Study on On-line Parameter Identification of Permanent Magnet Synchronous Motor

Xu Huang 1, Yanliang Xu 1, Bo Cui 1
1 School of Electrical Engineering, Shandong University, Jing Shi Road No. 17923, Jinan, Shandong, China
h201084@126.com

Abstract. Permanent magnet synchronous motor has the characteristics of high power density, small torque ripple and high operating efficiency, and thus has been widely used in servo control of industrial robots. In order to improve its control performance, especially when the operating conditions suddenly change, the real-time identification of servo motor parameters is particularly important. In this paper, the derivation of the motion equation of the servo permanent magnet synchronous motor in the rotating coordinate system, and the online recognition of the resistance, inductance and flux linkage of the servo motor are carried out by the recursive least square method. At the same time, the motor running and identification model was built in Matlab/Simulink, which verifies that the identification method used has strong accuracy and real-time performance. This method provides a good reference for adaptive control of servo-use permanent magnet synchronous motor.

1. Introduction
With the gradual improvement of modern industrial automation, the high-precision servo drive system has become the object of research. Among them, permanent magnet synchronous motors are widely used in AC servo control systems due to their advantages of simple structure, small size, high efficiency, low rotational inertia and good control performance. Servo control system has strong real-time. In servo control, when the load, temperature change, the permanent magnet synchronous motor stator winding resistance, inductance and rotor flux and other parameters may change, resulting in deviation of the servo control results. Therefore, in order to achieve real-time adaptive control of the servo motor, real-time identification of the motor parameters becomes more and more important [1].

The methods of on-line identification of motor parameters mainly include recursive least square method, model reference adaptive method, extended Kalman filter method and neural network method. The least squares method has the advantages of simple algorithm, low computational complexity, strong adaptability and easy implementation. It is widely used in system parameter identification. In this paper, through the derivation of the servo equation of the permanent magnet synchronous motor in the rotating coordinate system, the motor's resistance, inductance and rotor flux linkage are identified by measuring parameters such as voltage and current of the motor [2]. At the same time, the influence of the motor load on the identification results was studied.

2. PMSM mathematical model
The permanent magnet synchronous motor is a nonlinear, strongly coupled multivariable system [3]. In order to realize the control decoupling, we adopted the rotor flux linkage oriented synchronous
rotating coordinate system \[4\]. The voltage equation of permanent magnet synchronous motor in this coordinate system is as follows:

\[
\begin{align*}
    u_d &= R_s i_d + L_d \frac{di_d}{dt} - \omega_e L_q i_q \\
    u_q &= R_s i_q + L_q \frac{di_q}{dt} + \omega_e \left( L_d i_d + \psi_f \right)
\end{align*}
\]

In the equation, \(R_s\) is the resistance of the stator winding, \(u_d, u_q\) and \(i_d, i_q\) are voltage and current of stator winding in \(dq\) coordinate system respectively, \(L_d\) and \(L_q\) are the inductance of the stator winding in the \(dq\) coordinate system, \(\psi_f\) is the rotor permanent magnet flux linkage, and \(\omega_e\) is the rotor's electromagnetic angular velocity \[5~6\].

3. **The principle of recursive least squares**

Least square method is widely used in parameter estimation of engineering after it was proposed by Gauss. Many scholars proposed on the basis of Gauss: augmented least square method, generalized least square method, recursive least square method, auxiliary variable method and related two-step method and many other least squares algorithm \[7\]. We use recursive least squares to solve unknown system parameters.

The system's least squares format is as follows:

\[
y(k) = h^T(k)\theta + e(k)
\]

In the equation, \(y(k)\) is the system output; \(h^T(k)\) is the system input parameter; \(\theta\) is the system identification parameter; \(e(k)\) is the measurement error.

Let the criterion function be as follows:

\[
J(\theta) = \sum_{k=1}^{N} \left[ y(k) - h^T(k)\theta \right]^2
\]

When \(J(\theta)\) takes the minimum, the value \(\hat{\theta}\) is called the least square estimate of the parameter \(\theta\).

The recursive least squares recursion formula is derived as follows:

\[
\hat{\theta}(k) = \hat{\theta}(k-1) + K(k) \left[ y(k) - \varphi^T(k)\hat{\theta}(k-1) \right]
\]

\[
K(k) = \frac{P(k-1)\varphi(k)}{1 + \varphi^T(k)P(k-1)\varphi(k)}
\]

\[
P(k) = \left[ I - K(k)\varphi^T(k) \right]P(k-1)
\]

In the equation, and are iterative matrices.

In order to highlight the new data to weaken the old data and introduce the genetic factor \(\lambda\), the least squares method with the genetic factor \(\hat{\lambda}\) is obtained as follows:

\[
\hat{\theta}(k) = \hat{\theta}(k-1) + K(k) \left[ y(k) - \varphi^T(k)\hat{\theta}(k-1) \right]
\]

\[
K(k) = \frac{P(k-1)\varphi(k)}{\lambda + \varphi^T(k)P(k-1)\varphi(k)}
\]

\[
P(k) = \frac{1}{\lambda} \left[ I - K(k)\varphi^T(k) \right]P(k-1)
\]

The smaller the value of the new data, the smaller the value of the genetic factor \(\lambda\) is. The greater the general genetic factor range is 0.8~1. In the initial recursion, initial values for \(P\) and \(\hat{\theta}\) matrices need to be assigned as follows:
In the formula, $\alpha$ is a sufficiently large positive real number, generally taking $10^4 \sim 10^6$, $I$ is a unit vector, $\epsilon$ is a sufficiently small vector [8~9].

4. Establishment of PMSM identification model
For surface-mounted permanent magnet synchronous motors, its inductance $L_d = L_q = L$. When the control mode adopts vector control with $I_d = 0$ and the motor runs stably, its voltage equation is simplified as follows:

$$\begin{align*}
    u_d &= -\omega L_i_q \\
    u_q &= R i_q + \omega \varphi_f
\end{align*} \tag{11}$$

In order to apply the recursive least-squares method to identify the motor parameters, we rewrite the above voltage equation into the matrix form of the least-squares method [10]. The matrix equation is as follows:

$$\begin{bmatrix}
    u_d \\
    u_q
\end{bmatrix} = 
\begin{bmatrix}
    -\omega_L & 0 & 0 \\
    0 & i_q & \omega_L
\end{bmatrix}
\begin{bmatrix}
    L \\
    R
\end{bmatrix}
\begin{bmatrix}
    \varphi_f
\end{bmatrix} \tag{12}$$

Therefore, the parameter matrix to be identified in the least-squares method is $\hat{\Theta}(k) = \begin{bmatrix}
    L & R & \varphi_f
\end{bmatrix}^T$, the system output matrix is $y(k) = \begin{bmatrix}
    u_d \\
    u_q
\end{bmatrix}^T$, the system input matrix is $\varphi(k) = \begin{bmatrix}
    -\omega_L & 0 & 0 \\
    0 & i_q & \omega_L
\end{bmatrix}^T$.

When identifying motor parameters, the initial parameters are defined as follows:

$$\begin{bmatrix}
    P(0) \equiv 10^6 \\
    \hat{\Theta}(0) \equiv [0.01 \\
    0.01 \\
    0.01]^T
\end{bmatrix} \tag{13} \tag{14}$$

5. Simulation results and analysis
We built a permanent magnet synchronous motor parameter identification model in Matlab's Simulink. Its control method is double closed-loop vector control with $I_q = 0$, and its control simulation diagram is shown below. PMSM parameters are as follows: rated speed is 1000r/min, pole pair number $P_s = 4$, inductance $L_d = L_q = L = 12mH$, stator resistance $R_s = 0.958\Omega$, flux linkage $\varphi_f = 0.1827Wb$, moment of inertia $J = 0.003kg \cdot m^2$ and the initial load torque setting $T_L = 2N \cdot m$, which mutates to $4N \cdot m$ at 0.4seconds. The simulation results are as follows:
Figure 1. The inertia identification block diagram

Figure 2. The identification results of inductance
From figure 2 to figure 4, it can be seen that when the initial torque is changed from $2N\cdot m$ to $4N\cdot m$ at 4 seconds, the inductance, flux and resistance of the motor change slightly, but it quickly converges to the reference value. The simulation shows that the recursive least square method with genetic factors to identify permanent magnet synchronous motor parameters has good accuracy and anti-interference.

6. Conclusion
The on-line identification of motor parameters can effectively solve the instability caused by changes in load, temperature and other factors, and at the same time make the motor run more accurately and stably. In this paper, a recursive least-squares method with genetic factors is used to identify permanent magnet synchronous motor parameters. Under the simulation environment of Simulink, this identification method is verified to have high recognition accuracy, short identification time, and strong anti-interference ability. Because the identification method is simple, it has very good practical value.
Acknowledgement
This article is supported by the 2017 R&D Project of Shandong Province ‘Development of High Performance Servomotors and Drivers for Industrial Robots Based on Soft Magnetic Composites’ (2017CXGC0906)

References
[1] Tang RenYuan 2016 *Theory and design of modern permanent magnet motor* (Beijing: Machinery Industry Press)
[2] Wang Xiu He 2007 *Permanent magnet motor* (Beijing: China Electric Power Press)
[3] Chen L, Sun X, Jiang H 2014 *J Journal of Computational & Theoretical Nanoscience* 11(3) 706-710(5)
[4] Huang Fengxiang 2014 *Permanent magnet synchronous motor servo system parameter identification method* (Heilongjiang: Harbin Institute of Technology)
[5] Lee J H, Kim J C, Hyun D S 1999 *J Magnetics IEEE Transactions on* 35(3) 1199-1202
[6] Ding T, Takorabet N, Sargos F M 2009 *J IEEE Transactions on Magnetics* 45(3) 1816-1819
[7] Fu Xiaoli 2013 *Permanent magnet synchronous motor servo system parameter identification and control technology* (Shanghai: East China University of Science and Technology)
[8] Kim W H, Kim K C, Kim S J 2009 *J IEEE Transactions on Magnetics* 45(3) 1808-1811
[9] Wang Juping 2016 *Parameter identification of permanent magnet synchronous motor based on neural network* (Shanghai: Donghua University)
[10] Wang Lina, Sheffi 2015 *J electric drive* 45 (5) 16-20