Study on LabVIEW-based Aviation BLDCM Control System

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Abstract. With the increasing market demand and rapid development of aircraft technology, more electric concept has become an important trend for the future development of aircraft. Therefore, motors are widely applied in the aviation field increasingly. This paper mainly introduces the hardware environment and LabVIEW implementation process in the development of aviation high speed and high voltage BLDCM control system based on NI hardware and software platform. The test shows the control system is able to realize effective control over aviation BLDCM. This system is highly flexible and can lay a foundation for the algorithms used in subsequent related research efforts.

Keywords: LabVIEW FPGA; Brushless DC Motor (BLDCM); BLDC control; Aviation motor;

1. Introduction

With the development of more-electric and all-electric aircraft technology, motors are more and more widely applied in the aviation field, among which the high speed and high voltage BLDCM has become popular due to its high power density, high reliability, high power-weight ratio and other advantages\cite{1-2}. Motor control technology constitutes a vital part of motor development. An excellent motor control technology can unleash the motor potential to the utmost extent, and motor performance test conducted under the technology can promote the design of motor itself \cite{3-4}. The topological structure and principles of BLDCM drive are shown in Figure 1. The paper uses a three-phase full-bridge drive circuit. The rotor position is indicated by the three-phase Hall position signal to control the on-off time sequence of 6 switching tubes of the drive circuit and to further control the electrification time sequence of the stator coil of the motor to drive motor rotation.

![Figure 1 Schematic Diagram of BLDCM Drive](image-url)
The paper uses LabVIEW to develop the high speed and high voltage BLDCM control system. LabVIEW is a graphical programming language characterized by simple and direct programming, high development efficiency, usability and high learning property, etc. Development of motor control system based on LabVIEW is favorable for in-depth study and verification of motor control strategy and control algorithm in the future, which saves repetitive development and shorten iteration cycle [5].

2. Development of control system

2.1. Introduction to the architecture
The motor control system architecture is shown in Figure 2. The NI-based RCP semi-physical motor testing platform can be used to verify control strategy and control methods.

![Figure 2 NI-based Motor Control System Architecture](image)

Main hardware involved in the paper is shown in Figure 3, mainly including NI PXIe-1071 case, NI PXIe-8880 controller, NI PXIe-7858R board card, Infineon HybridPACK™ 6ED100HP1-FA drive module, optocoupler isolator, certain aviation BLDCM and multiple sensors (voltage, current and temperature), etc., among which NI PXIe-7858R is the FPGA board card of NI. It is characterized by rich resources and high running speed, etc. The default single-cycle frequency is 40MHz.

![Figure 3 Main Hardware on NI-based RCP Semi-Physical Motor Testing Platform](image)

2.2. LabVIEW Program Implementation
The LabVIEW-based motor control architecture is shown in Figure 4. The first is the acquisition of Hall signals and anti-shake treatment to obtain the on-off time sequence of 6 switching tubes with dead zone control. Meanwhile, the actual speed of motor is demodulated. Later the speed command and the actual speed command will be compared to output current command via the speed controller. It is then compared with the collected current to output the duty ratio command via the current controller. Finally the voltage is put to the motor to drive motor rotation.
2.2.1. Hall sensor acquisition and debounce treatment. Hall acquisition and debounce treatment program is shown in Figure 5. After the motor Hall position signal passes through the optocoupler isolator, it is acquired by the three-phase DI channel of NI PXIe-7858R. To reduce lag, the acquisition frequency is set to be 40MHz; meanwhile, debounce treatment is performed on Hall signal to eliminate the impact of interference signal. “Debounce” principle: when the signal acquired changes, the counting starts. If the signal remains the same in a certain period, the signal is recognized as correct signal. The signal is assigned variables HA/HB/HC, or variables should follow the previous values. The debounce time set in the program is 1us.

2.2.2. Six-way IGBT on-off time sequence control. The common breakover method for three-phase full-bridge drive circuit can be divided into two-two breakover and three-three breakover. The paper chooses the two-two breakover method, which refers to breakover of two phases on the motor every moment. The third phase is suspended. The breakover sequence and time of each phase are determined by rotor position signal. Under the method, when the motor is working normally, the upper and lower bridge arms are respectively equipped with one conductive power device only every moment. Even during commutation, the upper and lower bridge arms on the same bridge are difficult to be conductive simultaneously. Each time, the motor goes through a commutation, the direction of the resultant torque turns 60 electrical degrees. In a cycle, the torque has to go through six direction changes [6-7]. The signal logic of two-tow breakover is as follows:
Wherein, HA, HB and HC represent the three-phase Hall signal acquired; TA, TB and TC represent three top tubes; BA, BB and BC represent three bottom tubes. The control program is shown in Figure 6, dead zone is set in the program. The principle of a dead zone is similar to that of "debounce". As the commutation under two-two breakover is difficult to have conductive top and bottom tubes on the same bridge arm at the same time, the dead zone time may be set at a small value or even not set at all. The set value in the program is 0.5us.

2.2.3. **Duty ratio assignment control.** The duty ratio assignment control program is presented in the Figure 7. Nested loop is adopted on the output part of the duty ratio. The inner loop is the loop of duty ratio assignment, which is to assign the duty ratio signal to six-way IGBT via DO Interface. The loop frequency is 40MHz (single cycle timed loop). The stop condition for the loop is "once every PWM cycle"; the external loop is the conventional while loop, and it is to guarantee the internal loop in cycle.

The default PWM frequency for the program is 10kHz, which means each PWM cycle contains 40,000 ticks. Duty ratio control may be effectively realized via ticks counting. Besides, by logical judgment, the breakover time of IGBT in each PWM cycle happens to be the middle position of the whole cycle to guarantee the uniformity of current acquisition timing. Current acquisition trigger command is also set in the program.

2.2.4. **Other Parts of the Program.** The logic of speed calculation of Hall signal is relatively complicated. The main principle is to record the number of ticks between two groups of Hall signals,
which is T-method speed testing. Besides, the signal change problem, speed fluctuation in single Hall calculation and speed lag in six Hall calculation, etc. upon motor reversing and initial start shall be taken into consideration.

Compound control strategy of feedforward and feedback is adopted on the speed loop and current loop, which is suited to the filtering control method and variable parameter four-quadrant drive algorithm. Meanwhile, anti-integral windup PI controller is used to solve the excess integral problem. To guarantee the flexibility of algorithm, the paper has designed the anti-integral windup PI controller based on LabVIEW, which is able to realize the variable parameter control demand of the algorithm presented in the Figure 8. The basic idea is: when the controller output reaches its limit, the symbol of error signal is judged to determine whether to stop the integral action or not.

![Figure 8 LabVIEW-based Anti-Integral Windup PI Controller](image)

**3. The first section in your paper**

The paper tests and verifies the above control system via a certain aviation high speed and high voltage BLDCM. In the experiment, the current is acquired by Lime LA55-P SP50 current sensor. Both current sampling frequency and PWM frequency are 10KHz. The main parameters of the motor used in the experiment are presented in the table 1.

| Name                          | Numerical value |
|-------------------------------|-----------------|
| Rated power/W                 | 500             |
| Rated voltage/V               | 310             |
| Rated speed/rpm               | 20000           |
| Rotational Inertia/(Kg·m²)    | 1.8×10⁻⁵        |
| Winding phase inductance/mH   | 2.3             |
| Winding phase resistance/Ω    | 2.6             |
| Torque Coefficient/(Nm·A⁻¹)   | 0.13            |

In the experiment, the motor is respectively supplied with phase step command and sinusoidal command to observe its response. The left figure in Figure 9 shows the phase step response curve. The phase step command is ±2000r/min. The right figure in Figure 9 shows the sinusoidal response curve. The amplitude and frequency of the sinusoidal command are 11000r/min and 5Hz respectively. Wherein, the red line represents the speed command signal and the white line the speed response signal. It can be seen from the figure that the phase step response time is approximately 0.13s, and the overshoot is around 3.7%; the speed change of sinusoidal response near zero speed is not smooth. On one hand, it is because that BLDCM gives feedback of position signal based on Hall sensor and therefore the speed fluctuation in low-speed segment is large; on the other hand, it is caused by the switchover between the speed of single Hall calculation and the speed of six Hall calculation. The left and the right in Figure 10 respectively represent the speed of single Hall calculation and the speed of
six Hall calculation under the command of 2000r/min. It can be seen from the figure that the speed of single Hall calculation and the speed of six Hall calculation both fluctuates around 2000r/min. The maximum deviation is around 400r/min for the former and around 40r/min for the latter.

![Figure 9 Motor Phase Step Response and Sinusoidal Response Curve](image)

![Figure 10 Comparison between Speeds of Single Hall Calculation and Six Hall Calculation](image)

4. Conclusions
This paper introduces in detail the implementation process from Hall acquisition to PWM dispatch in the development of aviation high speed and high voltage BLDCM control system using LabVIEW based on NI RCP semi-physical simulation platform. The test result shows that the control system designed in the paper can effectively implement the control over aviation high speed and high voltage BLDCM. The control system is highly flexible and extendable, laying firm foundation for later studies on relevant algorithms.

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