Research on Improved Speed Identification Technology Based on MRAS

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Abstract. In order to accurately realize the asynchronous motor speed recognition, an improved speed recognition method based on MRAS is proposed, the motor body is used as the reference model and the stator current is used as the adjustable model. Based on MRAS, Considering the problems such as the poor output torque pulsation and high current harmonic content due to the influence of pure integral link, the low-pass filter plus compensation link is used to replace the pure integrator, the full range of stability is introduced on the basis of popov super-stability, and a new method of dead zone compensation is proposed. Finally, in the simulation and experiment, the whole asynchronous motor speed sensorless MRAS is tested. Through the observation and analysis of the speed error curve, the system can be accurately estimating the rotor speed and have a good static performance.

1. Introduction

Vector control [1, 2] as a kind of speed closed-loop control, requires the speed of the motor as feedback. Usually the actual speed of the motor is provided by the encoder mounted on the motor shaft, the use of the encoder to obtain the motor speed has installation difficulties, the need to occupy additional installation space, low reliability, poor economy and other shortcomings. Based on this, in 1983, Robert Joetten first proposed speed recognition technology and combined it with vector control to overcome the inconvenience of using encoders to obtain motor speed, using the measurable motor end voltage and end current to identify the speed of the motor. It solves many problems brought about by the use of encoder to obtain the actual speed, and its proposal is of great significance.

According to the different selection of reference model and adjustable model, there are three commonly used MRAS speed estimation methods: based on magnetic chain, based on anti-electric potential, and based on reactive power. Using the voltage model as a reference model and the current model with speed information as the magnetic chain-based MRAS speed estimation method [3], the algorithm is practical, but there is a pure integral link and zero drift problem in the model, and the MRAS speed estimation method of anti-electric potential is used in the literature. However, because the motor at low speed anti-electric potential is very small, and at the speed of zero anti-electric force change is slow, so that the algorithm is very sensitive to the change of stator resistance, resulting in inaccurate estimates, in order to increase the robustness of the algorithm, eliminate the problem of the motor parameters such as stator resistance, the literature put forward the instantaneous reactive power MRAS,
In the reference model and adjustable model of this algorithm, the coordinates do not contain stator resistance, but the adjustable model contains the derivative and square items of voltage and current, and the input signal contains a large number of noise signals, making it difficult to select the adaptive module parameters of QMRAS, and the prediction accuracy control is possible. And accelerate the induction motor to replace the straight accuracy is not high. This paper improves the traditional magnetic chain-based model reference adaptation:

1. the introduction of low-pass filter magnetic chain observation voltage model, can overcome the integration problem in the calculation of traditional voltage model, improve the DC bias of the pure integral link,

2. the introduction of MRAS global stability adaptive rate, the simulation analysis proves that the accuracy and adaptability of the system have been improved to a certain extent.

3. this paper has a large number of literature on the death area compensation method has been studied, based on the previous research results proposed a new death zone compensation strategy.

2. MRAS

Based on the motor ideal model mainly includes direct calculation, MRAS method [4] [5], based on closed-loop observer method, and based on the motor non-ideal model, the method mainly refers to the signal injection method, can usually inject high frequency rotation signal or high frequency pulsation signal. In many speed identification methods, the MRAS speed recognition technology is widely used because of its clear principle, simple implementation and high reliability. Based on the model reference adaptive method speed recognition of the basic principle is: the model without the identifiable parameters as a reference model, the model containing the parameters to be identified as an adjustable model, using the output of the two through the appropriate adaptive law to obtain the parameters to be identified, the basic principle figure in Figure 1 shows, The model reference adaptive speed recognition system based on the rotor magnetic chain takes the voltage model observed by the rotor magnetic chain as the reference model, and the current model as the adjustable model. Because the voltage model observation rotor magnetic chain does not need speed information, and the current model observation rotor magnetic chain needs to use speed information, the rotor magnetic chain observed by the two models through a certain adaptive law to correct the recognized speed. The conditions for accurate identification of motor speed are consistent with the rotor magnetic chain observed by the two models.

Firstly, the voltage model and current model of the magnetic chain observation of asynchronous motor rotor are given, which are derived from the mathematical model of asynchronous motor under the two-phase stationary coordinate system, and the mathematical model of asynchronous motor under the two-phase stationary coordinate system is:

(1) Voltage Equation:
\[
\begin{align*}
    u_{\alpha} &= r_{\alpha}i_{\alpha} + p\psi_{\alpha} \\
    u_{\beta} &= r_{\beta}i_{\beta} + p\psi_{\beta}
\end{align*}
\]  
(2) current equation:
\[
\begin{align*}
    \dot{u}_{\alpha} &= r_{\alpha}\dot{i}_{\alpha} + p\psi_{\alpha} + \omega_{\alpha}\psi_{\beta} \\
    \dot{u}_{\beta} &= r_{\beta}\dot{i}_{\beta} + p\psi_{\beta} - \omega_{\beta}\psi_{\alpha}
\end{align*}
\]
(2) Flux Equation:

\[
\begin{align*}
\psi_{so} &= L_s i_{so} + L_m i_{sm} \\
\psi_{sb} &= L_s i_{sb} + L_m i_{sm} \\
\psi_{ro} &= L_r i_{ro} + L_m i_{rm} \\
\psi_{rb} &= L_r i_{rb} + L_m i_{rm}
\end{align*}
\]  

(3)

Bringing the equation (1), (3) into the equation (4) can be used to obtain a voltage model for the rotor magnetic chain observation:

\[
\begin{align*}
\psi_{so} &= \frac{L_s}{L_w} \left[ \int (u_{so} - r_i) dt - \sigma L_i i_{so} \right] \\
\psi_{sb} &= \frac{L_s}{L_w} \left[ \int (u_{sb} - r_i) dt - \sigma L_i i_{sb} \right]
\end{align*}
\]  

(5)

You can see that the voltage model contains the integration operation. The rotor voltage \( u_{ra}, u_{rb} \) in equation (2), zero in the actual asynchronous motor, the current model of the rotor magnetic chain observation can be obtained by the type (4) into the equation (2):

\[
\begin{align*}
\psi_{ra} &= \frac{1}{T_s} \left[ (L_m i_{r_a} - T_r \psi_{rb} \omega_r) \right] \\
\psi_{rb} &= \frac{1}{T_s} \left[ (L_m i_{r_b} + T_r \psi_{ra} \omega_r) \right]
\end{align*}
\]  

(6)

The state equation for the rotor magnetic chain is:

\[
\begin{align*}
\dot{\psi}_{ra} &= -\frac{1}{T_r} \psi_{ra} - \omega_r \psi_{rb} + \frac{L_m}{T_r} i_{ra} \\
\dot{\psi}_{rb} &= -\frac{1}{T_r} \psi_{rb} - \omega_r \psi_{ra} + \frac{L_m}{T_r} i_{rb}
\end{align*}
\]  

(7)

The type (7) is compared to the equation (8) to get:

\[
\begin{align*}
\begin{bmatrix}
\dot{\psi}_{ra} - \dot{\psi}_{ra} \\
\dot{\psi}_{rb} - \dot{\psi}_{rb}
\end{bmatrix} &=
\begin{bmatrix}
-\frac{1}{T_r} & -\omega_r \\
\omega_r & -\frac{1}{T_r}
\end{bmatrix}
\begin{bmatrix}
\psi_{ra} - \dot{\psi}_{ra} \\
\psi_{rb} - \dot{\psi}_{rb}
\end{bmatrix} -
\begin{bmatrix}
0 & -\omega_r \\
\omega_r & 0
\end{bmatrix}
\begin{bmatrix}
\dot{\psi}_{ra} \\
\dot{\psi}_{rb}
\end{bmatrix}
\end{align*}
\]  

(9)

The formula (9) can be obtained based on the rotor magnetic chain model reference adaptive speed identification system rotor magnetic chain and speed estimation error structure, as shown in Figure 2.
3. Full range stable design of speed identification system

Based on the MRAS speed recognition strategy also need the speed recognition adaptive law, based on the rotor magnetic chain MRAS speed recognition adaptive law obtained by Popov super-stability law [6], the speed recognition adaptive law is obtained:

\[
\dot{\omega}_r = k_p \varepsilon + k_i \int \varepsilon dt
\]

\[
\varepsilon = \dot{\psi}_r - \dot{\psi}_r
\]

In the above equation, \(k_p\) and \(k_i\) are the proportional and integral coefficients respectively. Intuitively look at the 7 of \(\varepsilon\), which means the stator current error and the observed cross-multiplication of the rotor flux linkage \(\dot{\psi}_r\). The introduction of the PI controller can guarantee the steady state. Zero, but \(\varepsilon\) zero can mean that the angle between \(\varepsilon\) and \(\varepsilon\) is zero. This does not physically indicate that the identified speed is tracking the actual speed. On the other hand, if the current error vector 1 can be guaranteed to be zero, it seems that the recognized speed can be considered. Tracking the actual speed, so consider the modified adaptive law as equation (10), which will superimpose the \(\varepsilon\) and \(\dot{\psi}_r\) cross multiplication and point multiplication to ensure that the current error \(\varepsilon\) is zero when the system is steady state, where \(k\) is the proportional coefficient, design \(k\) Value to ensure system stability

\[
\dot{\omega}_r = k_p \left[ (e_{\omega r} \dot{\psi}_{r\beta} - e_{\beta r} \dot{\psi}_{r\alpha}) + k (e_{\omega r} \dot{\psi}_{r\alpha} + e_{\beta r} \dot{\psi}_{r\beta}) \right] + k \left[ (e_{\omega r} \dot{\psi}_{r\beta} - e_{\beta r} \dot{\psi}_{r\alpha}) + k (e_{\omega r} \dot{\psi}_{r\alpha} + e_{\beta r} \dot{\psi}_{r\beta}) \right] dt
\]

Asynchronous motor fourth-order state equation:

\[
\frac{d}{dt} \begin{bmatrix} i_{\alpha} \\ i_{\beta} \\ \psi_{r\alpha} \\ \psi_{r\beta} \end{bmatrix} = A \begin{bmatrix} i_{\alpha} \\ i_{\beta} \\ \psi_{r\alpha} \\ \psi_{r\beta} \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} u_{\alpha} \\ u_{\beta} \end{bmatrix}
\]

The characteristic matrix of the motor system is A:
The full-order state observer state equation is:

\[
\begin{bmatrix}
\dot{i}_a \\
\dot{i}_\beta \\
\dot{\psi}_a \\
\dot{\psi}_\beta
\end{bmatrix} =
\begin{bmatrix}
- \frac{1}{T_a} & 0 & \frac{1}{L_a T_m} & \frac{\omega}{L_a} \\
0 & - \frac{1}{T_\beta} & \frac{1}{L_\beta T_m} & \frac{1}{L_\beta} \\
L_a T_m & 0 & - \frac{1}{T_\beta} & - \omega_\beta \\
0 & L_\beta T_m & \omega_\beta & - \frac{1}{T_\beta}
\end{bmatrix}
\begin{bmatrix}
i_a \\
i_\beta \\
\psi_a \\
\psi_\beta
\end{bmatrix}
+ \begin{bmatrix}
0 \\
0 \\
1/\sigma L_a \\
0
\end{bmatrix}
\begin{bmatrix}
i_a \\
i_\beta \\
\psi_a \\
\psi_\beta
\end{bmatrix}
+ G \begin{bmatrix}
i_a^0 - i_a \\
i_\beta^0 - i_\beta \\
\psi_a^0 - \psi_a \\
\psi_\beta^0 - \psi_\beta
\end{bmatrix}
\]  

(14)

In the formula, the superscript "^\wedge" indicates the observation, and the superscript "^\bot" indicates the actual measurement. \( G = \begin{bmatrix} \hat{g}_1 & \hat{g}_2 & \hat{g}_3 & \hat{g}_4 \end{bmatrix}^T \) is feedback matrix for observers.

Next, the appropriate coefficient \( k \) is designed to ensure the stability of the system, Formula (12) and Formula (14) do the difference, while the feedback matrix \( G \) in the formula (14) is zero to get:

\[
\dot{e} = Ax - \dot{\hat{A}}\hat{x} = Ae + (A - \dot{\hat{A}})\hat{x} = Ae + \Delta A_\Delta\omega_\beta\hat{x}
\]

(15)

\[
e = (sI - A)^{-1}\Delta A_\Delta\omega_\beta\hat{x}
\]

(16)

\[
e_\theta = C(sI - A)^{-1}\Delta A_\Delta\omega_\beta\hat{x}
\]

(17)

Matlab calculations can be obtained:

\[
\begin{bmatrix}
e_{ia} \\
e_{i\beta}
\end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\
c_{21} & c_{22} & c_{23} & c_{24} \\
c_{31} & c_{32} & c_{33} & c_{34} \\
c_{41} & c_{42} & c_{43} & c_{44}
\end{bmatrix}
\begin{bmatrix}
0 & 0 & 0 & \frac{1}{L_a} \\
0 & 0 & - \frac{1}{L_\beta} & 0 \\
0 & 0 & 0 & -1 \\
0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
\dot{i}_{ia} \\
\dot{i}_{i\beta} \\
\dot{\psi}_{ia} \\
\dot{\psi}_{i\beta}
\end{bmatrix}
\Delta \omega_\beta
\]

(18)

\[
e_r = (e_{ia}\hat{\psi}_r - e_{i\beta}\hat{\psi}_m) + k(e_{ia}\hat{\psi}_r + e_{i\beta}\hat{\psi}_m)
\]

And assume that the system is working under the rotor magnetic chain orientation then there is:

\[\Delta 5\]
\[ \Delta \omega_i = G(s) = \frac{c_{22} - c_{24}}{L_{sr}} \frac{c_{12} + c_{14}}{sI - A} \]

So the resulting system dynamic frame diagram is shown in the figure:

\[ \Delta \omega_i = 0 \]

\[ \Delta \omega_i \]

\[ \epsilon \]

\[ k \]

\[ k \]

\[ \frac{k_v}{s} \]

\[ \Delta \omega_i \]

**Figure 3.** Speed recognition system after changing the speed adaptive law

By the system dynamic block diagram can know that if the zero poles of the transfer function \( G(s) \) are located in the left half plane of the complex plane, then the system can ensure that the full range is stable, the transfer function \( G(s) \) of the pole corresponding to the characteristics of the motor, is located in the left half plane of the complex plane, so only need to ensure that the transfer function \( G(s) \) All zeros in the left half plane of the complex plane can guarantee the stability of the system, matlab can be used to calculate the matrix \( sI - A \) inverse matrix, and then get \( G(s) \) zero expression is:

\[ z(s) = s^3 + n_1 s^2 + n_2 s + n_3 \]

\[ n_1 = (a_i + \frac{1}{T_i}) - k \cdot \omega_i \cdot n_2 = \left( \frac{r_i}{\sigma L_s T_r} + \omega_i^2 \right) + k \left( \frac{r_i \cdot \omega_i}{\sigma L_s} \right) \cdot n_3 = \omega_i \left( \frac{1}{\sigma} - k \omega_i \right) \cdot \omega_i + \left( \frac{r_i + \omega_i}{\sigma L_s} + k \frac{r_i}{\sigma L_s T_r} \right) \cdot a_1 = \frac{1}{\sigma L_s} \left( \frac{r_i + \omega_i}{L_s T_r} \right) \]

Use the Lawes to know the need to meet:

\[ \begin{cases} n_1 > 0 \\ n_2 - \frac{n_3}{n_1} > 0 \end{cases} \]

Assuming that the motor is running at full load, the corresponding frequency of the motor transfer is selected \( \omega_i \approx 10 \text{rad/s} \). Select the motor electric angle speed to select the horizontal coordinate range - 50rad/s~50rad/s, The k value is -20~10 for the ordinate range, and the stable region is made using the stable condition as shown in the figure 4:

**Figure 4.** Distribution of system stability

Select the k value in the stable area as shown by the blue line:
4. low-pass filter

In order to eliminate the error caused by the integral operation, the commonly used method is to replace the integrator with a low-pass filter [7]. The transfer function of the low-pass filter is $G_L = \frac{1}{s + \omega_c}$ and $\omega_c$ is the cut-off frequency of the low-pass filter, but substitution of the integral operation into a low-pass filtering operation causes a deviation in the amplitude and phase angle of the operation result at low frequencies. Therefore, the compensation of amplitude and phase is required when replacing the integral operation with a low-pass filter.

The formula for improving the integrator of the $\alpha$-axis component of the rotor flux linkage is:

$$\left(U_{sa} - i_{sa}R_{sa} - \sigma L_s i_{sa}\right) \cdot \frac{L_m}{L_m} \cdot \frac{1}{s + \omega_c} + \frac{\omega_r}{s + \omega_c}\psi_{ra} = \psi_{ra}$$

The formula $\frac{\omega_r}{s + \omega_c}\psi_{ra}$ is to replace the integrator offset compensation with a low-pass filter.

Figure 5 shows the block diagram of the improved integrator.

5. A new dead zone compensation method

Based on the previous research results, this paper proposes a new dead zone compensation strategy [8]. The schematic diagram of the dead time is shown in Figure 2. The dead time is set to $t_z$. The dead zone compensation is to ensure that there is dead zone time a phase output voltage and no. The dead phase time a phase output voltage is the same, that is, the (e), (f) waveform is the same as the (d) waveform, as shown in Figure 6.
When the switching operation time is appropriately moved forward or backward, the operation time of the upper and lower tube is changed from time to time and time, so that the output voltage waveforms with dead time (e), (f) and outputs without dead time (c) can be guaranteed. The voltage waveform (d) is the same. The time to move forward or backward is the dead time. Whether the forward or backward shift is related to the direction of the phase current and whether the triangular carrier is rising or falling. The specific relationship is shown in Table 1. The situation of B and C is similar. When the triangular carrier rising edge is \( i_a > 0 \), the triangular carrier falling edge is \( i_a < 0 \), and the dead zone effect compensation can be realized by adjusting the value of the modulated wave.

**Table 1. Dead Zone Compensation Switch Time Movement Direction Selection Table**

| Triangular carrier | Current \( i_a \) | Rising edge | Falling edge |
|--------------------|------------------|-------------|-------------|
| \( i_a > 0 \)      | move forward     | no move     |
| \( i_a < 0 \)      | no move          | move forward|

In this paper, the phase current \( i_a \) is judged by adopting the method of low-pass filtering the sampled stator current in a two-phase rotating coordinate system, and then transforming the obtained current into a three-phase stationary coordinate system, so as to ensure the sampled three. The sinusoidal phase current avoids the influence of the zero potential clamping phenomenon on the current judgment. It is proved that this processing method is feasible in practical applications.
6. Simulation result
In order to verify the performance of the proposed method, the simulation model of the asynchronous motor speed identification vector control system is built by Matlab/simulink module. The asynchronous motor parameters used in the simulation are shown in Table 2:

| Parameter                  | Value  |
|----------------------------|--------|
| Motor rated power /W       | 3000   |
| Rated voltage /V           | 380    |
| Rated frequency /Hz        | 50     |
| Polar number               | 3      |
| Stator resistance /Ω       | 1.8140 |
| Rotor resistance /Ω        | 1.8429 |
| Stator leakage inductance /H| 0.1835 |
| Mutual inductance /H       | 0.1733 |
| Switching frequency/Hz     | 4k     |

The simulation control conditions are as follows: the initial time respectively accelerates the motor to 40r/min and 1000r/min, respectively corresponding to the low speed and rated speed of the asynchronous motor, and the load torque rises stepwise at 1s, from 0N.m to 20N.m, after 1s of operation, the load torque drops step by step at 2s, from 20N.m to -20N.m, and the simulation ends after 2s of continuous operation.

From Figure 7 to Figure 14 respectively correspond to the simulation results at low speed and rated speed. In the simulation, the given speed, identification speed and actual speed of the observation system are observed. At the same time, the α-axis of the rotor flux linkage based on the improved voltage model and current model is observed. The components were compared and the simulation results confirmed the feasibility of the proposed scheme.

In the simulation result, $\omega_{r\_obs}$ is the speed recognized by the identification algorithm, $\omega_r$ is the actual motor speed, and $\omega_{r\_ref}$ is the motor's given speed, which is the α component of the rotor flux linkage observed by the improved voltage model and current model.

![Figure 7. 40r/min Speed identification results](image)

![Figure 8. 40r/min Speed identification results partial amplification](image)
Figure 9. Simulation results based on rotor $\alpha$-axis flux linkage MRAS low speed operation

Figure 10. Simulation results based on rotor $\alpha$-axis flux linkage MRAS low speed operation partial amplification

Figure 11. 1000r/min Speed identification results

Figure 12. 1000r/min Speed identification results partial amplification
It can be seen from the simulation results that the speed based on the adaptive identification of the modified flux model rotor flux linkage model can track the actual motor speed very well. The identified rotational speed is used for asynchronous motor vector control, the motor speed can well track a given speed, and the dynamic performance is good. The rotor flux linkage obtained based on the improved voltage model is basically consistent with the rotor flux linkage based on the current model observation. When the motor runs at the rated speed, there is a certain amplitude deviation, but the phase angles of the two are consistent. The simulation includes the low, high speed, positive and negative load of the motor running. The system can maintain stable operation regardless of the operating state. The simulation results confirm the effectiveness of the improved voltage model rotor flux linkage observation method.

7. Experimental result
This section gives the experimental results of the asynchronous motor speed identification vector control. In the experiment, the speed obtained by the identification algorithm is used for the vector control feedback speed. After the system starts, the motor is accelerated to the low speed (40r/min) and high speed (800r/min) and run for a while, then suddenly load is applied, and the load is released after a stable operation for a while. The experimental results are shown in from Figures 15 to Figures 18.

Figure 13. Simulation results based on rotor $\alpha$-axis flux linkage MRAS high speed operation

Figure 14. Simulation results based on rotor $\alpha$-axis flux linkage MRAS low speed operation partial amplification

Figure 15. Schematic diagram of the observation speed in a given speed of 40r/min, -50% load system operation
It can be seen from the experimental results that the rotor flux linkage MRAS speed identification system can achieve full range stability. At the same time, it can also explain the effectiveness of the proposed score improvement strategy.

8. Conclusion

Based on the research on the speed recognition of the rotor magnetic chain MRAS asynchronous motor, the integral operation of magnetic chain observation voltage model will bring a series of problems, replace the integrator with low-pass filter and compensation link, and propose a new method of selecting the dead zone compensation link and introducing the full range of stability. This method has the characteristics of achieving high simple reliability, which is very suitable for engineering applications. The test method is verified by simulation and experiment, and the validity of the proposed method is
proved to be based on the rotor magnetic chain model reference adaptive speed identification method can ensure the stability of the full speed range of the speed recognition system.

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