Design of Brushless Torque Motor with High Load and Low Static Friction Torque

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Abstract

A new type of permanent magnet limited-angle brushless torque motor (LABLTM) is studied in this paper. The structure and characteristics of the motor are analyzed. The electromagnetic torque and the back EMF are deduced by using the magnetic circuit calculation method, and the parameter calculation formula is obtained. The prototype was tested. By the shock vibration test of the prototype, the main parameters of the motor were compared and analyzed after the shock vibration. The results show that the derived formula for parameter calculation is effective, and the motor has strong bearing capacity, small static friction torque and large output torque, and the impact vibration has little influence on the motor parameters. The motor can fully meet the requirements of the harsh environment, and it has a wide application prospect.

Keywords

Permanent magnet, limited angle, torque motor, design method.

1. Introduction

The LABLTM is a servo motor which can drive load directly and be positioned accurately in a certain range. This kind of motor has simple structure and high reliability. It can be widely used in multiple control systems, such as the aviation servo valve, the robot joint and other electrical servo systems, which can drive the load directly within a limited angle.

At the end of 1980s, it has been applied to the precise control of fluid propulsion device and satellite radiation scanning mirror abroad. The domestic is in the initial stage to research on the motor. A double redundancy limited angle brushless torque motor is proposed. The motor has large output torque and quick response, but the cogging effect is obvious and the static friction force is large. A kind of limited angle brushless torque motor which has magnetoresistivity is proposed [1]. The motor utilizes the principle of reluctance motor to realize the positioning control of the angle of 0°、45°、90° in the 90° range.

In this paper, the motor is designed in order to meet the requirements of fire control system include large bearing capacity, small static friction moment and large torque. The prototype was tested and the experimental results show that it can meet the expected requirements.

2. Structure and Characteristics of the Motor

The structure of brushless torque motor with finite rotation angle is shown in figure 1.The oo' is motor angle zero line. The motor operating within ± α angle range, and the theoretical maximum of α is $\frac{90^{\circ}}{P}$.

The maximum torque generated constant value of Q is $\frac{90^{\circ}}{P}-\frac{\alpha_P}{2}-\frac{\zeta}{2}$.

Where the P is the number of pole-pairs, and the α_P is the circumference angle corresponding to a single magnetic pole, and the ζ is the circular angle corresponding to fixed block of the single stator magnetic ring. The winding connection mode is shown in figure 2: the (a) is series winding, and the (b) is parallel winding, and the (c) is hybrid winding. Under the same condition of producing torque, the three connection modes require different rated voltage and rated current of the motor, so the winding connection mode can be chosen according to the actual situation. The design uses a hybrid winding.

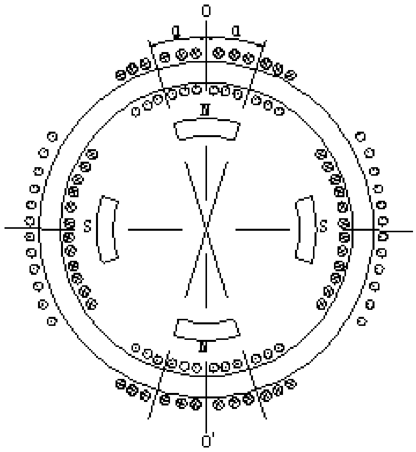

Fig. 1 Schematic diagram of cross section of motor structure

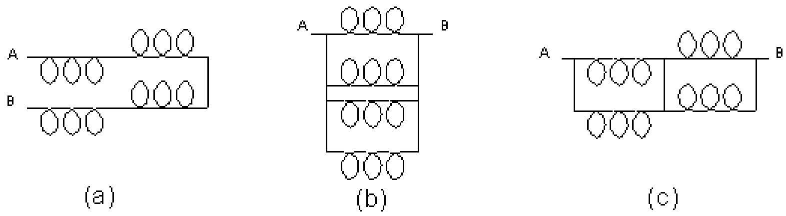

Fig. 2 The motor winding connection diagram

The stator magnetic conducting ring is composed of an annular soft magnet, and the winding coil is wound uniformly along the magnetic ring [2]. The stator has a compact structure without the cogging effect and the static friction torque. The defects are that the windings on the outer side of the stator magnetic conduction ring do not generate torque, meanwhile the diameter of the motor is increased and the copper material is wasted. The rotor consists of neodymium iron boron (NdFeB) magnet. Its structure is four poles excitation, so it has the ability of producing larger peak torque and anti demagnetization. Meanwhile, it reduces electromechanical time constant and improves rapidity.

The kind of structure stator and rotor can be made into split structure and integral structure. The split is characterized by small volume, independent rotor and no shell [3,4]. Its mutual position is provided by the use environment and the axial bearing capacity is small. The electrical performance of the motor is easily affected by the environment. The rotor magnetic steel has a high intrinsic coercivity, when it forms a closed magnetic circuit with the soft magnetic material in the environment, the magnetic flux leakage is larger, and the static friction moment is directly affected. The characteristics of the integral structure include the large volume, the fixed shell and fixed rotor position, and the stable electrical performance. The shell can adopt non-magnetic material or magnetic material with weak magnetic permeability to reduce magnetic leakage in order to improve the performance. A small static friction moment is generated, but the axial bearing capacity is large, because the fixed rotor uses the bearing. The design adopts the integral structure, which improves the axial bearing capacity greatly under the condition that the static friction moment is allowed.

The method of magnetic steel magnetizing can be divided into parallel magnetizing and radial magnetizing. The characteristics of parallel magnetization include that the magnetizing mode is easy to realize, and the large-batch simultaneous magnetizing can be realized. Its disadvantage is that the waveform of the air gap magnetic field is poor, and it affects the electrical performance of the motor. The characteristics of radial magnetization includes that the magnetization is more difficult, because only a single magnetizing can be performed at a time, the magnetizing device cannot be magnetized in large quantities at the same time. It has the advantages of better air gap magnetic field waveform. Considering that the batch production and air gap magnetic waveform have little effect on the electrical performance of the motor, the parallel magnetization is adopted in this design.

3. Electromagnetic Torque and Reverse EMF

Since the two redundancy of the motor is symmetrical and the basic parameters of each winding are the same, the expression of a single winding can be analyzed firstly [5,6].

A schematic diagram of the motor's profile structure when working on a single winding is shown in the figure 3. The magnetic density of air gap is shown in figure 4. The relative position of armature winding and rotor pole is the reference position for analysis. The magnetic pole axis is x axis with the $\theta = 0$, where θ is the angle of rotor rotates from reference position.

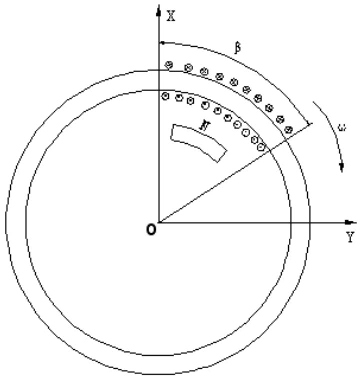

Fig. 3 Schematic diagram of single winding motor section structure

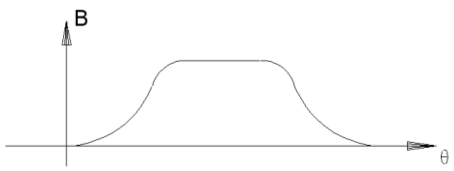

Fig. 4 The magnetic density of air gap of single winding

Reverse potential of single wire at x point:

$$e = B_{(\theta)} lv = B_{(\theta)} lr\omega \tag{1}$$

Where $B_{(\theta)}$ ——Magnetic induction intensity at θ point.

ω ——Rotor angular velocity.

l ——The effective length of the relative motion wire in a magnetic field.

r ——Rotor radius.

The average reverse potential of a single wire in the whole range of motion:

$$\bar{e} = \frac{1}{\tau}\int B_{(\theta)} lvd(\theta) = \frac{\omega}{\tau}\int B_{(\theta)} lrd(\theta) = \frac{\omega}{\tau}\Phi_{\delta} \quad (2)$$

Where τ ——Polar distance

Φ_{δ} ——Effective magnetic flux per pole

The reverse EMF of whole motor:

$$E = 2E' = \frac{2N\partial_i}{\tau}\omega\Phi = C_e\omega\Phi \quad (3)$$

Where $C_e = \frac{2N\partial_i}{\tau}$ is the coefficient of potential.

The torque generated at θ by single wire:

$$M = B_{(\theta)} ilr \quad (4)$$

The average torque of a single conductor in the entire range of motion:

$$\bar{M} = \frac{1}{\tau}\int B_{(\theta)} ilrd(\theta) = \frac{i}{\tau}\Phi_{\delta} \quad (5)$$

Single winding torque:

$$T_e' = N\bar{M} \quad (6)$$

Whole motor torque:

$$T_e = 4T_e' = \frac{2IN}{\tau}\partial_i\Phi = C_T\Phi I \quad (7)$$

Where i ——Current in the wire

I ——Motor input current

$C_T = \frac{2\partial_i N}{\tau}$ is the moment coefficient.

4. Experiment and Results

The prototype has been used in the control system of the anti-image successfully. Main index of prototype: the motor rotation angle is $+12° \sim -12°$, and the peak voltage is less than 27V, and the peak torque is $2.5N \cdot m$, and the static friction torque is less than $0.015N \cdot m$.

The table 1 shows the prototype test results. The results show that the electric motor structure, the electromagnetic torque and the inverse potential calculation method are correct and effective, meanwhile it is reasonable .

Table 1. The test results of prototype

index name	static friction torque (N•m)	motor rotation angle (°)	peak voltage (V)	peak torque (N•m)	state
proto 1	0.015	±12	23.5	2.6	pre-shock
proto 1	0.013	±12	23.7	2.6	after shock
proto 2	0.014	±12	23.9	2.7	pre-shock
proto 2	0.013	±12	24.0	2.7	after shock

The data of the two prototypes are different from the ideal indexes of the motor slightly, but the difference is very small in general, which proves the correctness of the above theory.

5. Conclusion

The finite angle brushless torque motor has many advantages, such as high reliability, strong impact resistance, small volume and light weight. It can meet the requirements of the control system, meanwhile it has completed the system matching successfully.

The motor has important application value and development prospect in military aerospace and other fields. The test results of the principle prototype show that the proposed method is correct, such as the high load, high torque, low static friction torque and so on. Meanwhile, this paper enriches the design theory of the kind of motor.

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