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The Torque Vector Control System of The Switched Reluctance Motor Used in Electric Vehicle

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Abstract—***In the paper,the micro-step method based on the phase current aiming to reduce the torque ripple is proposed.The SRM driving system used in the electric vehicle is presented by TMS320LF2407 as main controller. The hardware circuit and the software block diagram is presented.The system adopted the novel torque vector control strategy,it can effectively reduce the torque ripple.The result from simulation and experiment show that this system possesses the advantages of simple hardware;good real-time with dynamic and static characteristic,and can effectively minimize the torque ripple and is satisfied for the demand of the electric vehicle performances.***

Keywords-SRM; micro-step; DSP controller; the electric vehicle

I. INTRODUCTION

The maturing of environmental awareness worldwide has led to the development of a market for transportation with reduced environmental impact. Although there are variety of technological options being developed, the electric vehicle (EV) has been the most commercially successful to date. The modern electric vehicle is the product by combing the new technologic in the motor driving, the power electron, the intelligent controller, the chemical source, computer, new energy and material. Today the well-known vehicle company has been made the electric vehicle in a small amount. The Electrical and Computer Engineering Department at the University of Canterbury has been involved in the research and development of electric vehicles since the oil crisis of 1974. The first two cars use standard induction motors, which have been rewound to operate at frequencies up to 150Hz, and therefore have a high power to weight ratio. EV3, a Toyota MR2 sports car, is the latest electric vehicle in the department which is currently being converted into an electric car. The induction motor used for the new car has been selected so as to operate with a high nominal frequency. To make the electric vehicle more competitive against the internal combustion engine, the EVs must provide not only the driving range but also the attractive driving performance for general users. Therefore the induction motor must be able to generate high torque at low speeds. In our country, Tsinghua University has been studied the vehicle from 1970 and the research work has been classified as a major tackle key problem by the science committee of our country in the Eight-five plan and the Ninefive plan. Now, the prototype of a machine has been produced, but, the electric vehicle has not been used in the business. As the green environmental protection conveyances, the electric vehicle has some key problems before it has been put into the market: First, the battery exists the problems of the small capacity, the great mass, the short life, the long charge time and the high price, and it has not the storage battery for the electric vehicle; Second, the electric vehicle is not better in the function than the fuel vehicle in the high speed, the accelerate and the travel mileage[1,2]. Therefore, the key way is to research the driving system with the low-consumption and the high efficiency. Switched reluctance motors are a good choice for an EV motor as they are relatively cheap and robust, and can be designed to have minimum weight. The recent advances in power electronictechnology have made SRM an attractive candidate for EV applications. Because of its desirable features such as simple and rugged motor construction, SRM technology offers an impressive list of advantages that is making industrial users seriously looking at switched reluctance motor drives. In the paper, the SRM drive system used in electric vehicles is designed, which utilized TMS320LF2407 as main controller and the hardware circuit and the software block diagram is presented, the speed character; the control way and the design of the motor structure has been researched.

II. THE METHOD OF THE VECTOR CONTROL FOR THE SRM

A. The Characteristic of The Torque-Angle

By the theory of the SRM, torque is developed by the tendency of the magnetic circuit to adopt a configuration of minimum reluctance and is independent of the direction of current flow. Consequently, unidirectional currents are required and a simple configuration is sufficient as the drive circuit. The torque is calculated by the magnetic field energy, as follow[3]:

$$T_k(\theta,i)=\frac{\partial W(\theta,i)}{\partial\theta} \qquad (1)$$

Where θ is the position angle of the rotor, i is the phase current, k is the phase number of the motor. Over looking the magnetic circuit saturation and the influence of the edge, the

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phase current is not relation with the phase inductance and the expression of the torque is simplified as follow:

$$T_k(\theta, i) = \frac{1}{2} i^2 \frac{dL}{d\theta} \tag{2}$$

Where L is the self-inductance of the stator phase at any value of θ and it is direct ratio by the change of the pole number of the motor. By the methods of the Fourier Transform, the L is expression as follow:

$$L = L_0 + L_{\max} \cos(N_r \theta) \tag{3}$$

Where L_0 and $L_{\max}$ are the constant value and the maximum value of the self-inductance of the stator phase, and then, the torque is indicated as follow :

$$\begin{aligned} T_k(\theta, i) &= -(\frac{1}{2} N_r L_{\max} i^2) \sin(N_r \theta) \\ &= -T_{\max} \sin(N_r \theta) \end{aligned} \tag{4}$$

The expression 4 is the character of the Torque-Angle, the electric angle β is the Torque-Angle. In the SRM, when the centre line of the rotor pole and the stator pole is coincidence, the magnetic circuit is ought to saturation by the requirement of raising the torque and reducing the device number of the power circuit. Therefore, the self-inductance of the stator phase is the function of θ and i , the torque is also relationship with θ and i .

B. The Theory of The Torque Vector Control

By analysing the torque-angle character of the SRM the fundamental wave torque of the phase changes by the sine wave, the amplitude and the magnetic motive force of the winding are direct ratio by the square of the magnetic motive force, and the stable position of the phase torque is in the centre of the magnetic pole of the phase. Therefore, the phase torque is presented by the T_k , its position is coincidence with the center line of the phase magnetic pole, and than, the torque-star can be used in analysis the characteristic of the SRM.

For the 8/6 pole SRM, the stable position of the A, B, C, D phase torque is stagger one step angle, the mechanical angle is 15^0， the electric angle is 90^0. The T_A, T_B, T_C, T_D of the four phase is produced by turning on the four phase winding with the equal direct current and the SRM revolves step by step on the angle of 15^0.

If no considering the coupled-inductance of the SRM and by the theory of the torque vector composed, the stable torque may also be acquired by turning on any two winding. The Figure1 shows the torque-star for the 8/6 pole SRM which the $T_{AB}, T_{BC}, T_{CD}, T_{DA}$ is composed the torque vector which any two phase windings is turned on, T_{AB} advances T_A half step angle(that is 45^0 electric angle and 7.5^0 mechanical angle). The T_A, T_B, T_C, T_D is thought the basic torque vector, its position is in the centre of the phase pole and has not relationship to the value of the winding current; the $T_{AB}, T_{BC}, T_{CD}, T_{DA}$ is regarded as the composed torque vector which is affected by the current of the phase winding.

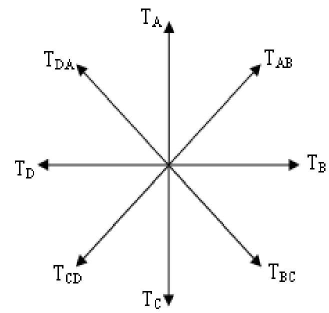


Figure1. Diagram of the torque-star

By the method, we can acquire any position torque vector by adjusting the current of the two phase winding,. As stated above, we can suppose by the basic torque vector and the composed torque vector, the torque vector T_{AB} is composed of T_A and T_B by the torque vector compose, and than, we can acquire any composed torque vector between the phase A and the phase B controlling the current of the winding, this is the theory of the micro-step control[3.4].

C. The Restraint of The Torque Ripple

By the character of the SRM, although the optimum point of the change phase has been adopted, the torque ripple has been produced, the way which control the torque by turning on the winding in turn certainly emerges the concave torque in the point of the change phase and make the torque ripple, as the shortage, the apply of the SRM has seriously been influenced.

By the tradition control way, the SRM is revolved step by step by turning on the phase winding in turn and the torque ripple has been produced. But, by the theory of the micro-step control, the multi derivative torque vectors can be derived in the space by using the control of very phase current via rotor position, the motors step angle is reduced and a smooth torque can be improved, thus torque ripple of the SRM is diminished. For the 8/6 pole SRM, its step angle is 15^0 .By the control method of the micro-step, we can turn on the winding by the sequence of A-AB-B-BC-C-CD-D-DA-A，then the step angle is 7.5^0. We can change the winding current to acquire the eternally torque. The step angle may be further reduced by altering the phase winding current and smooth torque can be obtained, the torque ripple of SRM can be effectively controlled.

III. THE DESIGN OF THE DRIVE SYSTEM

A. *The Compose of The Vector Control System*

The TMS320LF2407 of Texas Instruments is used in the drive system of the electric vehicle. Figure2 shows the block diagram of the drive system. The drive system is composed of the SRM, power converters, controller and rotor position detector. The controller is the core of the drive system. By using the DSP processor, the capacity of the information processing has been improved, the control strategies is more flexible, the structure of the system is more compact. The micro processor is made by the TI company and is used for the motor control. The characteristic with the high speed computer and the high efficiency guarantees the control strategies to be implemented and makes the drive system have the high precision. The drive system is composed of the DSP and the outside circuit and implements the functions of the current sampling, speed detecting, instruct inputting and displaying.

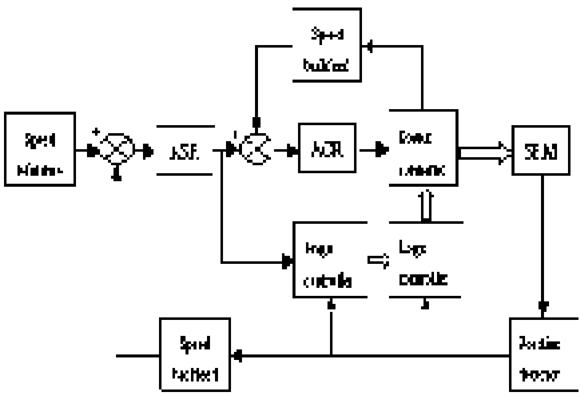


Figure2. the block diagram of the drive system

The core of the vector control of the SRM is control the current of the stator phase winding to follow the given current, as the stator phase current affects the composed torque vector. We adopt the electric current power circuit in the experiment. The SRM revolves one step and transmits a pulse signal of the rotor position to the counter, by the value of the step counter, the processor inquires into the given current value of the corresponding two phase winding and compares with the phase current value of the sensor current and control the power converter by the current regulator ACR and then output the PWM control signal. The high frequency and complete control power devices IGBT makes the output current to approach the ideal current value and guarantees the implementation of the vector control strategies.

As the SRM is inductance load, the exchange phase is impossible to implement in twinkling, especially in the condition of the high speed. The stator phase current follows the given current in short time, so the vector control strategies is only implementation in the limited parameter.

B. *The System Software*

The system software is composed of the main program and the interrupt subroutines. The Figure3 is the main program diagram, it fulfils the initial function of the system; the event manager (as timer; A/D; PWM channel etc); SRM parameter and speed displaying etc.

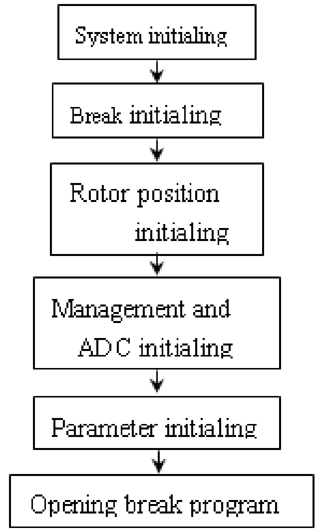


Figure 3. Flowchart of the main program

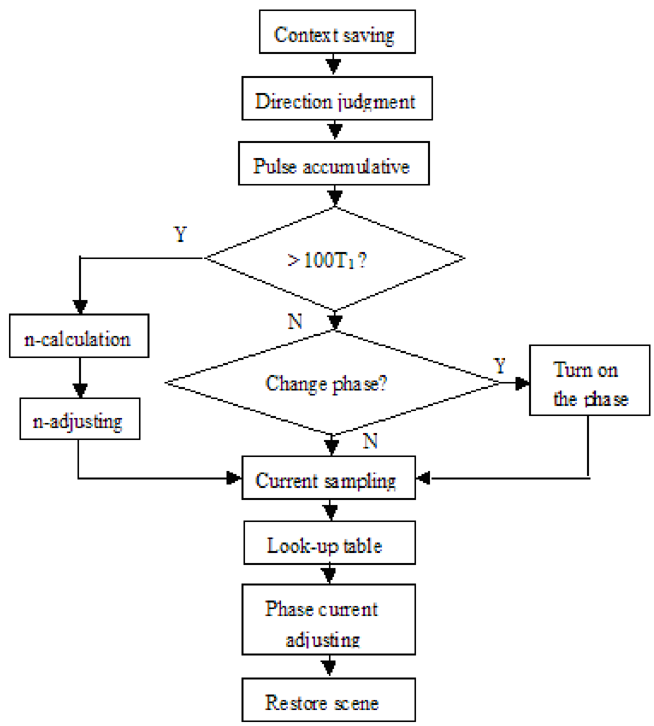


Figure4. Flowchart of the interrupt subroutine

The Figure4 is the interrupt subroutines, it includes the subroutines of the rotor-position and the T1 period. The rotor position of the interrupt subroutine is used for detecting the rotors position by the QEP capture. The T1 period subroutine is the core of the control system, it is compose of the subroutines of the ADC transformer; PWM adjusting, speed PI adjusting and change direction etc.

IV. THE SIMULATION OF THE SYSTEM

With the soft of the Matlab/simulink, the drive system simulation model has been set up. The Figure5 shows the Principle drawing of system simulation, it include the SRM module, the speed module, and the current module. the system parameter as follow:

Ns=8; Nr=6; U=460V; P_N=0.75kW; J=0.0016kg.m^2; L_{max}=110mH; L_{min}=10mH

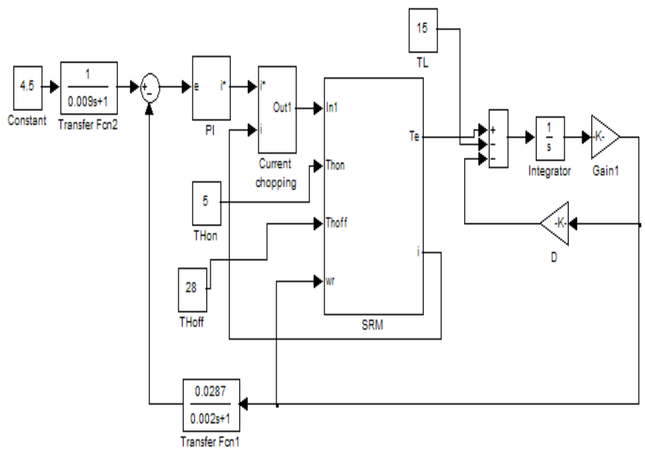
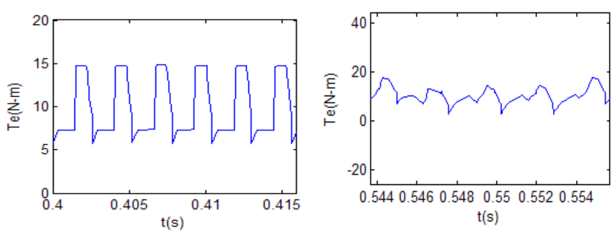


Figure5. the Principle drawing of system simulation

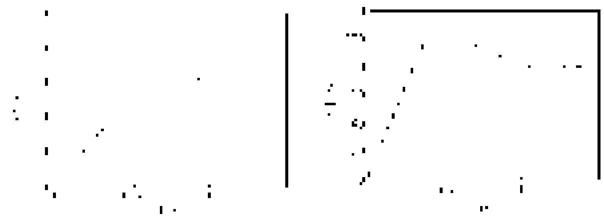


(a) the basic torque (b) the composed torque

Figure 6. The curve of the basic torque and the composed torque

The Figure6 (a) and (b) are the waveform of The curve of the basic torque and the composed torque.

The Figure7 (a) and (b) are the curve of the SRM speed when the given speed is increased (ω_r from 100rad/s to 200rad/s) and the given speed is decreased (ω_r from 100rad/s to 80rad/s).



(a) Increasing the given (b)Decreasing the given

Figure7. The influence of the given speed

The simulation result as follows: when the load varies, the system has rapid response and good stability, and it is more robust for the external disturbance; when the given speed is changed, the real speed can follow the given speed and it is without error. It shows that the system has the advantages of high precision and good dynamic characteristic.

V. THE CONCLUSION

Based on the linear model of the SRM, the idea of the torque vector and the micro-step control theory has been put forward. The drive system of the electric vehicle which takes the TMS320LF2407 as the core has been designed. The simulation and experiment results show that this system possesses the advantages of simple hardware; good real-time with dynamic and static characteristic, and can effectively minimize the torque ripple and is satisfied for the demand of the electric vehicle performances.

REFERENCES

[1] Zhao De-an, Liu Dong. Novel control system of switched reluctance integrated starter/generator used in vehicle[J]. Journal of Jiangsu University, 2006,27(1):59-62.

[2] Cheng Fei, Guo Xuexun. Study on motor for electric automobile and its controlling technology[J]. Explosion-proof electric machine, 2006,5(41):14-19.

[3] Li Jisheng. Study on the micro-step control system of the SRM. The master thesis of Fu Xin mine college, 1995.5.

[4] Husain I,Ehsani M. Torque ripple minimization in switched reluctance motor drive by PWM current control[J]. IEEE Trans on Power Electronics, 1996,11:83-88.

[5] Mao Jingfeng, Fang Tianzhi. Angle position control of switched reluctance generator for cars based on DSP[J]. Computer measurement and control, 2004(2):140-142.