A Novel Flux Linkage Indirect Measurement for Switched Reluctance Motor

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Abstract. This paper presents an indirect detection system of flux linkage characteristic of switched reluctance motor based on dSPACE, fixed rotor position by mechanical indexing for Static flux linkage detection, the phase windings is excited by the step voltage signal, the voltage and phase current are collected real-time, and calculate flux linkage. The advantages of the method is that the parameters are optimized by ControlDesk, the flux linkage detection model is built by Simulink, no writing program, simple, easy implementation. An 1.5kw three-phase 12/8 SRM experimental prototype was constructed, the detection results of the Static flux linkage and dynamic flux linkage verified its validity and feasibility.

1 Introduction

The switched reluctance motor (SRM) is a robust, low-cost, fault-tolerant machine suitable for several niche applications, salient pole structure, the magnetic of the motor is relatively saturated, the motor is nonlinear characteristics, so the flux linkage characteristic is detected difficultly. But flux linkage characteristic is important to optimize motor design, and improve motor performance and sensorless control, so the detection of the magnetic flux linkage characteristics has attracted extensive attention of many scholars.

The method of obtaining the characteristic of SRM flux linkage mainly have the finite element simulation method, the direct detection and the indirect detection, the flux linkage data is obtained by the finite element simulation, and established two dimensional model[1], but the model of finite element simulation is built difficultly, the results also need to verify by experiment, the method is not commonly used in practical applications. The hardware is installed in motor stator polar[2], and measure the polar magnetic density directly, multiplied by the cross-sectional area of the stator and the number of turns of the winding, and the flux linkage of motor winding is obtained. the defect of the method has larger measurement error. The motor winding inductance is measured directly by the alternating current bridge[3], and obtained the flux linkage, the method needs to be applied the pulse
detection signal, the measurement method is complex, measurement accuracy is not high. In the literature [4], the phase winding voltage and current value is collected by the sensor, and obtained the flux indirectly by evaluation of integrals, the method requires software design. The function analytic method is proposed in the literature [5], the method optimize system performance, but it is not adaptable to the change of load and environment. The neural network and variable structure fuzzy neural network are used to the flux detection model [6-8], but the advanced intelligent method is very high to the microprocessor, the algorithm is more complex.

The flux linkage indirect detection model is proposed in the paper based on dPACE. The Simulink model is proposed in the system, the parameters of the system are adjusted quick-acting computational efficiency utilizing the virtual control of the ControlDesk. The process of the flux linkage characteristic detection are simplified and the software design be ignored, for checking the accuracy of the flux linkage characteristic detection, the experimental prototype was constructed and verified its validity and feasibility.

2 Flux linkage detection principle
Ignored hysteresis and turbulence and mutual inductance between windings, the phase voltage equation of SRM is proposed

\[ u_k = R_k i_k + \frac{d\psi_k}{dt} \]  

(1)

Where \( u_k \) is the \( k \) phase voltage, \( R_k \) is \( k \) phase winding resistance, \( i_k \) is phase winding current, \( \psi_k \) is phase winding flux

From (1), the flux linkage expression is defined as

\[ \psi_k = \int_0^t (u_k - R_k i_k)dt + \psi_k(0) \]  

(2)

Where \( \psi_k(0) \) is initial value of the phase flux linkage, the voltage and current value are collected real-time from 0 to \( t \) time, \( \psi_k(0) \) and \( R_k \) are known, the phase flux linkage \( \psi_k \) is calculated from (2).

Numerical integration method, therefore, equation (2) is shown as discretely

\[ \psi_k(n) = \left\{ \sum_{i=1}^{n} [U_k(n) - R_k i_k(n)]T \right\} + \psi_k(0) \]

\[ \Rightarrow \psi_k(n) = \psi_k(n-1) + [U_k(n) - R_k i_k(n)]T \]  

(3)

Where \( T \) is discrete computing period, \( N \) is sample times, Continuously improve the test voltage, the steady state test current is obtained, and then the winding flux is obtained.

In order to improve the detection accuracy of flux linkage characteristic, and decrease error, when the winding temperature reaches the rated temperature rise, the phase winding resistance is collected, because the resistance value changes with the winding temperature.

In the process of SRM flux linkage characteristic detection, the phase winding voltage power supply ways are the step voltage and drop voltage. The motor rotor is fixed at a certain angle position, the step voltage is applied to the phase winding, as can be seen in the Fig.1, the phase voltage and phase current were collected between 0-\( t_1 \), and the flux linkage value was calculated by equation (2). The current was imposed to the phase winding, and current stability, suddenly turn off the power, the current will slowly drop from steady state to zero, as shown in the Fig.2, the phase voltage and phase current were collected in current decline process, and the flux linkage value was calculated by equation (2).
The method of the step voltage is convenient, simple and the phase winding heat is not obvious, the phase winding heat is obvious for the method of the drop voltage, and accuracy of flux linkage detection is reduced, so the flux characteristic of SRM is detected by step voltage method in the paper.

3 Flux linkage indirect detection system

3.1 Detection platform

According to the detection principle, the power converter of the proposed system was constituted, and three-phase asymmetry half-bridge inverter, using IGBT as main switch devices, the flux linkage characteristic detection platform was designed from the 12/8 SRM, as shown in the Fig. 3 using the dSPACE 1104 as core controller, the mechanical indexing as orientation system.

3.2 Detection process

Can be known from equation (2), the value of phase current and phase voltage and phase resistance influence the flux linkage detection, so these parameter ware checked before measuring, if the error of the motor processing is ignored, the each phase winding flux characteristic is same. The 12/8 SRM as the research object, the A phase flux linkage was measured, the two switch valves of A phase were turn on, provided supply power, when the electromagnetic torque is greater than the friction resistance of the motor, the rotor rotates to the pole align position, and the rotor position is 22.5 degree and...
standstill, align position as the starting point for the detection of flux linkage characteristics, the resistance value of the motor winding is measured at the rated temperature, and turn off the power supply, after the electric charge of the winding full discharge, and the initial flux value is zero, the detection model of flux linkage is download to dSPACE and calculated flux. Then, the rotor position of the motor is rotated 1 degrees, and repeat the above steps for flux linkage detection.

3.3 Detection model
Because the phase winding flux linkage characteristics is same, the detection model is also same. For example, the A phase winding flux linkage is measured, two power switch tube ware turn on at the same time, $U_d$ is power supply of A phase,$U_i$ is the voltage of power switch tube guide, the A phase winding voltage $U_s$ is shown

$$U_s = U_d - 2U_i$$

According to equation (2), the detection model of flux linkage was built, as can seen in Fig.4. The DS1104ADC_C8 is the eighth way of dSPACE, and collect bus voltage real-time, the DS1104ADC-C5 is the fifth way of dSPACE, and collect the phase current real-time, the DS1104BIT_OUT_C is the third way I/O, and output the switching signal of power switch tube.

![Fig.4 Detection model of flux linkage](image)

4 Experiment
The detection strategies described above have been implemented in the experimental system shown in Fig.5, A is the electric source, B is dSPACE1104, C is conditioning circuit, D is power converter, E is Mechanical indexing, F is SRM. Test results were obtained from 12/8 poles SRM, 1.5kW.

![Fig.5 Experimental platform](image)

4.1 Static flux linkage detection
The step voltage of 20 V is given for the align position (22.5 degree) and no align position (0 degree) in Fig.6 and Fig.7, as can be seen from the voltage waveform and response current waveform, which the response current waveform of align position rise slowly, because the value $L/R$ of the align position is larger than the value $L/R$ of the no align position.

Fig.6 Waveform of align position

At the align position (22.5 degree) and no align position, measured flux characteristic curve was shown in the Fig.8, the magnetic circuit reluctance of the aligned position is small, the magnetic is easy saturation, so the flux and current are non-linear relationship, that of the no align position is contrary, the flux linkage and current are linear relationship. Then, the 22.5 degrees for the starting point, measured flux at every 1 degrees in Fig.9.

Fig.8 Measured flux of 22.5 and 0 degree

4.2 Dynamic flux linkage detection

Fig.10 shows the dynamic flux linkage characteristics by non chopping control mode, Fig.11 shows the dynamic flux linkage characteristics by chopping control mode, as can be seen from the test waveform, the real-time flux can dynamically reflect the running state of the motor.
5 Conclusion
In this paper, the flux linkage characteristic of switched reluctance motor is proposed based on dSPACE and mechanical index, the flux linkage detection model is built by Simulink, do not need to write programs, the advantages of the method is that the parameters are optimized by ControlDesk. The experiment results of a prototype machine (three-phase 12/8 pole SRM) verified validity and feasibility of the proposed method.

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