Position Measurement of the Direct Drive Motor of Large Aperture Telescope

Li Ying[a,b,c] **Wang Daxing**[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]Graduate University of Chinese Academy of Sciences, Beijing 100049, China

ABSTRACT

Along with the development of space and astronomy science, production of large aperture telescope and super large aperture telescope will definitely become the trend. It's one of methods to solve precise drive of large aperture telescope using direct drive technology unified designed of electricity and magnetism structure. A direct drive precise rotary table with diameter of 2.5 meters researched and produced by us is a typical mechanical & electrical integration design. This paper mainly introduces position measurement control system of direct drive motor. In design of this motor, position measurement control system requires having high resolution, and precisely aligning the position of rotor shaft and making measurement, meanwhile transferring position information to position reversing information corresponding to needed motor pole number. This system has chosen high precision metal band coder and absolute type coder, processing information of coders, and has sent 32-bit RISC CPU making software processing, and gained high resolution composite coder. The paper gives relevant laboratory test results at the end, indicating the position measurement can apply to large aperture telescope control system. This project is subsidized by Chinese National Natural Science Funds (10833004).

Keywords: astronomy, large aperture telescope, direct drive, position measurement, SVPWM

1. INTRODUCTION

The fast development of astronomy and astrophysics requires space and ground-based telescopes with stronger light-gathering power, higher resolution ratio and greater diameter. In recently years, countries around the world successively advanced research plans of establishing 30-100 meters ground-based optical/ infrared telescopes, including the100-meter telescope plan of ESO (European Southern Observatory) (OWL), the Euro_50[1] meters telescope plan of Europe, the two plans of 30-meter telescope of US(CELT and GSMT[2][3]), the VLOT_20 meters telescope plan, the 30-meter telescope plan of Japan（JELT[4]）and so on.

Presently shift-driving approaches of extremely large optical telescopes[5] in the advanced researches over the world mainly contain gear drive, friction drive, direct drive, etc. Some approaches are showed in table 1, from which we can see the direct driving approach is used mostly because of the simple structure, high transmission stiffness, small nonlinear friction torque, easy installation and debug and little maintenance, etc advantages[6].

The core of direct driving technology is designing of special electric motor for it to gain low speed and great output

Software and Cyberinfrastructure for Astronomy, edited by Nicole M. Radziwill, Alan Bridger,
Proc. of SPIE Vol. 7740, 774035 · © 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.855166

of torque so that the reducer is unnecessary in use and meanwhile a better driving performance is gained. The research subject of the National Natural Science Foundation of China of our institute is a precise direct driving turntable with diameter of 2.5 meters and a split multiple servo motor. The motor can optionally joint and output different electric torques in according to the loading capacity of torque, which enables the telescope to be a fixed huge direct driving motor. This paper briefly introduces the industrial design of the electric motor and mainly introduces the position measurement and control system of it.

telescope	driving approach
TMT	direct drive
JELT	direct drive
OWL	direct drive
GMT	gear drive

Table 1. drive approach of extremely large optical telescopes

2. THE EXPERIMENTAL PLATFORM OF DIRECT DRIVE

Astronomical telescopes apply low speed. The rotational velocity of ordinary servo motor is relatively high, so mechanical reducers are used in drives of telescopes. Since mechanical reducers have assembling clearance and more or less sub-harmonic processing errors that are the major factors for tracking errors of telescopes, ordinary telescope systems generally adopt closed-loop position controls to solve this[7]. As to the large aperture optical telescopes for astronomy, because the dynamic mechanical inertia on the turning part is relatively great, thereby the traditional driving methods will reduce precision of dynamic tracking and restrict its application in large optical telescopes for astronomy.

Provided frequency is fixed, the best way to reduce rotational velocity is adding number of pole pairs of the motor. Traditional AC motors have three-phase winding corresponding to each pole, namely there are at least three slots in every pole. Adding pole pairs of the motor will lead to double increase of number of metallic core slots. The subject introduces a new method to match poles and slots, joining 15 sets of motor units to an entire precise turntable, with each set of motor unit composed by 8 poles and 9 slots, to form an AC Permanent magnet servo motor with its pole pair of P=60.

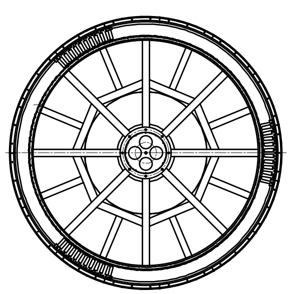

Figure 1.the experimental platform of direct drive

The direct driving electric motor is actually a permanent magnet linear synchronous motor, in inner rotor structure, with 120 pieces of magnetic steels evenly distributed around the rotor[8]. As shown in Figure 1, the rotor of the motor is directly fixed on the rotating frame of the load and the stator is fixed on the base, the motor and the load share a set of highly precise bearing, and the motor and the frame form an entire machine. An absolute and incremental photoelectric encoder is installed on the same bearing of the motor, to directly drive reversing and test of position (speed) of the motor. The encoder and control driver compose the mechtronics direct driving control system of astronomical telescope.

3. PRINCIPLE OF SVPWM AND MOTOR COMMUTATION

The principle of SVPWM: three-phase inverter drive circuit outputs 8 basic voltage vectors (including 6 specific vectors and 2zero vectors) expressed with （Sa, Sb, Sc）=(000,001,011,010… 110,111), as shown in Figure 2. Therein 000 and 111 are zero vectors, in this way equivalent voltage vectors are expressed with(Sa, Sb and Sc)=(001, 011, 010, 110, 100 and 101). So we can see fluctuation of the voltage vectors is relatively great, close to 15%[9][10]. In order to make the voltage vectors outputted by the inverter of the drive circuit approach being round, lower torque fluctuation of the motor to minimum, then use the 8 basic voltage vectors to compose random and equivalent space vector shown as Figure 3. So as to ensure reliable work of AC servo motor, we must guarantee the reliable and ordered open and close of IGBT power tubes besides three-phrase inverter circuit in corresponding space, to enable direct driving motor to reverse in corresponding electrical angle within the limits of 360°in according to requirements of composed space vectors[11].

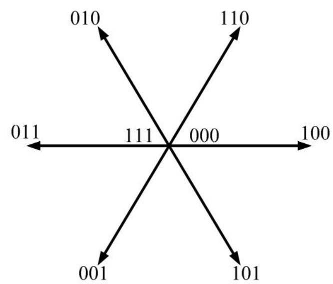

Figure 2. 8 basic voltage vectors

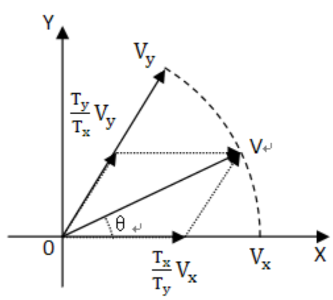

Figure 3. equivalent space vector

The phase relations of the count EMF Eu, Ev and Ew correspondent with motor and the reversing signals of AC three-phrase (Brushless DC) servo motor Pu, Pv and Pw are showed in Figure 3.

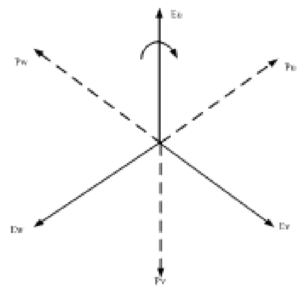

Figure 4. The phase relation of EMF and reversing signal

Based on electromechanical structure of the direct driving of the experimental platform, each 6°of mechanical angle is equal to 360°of electric angle, so in accordance with the requirements of basic vectors of three-phrase inverter, within the scope of electric angle of 360°, the 360°angle should be divided into 6 equal parts evenly in the way of （001 ，011 ，010 ，110 ，100 and 101 ），and a change is needed for per 60°. It means that each 1° changes once in the entire mechanical device, simplified with logical methodology , we can find that means the reversing mechanism of the motor needs a change for per 2°. In Figure 1 of structure diagram, the mechanical angle of each motor unit is 12° and the electric angle is 720°, so 12 reversing change positions are needed.

Common reversing methods for motor include: (1) HALL reversing sensors; (2) incremental photoelectric encoders for reversing; (3) composite incremental photoelectric encoders for reversing (4) rotary resolver for reversing. HALL sensors get reversing signals through sensing intensity of magnetization of N pole and S pole of magnetic steels affixed on the rotor. Its advantage is simple and reliable and disadvantage is inconformity of reserving positions for positive and opposite directions result from delay of HALL components. Incremental photoelectric encoders for reversing must have guarantee of circuit and software with memory function. Once it was locked, the mechanical positions of inner components are not allowed for changing. The resolution ratio of highly precise multi-pole rotary resolver can't meet the requirement of large astronomical telescope on highly precise numerical control. Currently, most of AC servo motors use composite (absolute-incremental) encoders for they have advantages of precise reversing position, precise position of incremental encoder and high resolution ratio, with commercial products available for selection.

The absolute encoder can save position information, so it can find correct position when started, but its precision cannot meet the requirement, while the incremental encoder can't save information and find correct reserving signals when started. In according to the tracking requirements of low speed and high precision of the large caliber astronomical telescope, the signal acquitting system of the servo system is required to be highly precise and accurate. Position measuring system is not only required to measure position of the rotor in highly precision but also provide accurate reserving signals.

The combination of absolute encoder and incremental encoder is used in our measuring system. The absolute encoder is ARS60 of SICK from Germany. With 3600 lines, it can reverse driving motor and control positive and opposite reserving, and can also use AC synchronous motor in other numbers of pole pair to reverse after programming. The incremental encoder chooses ERA-780 strip encoder of HEIDENHAIN from Germany with 90000 line/R. The highly precise composite encoder composed by an absolute encoder and an incremental encoder accomplishes the position measurement. The resolution ratio is finally decided by ERA-780C encoder produced by HEIDENHAIN in Germany, which has 400 sub-circuits and can gain resolution ratio of 0.036″.

4. DESIGN OF THE CONTROL CIRCUIT OF MEASURING SYSTEM

This control system requires the function of acquiring signals from incremental encoder and absolute encoder and outputting satisfied reversing signals in accordance with the reversing principle.

The signals outputted from incremental encoder are in differential electrical levels, and need differential treatment, 4 subdivision and accounting, and then are sent to 32-bit RISC CPU. Signals outputted by the absolute encoder need to pass photo coupler circuit before sent to 32-bit RISC CPU. Since the format of data outputted by absolute encoder is 14-bit gray code, it must be converted into binary by software, the converting principle is:

14-bit gray code $G_{13}G_{12}.....G_2G_1G_0$,

according binary code $B_{13}B_{12}...B_2B_1B_0$,

$B_{13} = G_{13}$,

$$B_{i-1} = G_{i-1} \oplus B_i, i = 1,2,...12$$

CPU processes mathematical conversion in according to signals collected from the absolute encoder and outputs reversing signals that is to be sent to the driver of the motor after passing differential circuit. Figure 4 is the control circuit of measuring system. Figure 5 is the result of the reversing signal.

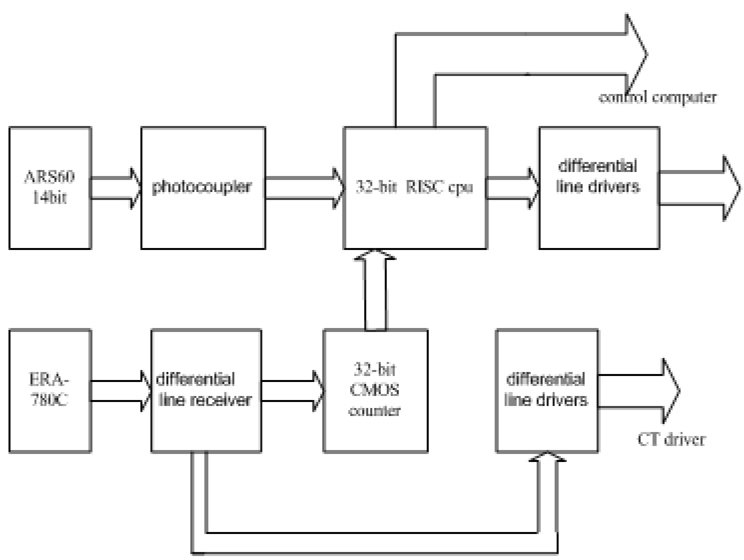

Figure 5. the control circuit of measuring system

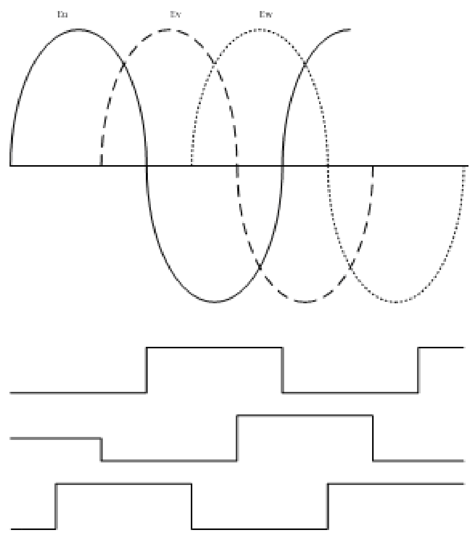

Figure 6. the result of the reversing signal

5. CONCLUSION

Along with development of the direct driving technology, it will be more and more used in extremely large astronomical telescopes. The paper mainly introduces position measuring system. There are still many difficulties in direct driving technology, such as design of motor driver, influences of electromagnetic interference, etc. which still need further researches so that the direct driving technology will be better used in design of telescopes.

ACKNOWLEDGMENTS

This project is subsidized by Chinese National Natural Science Funds (10833004).

REFERENCES

[1] Holger Riewaldt, Martin Lastiwka, et al., Wind on the Euro50 enclosure[J], Proc. SPIE of Vol. 5495, 537-548, 2004

[2] Jerry Nelson, Gary H. Sanders, et al., TMT Status Report, Proc. SPIE of Vol. 626728, 1-17, 2006

[3] James Roger P. Angel, Jon S. Lawrence, et al., Concept for a second Giant Magellan Telescope (GMT) in Antarctica[J], Proc. SPIE, Vol. 5382, 76-84, 2004

[4] M. lye, JELT WG, Concept study of Japan Extremely Large Telescope[J], Proc. of SPIE Vol. 5489, 2004

[5] Jerry Nelson, Thirty-Meter Telescope: Progress and Approaches[J], Proc. of SPIE Vol. 6986, 698602, 2008

[6] Dario Mancini, VST project: drive system design and strategies for performance optimization[J], Proc. of SPIE Vol. 4837, 389-400, 2003

[7] Leonardi, F., Venturini, M.1, et al., Design and optimization of very high torque, low ripple, low cogging PM motors for direct driving optical telescope[J], Proceedings of the 29th IAS(IEEE Industry Applications Society) Annual Meeting. v1, p272-278, 1994

[8] M. Suárez, J. Rosich, et al., The GTC main axes servos and control system[J], Proc. of SPIE Vol. 7019, 70190J, 1-12, 2008

[9] R.D.Lorenz., High-resolution velocity estimation for all-digital servo drives[J]. IEEE Trans. Ind. Applieat.,1991,27(4):1121-1128

[10] F. Blaschke. The principle of field orientation as applied to the new Trans vector closed loop control system for rotating field machines[J]. Siemens Review[C], 1972, 39: 217-220

[11] Ben-Bralum, L.The analysis and compensation of dead-time effect in three phase PWM inverters[C], IEEE IECON'98, Rec, 1998:202~205Booth, N. and Smith, A. S., [Infrared Detectors], Goodwin House Publishers, New York & Boston, 241-248 (1997).