Research on IPMSM position decoupling control without filter

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Abstract. In this paper, a new method of decoupling sensorless and filterless IPMSM (Interior permanent magnet synchronous motor) high frequency square wave is proposed, which is a new method of decoupling the rotor position of the motor and forming a stable control system by injecting high frequency square wave into the static shafts and computing the signal delay. Due to the high frequency square wave injection method, the influence of rotor resistance is reduced and the estimation accuracy is improved. At the same time, the decoupling method without filter is adopted to avoid filter interference and improve system bandwidth. In this paper, a better observer than PI observer is adopted, so that the system estimation accuracy is higher and the anti-interference performance is stronger. Finally, the simulation is realized by matlab.

1. Introduction

DC motor has many advantages. IPMSM is widely used in electric vehicle drive, ship propulsion, numerical control system and household appliances because of its high torque density and high efficiency. High performance IPMSM control techniques such as vector control require accurate rotor position information. In general, rotor position information is obtained by mechanical position sensor. However, the installation of this sensor will increase the cost and size of the system and reduce the reliability of the system. Moreover, mechanical sensors cannot be used in special environments [1-3].

IPMSM has no position sensor control and is divided into high speed and low speed fields. For low speed/zero speed operation, the salient pole tracking method is based on rotor salient pole characteristics (structural salient pole), Obtain rotor position information. The more common and mature method is high frequency signal injection, including high frequency sinusoidal signal injection and high frequency square wave injection. In the specific implementation of the high-frequency signal injection method, it is usually necessary to use the filter link to achieve carrier signal separation, that is, the current feedback can be achieved by extracting the current fundamental frequency component through the notch filter or low-pass filter, and the position information decoupling can be achieved by extracting the high-frequency response signal through the band-pass filter or high-pass filter. In addition, in the process of rotor position tracking, low pass filter is needed to reduce noise interference and realize smooth speed observation. However, the introduction of filter limits the bandwidth of the controller and tracker, and reduces the dynamic performance of IPMSM sensorless control system [4-8].
In the field of high speed sensorless control technology is model method, this is a fundamental frequency excitation through the counter electromotive Force (Back company Motive Force, the Back - EMF) or by motor magnetic chain model to estimate the rotor speed and position information, because do not need the rotor salient information and additional test signals, just by motor model can realize the estimate of the rotor magnetic pole position information, as a result of the implementation method is relatively simple, so the model method in the sensorless permanent magnet synchronous motor vector control is widely applied in the system [9-10].

In the low speed field, due to low counter electromotive force and low signal-to-noise ratio, high frequency square wave injection method is needed to get the rotor position of the motor. At the same time, because there are two signals of different frequencies, in order to get the motor position parameters, it is necessary to decompose them. The traditional scheme adopts high-pass filter or band-pass filter, but the use of filter leads to the reduction of system bandwidth and robustness. In order to deal with this situation, this paper adopts a strategy of signal lag subtraction, which saves the use of filter and improves the system bandwidth and control accuracy. At the same time, the new observer scheme is used to decouple the position signal, which improves the convergence speed, control precision and anti-interference ability. Finally, the proposed scheme is simulated.

2. IPMSM mathematical model
Since all high-precision control of modern motors are based on 3-2 transformation, the high-coupling motor system is converted into a static shafting model for calculation. Therefore, the mathematical model of IPMSM can be expressed in the d-q axis as follows:

$$\begin{bmatrix}
u_d \\ u_q \\ \end{bmatrix} = \begin{bmatrix} R + pL_d & -w_L L_d \\ w_L L_d & R + pL_q \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} 0 \\ w_L \psi_f \end{bmatrix}$$

(1)

In the equation, $u_d, u_q$ is the voltage component under the d-q axis, $i_d, i_q$ is the current component under the d-q axis; $R$ stands for stator resistance, $L_d, L_q$ is d-q inductance, $\omega_c$ represents the angular velocity of the rotor, $\psi_f$ is a permanent magnet, $p$ is a differential operator [11-13].

In the high frequency square wave injection method, because the injected square wave signal is $u_c = U_{\omega}(-1)^{\gamma}$. In the formula, $n$ is the sampling frequency, the frequency of $n$ is very high, far higher than the fundamental wave operating frequency, so the influence of stator resistance voltage drop, rotary voltage and counter electromotive force can be ignored, On this basis, IPMSM can be approximately equivalent to the inductive load.

Mathematical expression of an injected high-frequency voltage signal ($\gamma - \delta$) observation of shafting:

$$\begin{bmatrix}
u_{\gamma} \\ u_{\delta} \\ \end{bmatrix} = \begin{bmatrix} U_{\gamma} \sin \omega T(n) \\ 0 \end{bmatrix}$$

(2)

After simplification of equation (1), the following model can be obtained through r-s transformation and integration [14] equation (2):

$$\begin{bmatrix}
p\dot{i}_{\gamma} \\ p\dot{i}_{\delta} \\ \end{bmatrix} = \frac{1}{L_0^2 - L_1^2} \begin{bmatrix} L_0 - L_4 \sin 2\theta_c & -L_4 \cos 2\theta_c & \nu_{\gamma} \\ L_0 \sin 2\theta_c & L_0 + L_4 \cos 2\theta_c & \nu_{\delta} \end{bmatrix}$$

(3)

Further simplification leads to the following formula:

$$\begin{bmatrix}
\Delta i_{\gamma} \\ \Delta i_{\delta} \\ \end{bmatrix} = \frac{U_{\gamma} \Delta T}{L_0^2 - L_1^2} \begin{bmatrix} L_0 - L_4 \sin 2\theta_c \\ -L_4 \cos 2\theta_c \end{bmatrix}$$

(4)
where $\Delta T$ is half cycle, $\Delta i_{\alpha_c}, \Delta i_{\beta_c}$ denote the difference between the former sampling time and the latter sampling time of the $\alpha, \beta$ axis respectively.

After signal processing and standardization, the following formula can be obtained:

$$
\begin{bmatrix}
\Delta i_{\alpha_c}^* \\
\Delta i_{\beta_c}^*
\end{bmatrix} = \frac{U_{inj} \Delta T}{L_0^2 - L_1^2} \begin{pmatrix}
L_0 - L_1 \cos 2\theta_c \\
- L_1 \sin 2\theta_c
\end{pmatrix}
$$

(5)

In order to get the desired location information, the above equation is simplified, the invariant part of the above equation is removed, and the obtained equation is standardized to obtain the following equation:

$$
\begin{bmatrix}
\Delta i_{\alpha_c}^{**} \\
\Delta i_{\beta_c}^{**}
\end{bmatrix} = \begin{pmatrix}
\sin 2\theta_c \\
\cos 2\theta_c
\end{pmatrix}
$$

(6)

3. High frequency signal without filter separation

For the high-frequency square wave signal, the traditional method is to filter it through the low-pass filter, so as to obtain the required low-frequency signal. Although the digital filter can achieve the function of high-frequency signal filtering, it also brings a new problem, which will reduce the bandwidth of the system and cause instability of the system. A more clever approach is needed to deal with this problem.

Because the input frequency is the square wave of the sampling frequency, the specific waveform is as follows:

![Figure 1. Motor signal.](image)

The following equation can be obtained from Figure 1:

$$
i_{\alpha, \beta} (n-1) = i_{\alpha, \beta} (n) - i_{\alpha, \beta} (n-1)
$$

$$
i_{\alpha, \beta} (n) = -i_{\alpha, \beta} (n) + i_{\alpha, \beta} (n)
$$

(7)

In the formula, $i_{\alpha, \beta} (n)$ represent the high-frequency response current vector, the sampling current vector and the fundamental current vector at n sampling time, respectively.

By using this method, useful signals can be extracted, which can replace the traditional high-pass filter or bandpass filter.
4. Location of decoupling

From equation (5) the position information of the rotor can be get, but the arctangent function is sensitive to noise, which will reduce the robustness of the system. Therefore, the following methods are adopted in this paper:

\[
\begin{pmatrix}
\sin 2\theta_e \\
-\cos 2\theta_e
\end{pmatrix}
\begin{pmatrix}
\Delta i_{ac}^{**} \\
\Delta i_{pk}^{**}
\end{pmatrix}
= \sin (2\Delta \theta)
\] (8)

In the formula, \(\Delta \theta\) is the difference between the observed position of the rotor and the actual position, when \(\Delta \theta\) is a minimum, it can be assumed \(\sin (2\Delta \theta) = \Delta \theta\). Therefore, a decoupling device can be designed to decouple its positions. The goal can be achieved by using the observer [4], and the observer transfer function is as follows:

\[
\frac{\theta_e}{\theta_r} = \frac{2k_{po} s^2 + 2k_{io} s + 2k_{do}}{s^2 + 2k_{po} s^2 + 2k_{io} s + 2k_{do}}
\] (9)

The control block diagram is as follows Figure 2 [15]:

![Figure 2. \(\alpha\) observer control block diagram.](image)

5. Simulation Debugging

The control block diagram adopted in this paper is Figure 3:

![Figure 3. Schematic diagram of high frequency square wave without filter.](image)
High frequency square wave is injected into the d axis and acted on the motor to obtain the signal. After the algebraic digestion step adopted in this paper, the high frequency signal in the stator signal is separated and the low frequency signal is eliminated to obtain the high frequency signal with rotor position information. Through $\alpha$ observer, the motor position information $\omega$ and $\theta_e$ can be decoupled, The information obtained will be used for motor control.

The difference between the previous moment and the current moment. The waveform obtained after transformation is shown in Figure 4, the converted waveform contains the rotor position information, and it can be seen from the figure that the selected waveform is distorted.

![Figure 4. $\Delta i_\alpha$, $\beta$ oscillogram.](image)

The difference signal is imported into the $\alpha$ observer for decoupling, the position signal obtained is shown in Figure 5. It can be seen that the rotor position information obtained by the no filter decoupling method is exactly coincident with the actual information, this shows that the decoupling method without filter is completely correct.

![Figure 5. $\theta_e$, $\theta_\alpha$ oscillogram.](image)

Through the above simulation, it can be seen that the results obtained by using the filter free control algorithm are consistent with the actual rotor position. The entire system is not limited by the filter bandwidth, which improves the system bandwidth, increases the system sensitivity and improves the system response speed.

The observer is used instead of the traditional PI observer to estimate the rotor Angle and angular velocity, which improves the anti-interference ability of the system and improves the estimation accuracy of the Angle.
6. Conclusions

Motor control technology develops rapidly and advanced control technology has advantages and disadvantages. Based on the complex model of the motor, the motor control technology tends to be complex, but basically it's current, position double loop control. Because of its classical control concept, the double loop control system has been greatly developed. Various deformation, improvement methods continue to improve the system, but for the motor control, has been unable to get perfect. The sensorless control strategy makes the motor control system no longer huge. Because the original sensorless control method is not perfect for the system bandwidth and the connection between low speed and high speed, filter less control is used to solve this problem, so that the system can get rid of the constraint of bandwidth and get better application. It can be seen from the research in this paper that the position decoupling method without filter has good practical value.

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