Computer Simulation and Study of Flux-Observed Vector Control in Time-Varying of Rotor Parameters

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Abstract: Starting from the radical principle of the asynchronous machine equation and asynchronous machine vector control under synchronous M-T coordinate system, this article analyzes the effect of rotor parameters (inductance and resistance) on magnetic test-type vector control performance in detail. Considering that machine rotor parameters in real experiment system will change as the circulation state of machine, while the asynchronous machine mold in *MATLAB* simulation software electric system tool box can't timely change its parameters in circulation, the writer composed the machine model that can simulate rotor parameters timely change by making use of the S-function in *MATLAB* by himself. On the basis of that, establish a simulation system for the whole asynchronous machine vector control, and firstly simulate and analyze the system under conditions of ignoring and considering rotor parameters. Simulation results show, the rotor parameters change caused by skin effect in reality makes the dynamic performance of asynchronous machine vector control become worse.

Key-Words: Asynchronous Machine; Vector Control; S-Function; Dynamic Simulation

1 Introduction

Alternating current asynchronous machine is a system of multi variable, strong couple, nonlinear and time varying. Its instantaneous torque is hard to control. So it's difficult to gain the same high dynamic timing performance as direct current machine. In 1971, German scholar, *Blaschke,* put forward the vector counterchange control technology [1] based on field-orientation which is mainly reached by coordinate counterchange and decomposing stator current into torque current and excitation current. In asynchronous machine rotor field-orientation control, the accurate decouple between the two is assured by the accuracy of field-orientation, that is, it's a must to get exactly the rotor flux vector timely location.

Rotor flux is usually gained by the following two methods[2]: (1) Direct method, i.e., embedding Whoer magnetic test sensor inside the machine to test air flux and then get rotor flux; (2) Indirect method, calculating the location of rotor flux according to its speed and slippage. Usually we adopted indirect method instead of direct method because a sensor needs to be installed. While, indirect method has an important defect, i.e., it's easy to be affected by machine parameters, especially by rotor time constant. Literature [3] only listed the advantages and disadvantages of the few existing rotor linkage test methods without dietailed analysis on the effect of asynchronous machine rotor parameters on vector counterchange control performance and without showing relative simulation or experiment analysis results as well.

I n view of that, this article, starting from the circulation mechanism of the asynchronous machine equation and asynchronous machine vector control under the synchronous $M-T$ coordinate system, analyzes the effect of machine rotor parameters on vector counterchange control performance in detail. Considering that the machine rotor parameters (inductance and resistance) in real system will change according to the working conditions of machine, as the asynchronous machine model in *MATLAB* computer simulation software electric system tool box can't change its parameters timely in circulation, this article composed the machine model of which the parameters can timely change by making use of S-function in *MATLA*. Based on this, establish a computer simulation system for the whole asynchronous machine vector control, firstly simulate and analyze the system under conditions of rotor parameters unchangeable and considering rotor parameters timing separately. Simulation research shows that the rotor parameters change caused by actual skin effect makes the dynamic performance of asynchronous machine become worse.

2 Analysis on asynchronous machine vector control mechanism

2.1 Asynchronous machine model under synchronous M-T coordinate system

The asynchronous machine mathematical model under 3-phase static coordinate system can get the mathematical model[4] under synchronous M-T coordinate system by counterchanging and rotating coordinate: [4]:

$$\begin{bmatrix} u_{M1} \\ u_{T1} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_1+L_{11}p & -\omega_1 L_{11} & L_m p & -\omega_1 L_m \\ \omega_1 L_{11} & R_1+L_{11}p & \omega_1 L_m & L_m p \\ L_m p & -(\omega_1-\omega)L_m & R_2'+L_{22}'p & -(\omega_1-\omega)L_{22}' \\ (\omega_1-\omega)L_m & L_m p & (\omega_1-\omega)L_{22}' & R_2'+L_{22}'p \end{bmatrix} \begin{bmatrix} i_{M1} \\ i_{T1} \\ i_{M2}' \\ i_{T2}' \end{bmatrix} \quad (1)$$

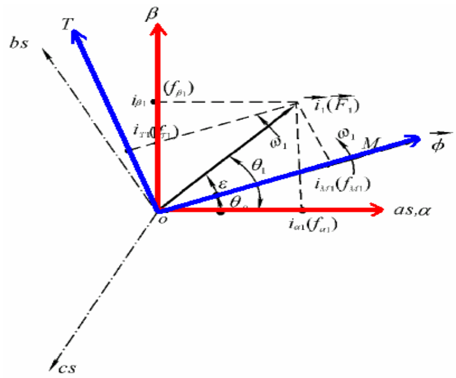

Fig.1 Quiescent coordinate as-bs-c, α-β and rotating coordinate M-T

In the formula: R_1、R_2' are the resistance of stator and rotor. L_{11}、L_{22}' 、L_m are self-induction and mutual induction of stator and rotor. u_{M1}、u_{T1}、i_{M1}、i_{T1}、i_{M2}'、i_{T2}' are stator direct and quadrature axis pressure, stator direct and quadrature axis current and rotor direct and quadrature axis current. P is the arithmetic operators of differential coefficient.

Take rotor whole flux $\bar{\Phi}_2'$ (opposite to rotor whole linkage $\overline{\Psi}_2'$) as the direction of M axis. That is,

$$\begin{cases} \Psi_{M2}' = \Psi_2' \\ \Psi_{T2}' = 0 \end{cases} \quad (2)$$

From that, we can get the asynthronous machine vector control mathematical model [4] of rotor field-orientation [4]:

$$\begin{bmatrix} u_{M1} \\ u_{T1} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_1+L_{11}p & -\omega_1 L_{11} & L_m p & -\omega_1 L_m \\ \omega_1 L_{11} & R_1+L_{11}p & \omega_1 L_m & L_m p \\ L_m p & 0 & R_2'+L_{22}'p & 0 \\ (\omega_1-\omega)L_m & 0 & (\omega_1-\omega)L_{22}' & R_2'+L_{22}'p \end{bmatrix} \begin{bmatrix} i_{M1} \\ i_{T1} \\ i_{M2}' \\ i_{T2}' \end{bmatrix} \quad (3)$$

From the third and fourth line of formula （3）, we Get

$$0 = p(L_m i_{M1} + L_{22}' i_{22}') + R_2' i_{M2}' = p\Psi_{M2}' + R_2' i_{M2}' \quad (4)$$

$$0 = (\omega_1 - \omega)(L_m i_{M1} + L_{22}' i_{22}') + R_2' i_{M2}' = (\omega_1 - \omega)\Psi_{M2}' + R_2' i_{M2}' \quad (5)$$

2.2 Analysis on vector control mechanism

Considering that rotor linkage $\bar{\Psi}_2'$ is unchanged, substitute the first 2 lines of formula (3) in electromagnetism power express, we can get

$$P_e = \frac{3}{2}(u_{M1} i_{M1} + u_{T1} i_{T1}) = \frac{3}{2}\omega_1 L_m (i_{T1} i_{M2}' - i_{M1} i_{T2}') \quad (6)$$

From formula (4), and ignore the $\bar{\Psi}_2'$ change, i.e., $p\bar{\Psi}_{M2}' = 0$, we get $i_{M2}' = 0$,

So electromagnetism power is further expressed as

$$P_e = -\frac{3}{2}\omega_1 L_m i_{M1} i_{T2}' \quad (7)$$

Substitute formula (2) in (7), we get

$$P_e = \frac{3}{2}\omega_1 \frac{L_m}{L_{22}'}\Psi_{M2}' i_{T1} \quad (8)$$

While electromagnetism torque is expressed as

$$T_e = \frac{3}{2}P\frac{L_m}{L_{22}'}\Psi_{M2}' i_{T1} \quad (9)$$

Considering formula （2）、（4）、（5）, we can get rotor linkage

$$\Psi_{M2}' = \frac{L_m}{1+T_2 p} i_{M1} \quad (10)$$

In the formula, $T_2 = L_{22}' / R_{22}'$ is rotor time constant.

Seen from torque expression (9) and torque linkage expression (10), torque linkage is just relevant to the stator current excitation component i_{M1} on M axis, and electromagnetism torque is relevant to rotor linkage and the stator current torque component i_{T1} on T axis. As the stator current on M\T axis has decoupled and is independent, torque control can be realized by independently control the stator current component i_{M1}、i_{T1} on M,T axis, and then further realize the static decoupled control between asynchronous machine torque and linkage, realizing the dynamic timing performance as direct current machine. It's also seen that the existence of rotor time constant will surely delay the dynamic performance of torque to some extent. In reality, the change of rotor parameters makes T_2 change, and so makes the accuracy of field-orientation decrease, the dynamic and static performance of vector control become worse

The key to effectively implement vector counterchange control is to accurately confirm $\bar{\Phi}_2^{'}$ space location and realize the orientation of M,T coordinate system. The article calculates the whole flux $\bar{\Phi}_2^{'}$ and its separation angle θ_0 relative to α axis by testing pressure and current, according to machine mathematical model. And then get the block diagram of flux surveyor as diagram 2.

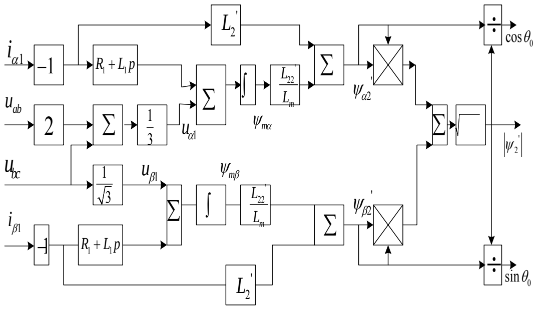

Fig.2 Principle diagram of flux observer

3 Establishment of system simulation model

According to the above analysis, the writer composed the machine model of which the machine parameters can timely change by making use of S-function in MATLAB, and established a simulation system for the whole asynchronous machine vector control on this basis.

3.1 Vector control system model

Build the block diagram of the whole vector control system as diagram 3. The whole system includes speed loop (outer loop) and current loop (inner loop). The outputting of speed loop is the imputing of current loop. Current loop mainly realizes the torque decoupled control of rotor field-orientation. The ac-motor model in the diagram is the machine model of which the machine parameters can timely change composed by the writer making use of S-function in MATLAB. The followings are detailed analysis on the way of building model.

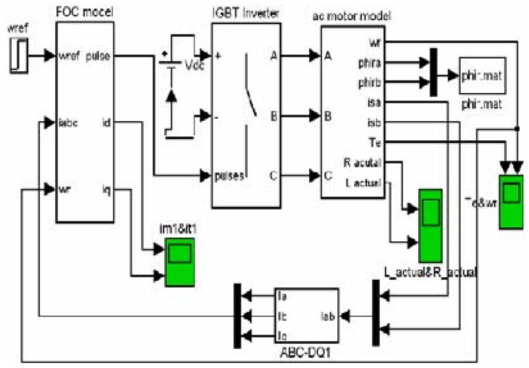

Fig.3 Vector-controlled system of AC motor

3.2 Asynchronous machine model based on S-function

While asynchronous machine actually circulates, rotor parameters (inductance and resistance) will change according to the working condition of machine circulation. As of the asynchronous machine model in MATLAB/SIMULINK can't meet the demands in actual system circulation, as per the below machine equation, composed the machine model of which machine parameters can timely change and simulated the actual circulation conditions of asynchronous machine by making use of S-Function in MATLAB.

One 3-phase rat cage-type synchronous machine, under the $\alpha-\beta$ coordinate system of 2-phase static, its pressure equation is

$$\begin{cases} u_{s\alpha} = R_s i_{s\alpha} + \dfrac{d\varphi_{s\alpha}}{dt} \\ u_{s\beta} = R_s i_{s\beta} + \dfrac{d\varphi_{s\beta}}{dt} \\ 0 = R_r i_{r\alpha} + \dfrac{d\varphi_{r\alpha}}{dt} + n_p \omega \varphi_{r\beta} \\ 0 = R_r i_{r\beta} + \dfrac{d\varphi_{r\beta}}{dt} - n_p \omega \varphi_{r\beta} \end{cases} \quad (11)$$

Linkage equation is

$$\begin{cases} \varphi_{sa} = L_s i_{s\alpha} + M i_{r\alpha} \\ \varphi_{s\beta} = L_s i_{s\beta} + M i_{r\beta} \\ \varphi_{ra} = L_r i_{r\alpha} + M i_{s\alpha} \\ \varphi_{r\beta} = L_r i_{r\beta} + M i_{s\beta} \end{cases} \quad (12)$$

The circulation equation of machine is

$$\frac{d\omega}{dt} = \frac{n_p M}{J}(i_{s\beta} i_{r\alpha} - i_{s\alpha} i_{r\beta}) - \frac{T_L}{J} \quad (13)$$

Meanings of each symbol:

R、i、φ、u、L、M represent resistance, current, linkage, imputing pressure, inductance and mutual inductance. α、β represent α and β axis of 2-phase static coordinate system. s、r represent stator and rotor. J、n_p、ω、T_L refer to the moment inertia, polar logarithm, mechanical angular speed and load torque of machine.

By delaminating the middle variable $i_{r\alpha}, i_{r\beta}, \varphi_{s\alpha}, \varphi_{s\beta}$ in formula （11）、（13）, we get the 5-phase nonlinear dynamic equation[4] of machine. [4]

$$\begin{cases} \dfrac{d\omega}{dt} = \dfrac{n_p M}{J L_r}(\varphi_{r\alpha} i_{s\beta} - \varphi_{r\beta} i_{s\alpha}) - \dfrac{T_L}{J} \\ \dfrac{d\varphi_{r\alpha}}{dt} = -\dfrac{R_r}{L_r}\varphi_{r\alpha} - n_p \omega \varphi_{r\beta} + \dfrac{R_r}{L_r} M i_{s\alpha} \\ \dfrac{d\varphi_{r\beta}}{dt} = -\dfrac{R_r}{L_r}\varphi_{r\beta} + n_p \omega \varphi_{r\alpha} + \dfrac{R_r}{L_r} M i_{s\beta} \\ \dfrac{di_{s\alpha}}{dt} = \dfrac{M R_r}{\sigma L_s L_r^2}\varphi_{r\alpha} + \dfrac{n_p M}{\sigma L_s L_r}\omega \varphi_{r\beta} - \dfrac{M^2 R_r + L_r^2 R_s}{\sigma L_s L_r^2} i_{s\alpha} + \dfrac{1}{\sigma L_s} u_{s\alpha} \\ \dfrac{di_{s\beta}}{dt} = \dfrac{M R_r}{\sigma L_s L_r^2}\varphi_{r\beta} - \dfrac{n_p M}{\sigma L_s L_r}\omega \varphi_{r\alpha} - \dfrac{M^2 R_r + L_r^2 R_s}{\sigma L_s L_r^2} i_{s\beta} + \dfrac{1}{\sigma L_s} u_{s\beta} \end{cases} \tag{14}$$

Thereinto, $\sigma = 1 - M^2 / L_s L_r$.

According to this, the machine model built in SIMULINK is as diagram 4.

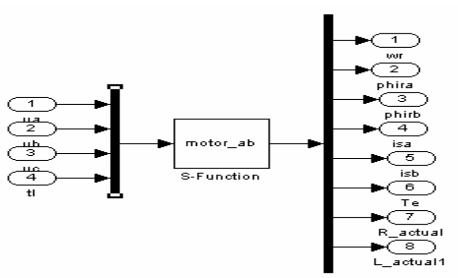

Fig.4 AC motor model based on S-Function

5 Conclusion

Considering that the parameters inductance and resistance of machine rotor will change according to the circulation conditions of machine (load change) in real experiment system, while the asynchronous machine model in MATLAB/SIMULINK can't timely change its parameters in circulation, compose the machine model of which machine parameters can timely change by making use of the S-Function in MATLAB. Based on that, establish a simulation system of the whole flux test-type asynchronous machine vector control, firstly simulate and compare the system under conditions of ignoring rotor parameters and considering rotor parameters timely change (resistance and inductance). Simulation result simulates the rotor parameters change caused by skin effect in reality and thus leads to the worseness of torque dynamic performance of asynchronous machine vector control.

Appendix: asynchronous machine parameters

$P = 3$ kW，$2P = 4$，$T_N = 21.45$ Nm，$n_N = 1420$ r / min，$I_N = 6.8$ A

$R_1 = 1.898\,\Omega$， $R_2 = 1.45\Omega$，

$L_m = 187$ mH， $L_1 = 196$ mH，

$L_2 = 196$ mH，$J = 0.0067$ kgm^2

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