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Position tracking control of switched reluctance motor with adaptive linear element based on current-sharing method

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ABSTRACT

A novel position tracking control strategy is proposed for switched reluctance motor (SRM) in this paper. The control strategy design can be divided into two steps. The first step is the position control loop design for the SRM, which is composed of proportional plus derivative (PD) controller and adaptive linear element (Adaline). The weights of the Adaline are trained with sliding-mode-learning algorithm (SMLA). The position controller has the united merits of the Adaline and sliding mode control (SMC). The second step is the inner current control loop design. The output of the position control loop is considered as the virtual reference current. The virtual reference current is divided into referenced phase current of the SRM with the proposed current-sharing method (CSM). The proposed position tracking control strategy need any model information on the SRM besides the phase number of the SRM. Simulation results certify that the proposed method not only can realize the position tracking of the SRM, but also has high control performance.

1. Introduction

Switched reluctance motors (SRMs) have simpler and more robust construction compared with induction motors (IMs) and permanent-magnet synchronous motors (PMSMs). Although SRMs have many good characteristics, the double-salient structure and highly saturated working features make the SRMs possess strong nonlinearities. SRMs have never been a popular choice in high-accuracy position control, due to the drawback of higher torque ripple compared with conventional motors that cause vibrations and acoustic noise [1–3]. At present, almost all the researches focus on speed or torque control of SRMs [4,5]. As an important application aspect, position control of the SRMs still has many key problems that need to be solved. The motivation of the position control of the SRMs can be divided into two aspects. Firstly, the research on position control of SRMs can extend the application area of the SRMs in the servo control. Secondly, the search on the position control without model information of the SRMs can make them easier to be realized. Thus, the realization of the high performance position tracking control for the SRMs is the main objective of this paper.

At present, almost all high performance control of the SRMs need the modeling of the SRMs [6–10]. And the modeling of the SRMs is an important aspect in the control design of the SRMs. The modeling of the SRMs mainly acquires the relation of flux-linkage or electromagnetic torque with rotor position and phase current. In Refs. [6,7], analytical flux-linkage models are constructed with the geometry or material parameters of the SRMs. In practice, these parameters of the SRMs are not available to the researchers. In Ref. [8], the static electromagnetic characteristics of the SRM are measured with off-line experiment and computation. In Refs. [9,10], neural networks are applied to the off-line or online modeling of the SRMs. At present, the control methods using the modeling information of the SRMs have many problem. Firstly, the off-line modeling need measurement devices, which increases the prices of the control design. When the rated power of the SRMs is very large, this modeling method may be impossible. Secondly, the parameters of the SRMs are not constant when the working conditions change. This will decrease the control performance of the SRMs. And thirdly, the online modeling of the SRMs will increase the complexities of the control design. And this need more advanced control strategies. Elimination of the dependence of the controller on the model of SRMs is another objective of this paper.

In traditional position tracking control of the motor, three control loops are needed, which are position control loop, speed control loop and current control loop. In this paper, only position control loop and current control loop are required for the position tracking of the SRM. The PD controller is easily realized and widely applied in the control system. The shortcoming of the PD controller is that it has low robustness and adaptiveness to parameter uncertainties and disturbances. To enhance the robustness and adaptiveness of PD controller, the position controller for the SRM

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is the combination of the PD controller and Adaline. Among the neural networks, the Adaline is the simplest with a single layer adaptive linear neurons [11]. Due to the simple structure of the Adaline, the weight learning algorithm has a very low computational complexity and it makes this method suitable for online system identification and adaptive control. In the application of the Adaline, how to get the optimal weights of the neurons is a very attractive problem. Recently, SMLA is applied to the training of the neural networks. Ramires and his coauthors firstly applied the SMLA to the weight training of the Adaline [12]. In Ref. [12], the proposed SMLA is simple, robust and can guarantee finite time reachability of the zero learning error. Efe and his coauthors gave a relation of sliding surface for the control system and the zero learning error of the parameters of the Adaline controller, and tested the method in the anthropoid robot control [13]. Topalov and his coauthors gave a deep research on the SMLA for the neural networks. He applied the method to nonlinear control system [14] and the speed control of PMSM [15] respectively.

In the position tracking control of the SRMs, the torque ripple has vary large effect to the performance of the position control. How to reduce the torque ripple is a very urgent problem that should be resolved to extend the application area of the SRM drives. Torque-sharing function (TSF) is a promising solution to reduce torque ripples of the SRM. Several TSFs have been reported, such as linear, cubic, and exponential TSFs [16,17]. Although TSF can divide the reference torque into phase torque, it needs the relation of the torque with rotor position and phase current. To eliminate the dependence of control design on the model of the SRM, a novel CSM is proposed in this paper, which can realize the sharing of the virtual reference current between the phase current.

The main contribution of the paper can be summarized as following three aspects.

(1) A novel CSM is proposed, which not only can divide the virtual reference current into symmetrical phase current, but also can eliminate the dependence of the controller on the model of the SRM.

(2) The Adaline with SMLA can enhance the adaptiveness and robustness of the position controller for the SRM. SMLA can avoid the computation of the Jacobian coefficient of the Adaline. And in addition, the SMLA can increase the weight learning speed of the Adaline.

(3) The combination of the PD controller and Adaline with SMLA can realize high performance control of the position tracking for the SRM without the speed control loop.

This paper is organized as following sections. Section 2 gives the design of the position tracking controller for the SRM with PD controller and Adaline. Section 3 introduces the CSM for a four-phase 8/6 SRM. Section 4 shows the simulation results and analysis of the design method. And Section 5 summarizes the paper.

2. The design of the position controller for the SRM

2.1. The gradient-descent training method of Adaline

The structure of the Adaline is given in Fig. 1(a). In Fig. 1(a), the input of the Adaline is the state vector $X=[x_1,x_2,\ldots,x_n,b]^T$ and the output is y, where the constant $b>1$ is a bias and the vector $W=[W_1,W_2,\ldots,W_n,W_{n+1}]^T$ is the weight vector of the Adaline. The output signal y is computed with the following equation:

$$y=W^TX, \tag{1}$$

where the vector W^T represents the transpose of the vector W.

Remark 1. The input state variables $x_1,x_2,\ldots,x_n$, the weights W_1, $W_2,\ldots$, W_{n+1}, and the output signal y are all time-varying variables.

The desired output of the Adaline is presented by y_d , the cost function is defined as

$$E=e_a^2=(y_d-y)^2, \tag{2}$$

where $e_a=y_d-y$ is the error between the desired output and actual output of the Adaline. The weights of the Adaline can be trained with the gradient-descent method (GDM)

$$W_k(j+1)=W_k(j)-\eta_k\frac{\partial E}{\partial W_k}, \tag{3}$$

where j is the sample time, η_k is the learning-rate parameter and $k=1,2,\ldots,(n+1)$. And $\frac{\partial E}{\partial W_k}$ can be computed with the following method:

$$\frac{\partial E}{\partial W_k}=\frac{\partial E}{\partial y}\frac{\partial y}{\partial W_k}=-2e_a\frac{\partial y}{\partial W_k}. \tag{4}$$

2.2. The Adaline with SMLA

The proposed controller of the position tracking control for the SRM drive is composed of the PD controller and Adaline with SMLA [12]. The control structure of the PD controller and the Adaline with SMLA is given in Fig. 1(b). Before the design of the SMLA, some assumptions are given as following.

Assumption 1. In Fig. 1(a), the state vector X, its time derivative vector $\dot{X}$ and the weight vector W are assumed to be bounded variables, i.e.,

$$\|X\|=\sqrt{x_1^2+x_2^2+\cdots+x_n^2+b^2}\le M_x, \tag{5}$$

$$\|\dot{X}\|=\sqrt{\dot{x}_1^2+\dot{x}_2^2+\cdots+\dot{x}_n^2}\le M_{\dot{x}}, \tag{6}$$

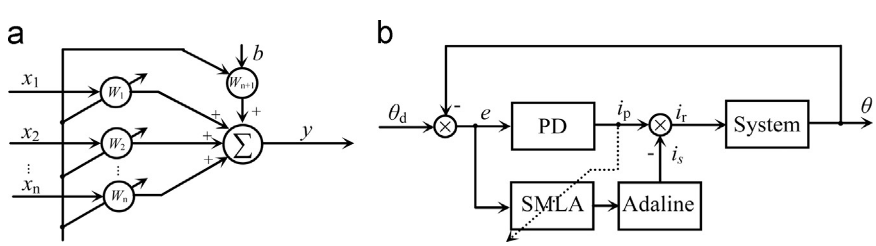

Fig. 1. (a) The structure of the Adaline. (b) The control structure of PD controller and Adaline.