The Analysis of a few Point about Sensorless Brushless DC Motor Driver Design

Huizong Feng [1, a], Xiaochuan Tan [1, b], Ju Tao [1, c] and Xiaohong Tang [2, d]

[1]School of Automation, Chongqing University of Posts and Telecommunications, Chongqing 400065, China

[2]Chongqing Qianjiang National Vocational Education Center, Chongqing 409000, China

[a]fenghz@cqupt.edu.cn, [b]tanxiaochuan1987@163.com, [c]taoju19901126@126.com, [d]892850615@qq.com

Abstract

Based on the ST company's dedicated brushless dc motor chip ST7FMC1K2 and the intelligent power module IGCM20F60GA of Infineon,a brushless dc motor driver used for air conditioning compressor was designed. Aimed at the design process's problems of position detection precision, starting current limit, IPM over-current protection, motor noise,this article have analyzed and summarized these issues,and put forward some effective and convenient solutions, experiments prove that the motor running effect is excellent.

Keywords

brushless DC motor, position detection, starting current limit, IPM over-current protection, motor noise.

1. Introduction

Brushless DC motor is made up of stator winding and permanent magnetic rotor. The air-gap field generated by permanent magnet rotor is distributed as trapezoidal wave. And the flat top maintains an electrical angle of 120° [1,2]. As the rotor is featured with small volume, light weight, reliable operation, effective energy saving, easy control and other advantages, it has been widely applied in automotive electronics, aerospace, household appliances and office automation and other fields [3,4].

For the position detection of sensorless brushless DC motor, the mature detection of back EMF is mostly adopted [4]. The back emf zero-crossing point can be detected at the turn-on time or turn-off time of PWM (pulse width modulation) through this method. However, the detection precision is different, which can directly influence the motor's running stability. Starting brushless motor will produce big dash current. If the current is not limited, switching elements will be easily damaged. However, if the current is limited too much, the smoothness of starting will be affected. As the switching element, IPM simplifies the circuit design and shortens the development period to a great extent. However, due to its high cost, IPM protection, especially for overcurrent protection becomes a very important design feature. It is well known that the electromagnetic torque ripple of brushless DC motor causes loud noise. On the basis of not changing motor structure, commutation strategy and control mode can be optimized and remedied, which is the lowest-cost scheme.

Based on the analysis of position detection accuracy, starting current, IPM overcurrent protection and motor noise, in combination of a larger number of experimental results, this paper puts forward to some more effective and convenient solutions.

2. Structure of Control System

The structure diagram of the driver control system of the brushless dc motor for air conditioning compressor is as shown in Fig. 1. For control chip, the special motor control chip produced by ST company is adopted, which integrates position detection and commutation control modules, with programming function. In addition, this chip can guarantee control accuracy and extra function can be added. Infineon's IGCM20F60GA is an intelligent power module integrating three phase full bridge and relevant driving circuit, featured with easy operation, various protection functions and interfaces. The two special chips facilitate the design of driver, which make the engineering personnel focus on motor control algorithm. The brushless dc motor described in this paper is position-sensorless permanent magnet motor and rotor air-gap field is distributed as trapezoidal wave. Pole of pairs is 3. Rated rotor speed is 3000 revolutions. Rated power is 1KW. The way of winding is concentrated winding.

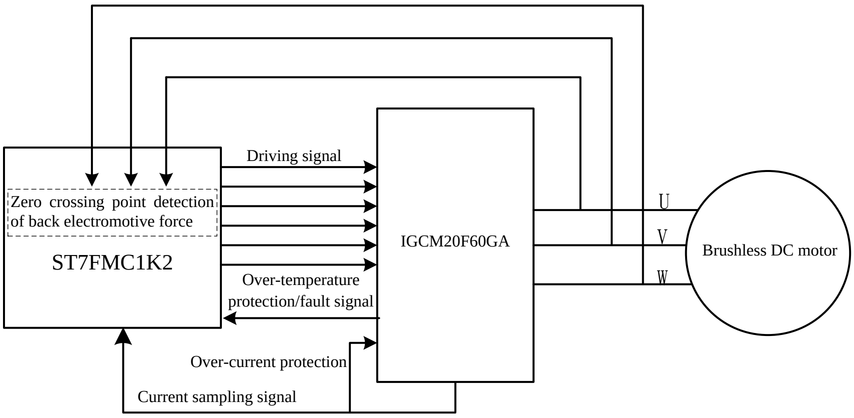

Fig. 1 Structure diagram of the control system for motor driver

3. Design Analysis of Brushless DC Motor Driver

3.1 Influence of Position Detection Mode on Detection Precision

For sensorless brushless dc motor, there are various kinds of methods for detecting position, among which, back-electromotive force method is the maturest and most widely used position detection method, by which the detected back-electromotive force zero-crossing signal is delayed by an electrical angle of 30°. And 6 discrete signals of rotor position can be gained to provide correct commutation information for logic switching circuit, so as to achieve the position sensorless control of brushless dc motor.

Among back-electromotive force methods, direct b-emf method is the most common and practical method. Its advantage lies in that the zero crossing point of back electromotive force can be accurately measured without lowpass filtering and bleeder circuit [1].The ST company with the technical patent of new back electromotive force sampling applies this method to the hardware unit of control chip, which makes the motor position detection become simple and reliable. For application of direct back electromotive force method, the sampling of back back electromotive force of floating phase at turn-on time or turn-down time during PWM period can be performed. The two methods have their own advantages and disadvantages. In Literature [5] and [6], the principle of these two methods and described in details. And the related applied circuits are also introduced.

At the turn-down time of PWM, the method of detecting the back electromotive force of floating phase,The floating phase terminal voltage is:

$$v_c = e_c + v_n = \frac{3}{2} e_c \tag{1}$$

The floating phase terminal voltage and approximate zero potential can be compared. When the two is equal, the rotor position signal can be gained.

Similarly, for the position detection method at the turn-on time of PWM, the floating phase terminal voltage is:

$$v_c = e_c + v_n = \frac{3}{2}e_c + \frac{v_{dc}}{2} \tag{2}$$

Compare the partial pressure of floating phase terminal voltage with the half partial pressure of busbar voltage. When the two are equal, the position signal can also be obtained. This method can make full use of the rotor speed. PWM duty cycle can reach up to 100%. The Signal to Noise Ratio of the former is higher and more accurate. Within greater speed range, good detection results can be obtained. To achieve this, partial duty cycle (namely rotor speed) is required to be reduced. This is because the signal is collected at the turn-down time of PWM and it will be completed by the resonance oscillation generated by switch change-over after a period of time.

The lefe figure in Fig. 2 is wave of position detection during the PWM on,and righ figure sample the signal during PWM off .We can find the effect of PWM off is better.

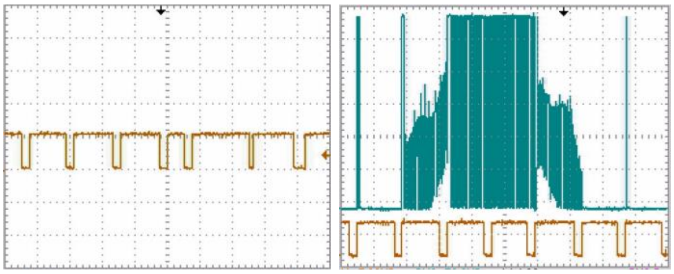

Fig. 2 Position detection accuracy comparison for PWM on and PWM off

3.2 Influence of Starting Current Limiting on the Protection of IPM and the Smoothness of Starting

Voltage equation for brushless dc motor during steady-state conditions:

$$U = 2E + 2RI \tag{3}$$

In which, E is the rotational electromotive force of phase winding, which is proportional to rotate speed. And R is armature winding resistance.

In the motor startup phase, the rotate speed is not achieved. At this time, the impulse current of motor is large, which is usually ten times normal current. This increases the probability of damaging switching elements. The startup stage of brushless dc motor is divided into self-localization phase and external synchronization phase. Self-localization is to rotate the rotor to permanent position and then input the commutation sequence signal listed in the table to make the motor gradually rotate. During the two phases, sufficient current is required to make the motor start smoothly.

Thus, for limiting starting current, the smoothness of starting shall also be guaranteed. In the experiment, for debugging, small limited current for starting shall be set at first. Then observe the smoothness of starting. Otherwise, increase the limited current until the motor can start smoothly under various input voltage and load.

The waveform of the current without restrictions on starting current is as shown in Fig. 3 (left-hand side). While the current waveform with starting current limiting is as shown in right-hand figure. It can be seen that when the starting current is limited, the starting current decays a lot.

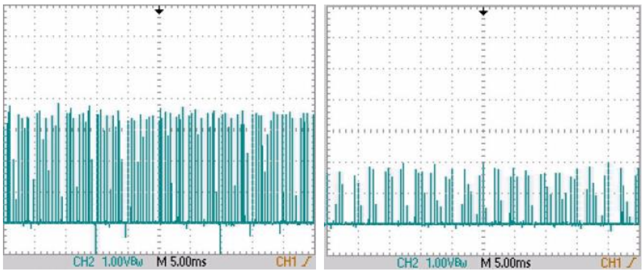

Fig. 3 Influence of current limiting on starting current

3.3 IPM Over-Current/Short-Circuit Protection Circuit Design

In the system, intelligent power module IGCM20F60GA is adopted as power switching device. And its partial parameters are as shown in the following table:

Table 1 Maximun operating current and short-circuit withstand time of intelligent power module

Description	Condition	Sign	Value	Unit
Output current	T_C=25°C,T_J<150°C	I_C	20	A
Maximum peak output current	<1ms	I_C	45	A
Short-circuit withstand time	V_{DC}≤400V,T_J=150°C	t_{SC}	≤5	us

From Table 1, we can see that short-circuit withstand time of the module is about 5us, which is a limit value. Actually, from short-circuit module detection to internal module protection, the motor response time is 1~2us, which is called as t_2. In addition, in order to prevent misoperation due to noise signal, RC filter is required for current detection. This also leads to a part of time delay t_1. Thus, the following requirement is required to be met:

$$t_1 + t_2 \le 5\text{us} \tag{4}$$

It is very appropriate to set the time constant of RC filer within 1.5~2us. In addition, for calculate the protective current, the quick charge characteristics of RC charge current within the first time constant shall be used rather than the voltage value when RC charge circuit is stable. The current sampling current and overcurrent protection circuit adopted in the system is as shown in Fig. 4. R_1 and R_2 are to facilitate the adjustment of overcurrent parameter values after the sampling resistance is determined.

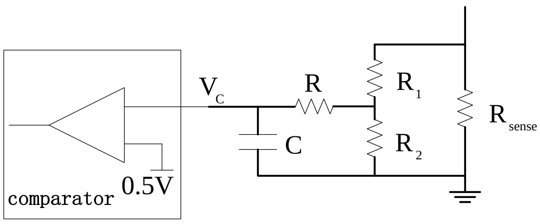

Fig. 4 Current sampling and over-current protection circuit

When Vc exceeds the benchmark of the comparator inside the module, all the low voltage terminals IGBT inside module shall be closed. At the same time, a fault signal shall be stated for the control of chip reading.

For overcurrent, the overcurrent protection function waveform is as shown in Fig. 5. The curves from top to bottom are fault signal waveform, current waveform and Vc waveform respectively.

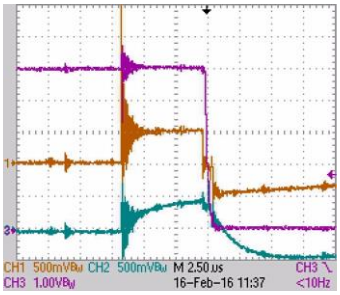

Fig. 5 Over-current protection function of intelligent power module

3.4 Improving Motor Noise Based on Commutation Strategy and Control Mode

The electromagnetic torque ripple of brushless dc motor leads to lound noise. At present, torque ripple minimization for brushless dc motor focuses on motor design and current control. In Literature [7-8], for torque ripple improvement, the author is concluded from magnetic pole, stator shape and size and other aspects. In Literature [9], we can find out that the motor current is more stable in current mode based on the optimization of commutation strategy and the comparison of the influence on torque by using voltage mode and current mode.

At present, the design of motor structure has become relatively mature. It is very difficult to optimize the structure. In addition, the design modification is complicated, especially in later design phase. the modification and optimization of control algorithm is more flexible, which will not change the machinery and hardware part. For system design, the control algorithm is mainly optimized and good operation effect is obtained.

In Literature [9], the following is concluded. Due to influence of motor coil inductance, it is impossible that the current rise time is infinitely short to cause phase current lagging phase back electromotive force, so as to make output torque decline, which is more obvious at high rotation speed or multipolar logarithm and high power. The dotted line and full line represent the electromotive force waveform and the lagging phase current waveform respectively in Fig. 6.

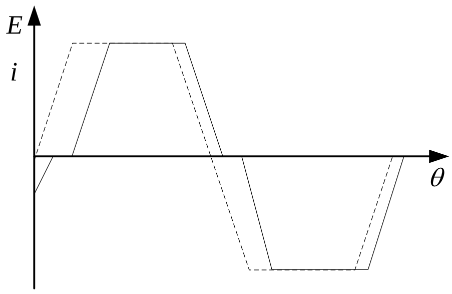

Fig. 6 Phase current and back electromotive force waveform

In order to improve torque effect, early commutation strategy shall be adopted. There is detailed formula for calculating the best early commutation point in the literature. During experiment, the parameters are selected by debugging, which is more visual and convenient. However, it shall be noted that every parameter is related to the working condition (working voltage and load). For operation within broad range, it is required to select and optimize the parameter.

For control mode, when motor is controlled by using the voltage mode, it is featured by simple control. For undemanding situation, open-loop control can be adopted and it is only required to adjust the PWM duty cycle to adjust the motor speed. However, the disadvantage lies in that the fluctuation of current waveform is large, especially during commutation process, the response speed of motor is slow and current waveform appears hollow part, which makes motor torque ripple increase. The phase current waveform in voltage mode is as shown in Fig.7 (left-hand side).

The current mode has the following advantage. When the response speed of motor increases, the current waveform ripple is small. With the optimization of commutation strategy, the motor torque ripple decrease and the noise is improved. In the system, peak current mode is adopted. And peak current mode control PWM is dual-loop control system. The external loop is speed loop and the internal loop is current loop [10]. See Fig. 7 for the phase current waveform in current mode.

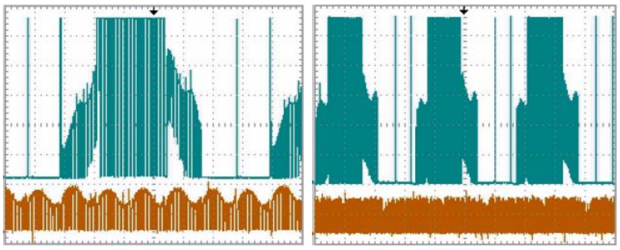

Fig.7 Influence of control mode on motor phase current

4. Conclusion

Permanent magnet sensorless brushless DC motor has the advantages of simple structure, big torque/volume ratio and high efficiency. For control system, if special attention is paid to the position detection, starting current limiting, power element protection, motor noise and other aspects, the control system will be more stable and widely used. The paper puts forward to solutions and optimization scheme based on the problems encountered during system design and proves that the motor is running well through experiments.

References

[1] F.H. Dong, Y.X. Shen, Z.C. Ji. Review on Position Estimation Methods of Brushless DC Motor Sensorless Control, Micromotors Serve Technique, Vol. 36 (2003) No. 9, p. 39-46.

[2] Y.Q. Tang: Electromechanics (China Machine Press, China 2011), p. 341-347.(In Chinese)

[3] X.J. Zhang, B.S. Chen. The Different Influences of Four PWM Modes on Commutation Torque Ripples in Brushless DC Motor Control System, Electric Machines And Control, Vol. 7 (2003) No. 2, p. 87-91.

[4] C.L. Xia, H.W. Fang. Permanent-Magnet Brushless DC Motor and Its Control, Transactions Of China Electrotechnical Society, Vol. 27 (2012) No. 3, p. 25-34.

[5] J.W. Shao, D. Nolan,T. Hopkins. A Novel Direct Back EMF Detection for Sensorless Brushless DC(BLDC) Motor Drives, Proceeding From Applied Power Electronics Conference and Expositon, 2002, p. 33-38.

[6] J.W. Shao, D. Nolan. Further Improvement of Direct Back EMF Detection for Sensorless Brushless DC(BLDC) Motor Drives, 20th Annual IEEE Applied Power Electronics Conference and Expositon, 2005, p. 933-937.

[7] W. Liu, Q.L. Zhao. Method to Reduce the Noise of the Brushless DC Motor, Development & Innovation of Machinery & Electrical Products, Vol. 26 (2013) No. 1, p. 77-79.

[8] J.J. Li, J.B. Zou, Y.X. Xu. Analysis of Noise and Its Suppression for Brushless DC Motor, Small & Special Electrical Machines, 2009, p. 12-14.

[9] H.H. Luo, J. Wu, H.T. Zhao, et al.Commutation Control of Permanent Brushless DC Motors, Proceedings of the CSEE, Vol. 28 (2008) No. 24, p. 108-112.

[10] W. Hua. Study on Five PWM Feedback Control Modes of SMPS for Telecommunication, Telecom Power Technologies, 2001, p. 8-16.