong robustness; however, it relies on the mathematical model of the motor, and the algorithm is more complex to implement.

To overcome above problems, Gallegos-Lopez et al. presented the current gradient sensorless (CGS) method, which only required the phase current to determine rotor position [20]. The zero-crossing of the gradient of the phase current used to determine the reference position where the rotor and stator pole begin to overlap, but it did not have very good efficiency at low speed. Bateman et al. investigated the use of CGS scheme in an extra high speed SRM drive system. The influence of speed, bus voltage and advance angle on the method is analyzed by simulation in [21]. A new bus-current-sensor-based position estimation method is proposed in [22,23] by detecting excitation currents from the bus current. The rotor position is estimated from the excitation current, by a current-gradient method in the voltage-pulse-control mode in a high-speed operation. A new sensorless method for SRM based on inductance gradient was presented in [24]. The rotor position estimation is performed by detecting the aligned position of the rotor pole and stator pole. Similarly, the phase inductance slope zero-crossing detection method discussed in [25] uses the change of the gradient of the phase inductance to detect the un-aligned position of the rotor pole and stator pole. As can be seen from the above literature, this methods make a single measurement for each phase cycle.

For the medium-high speed operation of SRM, the position estimation algorithm should avoid the look-up table and the complex model calculation, so as to improve the real-time and rapidity of the algorithm. An effective solution to these problems is to detect a single special position in a single electric cycle. This sensorless approach detects a known special position within each electrical cycle to estimate motor position and speed information, enabling position sensorless operation. Thus, a novel sensorless control method of SRM based on the cross point of transformer-EMF and motional-BEMF is proposed in this paper. The crossing point position can be derived from the inductance model of SRM, and it is regarded as a reference position to estimate rotor position. The cross point of transformer-EMF and motional-BEMF occurs at the bottom zone of the phase inductance. It is not affected by the magnetic saturation of SRM, thus it is particularly suitable for the full- or over-load condition. The method is easy to implement and does not require the electromagnetic characteristics of SRM, which possesses good fault-tolerant capability, and is suitable for medium and high speed applications.

2. Switched reluctance motor with segmental rotors

SRM with new type of rotor construction, i.e., segmented rotor is proposed in [26]. The stator and rotor of SRM are salient-pole structure, which leads to large wind (oil) resistance at high speed. The SRM with segmental rotors consists of several rotor iron segments which are embedded in non-magnetic cover. The feature makes it have the advantages of low wind (oil) resistance and low iron losses at high speed, besides the advantages of the conventional SRM like simple structure, high fault tolerance as well as flexible control. Thus, the SRM with segmental rotors is particularly suitable for the drive systems in aerospace environments because of low wind (oil) resistance and iron losses at high speed.

2.1. Switched reluctance motor with segmental rotors

The segmented SRM consists of several independent stator iron segments, or several rotor iron segments which are embedded in non-magnetic cover. A three-phase 12/8 segmented SRM with windings spanning three teeth (termed as "fully pitched windings") is proposed in Fig. 1. The segmented switched reluctance machine consists of several independent stator iron segments, or several rotor iron segments which are embedded in non-magnetic cover. The segmented SRM achieves shorter magnetic paths to reduce core losses, the use of a cylindrical rotor assembly to reduce wind (oil) resistance, and electromagnetic isolation to enhance motor reliability and fault tolerance.

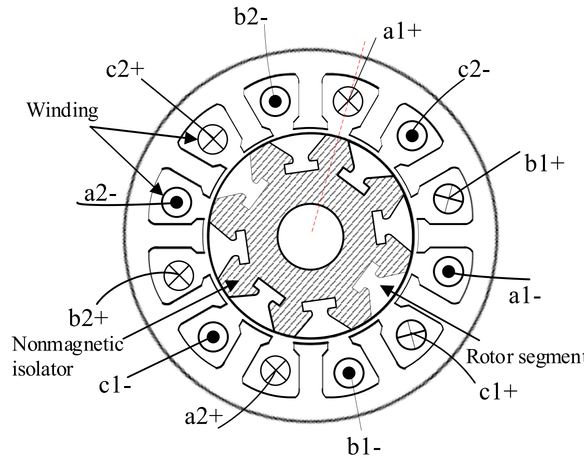

Fig. 1. 12/8 SRM with segmental rotors at 0° position of A phase.

2.2. Finite element analysis of switched reluctance motor with segmental rotors

The magnetic flux density distribution of 12/8 SRM with segmental rotor at the unaligned and aligned position are shown in Fig. 2(a) and (b), respectively. As shown in the figure, the magnetic flux is mainly through two adjacent stator teeth and the corresponding rotor teeth closed. Because the segmental rotor SRM naturally has short flux loops, and thus iron loss can be reduced by this feature.

The FEA of the studied SRM with fully-pitched windings and segmental rotors is conducted in software and the nonlinear flux profile and inductance profile of studied SRM is shown in Fig. 3 (a) and (b), respectively. Fig. 3(a) shows the flux linkage versus current curves for rotor positions from unaligned angle to aligned angle. Because of the double salient construction of the SR motor and magnetic saturation effects, in general, the flux linked magnetic characteristics in an SRM phase varies as a function of rotor position and the motor current. As shown in Fig. 3(b), the half cycle of the SRM phase inductance consists of three regions, i.e., the bottom region, the linear region and the top region. It can be seen from Fig. 3(b) that the inductance of the bottom region is less affected by the saturation of winding currents.

3. Proposed sensorless control method

3.1. Basic principle of the sensorless method

Conventionally, SRM is driven by asymmetric half bridges and there are three main control strategies for SRM: chopped current control, single pulse control and PWM voltage control. The SRM drive system adopts different control strategies in different speed ranges. Chopped current control and PWM voltage control are used for the low and medium speeds and single pulse control mode is chosen for high speed operation. This paper proposed a sensorless control strategy of SRM drive using single pulse control. The typical current waveform in the single pulse control is