Control of a BLDC Motor for Electromechanical Actuator

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***Abstract*- Since the aircraft has the special requirements for the electromechanical actuator (EMA), the electrical servo control system using brushless DC (BLDC) motor is designed to fulfill these requirements in this paper. An angular position detecting method of helm is proposed to overcome the electromagnetic interference from the PWM inverter. This method combines motor's discrete Hall sensors signal with a potentiometer signal to determine the position information. In order to realize the fast response of the system, and eliminate the DC-Link voltage pumping-up phenomenon, an improved reverse braking method is applied, which can realize the torque control. In order to improve the system response, the current controller and the position controller is applied. Experimental results show that the tracking performance of the proposed control system can fulfill the requirements.**

I. INTRODUCTION

As an important part in aircraft, the actuator is not only an actuating mechanism but also a major component in the guidance and control system. Compared with pneumatic actuators and hydraulic actuators, electromechanical actuator can provide the better control performance for the aircraft control system; meanwhile the control system has the simpler structure. So the EMA are used in many aircrafts, such as flights, missiles, unmanned aerial vehicle (UAV). Today, actuators are developed towards all-electronics, digital and smaller-size direction. It has become the trend of the actuator's development for its better performance, easier maintenance and higher reliability [1], [2].

Brushless DC motor has the simple structure as the induction motor. The control performance of the BLDC motor is as good as DC motor, which has high precision control ability. It has low acoustic noise and fast dynamic response. Moreover, it has high power density with high proportion of torque to inertia in spite of small size drive. All these merits make the BLDC motor widely used as the electromechanical actuator in servo system [3], [4].

In the normal BLDC motor drive system, the current closed loop is not applied usually. But in the EMA system, the electrical time constant of the BLDC motor is not much smaller than the mechanical time constant. So the current closed loop can improve the response of system, meanwhile the uncontrolled current during the braking process can be controlled. The design and implementation of control system of a brushless DC motor for EMA are investigated in this paper. A position detecting method is proposed. This detecting method combines motor's discrete Hall sensor signal with the potentiometer signal to determine the position information. Current measurement and brake strategy are analyzed. At the end of this paper, the experimental verification is carried out as well.

II. PROPOSED CONTROL SYSTEM OF THE BLDC MOTOR

A. Structure of EMA

The EMA system consists of the controller, drive, servo motor, reducer, and position sensor for helm. Normally the EMA system using BLDC motor is constructed as Fig.1. It is a typical position servo system. The system controller gives out the certain magnitude and amplitude control signal that based on the position of the aircraft, then the BLDC motor can control the rotation of the helm to control the movement of the aircraft. BLDC motor is usually running in the current open loop condition. The current closed loop can change the transfer function of the inner loop, which can realize the system fast response, and restrain the disturbance of the current loop, especially when the disturbance is caused by the back electromotive force (EMF). The maximum current can be controlled, which can provide the enough acceleration torque. In this case, the system can work properly. In order to improve the system performance, the current closed loop is necessary.

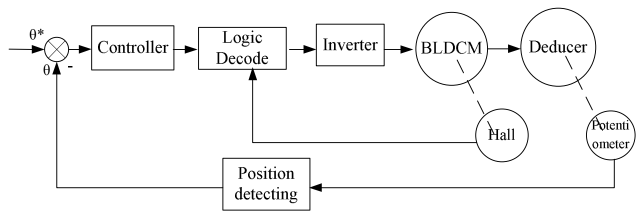

Fig.1 Structure of the conventional EMA

B. Proposed Control System of BLDC Motor

In the typically three-loop control system, the speed loop can restrain the load interfere, the inertia changes and the torque fluctuation; the position loop, as the outer loop of the system, is important for the system control. Through the position control loop, the accuracy of the position control could be high enough. The system control target can be achieved.

In the practical EMA system, the feedback potentiometer is used to measure the angle of the helm. Because of the sampling accuracy and the electromagnetic interference (EMI) noise caused by PWM, the position signal obtained from the potentiometer will not be precise, especially when the logic ground and the power ground are not isolated. For this reason, when the speed is low, the position error can make the speed measurement bad. In this case, the speed loop can not provide the good performance, and then the system performance is also going down. In this paper, only the position loop and the current loop are applied. The control structure is presented in Fig.2. In order to simplify the system and reduce the cost of the EMA system, the logic ground and the power ground of this system are not isolated. In the power supply system of the control board, there is no negative power, there are only +5V and +15V. How to improve the position detection accuracy and how to apply the current closed loop are the key points of this system.

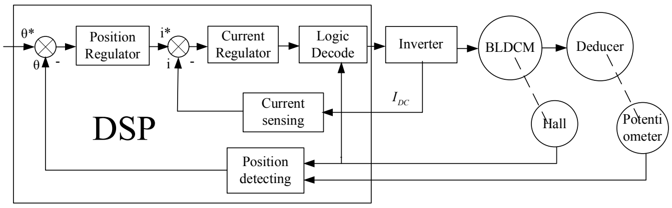

Fig.2 Structure of the proposed control system

C. Position Detection of EMA

The Hall sensors are used in the BLDC motor. In one electrical period there are six Hall pulse edges. The change of the Hall signal can not only provide the rotor position of the motor, but also present the movement of the helm. The Hall sensors replace the potentiometer to simulate the practical work condition of the EMA, and a large gear factor is used to reduce the measurement error of the hall sensors.

The angular position error θ_{err} is given by

$$\theta_{err} = \frac{360^{\circ}}{6 \times p \times i} \tag{1}$$

Where p is pole pairs of BLDC motor, and i is reduction of the reducer.

Increasing the p and i can improve the angular position precision. When p is 4 and i is 120, the angular position error is 0.125 mechanical degree. When the Hall sensor is used as the angular position detection devices, the accuracy of the position detection can be improved, but this signal is not the absolute position information. When the motor stalls, there is no EMI noise from the PWM inverter, the high accuracy of the absolute angular position information can be obtained through the potentiometer. So the potentiometer and the Hall sensor should be used in the system together to provide the position information. That means, in the initial process, the potentiometer provides the absolute position information, and then during the running process, the Hall sensor provides the change of the angular position, which could be called as the relative position information. This process is similar with the work process of the incremental encoder.

III. CURRENT MEASUREMENT AND BRAKING STRATEGY

A. Analysis during Motor Mode

As shown in Fig.3, a shunt resistor is used to measure the current. The shunt resistor is inserted between the sources of the power bridge lower side and the power board ground. Its value is set intentionally so that it activates the integrated over-current protection when the maximum current permitted by the power board has been reached. The voltage drop across the shunt resistor is converted by the Analog-to-Digital Converter (ADC) module, while it has been amplified to address the whole conversion range. Six-step 120 drive scheme and H_PWM_L_ON mode are applied. As shown in Fig.3, when the motor is running in the motor mode, the switch T1 is working in the PWM mode and the T4 is turned on continuously. When T1 is turned on, the current flows as loop① in Fig.3; when T1 is turned off, the motor winding current does not flow through the sampling resistor, the current flows as the loop ② in Fig.3.

As shown in Fig.4, the phase current is sensed every 50us in order to implement a 20 kHz current loop. It is of interest to note that, during Turn OFF, the shunt resistor does not have this current to sense, regardless of whether the inverter is driven in hard chopping or in soft chopping mode. This implies that it is necessary to start a current conversion in the middle of the PWM duty cycle. This sampling method can eliminate current ripple induced by PWM.

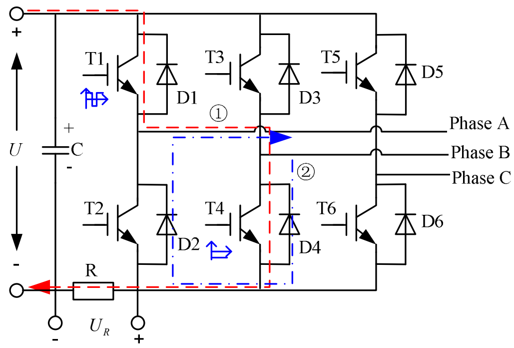

Fig.3 H_PWM_L_ON mode

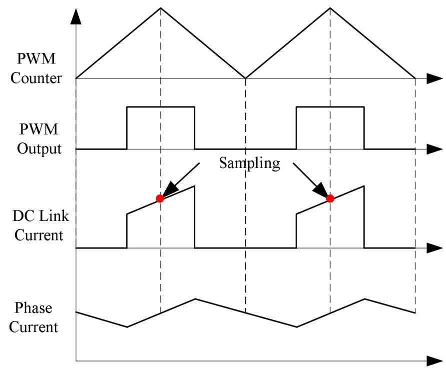

Fig.4 Current sensing during the drive state

B. Analysis during Braking Mode

During the reverse braking process, if H_PWM_L_ON mode is applied, then the switch T2 and T3 are under control, as shown in Fig.5.When the T2 is turned on continuously, T3 is under PWN mode. When T3 is turned on, the braking current flows as follows: power – T3 – motor winding B – motor winding A – T2 – power return. When T3 is turned off, the current flows as follows: motor winding B – motor winding A – T2 – D4- motor winding B. That means the winding A and winding B are connected directly, in this case the back EMF can not reverse immediately, and the current is going up under the back EMF effect. Finally the current spikes will appear.

The current spike is not good for the system reliability, so the H-PWM_L_PWM control mode is used in this plug braking period. Fig.5 shows the motor braking state. The reverse braking combined with the regenerative braking will be implemented in this case. In this case, switch T2, T3 are synchronously controlled in the PWM state; and the switch T1, T4 has always been turned off. When T2, T3 are turned on, the reversal current flows through loop ③, and the value of the phase current is increasing gradually. This current produces braking torque, and the motor is decelerated. At this moment the motor is in the reverse braking state. When T2, T3 are turned off, the reversal current flows via loop ④ to charge to the capacitor C, the current is decreasing, and the motor is in the regenerative braking state. Since the motor braking state is switching between the regenerative braking and reverse braking, the DC-Link voltage pumping-up phenomenon will be avoided. As shown in Fig.6, during Turn ON, the current through the shunt resistor is negative. So it can not be sensed in the measure system with single power supply. Each current sampling is carried out at the beginning of a PWM cycle. Then the motor winding currents can be controlled effectively and in this way the braking torque can be controlled as well.

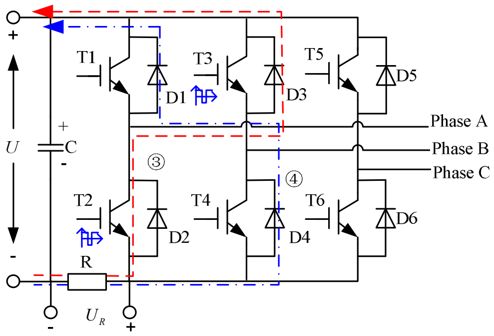

Fig.5 H_PWM_ L_PWM mode

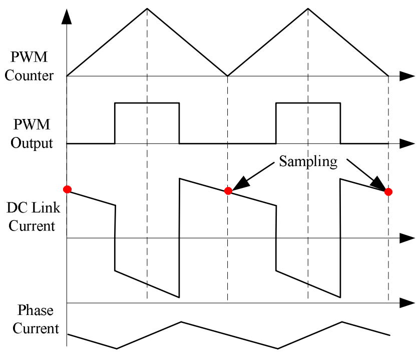

Fig.6 Current sensing during the brake state

IV. EXPERIMENTAL RESULTS

TMS320LF2407A is used to build the brushless DC motor control system. Motor parameters are shown in Table Ⅰ. Hall sensors simulate the position feedback information of the helm. The power voltage is 24V. A 0.05Ohm shunt resistor is used to measure the current. Some experiments are carried out as following.

A. Current Control Test

The sampling current value is sent into DSP. Then the signal is converted into the digital signal by ADC module with a frequency of 20 kHz. All signals are saved in RAM. Through the serial communication interface RS-232, these values are sent to the upper computer, and then these signals can be analyzed and plotted by the software Matlab. The current response curve is shown in the Fig.7. As can be seen in the figure, the response time can be reduced from 1.1ms to 0.5ms.

TABLE Ⅰ
PARAMETERS OF THE BRUSHLESS DC MOTOR

Rated torque	0.3Nm
Stall torque	0.6Nm
DC link voltage	24V
Rated speed	2500rpm
Number of poles	8
Phase resistance	0.42 Ω
phase inductance	0.53mH
Winding connections	Y-connected

During barking mode, when H_PWM_L_PWM mode (T2 is continuously turned on, and T3 is under PWM) is applied, the phase current curve during the reverse braking period is shown in Fig.8. Obviously, there is a current spike, the winding current and the torque can not be controlled well. So the H_PWM_L_PWM mode is better to control the winding current and the torque. The control performance is shown in the Fig.9.

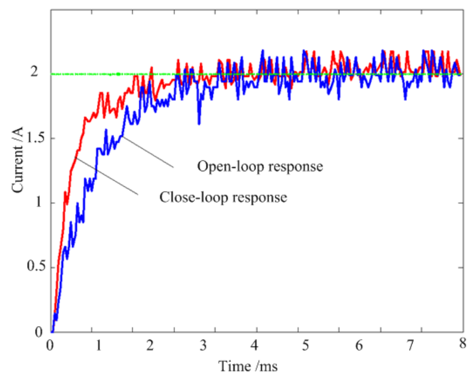

Fig.7 Current response

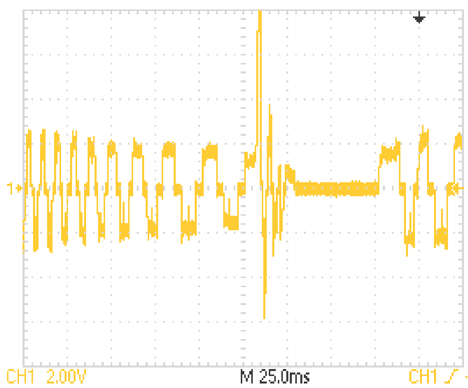

Fig.8 Phase current during H_PWM_L_ON mode

B. Position Tracking Test

In Fig.10, the no-load position tracking test curve is provided. The sinusoidal reference signal is 2Hz, and the amplitude is 24rad. From Fig.10, the conclusion can be drawn: under the sinusoidal position reference, the position tracking performance is good. The position feedback lags the position reference by a phase of 8.6 degree. In the stable state, the maximum position tracking error is 1.5rad, which is 6.25% of the position reference, and it is not quite big. Because the position signal is obtained from the Hall sensor, the position error is the motor position error. If the reducer with a 120 reducer is applied, the position error of helm is 0.71 degree.

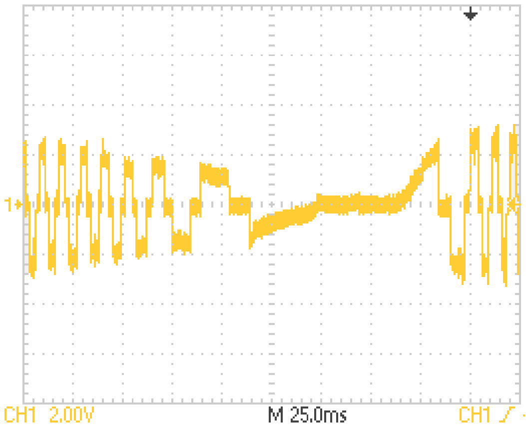

Fig.9 Phase current during H_PWM_L_PWM mode

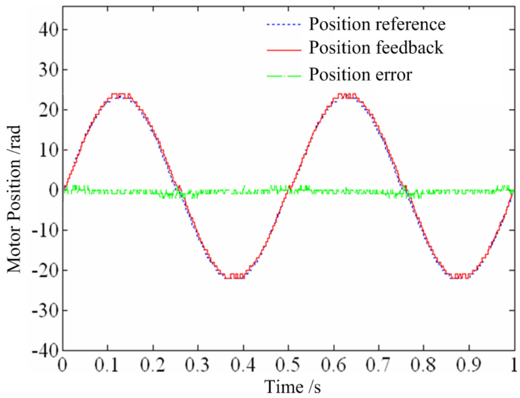

Fig.10 Experimental results with sinusoidal position reference

In the position tracking test, the rectangle reference signal is 2Hz, and the amplitude is 24rad. The test result of the no-load test is shown in Fig.11. As shown from this figure, the system can get to the target position soon, and the rising time is 0.028s, and the stable state error is about zero. The system position tracking accuracy is quite high, but the system has a big over-shoot, and the maximum over-shoot is 8.9%.

From the motor tracking performance, the provided control system presents the good tracking and response performance, which can fulfill the requirements of the aircraft.

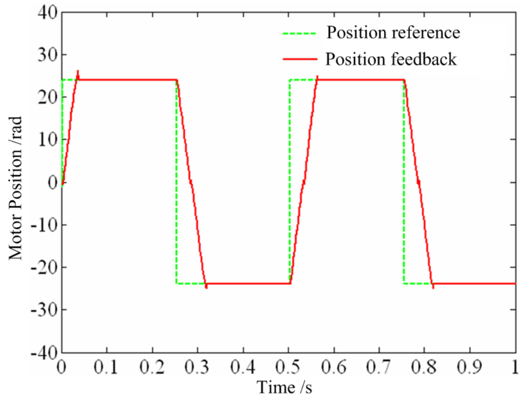

Fig.11 Experimental results with square-wave position reference

CONCLUSION

The control system of BLDC motor for electromechanical actuator is designed. A position detecting method is proposed. This detecting method combines motor's discrete Hall sensor signal with the potentiometer signal to determine the position information. Even with PWM interference, high-resolution position can be obtained. A shunt resister is used to measure the current. Because only positive voltage is needed, so the control system is simple. A brake strategy is used to control the motor current. The experimental results show that the control performance can fulfill the system requirements.

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