# Design of one large telescope direct drive control system based on TMS320F28xx

Xiao-li Song*[a,b], Da-xing Wang*[a,b],Chao Zhang*[a,b], zhen-chao Zhang*[a,b], Li-yan Chen*[a,b,c], Chang-zhi Ren*[a,b]

[a.] National Astronomical Observatories / Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Sciences, Nanjing 210042, China;

[b.] Key Laboratory of Astronomical Optics & Technology, Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Sciences, Nanjing 210042, China;

[c.] University of Chinese Academy of Sciences, Beijing 100049, China

## ABSTRACT

The mount drive control is the key technique which mostly affects astronomical telescope's resolution and its speed. However, the ultra-lower speed and the giant moment of inertia make it very difficult to be controlled. In this paper, one segmented permanent-magnet synchronous motor (PMSM), 4m diameter, is suggested for the mount driving. A method is presented to drive the motor directly, which is based on TMS320F28XX and Insulated Gate Bipolar Transistor (IGBT), also, HEIDENHAIN tape is used to detect the absolute position of the motor together with the Hall sensor. The segmented PMSM can work stable and the mount drive can realize nice tracking performance at ultra-lower speed with this drive system.

**Keywords:** direct drive, control system, IGBT, large telescope

## 1. INTRODUCTION

At present, with the development of astronomical technology, large aperture or extremely large aperture telescopes are being under construction or will be constructed in the near future. At the same time, the mount driving both for azimuth axis and elevation axis are becoming a real challenge. Large telescopes must have high-resolution and well-tracking performance to attain excellent image quality and well-tracking accuracy. Now, the methods of mount driving for large astronomical telescopes have been researching in many countries. With the development o f the control techniques, more and more mount drive of large-aperture telescopes are adopting direct drive of segmented linear motors, and to control the azimuth axis and elevation axis to have advanced imaging systems and high peak angular resolution. There are some large optical telescopes have been successfully used direct drive, which adopted direct drive system as the optimal drive solution to control mount to have advanced imaging systems and high peak angular resolution, such as the European Southern Observatory Very Large Telescope (VLT) [1], National Astronomical Observatory Subaru telescope [2] and Gran Telescopio Canarias(GTC) [3], the Atacama Large Millimeter Array (ALMA), which is composed of at least 66 high-precision antennae, also will used the direct drive at both azimuth and elevation axes [4]. The segmented linear motor is used as to control the mount of the telescopes. However, because of the ultra-lower speed and the giant moment of inertia make it very difficult to be controlled. In this paper, one segment permanent-magnet synchronous motor (PMSM), 4m diameter, is suggested for the mount driving. A large aperture telescope project will use direct drive to realize the azimuth and elevator axes driving. As to the motor, a method is presented to drive the motor directly,

Modeling, Systems Engineering, and Project Management for Astronomy VI,
edited by George Z. Angeli, Philippe Dierickx, Proc. of SPIE Vol. 9150, 91501L
 · doi: 10.1117/12.2055134

which is based on 32bits fixed-pointed processor TMS320F28XX and Insulated Gate Bipolar Transistor (IGBT), also, the current transducer LTS15-NP is used to sample the current signals, except for HEIDENHAIN tape is used to detect the absolute position of motor together with the Hall sensor.

## 2. SEGMENTED PMSM

### 2.1 Mathematical model of the PMSM

The d-q axes model is often utilized to develop the PMSM equations for implementation of Vector Control. The mathematical model of PMSM synchronous motor is derived under the assumption that, the saturation, eddy-current, high-order harmonic components are negligible, the stator windings are symmetric on space, and also the stator current produces sine magnetic motive forces.

According to the assumption, the equations of stator voltage the PMSM on the synchronized rotating d-q reference frame can be expressed. In the following equations, the superscript of r denotes a synchronized rotating d-q reference frame.

The vector equation of stator voltage is given by:

$$\begin{bmatrix} u_q{}^r \\ u_d{}^r \end{bmatrix} = \begin{bmatrix} R_s & 0 \\ 0 & R_s \end{bmatrix} \begin{bmatrix} i_q{}^r \\ i_d{}^r \end{bmatrix} + \begin{bmatrix} p & \omega_1 \\ -\omega_1 & p \end{bmatrix} \begin{bmatrix} \Psi_q{}^r \\ \Psi_d{}^r \end{bmatrix} \tag{1}$$

The vector equation of stator flux is given by:

$$\begin{bmatrix} \Psi_q{}^r \\ \Psi_d{}^r \end{bmatrix} = \begin{bmatrix} L_q & 0 \\ 0 & L_d \end{bmatrix} \begin{bmatrix} i_q{}^r \\ i_d{}^r \end{bmatrix} + \begin{bmatrix} 0 \\ \Psi_f \end{bmatrix} \tag{2}$$

The torque is given by:

$$T_e = 1.5 p_n [\Psi_f i_q{}^r + (L_d - L_q) i_d{}^r i_q{}^r] \tag{3}$$

Where

$u_d{}^r$, $u_q{}^r$, $i_d{}^r$ and $i_q{}^r$ are voltages and currents in synchronized rotating d-q reference frame;

$L_d$, $L_q$ are d-q axes inductances; $R_s$ is the stator armature resistance;

$\omega_1$ is the electrical rotor speed;

$\Psi_f$ is stator flux;

$p$ is the differential operator;

$p_n$ is number of pole pairs.

## 2.2 Overview of the segmented PMSM

The motor is especially designed to realize direct drive and the characteristics are ultra-low speed, ultra-precision and large electromagnetic torque. It is a radical gap PMSM, 400 poles, which is consisted of 8 stator units and segmented rotor. Each unit of the PMSM can be regarded as one "small powerful motor". One stator unit can work independently or work together with other stator units to compose different electromagnetic torque. Similarly, if the motor is designed to have more stators units, it will have larger electromagnetic torque and can drive larger aperture telescope. Traditional AC motors have the stator windings distributed around the rotor symmetrically, means that the motor is an independent servo system. The motor that we use introduces a new method to compose the segmented PMSM, the stator windings are connected by Y-type, and figure 2 shows the distribution of one stator windings.

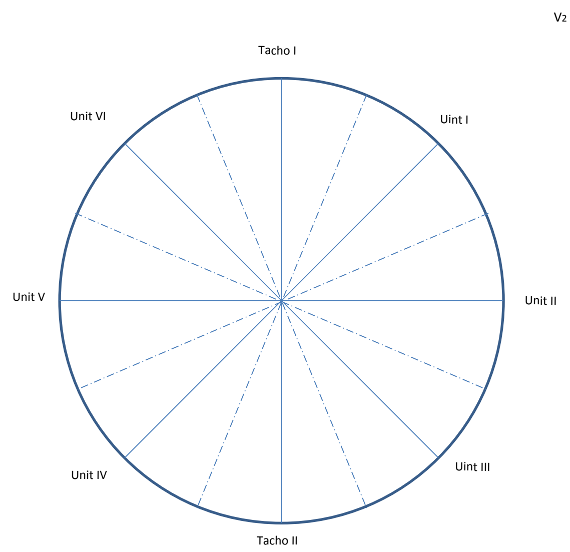


Figure 1. direct drive segmented PMSM

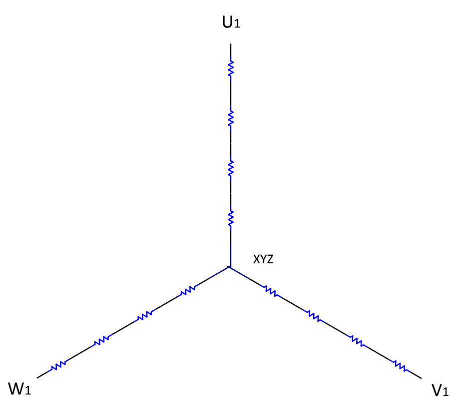


Figure 2. one stator windings connection

## 3. DRIVE CIRCUIT OF THE SEGMENTED PMSM

The technology of semiconductor has been developing by leaps and bounds, and the inverters that used to drive motor are more integrated. The IPM replaces the discrete components in inverter circuit. In this paper, a driving circuit is designed based on 32-bit microprocessor TMS320F28XX and IGBT. And to realize Field Oriented Control (Vector control ) and Space Vector Modulation strategy, stator windings phase-current has to be detected. An analog to digital converter of ADS8361 is used to distinguish the small change of the current. For the position and speed loop, to meet the pointing and tracking requirements, HEIDENHAIN ERA4282C tape incremental angle encoder in our measuring system.

### 3.1 Overview of the drive cirtuit based on TMS320F28XX

TMS320F28XX is a 32-bit fixed-point digital signal processor that developed by Texas Instruments for control application. It can work at clock frequency 150 MHz. It has two Event Manager EVA and EVB, three capture units; an incremental photoelectric position programming interface that dedicated to motor control. EVA and EVB can produce six PWM waves if you utilize the right control algorithm. The PDPINTx can quickly block the output signals of the PWMs to protect the IPM when there are some faults during the motor running, such as over-current, over-voltage, over low voltage and so on. Based on TMS320F28XX and IPM, the hardware circuit diagram is shown in figure 3. It should be noted that optical coupler between TMS320F28XX must be a high speed device; here we use the HCPL4504.

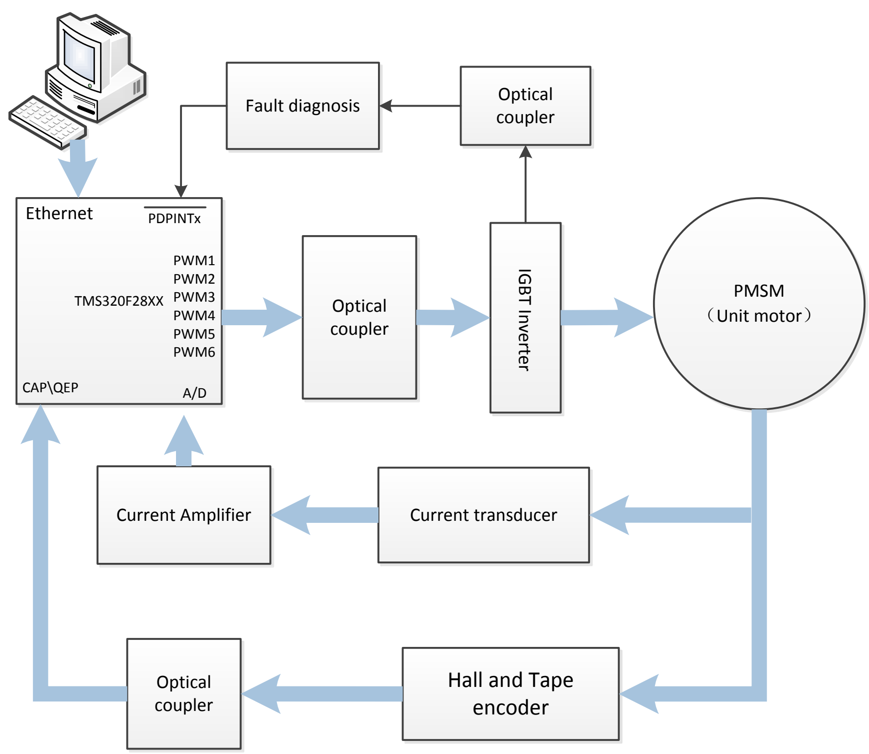


Figure 3. block diagram of the drive circuit system

### 3.2 Inverter circuit based on IGBT

IGBT is used in many fields, especially in inverter circuit. It supplies the protection of short circuit, over current, under voltage and over heat of the module. If these faults arise, it can send the faults signals to the PDPINTx pin of the TMS320F28XX to block the output signals of the PWM pins. From the characteristics of the IGBT, we know it can simple the circuit, lower the cost and improve the reliability of the control system. According to the PMSM and the requirement of the system, we choose the IGBT as the inverter device. Figure 4 shows the module of the inverter circuit based on IGBT, the module is composed of six IGBTS, and six optical-couplers. In order to produce sine wave, the algorithm is very important, and it can ensure the upper and lower bridge of the IGBT does not work simultaneously. Here, we use the Space Vector Modulation to form the rotational magnetic-field and ensure the sine characteristic of the output voltage. Compare to Sine Pulse Width Modulation, this method can make the DC bus voltage utilization increased by 15%.

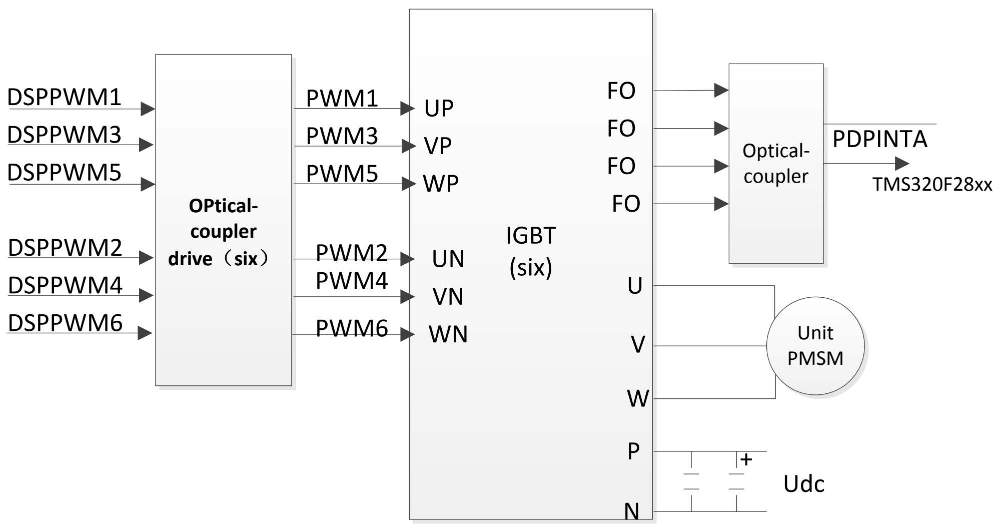


Figure 4. module diagram of IGBT inverter ciucuit

## 4. SOFT CONTROL SYSTEM OF LARGE ASTRONOMICAL TELESCOPE

The PMSM motor drives have been developed to let the d-axis component of current referred to synchronous frame, equal to zero for constant torque operation [5]. Figure 5 is the control the block diagram of the large astronomical telescope, which uses the SVPWM and direct drive techniques to control the salient PMSM based on Vector Control. SVPWM is very important to have the circular stator flux to control the motor. It was presented by a group of German researched in the 1980s.At first, it was used to control inductance motor, and then it was employed to the PMSM because of the several advantages as follows. The techniques of the SVPWM are offering better DC bus utilization, lower torque ripple and lower harmonic losses and the implementation is easier when use the DSP platform. 2r/2s, 2s/2r and 3s/2s mean the coordination conversion among rotating d-q, stationary α-β and three-phase reference frame through Park transformation or Park Inverse transformation or Clarke transformation. Use the id=0 control strategy to simulate telescope mount driving control system.

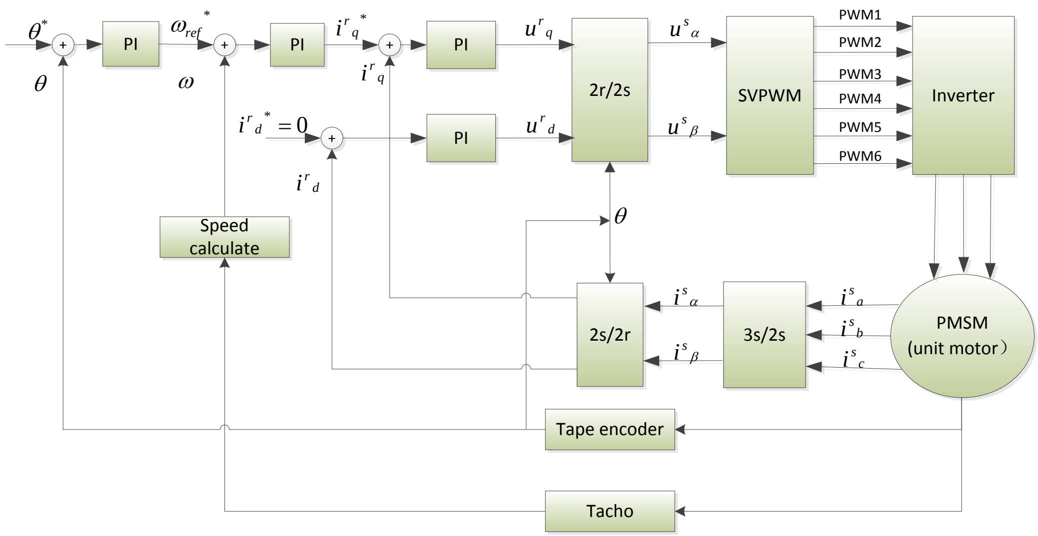


Figure 5. block diagram of software control system

## 5. CONCLUSION

In this paper, the drive system of one segmented PMSM is designed based on TMS320F28xx and IGBT, the position is detected by the encoder and hall sensors. During the software design stage, some special measures have to be implemented to match the speed of the whole segmented PMSM, or you can't let the telescope running at low speed and track target precisely. Although the driving circuit has completed, there are still more difficulties in some details when execute the whole systemof hardware and software system.

## 6. ACKNOWLEDGE

This project is subsidized by National Natural Science Foundation of China (11303065).And the author would like to thanks the colleagues who help me.

## REFERENCES

[1] Leonardi, F. Venturini, M. Vismara, A. McCleer Power Inc., Jackson, MI, "PM motors for direct driving optical telescope," Industry Applications Magazine, IEEE, Vol.2(4). pp. 10–16, August 1996

[2] Takeshi Noguchi, Wataru Tanaka, Toshiyuki Sasaki, Norio Kaifu, Junichi Noumaru, Kiichi Okita, Takeo Shimizu, and Noboru Itoh., "Evaluation of the Subaru telescope control system in-shop test erection," Proc. of SPIE,Telescope Control Systems III, SPIE Press, May 1998, pp.361-366.

[3] Suarez, M., et al. , "The GTC main axes servos and control system," Proc. of SPIE, Advanced Software and Control for Astronomy II, SPIE Press, SPIE Press, July 2008, pp. 70190J.

[4] L. Giacomel, C. Manfrin, and G. Marchiori, "The European ALMA Production Antennas: new drive applications for better performances and low cost management," Proc. of SPIE, Ground-based and Airborne Telescopes II, SPIE Press, June 2008, pp. 701236-701236-11.

[5] Pillay and R. Kishnan, "Modeling, simulation and analysis of permanent-magnet motor drives, Part I: The synchronous permanent-magnet motor drive," IEEE Trans. on Industry applications, Vol. 25, No. 2, pp. 265-273, 1989