Research on asynchronous motor vector control system based on rotor parameters time-varying

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Abstract: On the basis of the asynchronous motor equations in the M－T reference frame rotating at synchronous speed, the paper, in detail, analyses the affect of the rotor parameters, including reluctance and inductance, to the performance of the Flux-Observation based Vector Control. Considering the time-varying of rotor parameters along with the running state in the real experimental systems and the AC motor model included in the SimPowerSystems of Matlab can not change its own rotor parameters with time, an AC model is built, which can simulate real-time changes of its rotor parameters, making use of S-Function in MATLAB. Based on the model, a whole Vector Control simulation system is established, and for the first time, respectively it is implemented that the simulation and analysis of the system on the condition of both neglecting and considering the time-varying of rotor parameters. It is indicated that, from the simulation results, the variations of the rotor parameters resulting from the Skin Effect make the dynamic performance of AC Vector Control get worse. At the same time , A control system based on the TMS320F2812 digital signal processor produced by Texas Instruments is designed,the design of control circuit and control soft is accomplished.The paper adopts VC++ soft to compile the observation interface of Pc.The experimentation indicates the control system can implement the scheme and the control performance is fine.

Key-Words: Asynchronous Motor; Vector Control; S-Function; Dynamic Simulation; simulation model; rotor parameters

1 Introduction

Alternating current asynchronous motor 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 motor. 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 motor 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 motor 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 motor parameters, especially by rotor time constant. Literature [3] only listed the advantages and disadvantages of the few existing rotor linkage test methods without detailed analysis on the effect of asynchronous motor rotor parameters on vector counterchange control performance and without showing relative simulation or experiment analysis results as well.

I In view of that, this article, starting from the circulation mechanism of the asynchronous motor equation and asynchronous motor vector control under the synchronous $M-T$ coordinate system, analyzes the effect of motor rotor parameters on vector counterchange control performance in detail. Considering that the motor rotor parameters (inductance and resistance) in real system will change according to the working conditions of motor, as the asynchronous motor model in *MATLAB* computer simulation software electric system tool box can't change its parameters timely in circulation, this article composed the motor 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 motor 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 motor become worse.

2 Analysis on asynchronous motor vector control mechanism

2.1 Asynchronous motor model under synchronous M-T coordinate system

The asynchronous motor 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: [5] ：

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

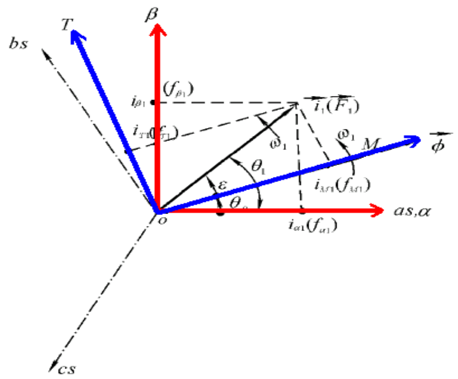

Fig.1 Quiescent coordinate as-bus-c, α-β and rotating coordinate M-T

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. UM1、uT1、iM1、iT1、iM2´、$i_{T2}^{'}$ are stator direct and quadrate axis pressure, stator direct and quadrate axis current and rotor direct and quadrate axis current. P is the arithmetic operators of differential coefficient.

Take rotor whole flux $\bar{\Phi}_2^{'}$ (opposite to rotor whole linkage $\bar{\Psi}_2^{'}$) 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 asynchronous motor vector control mathematical model [6] of rotor field-orientation [6] ：

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

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

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

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

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

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

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 motor torque and linkage, realizing the dynamic timing performance as direct current motor. 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 motor mathematical model. And then get the block diagram of flux surveyor as diagram 2. [8][9]

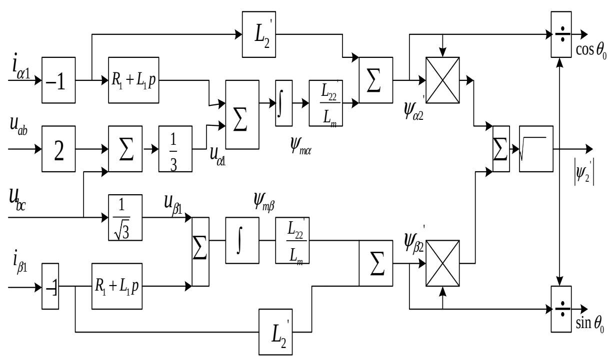

Fig.2 Principle diagram of flux observer

3 **Establishment** of system simulation model

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

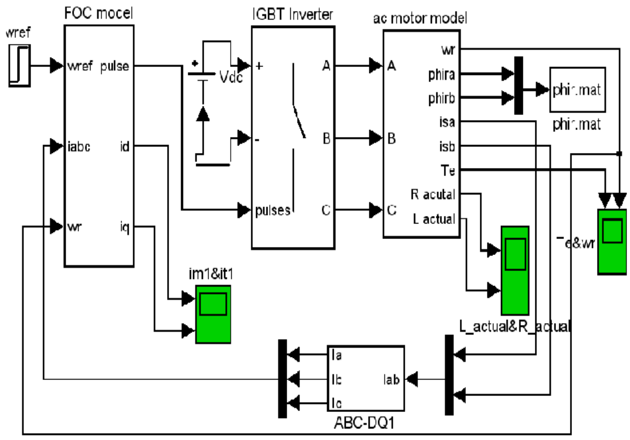

Fig.3 Vector-controlled system of AC motor

3.2 **Asynchronous motor model based on S-function**

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

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

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

Linkage equation is

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

The circulation equation of motor is

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

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, and mechanical angular speed and load torque of motor.

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 [7] of motor. [7]

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

They're into, $\sigma = 1 - M^2 / L_s L_r$.

According to this, the motor model built in SIMULINK is as diagram 4. [10]

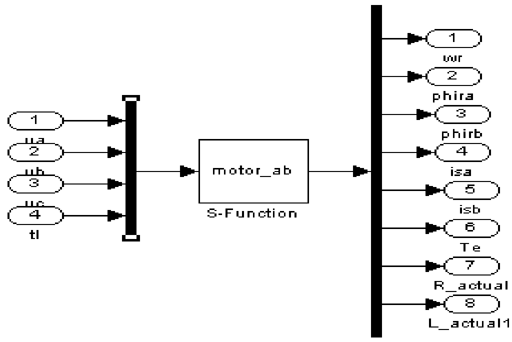

Fig.4 AC motor model based on S-Function

4 Simulation result

The simulation research on the flux test-type asynchronous motor vector control of rotor parameters time varying is carried on the motor shown in appendix. Diagram 5~7, 8~10 and 11~13 are the rotor linkage change waveform, rotor resistance and inductance real value and relevant alternating and direct current change waveform and rotating speed and torque change course on conditions of ignoring rotor parameters change, considering resistance timely change and considering rotor inductance timely change. Of which, the simulation result of diagram 5~7 well proves the torque dynamic decoupled performance of vector control on condition of ignoring parameters change. While considering rotor parameters change (diagram 8~10 and 11~13), simulate the conditions of asynchronous motor actual circulation. The detailed analysis is as below: In real circulation, the current of motor rotor increases because of load increase, rotor parameters change because of skin effect. That is, $L_{22}^{'}$ decreases (diagram12), $R_2^{'}$ increases (diagram 9), Therefore, time constant of motor rotor $T_2 = L_{22}^{'} / R_2^{'}$ increases. That is, the space location θ_0 (diagram 1) of rotor whole flux $\bar{\Phi}_2^{'}$ changes, incorrect M axis orientation affects M, T axis decouple and finally leads to the characteristics variation of torque dynamic control (the alternating and direct current change in diagram 9 and 12).

4.1 Ignoring the change of rotor parameters

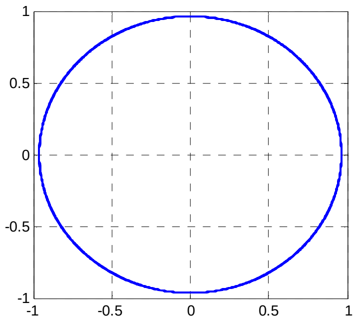

Fig.5 Rotor flux

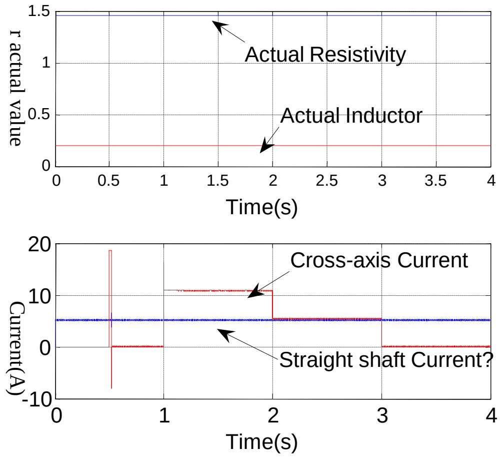

Fig.6 Changes of rotor resistance and inductance and corresponding M、T -axis current

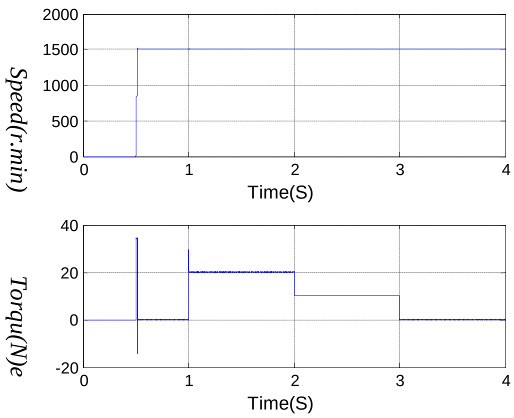

Fig.7 Changes of rotor speed and torque

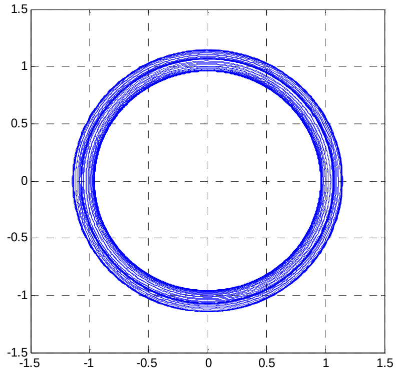

Fig.8 Rotor flux

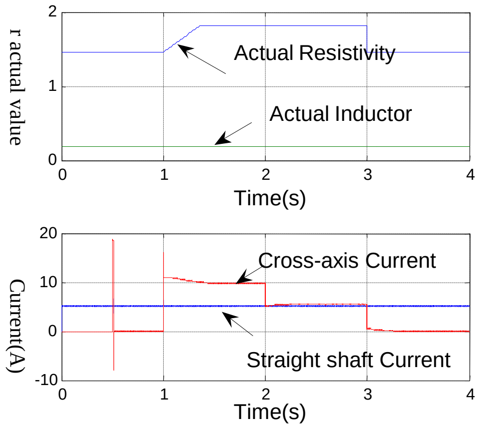

Fig.9 Changes of rotor resistance and inductance and corresponding M、T -axis current

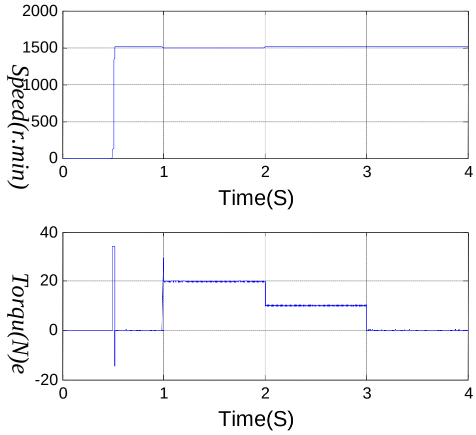

Fig.10 Changes of rotor speed and torque

4.2 Considering the change of rotor parameters

（1） Rotor resistance increase by 20% (inductance keeps unchanged)

（2） Rotor inductance decrease by 20% (resistance keeps unchanged)

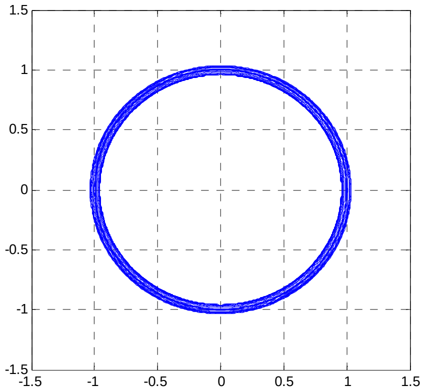

Fig.11 Rotor flux

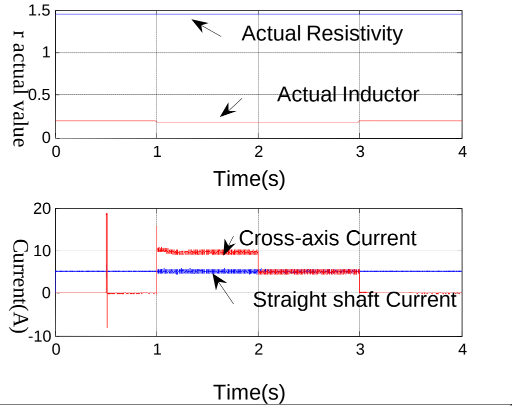

Fig.12 Changes of rotor resistance and inductance and corresponding M、T -axis current

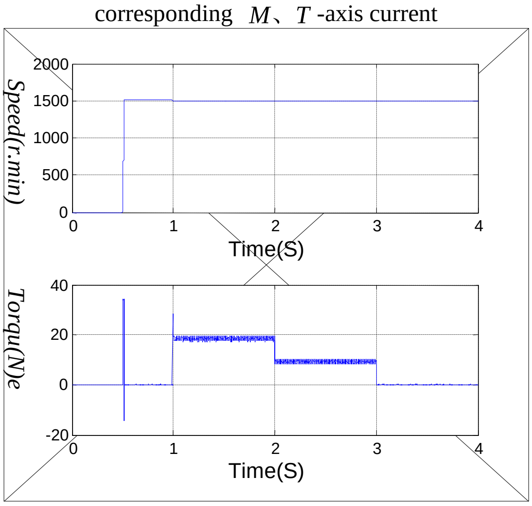

Fig.13 Changes of rotor speed and torque

The simulation results can be seen from this paper, the control system designed by the full realization of the stator current torque weight and the weight of bad excitation. Start fast response, the steady-state performance, and sudden changes in load torque system response time of less than looms, it has good dynamic performance.

Appendix: asynchronous motor parameters
P ＝ 3 kW,
2 P ＝ 4,
T_N ＝ 21.45 Nm,
NN＝ 1420 r/min,
I_N ＝6.8 A
R_1 ＝1.898 Ω,
R_2 ＝1.45Ω,
L_m ＝ 187 mH
L_1 ＝ 196 mH,
L_2 ＝ 196 mH, J ＝ 0.0067 kgm^2

5 Experimental results

Based on the simulation results, We have done on the actual asynchronous motor control experiment, To verify the performance of asynchronous motor vector control system based on rotor parameters time-varying,In order to test security, we are using the power of 1.1 KW small three-phase synchronous motor control experiment.

5.1 Experimenta three-phase asynchronous motor

Three-phase asynchronous induction motor parameters such as Table 1

Fig.14 to Fig.17 for different frequencies empty motor stator phase voltage and current waveforms. Its digital oscilloscope waveforms are measured, the results directly into the computer.

Table.1parameters

Parameters	Number	Units
Rated voltage u_n	380	V
Rated Current I_n	2.7	A
Rated frequency f_n	50	HZ
Electrodes on the few p	2	
Stator resistance R_s	6.1	Ω
Rotor resistance R_r	5.0	Ω
Stator leakage Inductance *Lsi*	22.5	mH
Rotor leakage Inductance *Lri*	30.0	mH
Excitation inductance *Lm*	475	mH

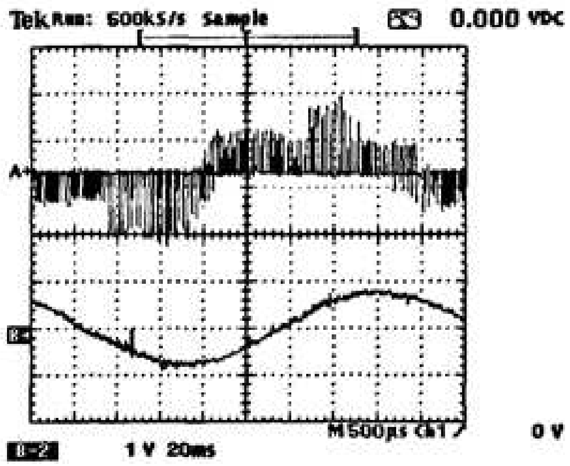

Fig.14 5Hz Waveform of Stator Voltage and Current when No-load

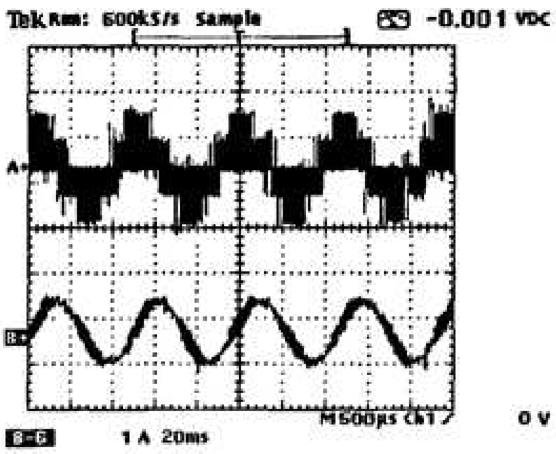

Fig.15 20Hz waveform of Stator Voltage an Current When No-load

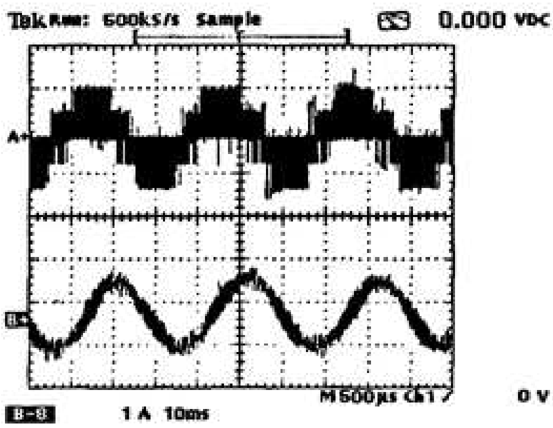

Fig.16 30Hz Waveform of Stator Voltage and Current When No-load

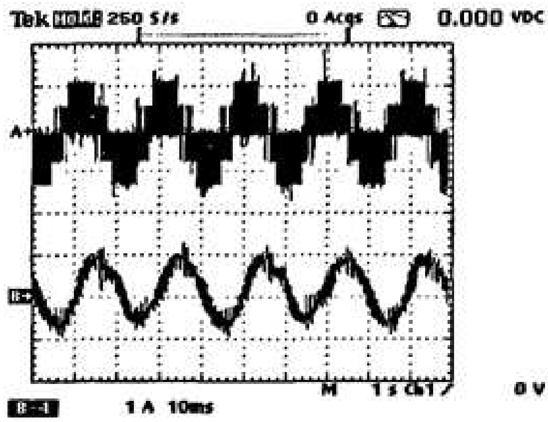

Fig.17 50 Hz Waveform of Stator Voltage and Current When No-load

Fig.17 to Fig.20 for different frequency band containing motor stator phase voltage and current waveforms (additional electrical load for 70% of rated load)

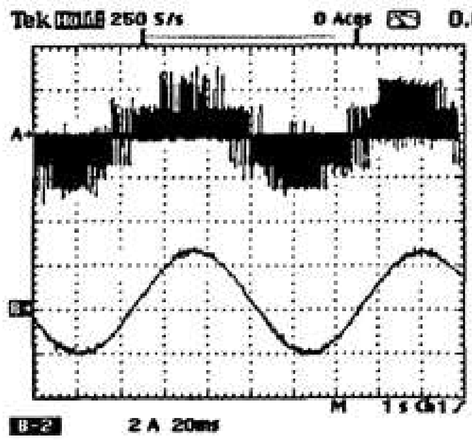

Fig.17 5Hz Waveform of Stator Voltage and Current When loading

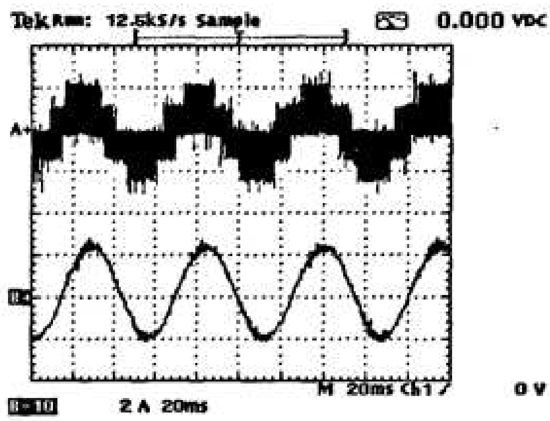

Fig.18 15Hz Waveform of Stator Voltage and Current When loading

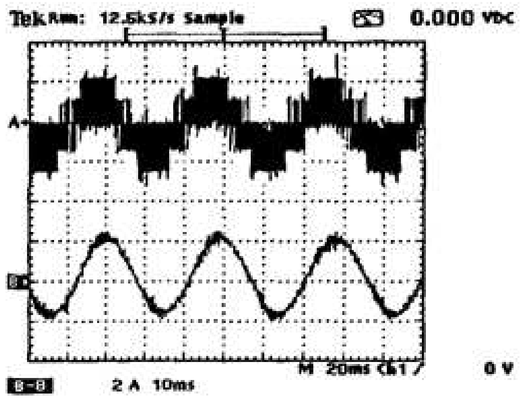

Fig.19 30Hz Waveform of Stator Voltage and Current When loading

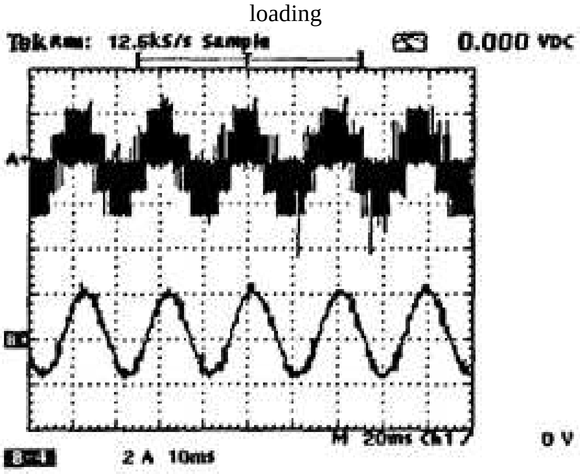

Fig.20 50Hz Waveform of Stator Voltage and Current When loading

Fig.21 for the motor to accelerate the speed and the actual stator current waveform, Fig.22 for motor deceleration speed and the actual stator current waveform.

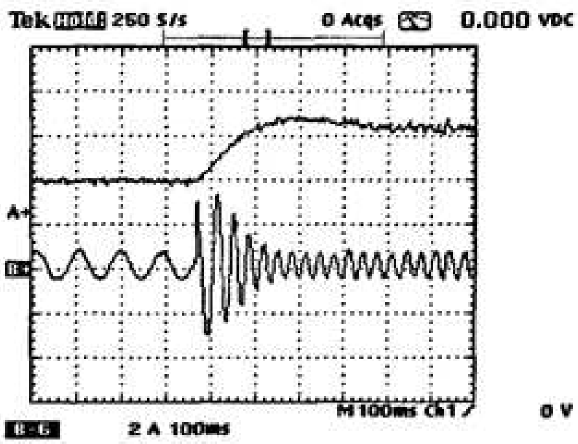

Fig.21 Waveform of Speed and Stator Current When Accelerating

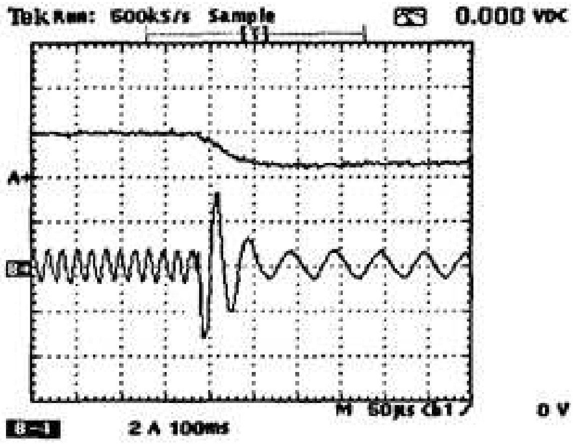

Fig.22 Waveform of Speed and Stator Current When Speed Reducing

Fig.23 for the electrical steady-state operation, given the speed from 300 rpm 1200 rpm sudden Add the rotor flux waveform Figure Fig.24 for the electrical steady-state operation, given the speed 1200 rpm from the process to reduce the rotor 300 rpm Flux waveform for Channel A flux waveforms, channel B for the actual motor speed waveform. Can be seen from the map, given the speed will lead to mutations in the rotor flux transient in about 10% of the changes, but in less than 0.5 s time and restored to the original values. Rotor flux will change because the voltage decoupling control in a dynamic process does not achieve complete decoupling, but to use direct cross between a small shaft coupling system to improve the dynamic response capability.

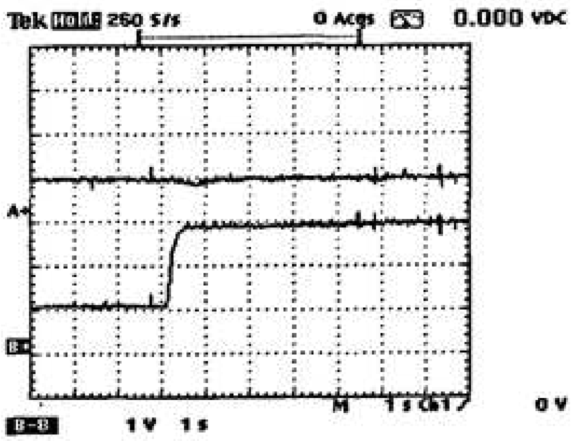

Fig.23 Waveform of Rotor Flux When Accelerating

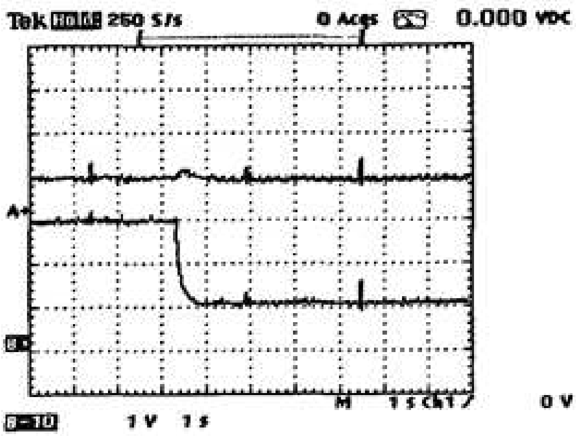

Fig.24 Waveform of Rotor Flux When Speed Reducing

Fig.25 for the motor to run at 1200 rpm stability, the electrical load torque rated suddenly from the 10% change to 70%, and the rotor flux motor speed waveform; Fig.26 for the motor to run at 1200 rpm stability, the electrical load suddenly Rated torque changes from 70% to 10%, and the rotor flux motor speed waveform for Channel A rotor flux waveforms, channel B for the speed waveform. The torque responsive, and the mutation on the load and speed flux little impact, as can be seen from Figure, the transient changes in the flux of not more than 10%, and about 0.5 s return to the previous value; speed Transient changes in not more than 5%, and 0.5 s, on the resumption of the pre-mutation to load value.

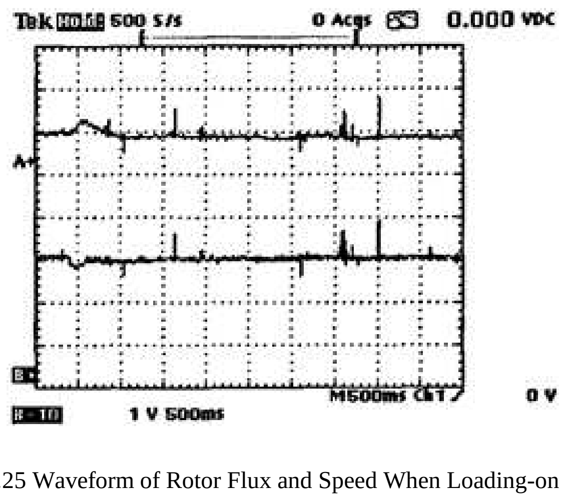

Fig.25 Waveform of Rotor Flux and Speed When Loading-on

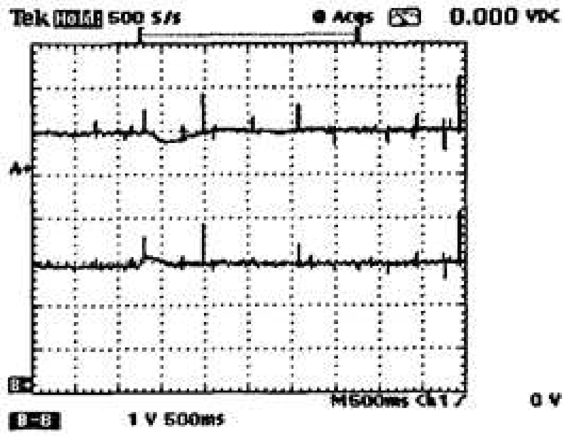

Fig.26 Waveform of Rotor Flux and Speed When Off-loading

In this paper the design of vector control system on motor speed closed-loop control can be carried out on the motor speed

Precise adjustment. Fig.27 for the motor speed to the speed of the response of the signal waveform for a given channel A speed signal waveforms, channel B for the actual motor speed response waveforms.

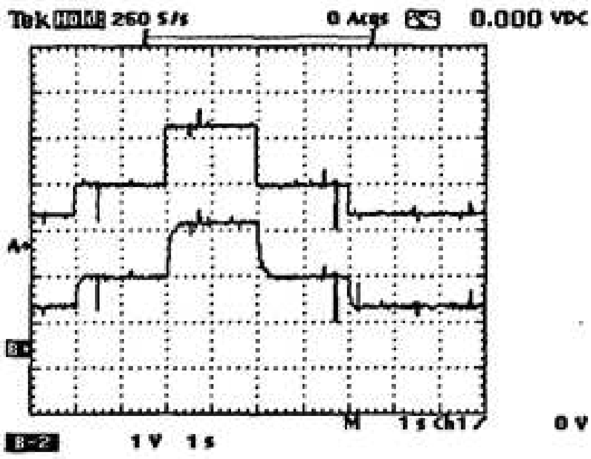

Fig.27 Waveform of Speed Response

6 Conclusions

Considering that the parameters inductance and resistance of motor rotor will change according to the circulation conditions of motor (load change) in real experiment system, while the asynchronous motor model in MATLAB/SIMULINK can't timely change its parameters in circulation, compose the motor model of which motor 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 motor 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 motor vector control.

At the same time, on the basis of simulation results, we designed a TMS320F2812 DSP chip as the core control system, completed a control circuit and control software design. The actual induction motor for a field experiment, and experiments show that the control system practical, good control performance, the rapid response system.

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