Comparison of PMSM and BLDC Applications in Servo System

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Abstract. Servo control requires fast following performance and high steady-state accuracy in position follow-up mode. Servo of special environment application has more strict requirements for motor performance and reliability. The development of servo system has experienced the initial electro-hydraulic servo, using DC brush motor, whose speed, reliability and service life are relatively limited. Today's AC servo system is mainly AC asynchronous or permanent magnet synchronous motor. The development of servo system is more and more alternating, permanent magnetization, intelligence, integration, miniaturization, networking and modularization. This paper mainly studies the servo control of permanent magnet synchronous AC motor. Permanent magnet synchronous AC motor is divided into permanent magnet synchronous motor and permanent magnet brushless DC motor. It is found that the servo control based on permanent magnet synchronous motor is better than that based on permanent magnet brushless DC motor in following performance and steady-state accuracy.

Keywords: Servo · PMSM · BLDC

1 Introduction

In the servo field, the performance requirements of the servo system mainly include: load capacity, control accuracy, dynamic response capacity, etc. In aerospace applications, there are strict requirements for the size, quality, environmental adaptability and reliability of the servo [1]. Due to the particularity of aerospace installation structure and different sizes, how to improve the power quality ratio of servo has become a key index to measure the servo system. This paper analyzes the power quality ratio of PMSM and BLDC in application from the perspective of motor body and control driver output power.

In any application, servo control accuracy and dynamic response are the basic performance. For scenes with high control accuracy, such as the industrial control console of the lithography machine, the accuracy reaches the nanometer level, which is the only

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manufacturer in the world. Aerospace servo is a kind of occasions with relatively high control accuracy but very high dynamic response ability.

This paper first analyzes the overall control scheme based on three closed-loop control servo systems, analyzes the power quality ratio of PMSM and BLDC from the mathematical principle, qualitatively analyzes the control accuracy difference between PMSM and BLDC, and finally analyzes the difference between PMSM and BLDC in speed, accuracy and dynamic response through experiments.

2 Overall Scheme of Servo System

First, the servo system generally requires that the rotor position can follow the given value. To control the rotor position well, the motor speed and torque need to be controlled. Therefore, the control structure is generally designed as three closed-loop loops: current loop, speed loop and position loop, which form the three closed-loop structure of the servo control system from the inside out, as shown in Fig. 1. This structure can effectively suppress the change of inner loop parameters and resist load disturbance. It is the most widely used PMSM servo system control structure [2].

As the inner loop of PMSM servo system, the current loop is mainly responsible for providing fast torque response and stability. Speed loop control, the speed and accuracy of speed regulation directly affect the quality of position following control. In order to make the motor obtain good dynamic characteristics at high and low speed, different position controllers can be designed for different position signals. For the slope position signal, the position feedforward control can effectively improve the following response speed of the AC servo system.

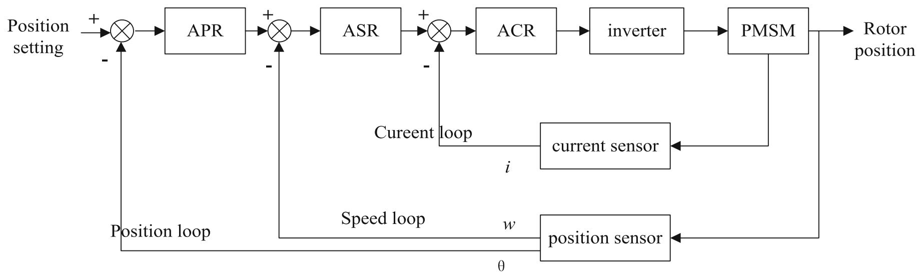


Fig. 1. Three closed loop position servo system

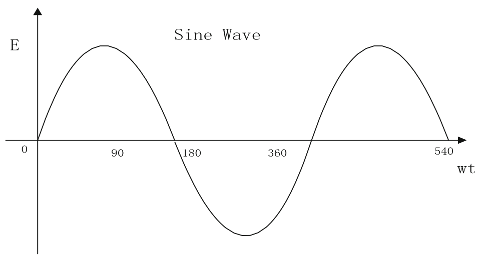
3 Servo Control Based on Permanent Magnet Synchronous Motor

3.1 Operating Principle of PMSM and BLDC

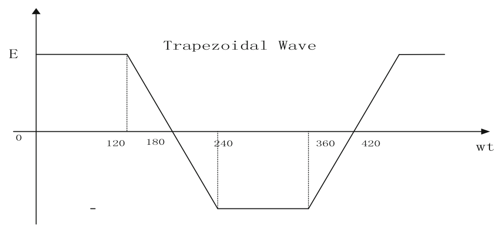
Permanent magnet synchronous motor (PMSM) and brushless DC motor (BLDC) have many similarities. Their structures are roughly the same. Both rotors are equipped with permanent magnets, but the permanent magnets of BLDC are in the shape of tiles, and the air gap magnetic field produced by BLDC is distributed in a rectangular wave in space, Back EMF waveform of BLDC is shown in Fig. 2(b).

The permanent magnet of PMSM is a circular parabola shape, and the air gap magnetic field is distributed as a sine wave in space, Back EMF waveform of PMSM is shown in Fig. 2(a). Both stators adopt three-phase balance winding, but BLDC is mostly concentrated and full pitch winding, and PMSM is mostly distributed and short pitch winding [3, 4].

PMSM and BLDC control drivers both use three-phase bridge inverter to control the motor, so the hardware design of the control driver is probably the same. The difference between them is in position acquisition and control strategy. Generally, BLDC only needs to accurately detect the time of current commutation point, and each phase of BLDC will conduct 120° in the forward direction within one cycle, Then conduct 120° in reverse. Form rectangular wave alternating current,three-phase current conduction waveform of BLDC is shown in Fig. 3. The mutual difference of three-phase current is 120°, At this time, only two-phase currents are connected at the same time at any time, Since the phase is changed once every 60° electrical angles, the rotor position only needs to be detected every 60°. Hall elements are commonly used in the market. A motor uses three



(a)



(b)

Fig. 2. (a) Back EMF waveform of PMSM. (b) Back EMF waveform of BLDC

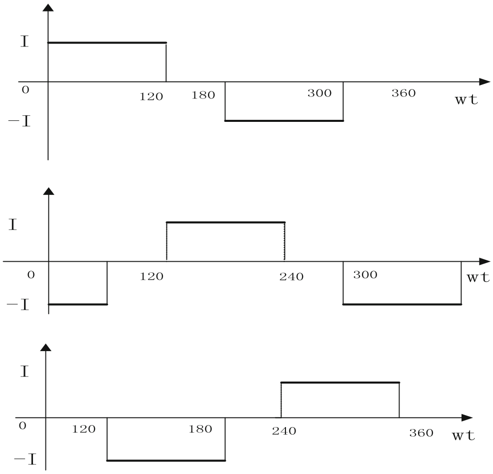


Fig. 3. Three-phase current conduction waveform of BLDC

Hall elements in total. The hall element placed in the air gap of the motor will generate a 180° Pulse width output signal, The three Hall elements are placed alternately at an interval of 120°, the back EMF pulse width signal with a mutual difference of 120° will be generated, and the pulse width signal of the hall element will be compiled into a logic signal to control the opening and closing of the switch [5, 6].

The three-phase current signal of PMSM is a three-phase AC symmetrical sine wave signal. Because there are many control variables, nonlinearity and mutual coupling, it is very complicated to directly control its current. In order to simplify the control model and realize coordinate transformation of control parameters, excitation current Id and torque current Iq are generated after three-phase current transformation. The formula is as follows:

$$u_s = R_s i_s + L_s \frac{di_s}{dt} + \frac{d(\phi_f e^{j\theta})}{dt} \tag{1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{1}{\sqrt{3}} & \frac{2}{\sqrt{3}} \end{bmatrix} \cdot \begin{bmatrix} i_A \\ i_B \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\phi_s & \sin\phi_s \\ -\sin\phi_s & \cos\phi_s \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = C_{2S/2R} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{3}$$

The Id and Iq after coordinate transformation control the strength of the breath magnetic field and the magnitude of the rotating torque respectively. Compared with BLDC, PMSM can control the strength of motor magnetic field [7]. Under the same bus voltage, PMSM can obtain higher motor speed through weak field speed regulation.

3.2 Control the Power Density of Drives and Motors

The rotor loss of permanent magnet AC servo motor is very small. The loss mainly occurs on the stator. The loss mainly includes copper loss, iron loss and mechanical loss. The mechanical loss of BLDC and PMSM depends on the mechanical design and process treatment. Under the same design conditions, it can be recognized that the mechanical loss of both is the same [8]. The iron loss of both accounts for a small proportion, and BLDC is slightly higher than that of PMSM. For the convenience of calculation, it is temporarily considered that the mechanical loss and iron loss of both are the same, so the loss is mainly concentrated on the copper loss. For PMSM, the copper loss of motor is pcu1:

$$P_{CU1} = 3\left(\mathrm{I}_{m1}/\sqrt{2}\right)^2 R_S \tag{4}$$

where: Im1 is the peak value of current fundamental wave, and Rs is the resistance value of each phase.

For BLDCM, in order to generate a constant torque, the stator of each phase needs to be fed at an interval of 120°. Rectangular wave current, copper loss of motor is pcu2:

$$P_{CU2} = 3\left(\sqrt{2}/\sqrt{3}\right)^2 \mathrm{I}_p^2 R_S \tag{5}$$

the parameters of stator and rotor are the same except that the shape of magnetic steel of rotor is different. In this case, it can be assumed that the copper loss and stator resistance of the two are the same, that is:

$$P_{CU1} = P_{CU2}, Ep = Em1 \tag{6}$$

where Ep and Em1 are the peak values of BLDC and PMSM induced electromotive force respectively,

From the formula (4), (5), (6):

$$\mathrm{I}_{m1} = 1.15 I_P \tag{7}$$

The output power ratio of the two is:

$$k = \frac{P_{BDCL}}{P_{PMSM}} = \frac{2Ep * Ip}{3\frac{Em1 * \mathrm{Im}1}{\sqrt{2}\sqrt{2}}} \tag{8}$$

Based on the above formula, k = 1.15 can be simplified, that is, PMSM and BLDCM with the same volume can provide 15% more input power than PMSM under ideal conditions. In practical engineering applications, even if PMSM and BLDCM with the same volume have different parameters, the motor controller cannot output the perfect controlled current waveform.

3.3 Power Density of Motor Controller

In aerospace applications, not only the output power of the motor should be increased as much as possible, but also the electromagnetic torque generated by the motor control driver per unit current should be as large as possible. In this way, the loss of the control driver is reduced, the rated capacity of the control driver is increased, the system cost is reduced, and the reliability of the system is increased. Assuming that the same control driver is used to control PMSM and BLDC, the overcurrent capacity of both depends on the overcurrent capacity of the IGBT of the control driver. For the same control driver, if the induced electromotive force peaks of the two are the same, that is, the output power ratio k = 1.33 can be obtained, that is, for the same control driver, the control driver controlling BLDC can output 33% more power, otherwise, When the driven BLDCM and PMSM have the same output power, the inverter capacity required by BLDCM is 1/3 less than that of PMSM.

3.4 Torque Fluctuation

The torque fluctuation of PMSM and BLDCM is mainly caused by cogging torque and ripple torque. Cogging torque is a mechanical characteristic, and the cogging torque of both is similar. The methods to eliminate cogging torque include stator inclined slot, rotor inclined pole, appropriate pole arc coefficient, etc. Ripple torque is the interaction between stator current and magnetic field force of permanent magnet. When the stator current deviates from the ideal current waveform, ripple torque will be generated [9].

It can be seen from Fig. 1 that the current waveform fed into PMSM is a sine wave, and the one that needs to be fed into BLDC is a rectangular wave. The control driver can generate an approximately continuous sine wave. However, because the motor inductance can not make the phase current sudden change, the control driver can not generate an ideal rectangular wave. The actual current waveform is similar to a trapezoidal wave, and the deviation current is the main reason for the ripple torque. In the high-speed region, the ripple torque caused by the rotor inertia is not obvious, but in the low-speed region, the ripple torque is outstanding, especially in the high-precision servo system, which affects the stability and accuracy of the servo system.

4 Test Description

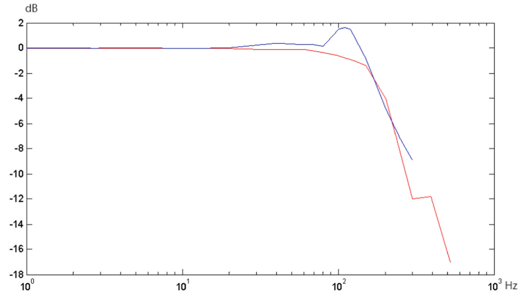
Permanent magnet synchronous motor (PMSM) and brushless DC motor (BLDCM) are selected for the comparison test, and the advantages and disadvantages of the two motors in the field of servo control are compared from many aspects. The test results of position and frequency characteristics are are shown in Table 1.

As shown in Fig. 4(a), (b), the zero bias, linearity, position symmetry and maximum linear speed of PMSM servo mechanism are better than those of BLDC; It shows the advantages of PMSM in control accuracy and dynamic response. Because the control accuracy and dynamic response of PMSM are related to control algorithm and structural machining accuracy, PMSM servo mechanisms are not all superior to BLDC servo mechanisms.

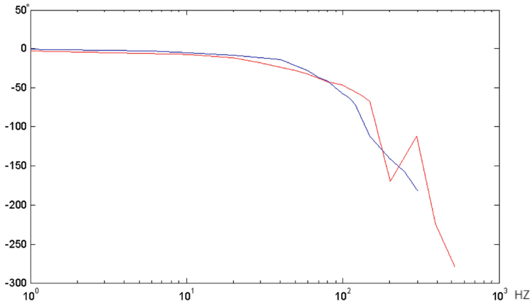
Thanks to the parameter adjustment of closed-loop control algorithm and high reliable sampling accuracy and machining accuracy, the amplitude frequency characteristics of PMSM and BLDC can reach about 25 Hz in the bandwidth of −3 db. It also has a high stability margin.

Table 1. Position and transient characteristics of PMSM and BLDC servo mechanisms

	BLDC	PMSM	Remarks
Forward direction (°)	30.9	31.794	Location characteristics
Opposite direction (°)	−31.002	−31.764	
Loop width (°)	0.126	0.148	
Zero bias (°)	−0.127	−0.07	
Linearity (%)	0.267	0.126	
Positional symmetry (%)	0.028	0.007	
Max linear speed (°/s)	164.56	207.541	Transient characteristics



(a)



(b)

Fig. 4. (a) Comparison of amplitude frequency characteristics of PMSM (red) and BLDC (blue) of 1°. (b) Comparison of PMSM (red) and BLDC (blue) phase frequency characteristics of 1°

5 Contributions

PMSM and BLDCM with the same volume can provide 15% more input power than PMSM under ideal conditions. And the control driver controlling BLDC can output 33% more power with the same control driver.

Based on the above principles and test results, BLDC is simpler in control than PMSM and can provide more output power and torque. However, in the high-end servo control field, especially in the aerospace flight servo field, spacecraft has higher requirements for control accuracy and dynamic response. Although the current BLDC motor control based on rotation can improve the control accuracy, PMSM is relatively more in line with the requirements of servo control.

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