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Research Article

Online Identification Methods of Load Rotary Inertia and Torque in Radar Servo System

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In radar servo system, the load is usually subject to movement and gust, which may cause instability of the system. In this paper, the online identification methods of load rotary inertia and torque in radar servo system are proposed, respectively. The radar servo system is based on synchronous motor. The load rotary inertia of the system is identified online by a disturbance observer. Moreover, a reduced order Luenberger observer is designed to observe the variation of the load torque and velocity online. The simulation models are established to verify the proposed disturbance observer for the load rotary inertia and the reduced order Luenberger observer for the load torque and velocity.

1. Introduction

In radar servo system, the revolution of the load is usually subject to movement and gust, which may cause instability of the load rotary inertia and torque. Therefore, the stability of the servo controller is facing higher requirements. If the parameters of the controller in the speed loop do not match the load rotary inertia, the dynamic response of the system may become slow and even cause oscillation [1]. Furthermore, the load torque is also subject to the disturbance of gust torque. In some cases, the value of the gust torque is very big and uncertain. As a result, the descent of the revolution speed at the transient state in the radar system is big and thus the target tracking is adversely affected [2]. In order to enhance the dynamic and static characteristics and the disturbance rejection ability of radar servo system, online identification of the load rotary inertia and torque is a premise [3].

As for the research on the online identification of load rotary inertia, a speed response method for AC servo system was proposed in [4]. By modifying the output current limitation value of the speed controller, the speed response value and response time under different current limitation values are obtained, and then the rotary inertia is calculated. This method may affect the normal operation of the motor in practice and is not applicable to identify the rotary inertia online. In addition, a model reference adaptive method for permanent magnet synchronous motor (PMSM) was presented in [5] to estimate the rotary inertia. However, both the speed response method and the model reference adaptive method neglect the effect of the viscous friction of the rotor. Comparatively, the online identification method of the rotary inertia based on disturbance observer (DOB) considers the external disturbance and friction, respectively [6, 7]. More methods on load torque and speed are extended Kalman filters for PM synchronous motors [8], recursive input estimation for PMSM [9], and robust estimation based on singular perturbation theory [10]. Besides, disturbance is regarded as a constant or function in some papers [10, 11]. Nevertheless, the load torque in radar servo system is usually subject to the effects of gust and environment that are difficult to be defined as some noise in analysis. Therefore, it is necessary to propose an effective algorithm to directly identify the load torque and speed online. In this paper, according to the characteristics of radar servo system, a more practical online identification algorithm of rotary inertia based on DOB is proposed. The external disturbance and the friction of the model are estimated by the designed DOB and then the rotary inertia is identified. As far as the research on load torque and speed is concerned, Luenberger state observer can be employed to estimate the disturbance torque and a reduced order Luenberger load torque observer is designed to overcome the randomness of the disturbance torque.

This paper is organized as follows. In Section 2, motion equations of servo system are built. In Section 3, the load rotary inertia is identified online by a DOB. Then, a reduced order Luenberger observer is designed to observe the variation of the load torque in Section 4. In Section 5, the simulation models are established, and the DOB for the load rotary inertia and the reduced order Luenberger observer for the load torque are verified by simulations, respectively, in Section 6. Finally, this paper is concluded in Section 7.

2. Motion Equations of Servo System

In dq-frame, the mathematical model of PMSM can be expressed as follows [1]:

$$\begin{aligned} u_d &= Ri_d + L_d p i_d - \omega_m L_q i_q, \\ u_q &= Ri_q + L_q P i_q + \omega_m L_d i_d + \omega_m \psi_f. \end{aligned} \tag{1}$$

The electromagnetic torque is given as

$$T_e = \frac{3}{2} p_m \left[\psi_f i_q + \left(L_d - L_q \right) i_d i_q \right], \tag{2}$$

where u_d, u_q are the armature voltage of the d-axis and q-axis, i_d, i_q are the armature current of the d-axis and q-axis, L_d, L_q are the winding inductance of stator in d-axis and q-axis, R is the winding resistance of stator, ψ_f is the PM (permanent magnet) flux linkage; p is the differential operator d/dt; p_m is the number of pole pairs of the rotor, and ω_m is the rotor electrical angular speed.

Motion equations of servo system are as follows [5]:

$$\begin{aligned} J\frac{d\omega_m}{dt} &= T_e - V\omega_m + T_L, \\ \omega_m &= \frac{d\theta_m}{dt}, \end{aligned} \tag{3}$$

where J is the rotary inertia of the system, T_e is the electromagnetism torque (i.e., driving torque), V is the viscous friction coefficient of the rotor, and T_L is the load torque.

Let T_d be the disturbance torque which is an unknown value estimated by the disturbance observer. Then T_d can be expressed as

$$T_d = -V\omega_m + T_L. \tag{4}$$

In one sampling period, T_d may be regarded as a constant, because the sampling frequency is much quicker than the variation of the disturbance torque in radar servo system. Hence, we have

$$\frac{dT_d}{dt} = 0. \tag{5}$$

From (3)–(5) the state equations can be got as

$$\begin{aligned} \dot{\mathbf{x}} &= \mathbf{A}\mathbf{x} + \mathbf{B}u, \\ \mathbf{y} &= \mathbf{C}\mathbf{x}, \end{aligned} \tag{6}$$

where $\mathbf{x} = \begin{bmatrix} \omega_m \\ T_d \end{bmatrix}$, $\mathbf{A} = \begin{bmatrix} 0 & 1/J \\ 0 & 0 \end{bmatrix}$, $\mathbf{B} = \begin{bmatrix} 1/J \\ 0 \end{bmatrix}$, $\mathbf{C} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$, and $u = T_e$.

For a PMSM with nonsalient pole structure, the dq-axis inductances are equal; that is, $L_d = Lq = L$. The load rotary inertia and torque are identified online based on the field orientation control (FOC) system, where i_d is controlled to be zero. The identification methods run in parallel with the vector control system. The block diagram of the whole system is shown in Figure 1.

3. Identification of Radar Load Rotary Inertia Based on DOB

3.1. Design of the DOB. Based on the state equations (6), the state observer with minimum order can be designed, where $\widehat{T}_d$ is the estimated value of the disturbance torque T_d [6]:

$$\frac{dz}{dt} = -\lambda z + \lambda J_n \omega_m + u, \tag{7}$$

$$\widehat{T}_d = -\lambda z + \lambda J_n \omega_m, \tag{8}$$

where J_n is the rotary inertia which is a constant, z is the intermediate variable, and $-\lambda$ is the pole of the observer ($\lambda > 0$).

Applying Laplace transformation to both sides of (7) and (8), respectively, we can get

$$\begin{aligned} sz(s) &= -\lambda z(s) + \lambda J_n \omega_m(s) + u(s) \\ \Longrightarrow z(s) &= \frac{\lambda J_n \omega_m(s) + u(s)}{s+\lambda} \end{aligned} \tag{9}$$

$$\begin{aligned} \widehat{T}_d(s) &= -\lambda z(s) + \lambda J_n \omega_m(s) \\ &= \frac{-\lambda^2 J_n \omega_m(s) - \lambda u(s)}{s+\lambda} + \lambda J_n \omega_m(s) \\ &= \frac{s\lambda}{s+\lambda} J_n \omega_m(s) - \frac{-\lambda}{s+\lambda} u(s). \end{aligned} \tag{10}$$

In order to simplify (10), introducing two intermediate variables $p_1(s) = \lambda\omega(s)/(s+\lambda)$ and $p_2(s) = \lambda u(s)/(s+\lambda)$ into (10), we have

$$\widehat{T}_d(s) = J_n s p_1(s) - p_2(s). \tag{11}$$

Applying inverse Laplace transformation, we get

$$\frac{dp_1}{dt} = -\lambda p_1 + \lambda u, \quad p_1(0) = 0, \tag{12}$$

$$\frac{dp_2}{dt} = -\lambda p_2 + \lambda \omega_m, \quad p_2(0) = 0, \tag{13}$$

$$\widehat{T}_d(t) = J_n \widehat{p}_2 - p_1, \quad \widehat{T}_d(0) = 0. \tag{14}$$

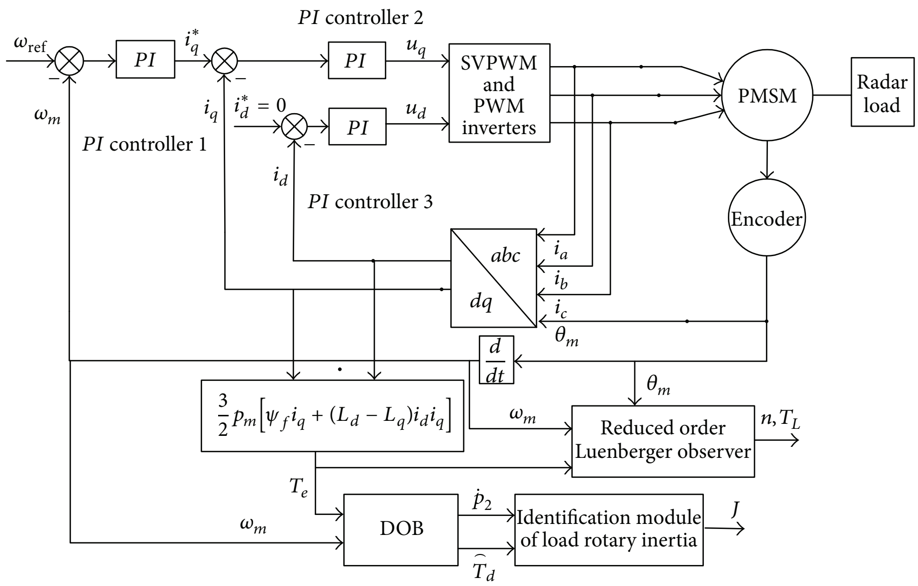

Figure 1: Block diagram of the load rotary inertia and torque identification.

3.2. Identification of Rotary Inertia Based on DOB. The rotary inertia can be expressed as

$$\delta J = J - J_n, \tag{15}$$

where J is the real rotary inertia, J_n is the rotary inertia, and δJ is the rotary inertia caused by load variation or error.

From (3), (7), (8), and (15), we can get the following differential equation:

$$\frac{d\widehat{T}_d}{dt} = -\lambda \widehat{T}_d - \lambda \left(\delta J \dot{\omega}_m + V\omega_m - T_L\right). \tag{16}$$

Applying Laplace transformation to (16), we get

$$\begin{aligned} &s\widehat{T}_d(s) = -\lambda \widehat{T}_d(s) - \lambda \delta J s \omega_m(s) - \lambda V \omega_m(s) + \lambda T_L(s) \\ &\Longrightarrow \widehat{T}_d(s) = -\delta J \frac{\lambda \omega_m(s)}{s+\lambda} s - V \frac{\lambda \omega_m(s)}{s+\lambda} + \frac{\lambda}{s+\lambda} T_L(s). \end{aligned} \tag{17}$$

In order to simplify (17), introducing two intermediate variables $p_2(s)$ and $p_3(s) = \lambda/(s+\lambda)$ into (17) and applying inverse Laplace transformation, we have

$$\frac{dp_3}{dt} = -\lambda p_3 + \lambda, \quad p_3(0) = 0, \tag{18}$$

$$\widehat{T}_d(t) = -\delta J \dot{p}_2(t) - V p_2(t) + T_L p_3(t), \tag{19}$$

where $\delta J \dot{q}_1(t)$ is the torque fluctuation caused by the variation of the rotary inertia, $Vq_1(t)$ is the torque generated by friction, and $T_L q_2(t)$ is the constant torque.

Multiplying both sides of (15) by $\dot{q}_1(t)$, we can obtain

$$\dot{p}_2(t)\widehat{T}_d(t) = -\delta J \dot{p}_2^2(t) - V\dot{p}_2(t)\, p_2(t) + T_L \dot{p}_2(t)\, p_3(t). \tag{20}$$

Therefore, it is not difficult to prove that $p_2(t)$ is orthogonal to $\dot{p}_2(t)$ and that $p_3(t)$ is orthogonal to $\dot{p}_2(t)$.

Proof. When radar servo system is in steady state, the angular velocity $\omega(t)$ is the periodic signal, and so $\lim_{t\to+\infty}[\omega(t) - \omega(t-T)] = 0$. From (13), because $\omega(t)$ is the input of $p_2(t)$, $p_2(t)$ is also the periodic signal, and so $\lim_{t\to+\infty}[p_2(t) - p_2(t-T)] = 0$:

$$\begin{aligned}
&\lim_{k\to+\infty}\int_{(k-1)T}^{kT} p_2(t)\,\dot{p}_2(t)\,dt = 0, \\
&\lim_{k\to+\infty}\int_{(k-1)T}^{kT} p_2(t)\,\dot{p}_2(t)\,dt \\
&\quad = \lim_{k\to+\infty}\frac{p_2^2(kT) - p_2^2((k-1)T)}{2} \\
&\quad = \lim_{k\to+\infty}\Big(\big([p_2(kT) - p_2((k-1)T)] \\
&\qquad \times [p_2(kT) + p_2((k-1)T)]\big) \times 2^{-1}\Big) \\
&\quad \xrightarrow{\text{From (13): } \lim_{k\to+\infty} p_2(kT) - p_2((k-1)T) = 0} \\
&\quad = 0, \\
&\lim_{k\to+\infty}\int_{(k-1)T}^{kT} p_3(t)\,\dot{p}_2(t)\,dt = 0, \\
&\lim_{k\to+\infty}\int_{(k-1)T}^{kT} p_3(t)\,\dot{p}_2(t)\,dt \\
&\quad = \lim_{k\to+\infty}\left\{[p_3(t)p_2(t)]\Big|_{(k-1)T}^{kT} - \int_{(k-1)T}^{kT}\dot{p}_3(t)\,p_2(t)\,dt\right\} \\
&\quad \xrightarrow{\text{From (18): } \lim_{t\to+\infty} p_3(t) = 1;\ \lim_{t\to+\infty}\dot{p}_3(t) = 0} \\
&\quad = 0.
\end{aligned} \tag{21}$$

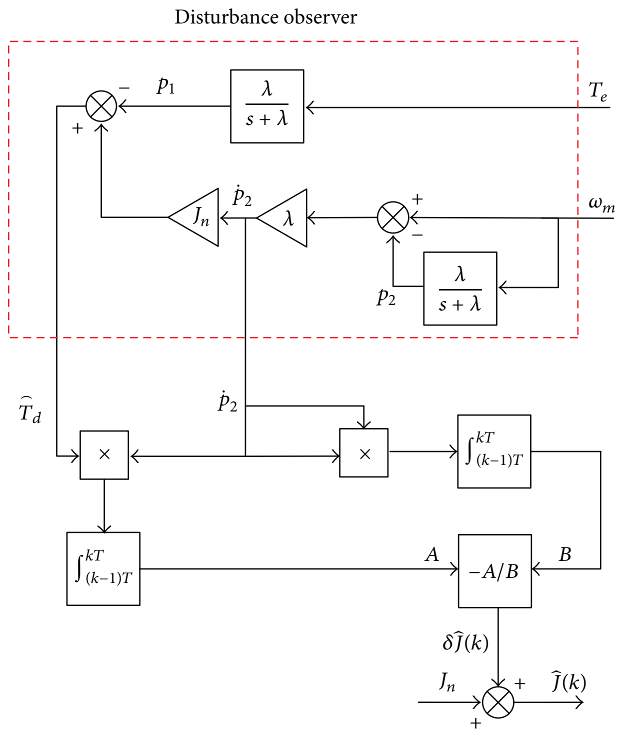

Figure 2: Block diagram of identification of the rotary inertia based on DOB.

Thus, the rotary inertia method based on DOB can be obtained. The two specific calculation steps are as follows.

(1) Use the orthogonality to estimate the variation value of the rotary inertia:

$$\delta\widehat{J}(k) = \frac{\int_{(k-1)T}^{kT} \widehat{T}_d(t)\,\dot{p}_2(t)\,dt}{\int_{(k-1)T}^{kT} \dot{p}_2^2(t)\,dt}, \quad (k = 1, 2, \ldots). \tag{22}$$

(2) Add the present variation value of the estimated rotary inertia to the previous value of the rotary inertia and then get the new value of the estimated rotary inertia:

$$\widehat{J}(k) = J_n + \delta\widehat{J}(k). \tag{23}$$

The overall identification process is shown in Figure 2. □

4. Observation of Load Torque and Speed Based on Reduced Order Luenberger Observer

Transform the motion equations (3) into state-space equations:

$$\begin{bmatrix} \dot{\theta}_m \\ \dot{\omega}_m \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -\dfrac{V}{J} \end{bmatrix} \begin{bmatrix} \theta_m \\ \omega_m \end{bmatrix} + \begin{bmatrix} 0 \\ \dfrac{1}{J} \end{bmatrix} (T_e - T_L). \tag{24}$$

Discretize the continuous system equation (3); then, we can get the discretized differential equation [12]:

$$\begin{bmatrix} \theta_r(k+1) \\ \omega_r(k+1) \end{bmatrix} = F \begin{bmatrix} \theta_r(k) \\ \omega_r(k) \end{bmatrix} + H\left[T_e(k) - T_L(k)\right], \tag{25}$$

where

$$\begin{gathered} F = e^{AT_s} = \begin{bmatrix} 1 & \dfrac{J}{f}(1-\lambda) \\ 0 & \lambda \end{bmatrix} = \begin{bmatrix} 1 & F_{12} \\ 0 & F_{22} \end{bmatrix}, \\ H = \int_0^{T_s} e^{At} B\,dt = \begin{bmatrix} \dfrac{1}{f}\left[T_s - \dfrac{J}{f}(1-\lambda)\right] \\ \dfrac{1}{f}(1-\lambda) \end{bmatrix} = \begin{bmatrix} H_1 \\ H_2 \end{bmatrix}, \end{gathered} \tag{26}$$

where $\lambda = e^{(-(f/J)T_s)}$ and T_s is the sampling time of the system.

Since the variation of the load torque is much slower compared to that of the sampling time, the load torque can be regarded as a constant in the sampling time interval; that is,

$$T_L(k+1) = T_L(k). \tag{27}$$

From (26)-(27), we can get

$$\begin{bmatrix} \theta_r(k+1) \\ \omega_r(k+1) \\ T_L(k+1) \end{bmatrix} = M \begin{bmatrix} \theta_r(k) \\ \omega_r(k) \\ T_L(k) \end{bmatrix} + Nu, \tag{28}$$

where

$$M = \begin{bmatrix} 1 & F_{12} & -H_1 \\ 0 & F_{22} & -H_2 \\ 0 & 0 & 1 \end{bmatrix}, \qquad N = \begin{bmatrix} H_1 \\ H_2 \\ 0 \end{bmatrix}, \qquad u = T_e. \tag{29}$$

Because radar servo system is a position control, the position can be obtained by position encoder and is known, while the speed and load torque are estimated and are unknown. Thus, the terms regarding position can be deleted in (28) and then the reduced order load torque observer can be obtained:

$$\begin{gathered} \begin{bmatrix} x_1(k+1) \\ x_2(k+1) \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \begin{bmatrix} x_1(k) \\ x_2(k) \end{bmatrix} + \begin{bmatrix} N_1 \\ N_2 \end{bmatrix} u \\ y(k) = \begin{bmatrix} I & 0 \end{bmatrix} \begin{bmatrix} x_1(k) \\ x_2(k) \end{bmatrix}. \end{gathered} \tag{30}$$

In (30),

$$\begin{gathered} x_1(k) = \theta_m(k), \qquad x_2(k) = \begin{bmatrix} \omega_m(k) \\ T_L(k) \end{bmatrix}, \qquad M_{11} = 1, \\ M_{12} = \begin{bmatrix} F_{12} & -H_1 \end{bmatrix}, \qquad M_{21} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \\ M_{22} = \begin{bmatrix} F_{22} & -H_2 \\ 0 & 1 \end{bmatrix}, \qquad N_1 = H_1, \qquad N_2 = \begin{bmatrix} H_2 \\ 0 \end{bmatrix}. \end{gathered} \tag{31}$$

Also, x_1 is the observable state variable and x_2 is the unobservable state variable.

From (30) we can further get

$$\begin{aligned} y(k+1) = x_1(k+1) &= M_{11}x_1(k) + M_{12}x_2(k) + N_1 u \\ x_2(k+1) &= M_{21}y(k) + M_{22}x_2(k) + N_2 u. \end{aligned} \tag{32}$$

Now, let $\overline{u} = M_{21}y(k)+N_2u$ and let $w(k) = M_{12}x_2(k) = y(k+1) - M_{11}x_1(k) - N_1u$, and the state equation of the reduced order system can be obtained:

$$\begin{aligned} x_2(k+1) &= M_{22}x_2(k) + \overline{u}, \\ w(k) &= M_{12}x_2(k). \end{aligned} \tag{33}$$

According to (33), the reduced order observer of the load torque can be constructed:

$$\begin{aligned} \widehat{x}_2(k+1) &= M_{22}\widehat{x}_2(k) + \overline{u} + l\left[w(k) - M_{12}\widehat{x}_2(k)\right] \\ &= \left(M_{22} - lM_{12}\right)\widehat{x}_2(k) + M_{21}y(k) + N_2u \\ &\quad + l\left(y(k+1) - M_{11}x_1(k) - N_1u\right). \end{aligned} \tag{34}$$

Equation (34) includes the term $y(k+1)$ which cannot be obtained directly. Moreover, $y(k+1)$ and $y(k)$ can play the role of differential which can amplify the position measurement error. Hence, an intermediate variable z is introduced:

$$z(k) = x_2(k) - ly(k). \tag{35}$$

Substituting (35) into (36), the term $y(k+1)$ can be cancelled:

$$\begin{aligned} z(k+1) &= \left(M_{22} - lM_{12}\right)z(k) \\ &\quad + \left[\left(M_{22} - lM_{12}\right)l + M_{21}\right]y(k) \\ &\quad + N_2u + l\left(-M_{11}x_1(k) - N_1u\right). \end{aligned} \tag{36}$$

Then, the estimated state variable can be restored by (35) as

$$\widehat{x}_2(k) = z(k) + ly(k), \tag{37}$$

where $l = \left[\begin{smallmatrix} l_1 \\ l_2 \end{smallmatrix}\right]$. In order to get the feedback gain coefficients l_1 and l_2, the poles of the desired observer are supposed to be p_1 and p_2, where the two poles are equal (i.e., $p_1 = p_2 = P$) and the characteristic polynomial of the observer is $|zI - (M_{22} - lM_{12})|$. Then, we have

$$\left|zI - \left(M_{22} - lM_{12}\right)\right| = (z - p)^2. \tag{38}$$

Let the two sides of (38) be identically equal; then, the feedback gain coefficients l_1 and l_2 can be got:

$$\begin{aligned} l_1 &= \frac{H_2\left(-2p + 1 + F_{22}\right)}{H_1 - F_{22}H_1 + F_{12}H_2} + \frac{H_1\left(F_{22} - p\right)^2}{F_{12}\left(H_1 - F_{22}H_1 + F_{12}H_2\right)}, \\ l_2 &= \frac{-(p-1)^2}{H_1 - F_{22}H_1 + F_{12}H_2}. \end{aligned} \tag{39}$$

Table 1: PMSM parameters and *PI*.

Rated power	1.5 kW
Rated torque	7.5 N·m
Rated speed	3000 r/min
Rated current	6 A
Winding resistance of stator	$R = 2.23\,\Omega$
d, q-axis inductance	$L_d = L_q = 22.5$ mH
PM flux linkage	$\Psi_f = 0.2865$ Wb
Combined inertia	$J = 0.01087\ \mathrm{kg{\cdot}m^2}$
Rotor viscous friction coefficient	$V = 0.004\ \mathrm{N{\cdot}m{\cdot}(rad{\cdot}s^{-1})^{-1}}$
Number of pole pairs	$p_m = 3$
PI controller 1	$P = 150$ $I = 20$
PI controller 2	$P = 1.8$ $I = 0.015$
PI controller 3	$P = 2.0$ $I = 0.018$

In order to guarantee the stability of the system [13], the pole p of the load torque observer should be within 0~1 of the unit circle in the z-plane. When the pole p is adjacent to 0, the response of the load torque observer is faster but it is more sensitive to the input noise. Therefore, in order to reasonably choose the pole of the load torque observer, both the response speed of the load torque observer and the noise rejection ability should be taken into consideration.

5. Simulation Model of the Parameter Identification System

The PMSM parameters adopted in the simulation are listed in Table 1. The parameters P and I of three *PI* controllers are shown in Table 1.

5.1. Simulation Model of the Identification of Load Rotary Inertia. The simulation model of the disturbance torque observer can be established according to (12)–(14). In MatLab/s-function, the program of online identification of rotary inertia can be written. The overall simulation model of online identification of rotary inertia is shown in Figure 3.

5.2. Simulation Model of Load Torque Observer. The reduced order Luenberger load torque observer consists of differential equations. The iteration algorithm can be programmed in MatLab/s-function according to (35). In the iteration algorithm, the sampling time is set to be 1 ms and the pole of the observer is set to be 0.65. The overall simulation model is shown in Figure 4.

6. Simulation Results and Analysis

6.1. Simulation Results of the Identification of Rotary Inertia. In the simulation model of the online identification of rotary inertia based on DOB, the test signal of the speed command is set to be a sine signal with the magnitude 50 rpm and the period 100 hz. Overlapping the command test signal onto the speed command signal and identifying the rotary inertia online, the identification results are shown in Figure 5.

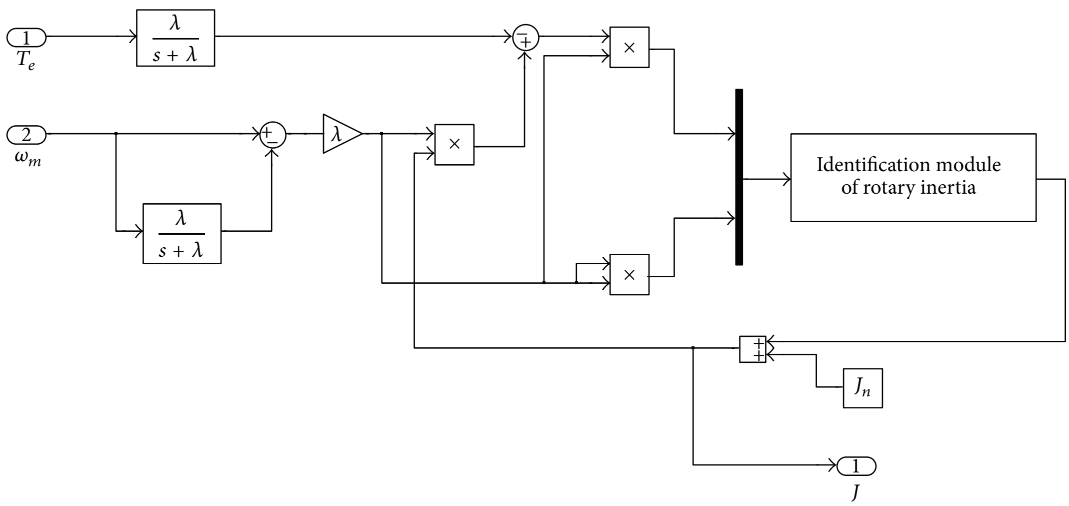

FIGURE 3: Simulation model of online identification of rotary inertia based on DOB.

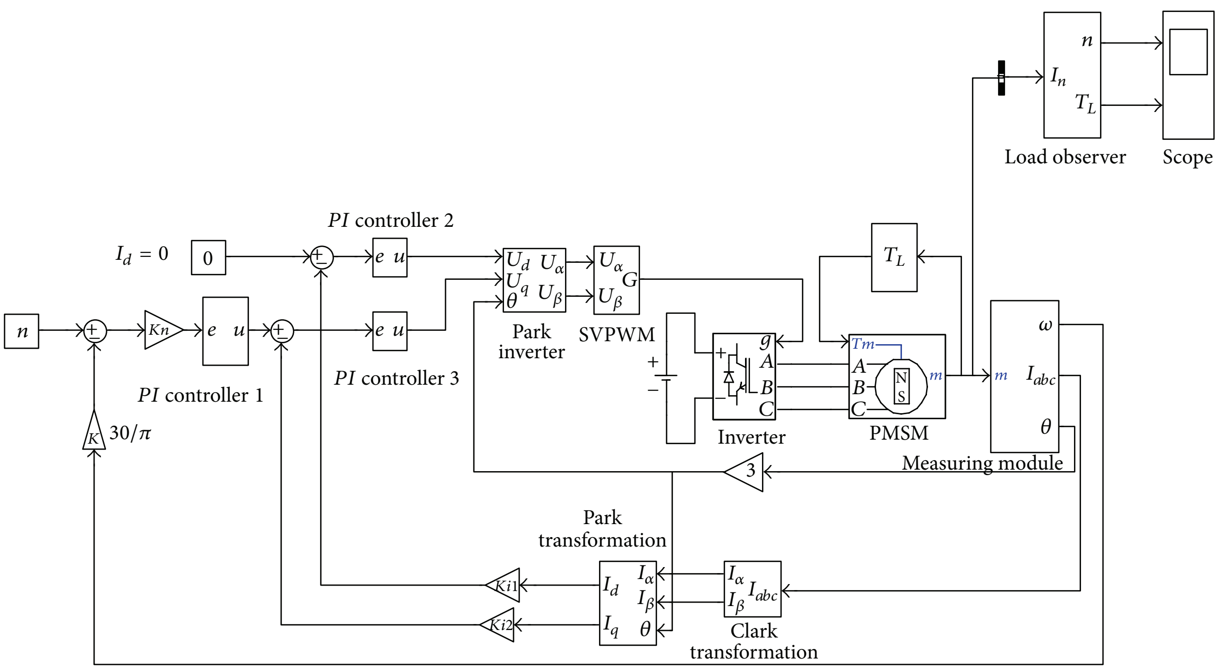

FIGURE 4: Simulation model of the load torque observer.

Here, the real value of the rotary inertia of the system is 0.01087 kg·m^2 and the identified value is 0.01077 kg·m^2. From the simulation results, it can be seen that the precision of the identification method of load rotary inertia is high and the speed is fast.

6.2. Simulation Results of Load Torque Observer. During the simulation of the load torque observer, the sampling frequency of the reduced order load torque observer is set to be 5000 HZ, the pole of the observer is configured to be 0.8, and the speed command is set to be 50 rpm. In order to study the tracking ability of the reduced order load torque observer to the variation of the load torque, the load torque disturbance is set to be a step signal variation and a sine signal variation, respectively. The tracking curves of the load torque observer to the load torque are shown in Figures 6 and 7.

In Figure 6, when $t = 0.1$ s, the given load torque is 1 Nm, when $t = 0.3$ s, the given load torque is 2 Nm, when $t = 0.5$ s, the given load torque reduces to 1 Nm, and when $t = 0.7$ s, the given load torque reduces to 1 Nm once again.

From Figure 7, the frequency of the given sine load torque is 100 rad/s and the magnitude is 3 Nm. From the tracking curves of the step signal and the sine signal it can be seen that the designed reduced order load torque observer can quickly and accurately track the variation of the load torque, which provides accurate compensation information to the load

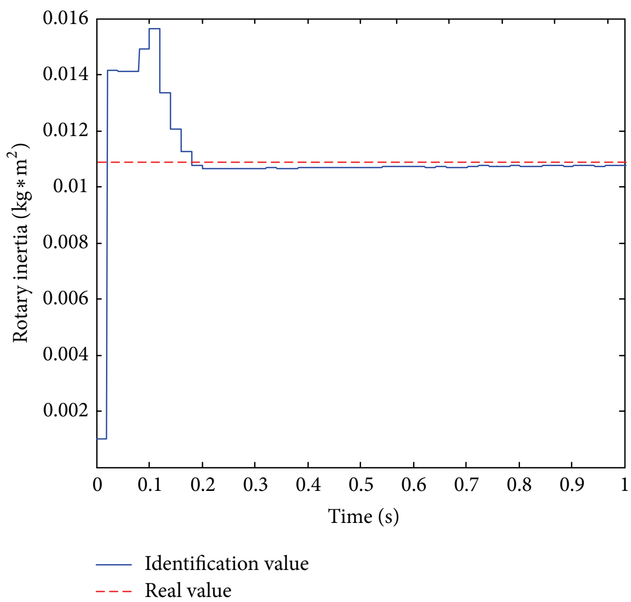

Figure 5: Curves of the identification of rotary inertia.

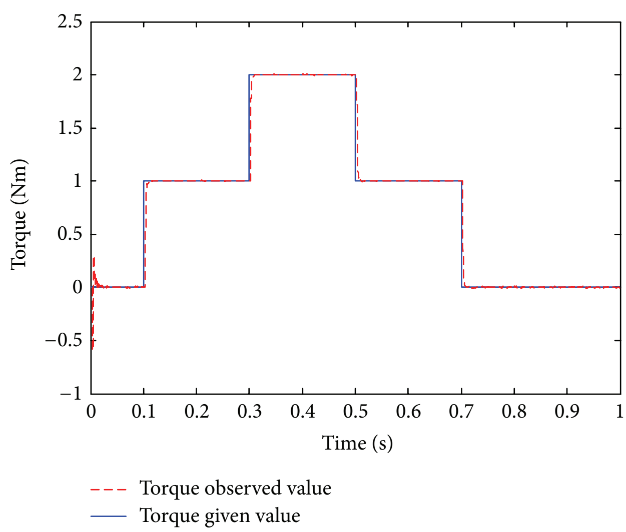

Figure 6: Tracking cures of the load torque (step signal variation).

compensation controller and makes the system have better disturbance rejection ability.

6.3. Simulation Results of Load Speed Observer. In order to study the observation ability of the designed load torque observer on speed, we add some white noise to the collected position signal in the simulation model and compare the speed curve obtained by the traditional differential with that estimated by the load torque observer. The speed is set to be 50 rpm and the load is still given by sine signal. The simulation results are shown in Figure 8. Figure 8(a) shows the speed calculated by the direct differential and Figure 8(b) is the speed estimated by load torque observer. From Figure 7 it can be seen that under the same noise disturbance the

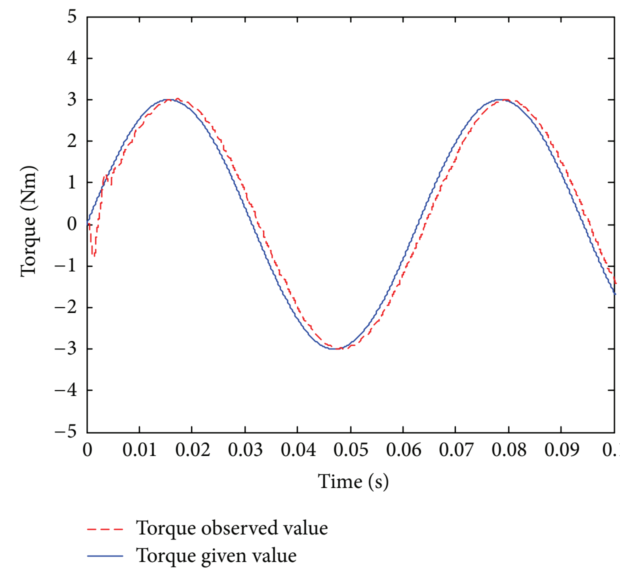

Figure 7: Tracking cures of the load torque (sine signal variation).

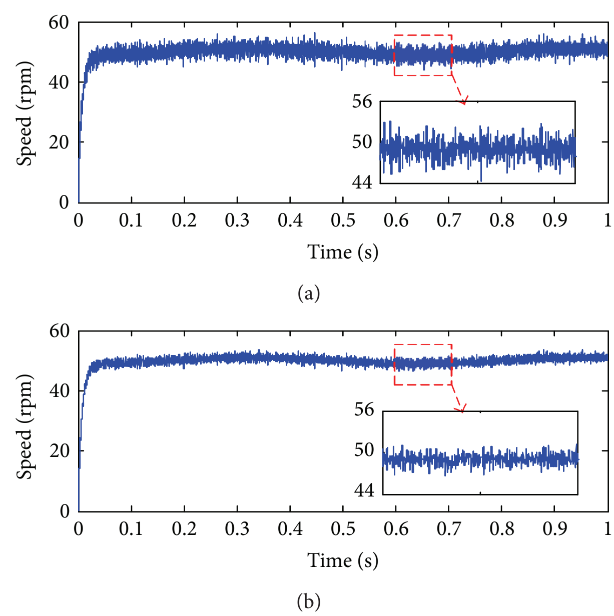

Figure 8: Speed tracking curves: (a) speed calculated by the direct differential and (b) speed estimated by the load torque observer.

speed curve estimated by the load torque observer is much smoother than that calculated by the direct differential. Since the load torque observer can suppress position noise signal, it can obtain more accurate speed values.

7. Conclusions

This paper presents online identification methods of load rotary inertia, load torque, and speed in radar servo system, respectively. First, the identification algorithm of load rotary inertia based on DOB is described. This algorithm can fast and accurately identify the load rotary inertia, which provides accurate and reliable rotary inertia values to parameter self-adjusting algorithm and other advanced control algorithms. Then, a reduced order Luenberger load torque observer is designed to accurately observe the variation of the load torque online. The designed torque observer provides accurate estimated torque to compensate for the load disturbance and thus enhances the disturbance rejection ability of the system. In addition, the designed torque observer can also estimate the speed value and overcome the amplification of the position noise error generated by the direct differential algorithm. Finally, the simulation models are established to verify the proposed online identification method of PMSM parameters. The simulation results illustrate the practicability and feasibility of the proposed identification method of rotary inertia and the proposed reduced order load torque observer. The proposed methods in this paper provide a solid theoretical basis for the experiments and practical application in the future.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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