Zhi LIU [1], Baifen LIU[2]

Central South University (1) East China Jiaotong University (2)

Sensorless Vector Control for Permanent Magnet Synchronous Motor based on Estimation of Model Error

Abstract. *A method, which estimates the position of the rotor based on arithmetic model of the motor, is presented in this paper. In this method, mathematical mode of PMSM is regarded as reference model. By detecting the phase current of PMSM, the real position of the rotor of PMSM is calculated. And this method eliminates the parameters variation of the PMSM. Simulation and experimental results proved that the proposed method was capable of precisely estimating the rotor position and speed. It also achieved good static and dynamic speed. Also, the parameters are fixed according to this method, so the simulation model of the whole PMSM speed servo is more precise.*

Streszczenie. *W artykule przedstawiono metodę estymacji pozycji wirnika w maszynie PMSM. Algorytm opiera się na pomiarach prądów fazowych, na podstawie których dokonywana jest estymacja, eliminując w ten sposób parametry maszyny. Przedstawiono wyniki symulacyjne i eksperymentalne, potwierdzające skuteczność działania. (**Bezczujnikowe sterowanie wektorowe maszyny PMSM – estymacja uchybu modelu**).*

Keywords: permanent magnet synchronous motor (PMSM); sensorless vector control; back EMF;
Słowa kluczowe: maszyna synchroniczna z magnesami trwałymi (PMSM), bezczujnikowe sterowanie wektorowe, EMF.

Introduction

Since the permanent magnet synchronous motor has the feature of small size, high efficiency and superior reliability, it is widely used in many important areas such as modern industrial automation, military, chemical industry, aviation and aerospace [1-4].

Permanent Magnet Synchronous Motor Sensorless vector control system is directly calculated using state estimation of parameter identification by means of indirect measurement. Such as stator voltage, stator current, etc. Most sensorless control algorithms are based on the flux and speed estimations which are obtained from the voltage equations, and therefore they are sensitive to the electrical and mechanical parameters. BP neural network has the capability of approaching to any nonlinear function, and its structure and learning algorithm is simple and clear, which is not dependent on the controlled object model[5-7].

One of the well-known way to enhance robustness is the sliding mode control (SMC).However, problems such as high frequency oscillation of motor torque, chattering effects, extra mechanical stresses and noise waveform occurred during practical applications. Many solutions have been proposed, to overcome the problem mentioned above. One of the best solutions is the continuous SMC. The problem of robust speed control of servo drive seems to be the actual research task. Various advanced control techniques like, nonlinear control, neural network control, robust control, variable structure control,and fuzzy control have been developed and implemented to overcome the issues of plant uncertainties under various operating conditions. Beside these, the performance of the model-based control methods such as variable structure control depends on the accuracy of the system[8].

Motor rotates due to the torque produced by two interacting magnetic fields. On the one hand, there is the magnetic field from the permanent magnets mounted to the rotor. On the other hand, there is the magnetic field generated by the coils of the stator[9].

When a force is given to a rotating system, it is called torque. It is defined by a linear force multiplied by a radius: $\vec{\tau} = \vec{r} \times \vec{F}$ .The maximum torque is produced when the magnetic vector of the rotor is at to the magnetic vector of the stator, because the poles of the rotor are forced to rotate in the direction of the stator field. The mechanical poles of the rotor are forced to rotate in the direction f the stator field[10]. The mechanical power is proportional to the angular speed. It is the torque which defines the ratio: $P_{mech} = \vec{\tau} \times \vec{\omega}$. On the other hand, the mechanical force is proportional to the current though the coils and the back EMF (electromotive force): $P_{elec} = I * V_{bemf}$

With sinusoidal commutation, the currents in the three coils follow a sine-wave which is phase shifted by an angle of 120 degree. As a result, the force created by the electromagnetic space vector is smoothly rotated along, so that the stator vector remains at a 90-degree angle from the rotor vector. An ideal motor with a sinusoidal drive does not show any torque ripple.

In this paper a fixed model of the sensorless vector control for permanent magnet synchronous motor is given so that the error of the estimation of the rotor position is gradually diminished.

Mathematical model of the BLDC model

In the corodinate system, the BLDC model is expressed as below:

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = \begin{bmatrix} R_s + PL_s & 0 \\ 0 & R_s + PL_s \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} - \omega\psi \begin{bmatrix} -\sin\theta \\ \cos\theta \end{bmatrix} \tag{1}$$

And the moment and the velocity equations are:

$$\begin{aligned} T_e - T_j &= Jp\omega + R_\Omega \omega \\ \frac{d\theta}{dt} &= \omega \end{aligned} \tag{2}$$

In the digital system, the discrete integral form can be expressed as

$$\hat{\psi}_d(n) = -T[u_d^*(n-1) - R_S i_d(n)] + \psi_d(n-1) \tag{3}$$

$$\hat{\psi}_q(n) = -T[u_q^*(n-1) + R_S i_q(n)] + \psi_q(n-1) \tag{4}$$

In the formula, T is the fixed sampling period ; $i_d(n)$ and $i_q(n)$ are the current measured values of the stator current they are transformed from the measured current. $u_d^*(n-1)$ and $u_q^*(n-1)$ are the voltage reference and also they can be substituted by the voltage which are measured this method can cause some calculated error. The next step is to estimate the current of the stator according to the $\hat{\psi}_d$（n）and $\hat{\psi}_q$（n）which are estimated from the previous step.

(5) $$\frac{de_\alpha}{dt} = -\omega_r \hat{e}_\beta + \omega_r e_\beta - he_\alpha$$

(6) $$\frac{de_\beta}{dt} = -\omega_r \hat{e}_\alpha + \omega_r e_\alpha - he_\beta$$

In the formula， h is a constant. The calculation of the deviation of the current of the stator is as bellow:

(7) $$\Delta i_d(n) = i_d(n) - \hat{i}_d(n)$$

(8) $$\Delta i_q(n) = i_q(n) - \hat{i}_q(n)$$

The accurate voltage of the rotor position is as below:

(9) $$u_q = (k_p + \frac{k_i}{s})\Delta i_q$$

If the estimation of the flux of the stator is correct, then the predictive deviation of the position of the rotor is caused by the deviation of the estimation of the stator current. So $\Delta\psi_d=0$ and $\Delta\psi_q=0$.

Simulation results

In this paper, the simulation model of servo system for PMSM has been established in simplorer. The actual parameters used for PMSM can be taken reference for simulation ones, as shown in table 1.

Figure 1 shows the block diagram of the sensorless speed control with field oriented control of a permanent magnet synchronous motor. From a control point of view, this method is comparable with that of dc motor. The basic concept is a cascade control with the important difference that the electrical variables are turning with the rotor. And the variables are fixed by the method which is stated previously.

Table 1. Motor parameters

Rated Speed	128 *rad/s*
EMF Coefficient	0.114 *V/(rad/s)*
Winding Resistance	0.11 *ohm*
Self-inductance	40.7 *mH*
Rotation inertia	$2.8*10^{-6} kg*m^2$

The block diagram of the whole system is shown as below:

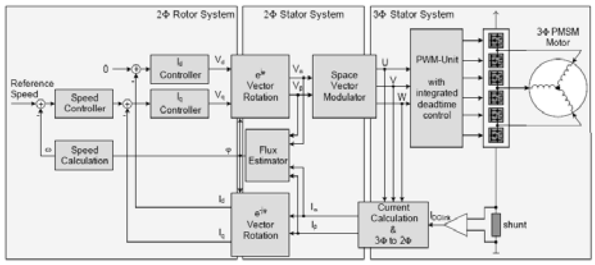

Fig.1 Block diagram of sensorless control system of PMSM

The simulation of the whole system based on simplorer is shown in Fig.2. Figure 2 shows the simulation of the control system. In the simulation a reference speed 128rad/s is given when the simulation is started. And the rated load is given. The waveform of the speed of the PMSM, the position of the rotor the phase current, the ripple of the torque are shown in Fig. 3 where P_m is pole numbers; N is total conductor numbers.

From figure 3 we can see that the proposed model is accurate and proposed algorithm has and improved performance compared to the conventional algorithms. Form figure 4 we can see the estimated rotor position follows the actual rotor position accurately.

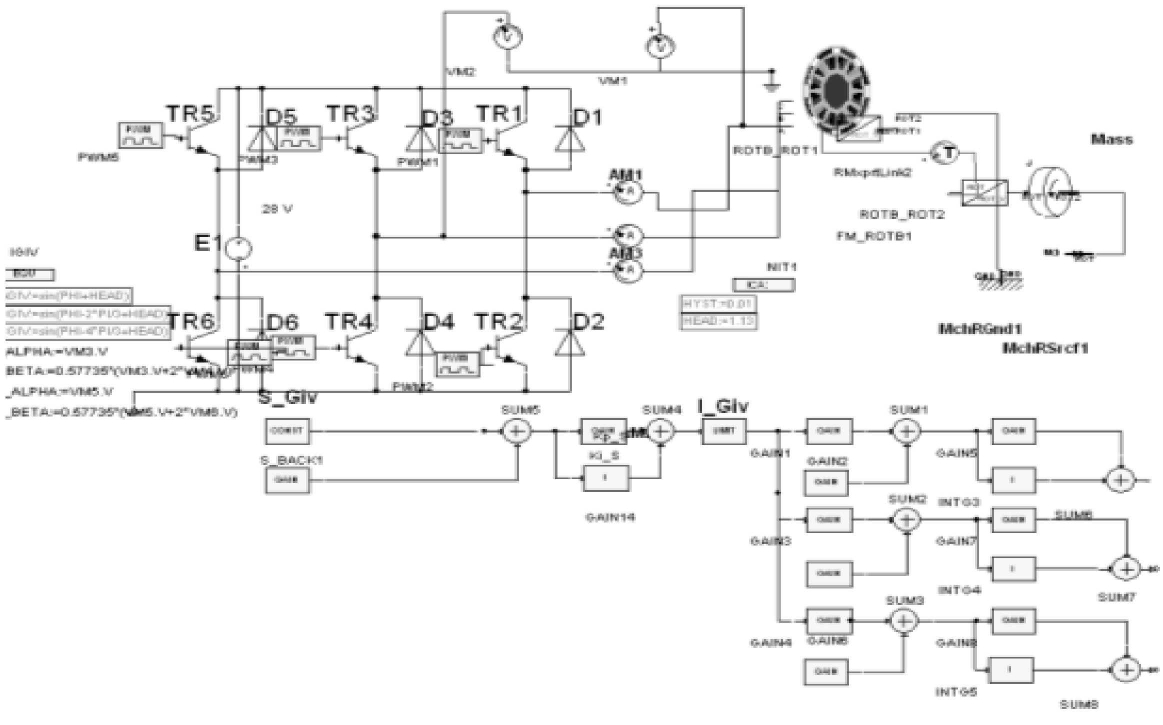

Fig. 2. The whole simulation of the control system

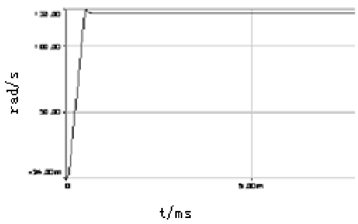

Fig. 3.The waveform of the speed of the PMSM servo drive

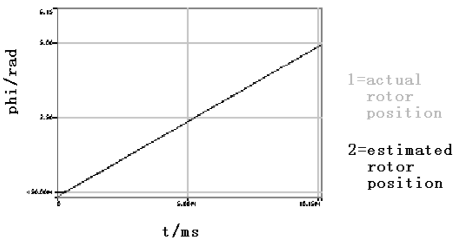

Fig. 4. The estimated position of the rotor

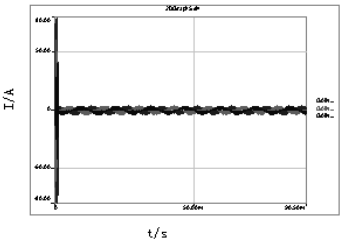

Figure.5 The waveform of the reference current of the stator

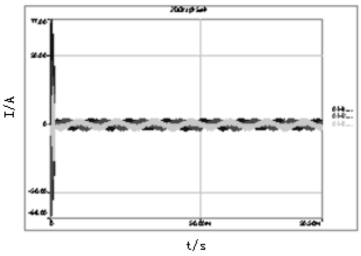

Figure.6 The waveform of the actual current of the stator

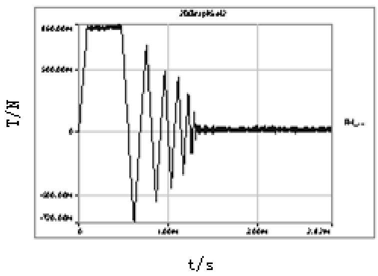

Fig.7 The torque ripple of the motor

From figure 5-figure 7, we can see that the actual current can follow the reference current and the torque ripple of the motors small when the speed of PMSM is stable.

Conclusions

The paper presents a fixed model of the permanent magnet synchronous motor without speed sensor. The procedure describes in this paper of the controller synthesis, yield good results and can be recommended for such control applications. In this method, mathematical mode of PMSM was regarded as reference model. By detecting the phase current of PMSM, the real position of the rotor of PMSM is calculated. Simulation and experimental results proved that the proposed method was capable of precisely estimating the rotor position and speed. It also achieved good static and dynamic speed. And also the parameters are fixed according to this method, so the simulation model of the whole PMSM speed servo is more precise.

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Authors:*Ph.D. candidate Zhi Liu, School of Traffic and Transportation Engineering, Central South University, Changsha, Hunan Province. E-mail: wisdom319@163.com.; Prof.Baifen Liu, School of Electrical and Electronic Engineering, East China Jiaotong University, Nanchang Jiangxi Province. E-mail: chair0088@yahoo.com.cn.*