Improvement of phase inductance slope method for Without Position Sensor control of switched reluctance motor

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Abstract—At present, the research hotspot of switched reluctance motor is to realize the accurate control of motor without position sensor. Among many control methods, the phase inductance slope method is concerned by researchers because it does not need to add additional power supply circuit, and does not need to calculate the flux linkage and inductance curve in advance. Aiming at the defect that the phase inductance slope algorithm can not advance the opening angle and the position signal error is easy to appear near the opening angle, this paper makes an improvement and verifies the experiment.

1. Introduction

The traditional flux linkage method, current method, inductance model method, intelligent control method and observer method all need to measure or calculate the flux linkage and inductance characteristic curve in advance, which undoubtedly greatly increases the amount of calculation [1]. The process of electromagnetic calculation is complex. It is nonlinear calculation, and the accuracy is very limited. Errors will directly affect the calculation of motor rotor position. The most important thing is that after establishing the model of the relevant prototype, there will be errors in the estimation of the rotor position after replacing other prototypes, and the portability of the whole system is very poor [2]. Therefore, this paper uses the phase inductance slope algorithm which does not need a lot of calculation as the position free control algorithm, and improves the algorithm. Then the relevant improvements and theories are verified by experiments.

2. Method for calculating rotor position using slope of phase inductance

When switched reluctance motor is running at high speed, due to the increase of rotation speed, less current information can be detected during the detection cycle [3]. Current chopping control is often not used, but a single pulse control mode which controls the on and off angles. As the speed of the motor increases, the single cycle becomes very short, so it can be seen that the speed of the motor does not change during the single cycle. As a result, the rotation speed does not change and the inductance characteristics do not change in a single cycle [4]. Therefore, the position information of the rotator can be estimated as long as a particular position in the electrical cycle is determined, and the Position-free control and speed estimation of the motor can be achieved. The advantage of using the method of detecting single-period special location points is that there is no need to predict the electromagnetic characteristics, no need to undergo complex electromagnetic calculation, and no need to store and decode. It does not need to increase the hardware burden of the system and is portable. It is often widely studied and applied in the high-speed field of switched reluctance motor without location control [5].
In the mathematical model of switched reluctance motor, the phase inductance changes periodically with the rotation of the motor. In the high-speed rotating phase of the motor, it can be approximated that the speed of the motor does not change during a single period of inductance change, which has the basic condition to detect the position of the rotor.

2.1 Slope calculation method of phase inductance

The value of the phase inductance is obtained by injecting high frequency and low amplitude pulses into the nonconducting phase.

\[ L(\theta) = \frac{zU_{dc}}{\frac{dI}{dt}|_{on} - \frac{dI}{dt}|_{off}} = \frac{2U_{dc}}{\Delta I} \]  

(1)

It can be seen from the formula (1) that the inductance of the estimated phase is only related to the difference of current slope and bus voltage. Therefore, the phase inductance can be calculated by injecting high frequency and low amplitude pulses into the non-conducting phase and by calculating the phase current when the switch is switched off and on.

In addition, besides the above calculation method, the phase inductance value must be zero by software after the current continuation is zero to prevent calculation errors. Because the phase inductance slope algorithm is a high-speed algorithm, the sampling interval is very short. To sum up, the method for calculating the phase inductance slope can be derived from (2).

\[ \dot{L} = \frac{\Delta L}{\Delta T} = \frac{L(K+1) - L(K)}{T_s} \]  

(2)

In Formula (2.1), \( \dot{L} \) Represents the slope of the phase inductance, \( L(K+1) \) and \( L(K) \) represent the sampled inductance values of the first \((k+1)\) and the second \((k+1)\), respectively, \( T_s \) is the sampling interval.

2.2 Basic Theory of Phase Inductance Slope

From the basic operation principle of switched reluctance motor, it is known that the phase inductance slope is zero in alignment position and misalignment position, the misalignment position is negative zero-crossing point, and the alignment position is positive zero-crossing point. Therefore, the alignment position and misalignment position of the rotor can be detected by detecting the phase inductance slope zero-crossing point. If the phase inductance slope is greater than zero, that is, from aligned position to misaligned position, set to high level. Set the range of phase inductance slope less than zero, that is, from aligned position to misaligned position, to low level. This will result in a position pulse showing the position of the rotor. Take the 12/8 SRM in Fig.1 for example, 12/8 SRM has 45 degree per cycle. Based on the symmetrical structure and electrical characteristics of switched reluctance motors, the interval between them can be summarized to estimate the speed, realize the speed adjustment, and realize the Position-free control of the motor.
3. Improvement of phase inductance slope algorithm
Although the phase inductance slope method has advantages such as no need to add external hardware, no need for complex modeling and analysis, it obviously has some drawbacks. First, when the current continues to flow to zero, the phase inductance cannot be calculated by the formula, and must be set to zero by software. However, there are some problems with the above treatment.

At the instant of switching on, the inductance value has a step signal from zero to the actual value due to the use of software zero. However, there are two possible scenarios for the error caused by this step signal, the first one illustrated in Fig.2(a).

There is also a second case, as shown in Fig.2(b). There is a positive step in the phase inductance slope at 0 degrees, but the phase inductance slope is not all positive in the range of 0 degrees to 22.5 degrees. It will produce two zero-crossing points with positive and negative values, which coincide with the detection of the special position point of the pole alignment of the stator and the rotator teeth, resulting in an error pulse in the position detection pulse P1, which affects the estimation of rotation speed and the position of the rotator.

In order to solve the above step error problem, this paper proposes the following solution: select the
maximum phase of the inductance as the position estimation phase. In this way, the zero crossing detection of the slope of the inductance at the on position can be avoided, and the above step error can be avoided. Table 1 shows the specific logic for selecting the maximum phase of inductance. Zoning the inductor can effectively avoid the occurrence of the above position pulse error pulse. Fig.3 is a schematic diagram of zero crossing detection of the slope of phase inductance after the opening angle is advanced, which proves the correctness of the above improvement.

### Table 1 Inductance partition logic

| Inductance relationship | Location interval | Estimated phase selection |
|-------------------------|------------------|--------------------------|
| $L_a \geq L_c \& L_a \geq L_b$ | Interval 1        | A                        |
| $L_c \geq L_a \& L_c \geq L_b$ | Interval 2        | B                        |
| $L_b \geq L_a \& L_b \geq L_c$ | Interval 3        | C                        |
| return                  | …                | …                        |

![Schematic diagram of zero crossing detection of phase inductance](image)

**Fig.3 Schematic diagram of slope zero crossing detection of phase inductance**

4. **Experiment of phase inductance slope method**

In order to prove the correctness of the above methods, experiments are carried out on the SRM experimental platform of 12/8. The experimental results are shown in Fig.4.

(a) Before improvement  
(b) After improvement

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5. Conclusion

Fig. 4 verifies that the logic of inductance zoning can eliminate the wrong pulse of rotor position signal near the opening angle and advance the opening angle. From the above experimental results, the improved phase inductance slope algorithm realizes the purpose of opening in advance, realizes the flexible adjustment of opening angle, and is more conducive to position free control under high-speed state.

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