The research on direct drives control system in the large aperture telescope

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ABSTRACT

A 30m giant telescope project, Chinese Future Giant Telescope (CFGT), has been proposed by Chinese astronomers. At present, a series of key techniques are being developed. This paper explores a method to control direct drive servo motor in giant telescope application, which is based on a segmented Surface-mounted Permanent Magnet Synchronous Motor (SMPMSM). The losses of SMPMSM and the method of reducing the losses are discussed in this paper. Phase-controlled rectification circuit is chosen to regulate rectified voltage according to the telescope status. Such design can decrease the losses of the motor to some extent. In the control system Space-vector PWM (SVPWM) algorithm acts as a control algorithm and three-phase voltage source inverter circuit acts as drive circuit. This project is subsidized by Chinese National Natural Science Funds (10833004).

Keywords: Chinese Future Giant Telescope (CFGT), Surface-mounted Permanent Magnet Synchronous Motor (SMPMSM), Space-vector PWM (SVPWM), Feedback

1. INTRODUCTION

Several giant telescopes, such as TMT, GMT, E-ELT, are now under design and construction. In the next decade, mankind may have chances to research astronomical problems using new generation telescopes. Chinese Future Giant Telescope (CFGT) has been proposed for several years. A series of key techniques are being developed. The CFGT features an aperture of 30-m with primary f-ratio of 1.2 and an alt-azimuth design. The Zenith range is from 0° to 70°, the Azimuth rotation is ±180°. Its primary mirror consists of 1020 annular segmented mirrors arranged in 17 concentric annuluses. [1] [2] Figure 1 shows the overview of the CFGT model.

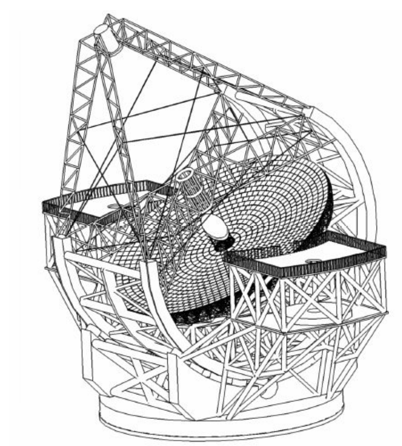

Fig. 1 Overview of the CFGT model

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Without using speed reduction devices such as gears, direct drive is capable of precise rotation control. With high stiffness and high bandwidth and without stick-slip, direct drive performs well in large astronomical telescopes such as VLT, Subaru. The core of direct drive is the specially-made motor with large capacity, high accuracy, low speed, wide speed range and large torque.

A novel Surface-mounted Permanent Magnet Synchronous Motor (SMPMSM) was designed which is composed of multi blocking motors. The rotor is surfacely mounted permanent magnet slices. Every segment is curve that coincides with the motion feature of the telescope. The motor and the telescope coupled directly together and designed at one time, so the parameter of the machine can be optimized. Figure 2 shows one segment of the SMPMSM.

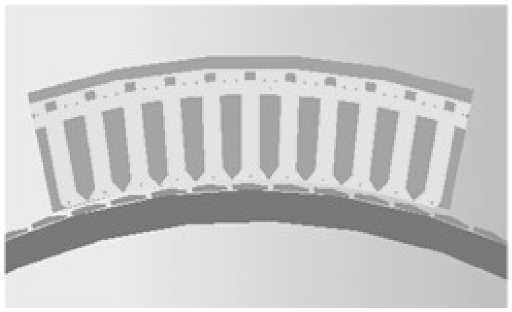

Fig. 2 One segment of the SMPMSM

2. SURFACE-MOUNTED PMSM

A Surface-mounted Permanent Magnetic Synchronous Motor (SMPMSM) has been built as an experiment bed of direct drive. It is composed of 15 blocking motors as drive motor, damper, and tachometer respectively [3] [4] [5]. Each blocking motor can work independently. Figure 3 shows the motor in the laboratory.

Fig. 3 The picture of SMPMSM

Some features of the SMPMSM are listed below.

Diameter of the rotor: 2.2m,

Thickness: 0.1m

Air gap: 2.5mm

Pole number: 60

Rated RMS of continuous torque (Nm): 12000

The speed range: 2° ~1″ /s

Acceleration: 0.0349 rad/s^2

When the motor runs, losses will be generated inside simultaneously. The loss of motor decides its efficiency, life and rated value. The loss of the motor mainly includes the copper loss and the core loss. The former is induced by the current in the winding, and the latter is brought by magnetic flux alternation in the core. Stray load loss is another factor of the losses, which is caused by harmonic magnetic field and leakage magnetic field. These losses will be transformed into heat, so that the temperature of some parts of the motor will be high and the life of insulation and the performance of the motor will be reduced.

2.1 Copper Loss

Copper loss is the main loss in the application of large torque motor. We must research a method to reduce the resistance loss of the wire, optimize the design to drop the core loss and the structure to take out heat from the machine by conduction.

Copper Loss is also called Ohmic Loss, which exists in all the windings. The value can be got from the equator [6]:

$$\mathrm{P_{Cu}} = qI_m^2 R_m \tag{1}$$

q : Phase number

$\mathrm{I_m}$: The effective value of the No. m winding current

$\mathrm{R_m}$: The resistance of the No. m winding

Copper Loss can reduce the magnetic flux of the permanent magnet and electromagnetic torque. The worst result may be that the electromagnetic torque doesn't exist and the motor damage irreversible. On the other hand, the loss energy transform to heat, so the temperature of some parts of the motor is high. That will cut down the insulations' life. The worst result may be that the motor may be burn down and the telescope will lost its light path. So it is the most important to decrease the motor loss to a reasonable level and to improve cooling condition to conduct the heat in the electromechanical design of large aperture telescope.

2.2 Core Loss

The core loss of PMSM includes hysteresis loss and eddy loss. For the rotor of PMSM is permanent magnet, the core loss of PMSM is mainly in the stator, that is to say the winding.

The hysteresis loss can be defined as following [6]:

$$\mathrm{P_h} = K_h f B_{\max}^n \tag{2}$$

$\mathrm{B_{max}}$: Flux density amplitude, n ranges from 1.5 to 2.5

f : Frequency

$\mathrm{K_h}$: Proportionality factor

The eddy loss varies with the flux density, frequency and the thickness of the lamination. Define the eddy loss [6]:

$$\mathrm{P_e} = K_e \left(B_{\max} f \delta\right)^2 \tag{3}$$

δ : The thickness of the lamination

$\mathrm{K_e}$: Proportionality factor

Optimizing design and reducing the thickness of the lamination is an available method to decrease core loss.

2.3 Other effect factors

2.3.1 High harmonics

The current output from the inverter has much high harmonics. This will bring motor high temperature when it exists in the motor.

Define copper loss under k harmonic as [7]:

$$P_{Cu,k} = \frac{t^2}{k^2} P_{Cu,1} \tag{4}$$

t: The percentage of k harmonic in the base voltage

That equator shows the copper loss under k harmonic is relevant to t, k and $P_{Cu,1}$.

An AC reactor is designed to suppress high harmonics and harmonics loss.

2.3.2 Voltage

The effect of the voltage on core loss [7]:

$$P_{Fe} = P_{Fe}\left(\frac{U}{U_e}\right)^2 \tag{5}$$

P_{Fe} : The core loss under the rated voltage

U: the input voltage

U_e: the rated voltage

The effect of the voltage on copper loss [7]:

$$P_{Cu} = I^2 R / 1000 \tag{6}$$

2.3.3 Frequency

The effect of the frequency on core loss [7]:

$$P_{Fe} = P_{Fe}\sqrt{\frac{f_e}{f}} \tag{7}$$

f_e: the rated frequency

The effect of the frequency on copper loss is [7]:

$$P_{Cu} = I^2 R / 1000 \tag{8}$$

2.4 A method to decrease the losses

According to the above, the losses of the motor can be restrained by reducing the input voltage and frequency.

On the one hand, the telescope usually runs in a low or ultra-low speed. The rated highest speed is 2°/s, while the lowest speed is 1"/s. So the speed regulation ratio is 7200:1. In lower speed, the induced electromotive force should be restrained is also lower. So the input voltage in demand can be reduced. On the other hand, the frequency of the voltage is also brought down.

On the other hand, the axis will rotate not immediately but when the output torque equal to or larger than the static friction. When the axis rotates, static friction (M_{f1}) will turn into kinematic friction (M_{f2}) which is much smaller than M_{f1}.

When the load torque changes from M_{f1} to M_{f2}, output torque, which is decided by the input voltage and current, must be much reduced. So input voltage and current can be reduced and the energy consumptions of the motor will also be lower.

3. DRIVE OF SMPMSM

3.1 Inverter drive circuit

The angular velocity of the SMPMSM is direct proportion to the frequency of the winding voltage, while inverse proportion to the pole number. So a simple method to control SMPMSM is to control the frequency of the winding voltage. 3-phase voltage source inverter is chosen to output different frequency voltage.

Phase-controlled rectify circuit is designed to provide the direct-current volts (V_{dc}). Different frequency of the IGBT shifting can produce different amplitude of PWM alternating voltage. So the 3-phase voltage source inverter outputs alternating voltage with different amplitude. Figure 4 shows the inverter and the rectify circuit.

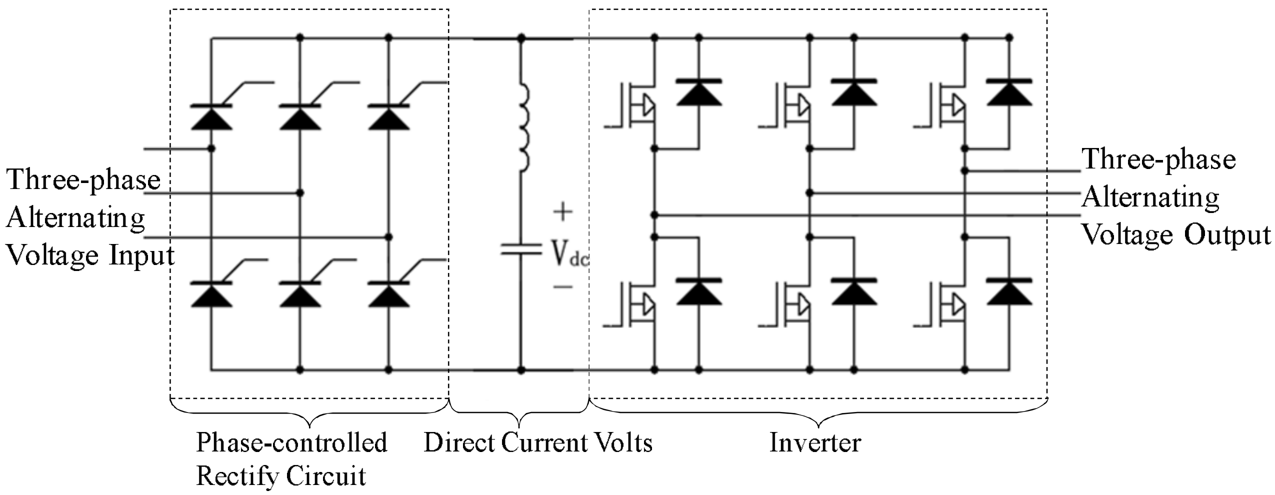

Fig. 4 Three-phase voltage source inverter

3.2 Vector control method

An equivalent transformation between a three-phase AC magnetic system and a rotator DC magnetic system can use the two-phase AC magnetic system as a bridge. That is the base idea of the 3-phase SMPMSM vector control method. Space Vector PWM (SVPWM) is one of the vector control method.

The principle of SVPWM can be described as follows. 3-phase inverter outputs 8 basic voltage vectors which include 6 given vectors (001,011,010,110,100,101) and 2 zero vectors (000,111). They are shown as figure 5. In order to get a round voltage vector by the drive inverter, the 8 basic voltage vectors make a resultant and equivalent space vector. In figure 6, vector V can be got by the near basic vector V_x, V_y and zero vector V_0 (or V_7) [8].

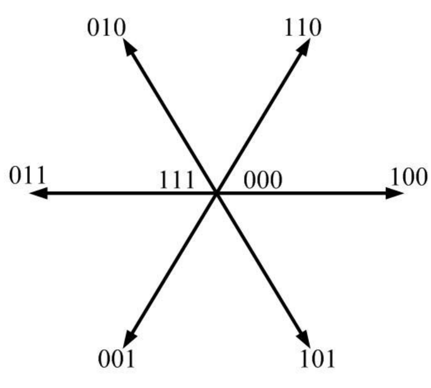

Fig. 5 Six given vectors and 2 zero vectors

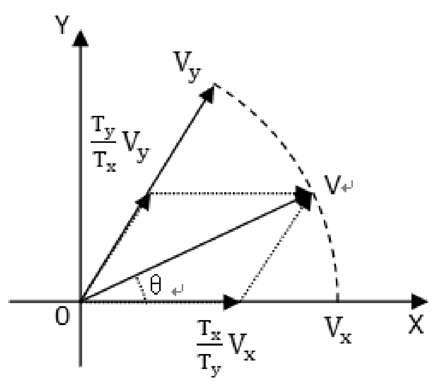

Fig. 6 the equivalent space vector V

Micro controller applies SVPWM arithmetic. The time and sequence of each basic vector are initialized. The micro controller and the drive circuit diagram are shown as figure 7.

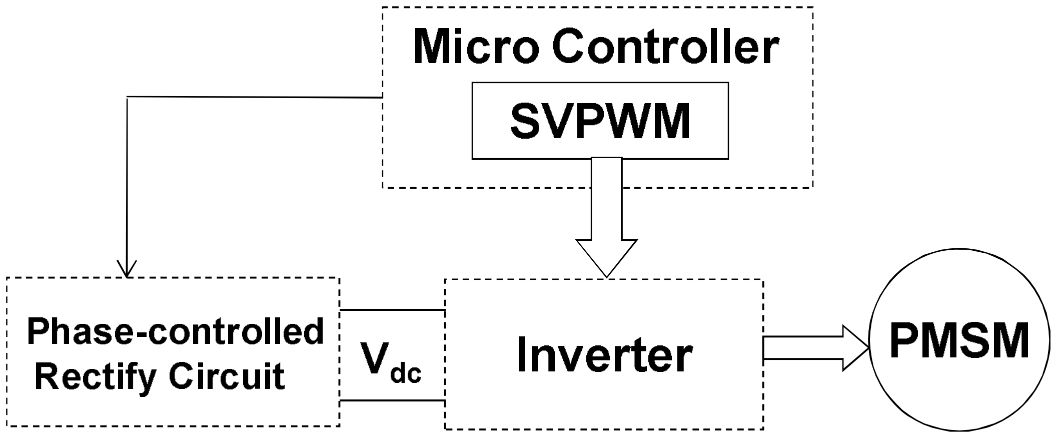

Fig. 7 The control arithmetic and drive circuit diagram

3.3 Control system block

An incremental encoder and current sensor are used to feedback position, speed and current parameter for control system. The control system block is shown as figure 8.

RS232 is the interface between the host computer and the slave computer. The host computer realizes the user interface, general management, centralized monitor, performance test and security guard, etc. The slave computer is a micro controller to provide control arithmetic and feedback detects, etc.

Figure 8 shows the servo control system diagram.

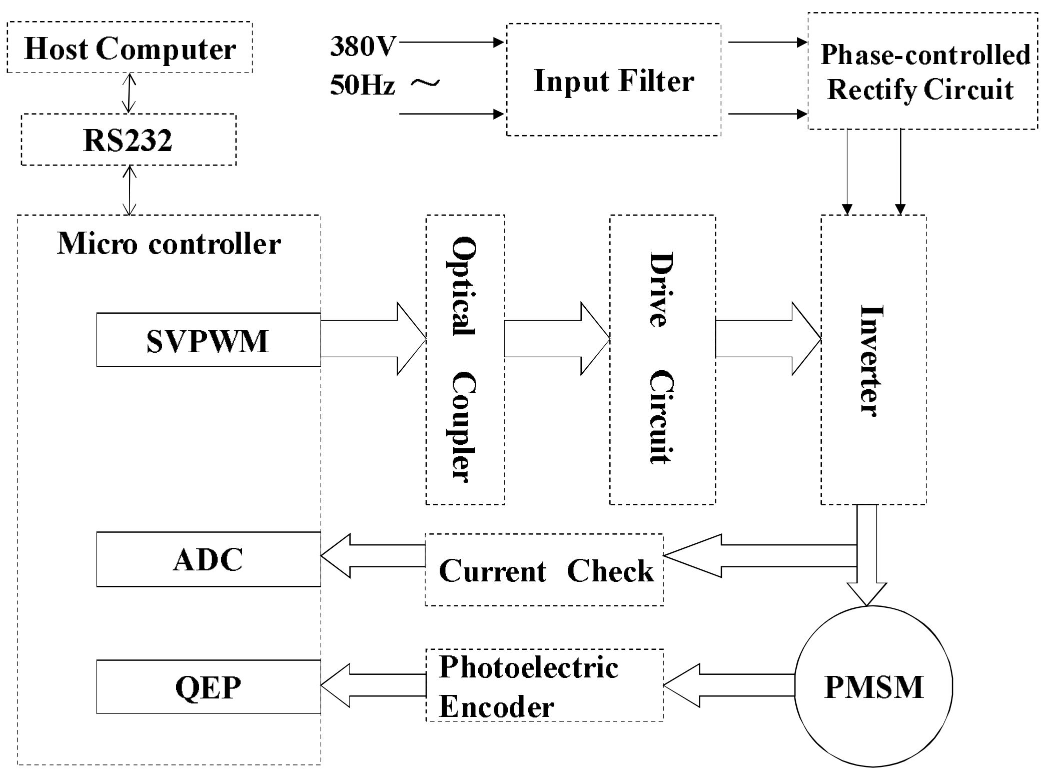

Fig. 8 Servo control system

4. CONCLUSION

Direct drive is still a novel technique in the field of astronomical telescope. In this paper a new Surface-mounted Permanent Magnet Synchronous Motor (SMPMSM) has been made. It can run in an arc trace which is accord with the telescope. A method to control this motor is discussed. A micro controller realizes vector control, 3-phase inverter as drive circuit, current sensor and photoelectric encoder as position feedback and speed feedback. It is proved that this method can control SMPMSM and cut down some motor loss to some extent.

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