Servo control system for friction drive with ultra-low speed and high accuracy

Shihai Yang[1, 2], Zhenchao Zhang[1]

1.National Astronomical Observatories / Nanjing Institute of Astronomical Optics& Technology, Chinese Academy of Sciences，Nanjing 210042. 2.Graduate School of the Chinese Academy of Sciences，Beijing 100049

ABSTRACT

Due to its high accuracy and good performance at low speed, friction drive is widely used in turntable and large astronomical telescopes such as LAMOST and Keck. Especially, friction drives are implemented on the axes of azimuth, altitude and field rotation in LAMOST telescope. This paper describes the study on servo control system for friction drive with ultra-low speed and high accuracy. The principle, constitution, control algorithm and realization of servo system based on friction drive are analyzed and explored.

Keywords：control system, friction drive, ultra-low speed

1. INTRODUCTION

These days there are two prevailing ways to drive large astronomical telescopes. One is friction drive, the other is direct drive. Both of them can satisfy the need of stability and accuracy of large astronomical telescopes. They possess their own unique features. Without the use of 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 perform well in large astronomical telescopes such as VLT. On the other hand, friction drive has been employed in a wide range of turntable and large astronomical telescopes such as LAMOST and Keck. Compared with direct drive, friction drive don't need so large capacity of motor. With low cost, high performance and without periodical error and backlash, friction drive is promiseful in the area of ultra-low speed and high accuracy drive.

But friction drive has its own deficiencies. Slippage, creepage, fluctuation of friction torque should be overcome. To achieve quick response and high accuracy at ultra-low speed (for example,0.1"/s), servo control system should take effective algorithm and be designed carefully. And ultra-low speed characteristic and stability of friction drive should be carefully studied including mechanism and servo control system . This paper describes servo control system only. A control system of large-inertia turntable is taken as an example, extracting experience from LAMOST (The Large Sky Area Multi-object Fiber Spectroscopic Telescope).

---

[*] Correspondence: Shihai Yang , Email: shyang@niaot.ac.cn Telephone: +86-25-5482-267; Fax: +86-25-5405562; Nanjing Institute of Astronomical Optics & Technology (NIAOT), Bancang Str. 188 210042 Nanjing P. R. China

Advanced Software and Control for Astronomy II, edited by Alan Bridger, Nicole M. Radziwill
Proc. of SPIE Vol. 7019, 70192B, (2008) · 0277-786X/08/$18 · doi: 10.1117/12.787730

2. STRUCTURE OF CONTROL SYSTEM

2.1 Overview

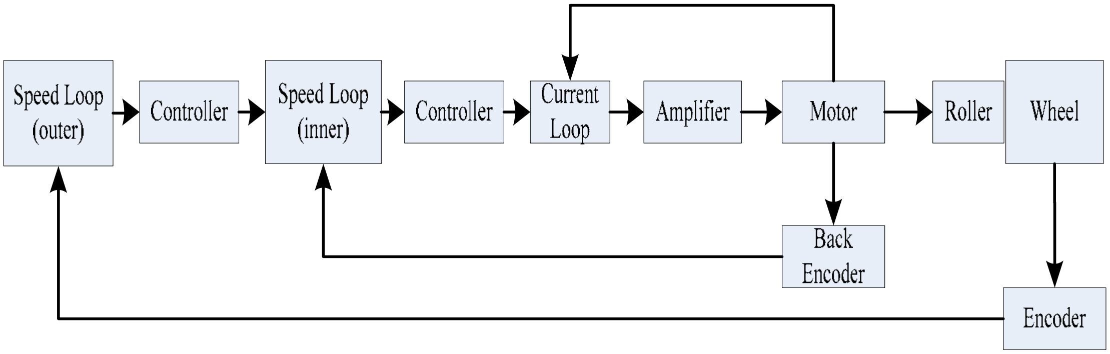

Fig. 1: Servo schematic

The friction transmission is provided with two sets of drive rollers. There are two sets of roller located on opposite sides of a big wheel to minimize the eccentric caused by preload against the big wheel. The friction rollers are 50mm thick and 100mm in diameter. The contact stress between the roller and wheel should maintain sufficient friction force to keep the necessary drive power and torque. The big wheel, namely, driven roller, 1000mm in diameter and 60mm thick made of bearing steel, is supported by three posts through ball bearings. [1]

Three control loops are employed in the control system.： current loop, inner speed loop, outer speed loop. They are cascade. Servo schematic is shown in Fig 1. Current loop is closed in the amplifier of motor. The function of current loop is to regular the current of motor and in this way to keep the stability of motor torque. At the same time, current loop should response as quickly as it can to control over- current. These requirements can be met by using a Proportional- Integral (PI) compensator.

The control system is a rate servo system indeed. Friction drive system study (FDSS) aims at studying the characters of friction drive at ultra-low speed and it requires high accuracy and stability of speed. Two speed loops are applied. The inner speed loop tries to decrease the position relevant periodical disturbance of motor and the function of outer speed loop is to reject load disturbance.

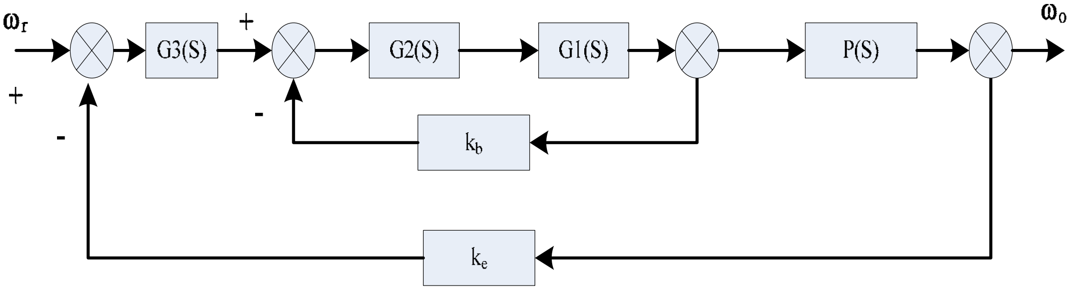

Fig. 2: Block diagram of the controlled plant

2.2 Control system hardware setup

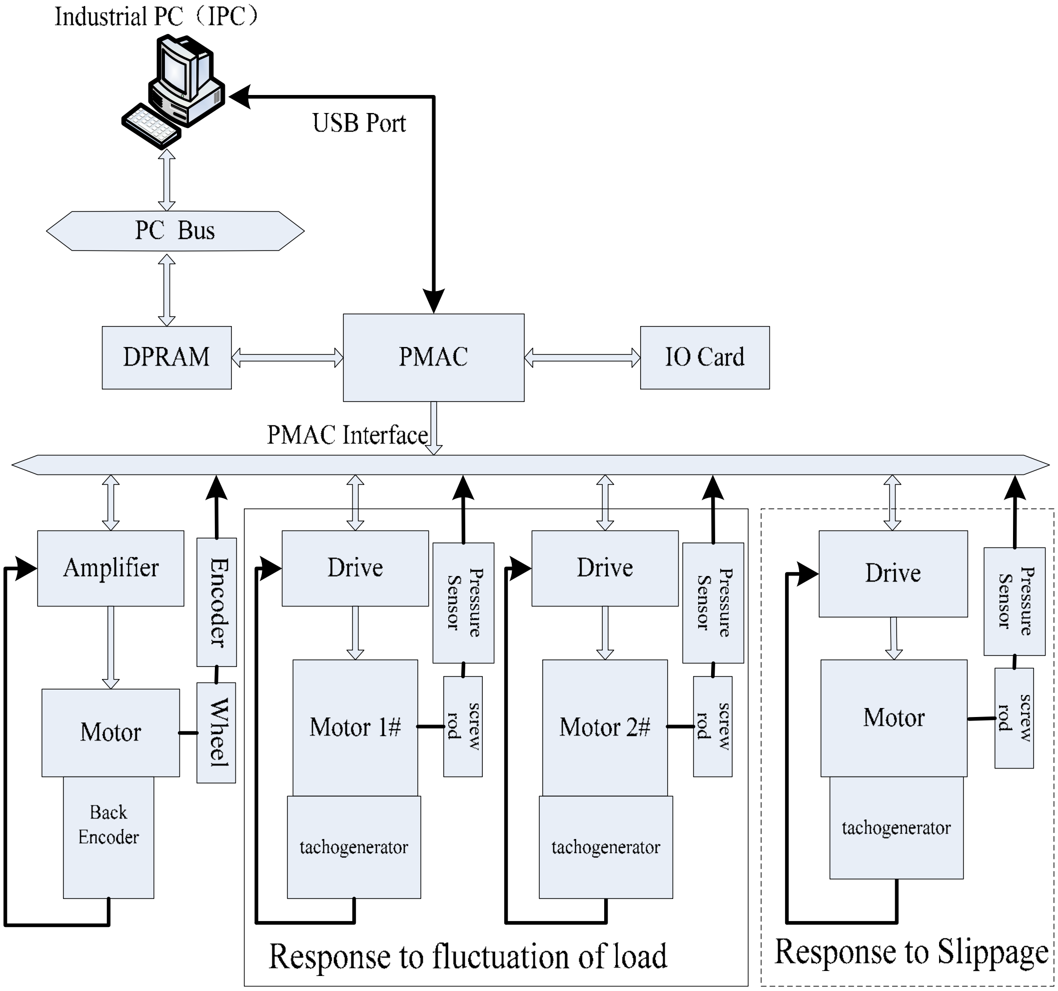

Fig. 3: Structure Schematic of Control System

The whole control system includes three parts. Friction Drive System (FDS) is supposed to rotate a big wheel at some velocities precisely through a drive roller which is manipulated by a torque motor. Stress Maintain System (SMS) is to maintain constant stress between the contact surface of the drive roller and the big wheel. The stress can be adjusted in real time to maintain sufficient friction force and better servo performance when load fluctuate. Stress sensors are applied as feedback. The relationship between the stress and speed precision will be studied. Geometrical Slip Control System is used to analyze the characters of stick-slip during friction transmission.

2.3 PMAC2A-PC/104 controller

A PMAC2A-PC/104 controller from Delta Tau Data Systems, Inc. is utilized, which is shown in Fig. 4.

The PMAC2A-PC/104 motion controller is a compact, cost-effective version of the Delta Tau's PMAC2 family of controllers. The PMAC2A-PC/104 can be composed of three boards in a stack configuration. The baseboard provides four channels of either DAC ±10V or pulse and direction command outputs. The optional axis expansion board provides a set of four additional servo channels and I/O ports. The optional communications board provides extra I/O ports and either the USB or Ethernet interface for faster communications. [5]

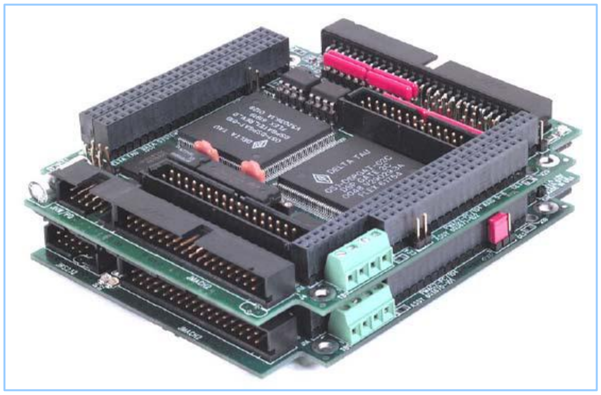

Fig. 4: PMAC2A/PC104 controller

The electronics configuration selected for FDSS is as follows:
_ 4 axes of motion control.
_ PMAC2A/PC104 CPU board
_ 80 MHz CPU
_8 K x 16 DPRAM
_ 4 TTL encoder inputs and 4 1-Volt ptp encoder inputs x 4096 interpolation.
_ Number and type of the digital inputs and outputs: 16 Inputs / 16 TTL outputs.
_ USB interface

Real-time tasks are fulfilled by PMAC. The outer speed loop is based on the PMAC. The PMAC2A PC/104 communicates through the RS-232 serial interface. But the speed of serial communication via RS-232 is slow. So Option 1A is selected, which provides a 12 Mbit/sec USB interface allowing USB communications with the PMAC2A PC/104 motion controller.

HEIDENHAIN encoder ROD 905 is used for outer speed loop.

PMAC can output pulse and direction signals for controlling amplifiers of torque motor. These signals are at TTL levels. Another way to command the motor is using one analog output signal. This signal can be either single-ended or differential, depending on what the amplifier is expecting. In FDSS , pulse and direction signals are used.

2.4 Analysis of the turntable system

2.4.1 Characteristics of the turntable

load inertia : 34.54Kg.m^2

transmission ratio : 10

Load inertia reduced to the motor axis= $34.54/10^2$=0.3454 Kg.m^2

Lowest velocity of the load : 0.1 ″/s

Speed accuracy of the load : 0.02 ″/s (RMS)

Highest velocity of the load : no requirement (tests are limited to very low velocity)

2.4.2 Characteristics of expected motors

With ratio 10 between diameter of wheel and diameter of roller:

Lowest velocity required: 1 ″/s

Continue torque : 1 Nm

Brushless servo motors perform well at very low speed. But rotational uniformity at minimum speed requires enough resolution of feedback encoder.

In general, at the lowest speed, if the feedback encoder frequency is still higher than the system control bandwidth, the rotation of motor will be perfect.

2.4.3 Specification for back encoder

HEIDENHAIN encoder ROD 255 : 18,000 pulses per rev with interpolation 8192.

$$\frac{3600*360}{18000*8192} = 0.0087890625''/\text{cts}$$

At the speed of 1 ″/s :

encoder frequency =1/ 0.0087890625 =113 counts/s .

Typically, system control bandwidth is 30-50 Hz. So, the feedback encoder frequency satisfies the lowest speed's need.

2.4.4 Specification for load encoder

HEIDENHAIN encoder ROD 905 : 36,000 pulses per rev with interpolation 4096.

The encoder is co-axis with the Wheel and is used for outer speed close loop.

$$1\text{ pulse}=\frac{360\times 3600}{36000\times 4096}=0.0087890625''$$

2.4.5 Envisaged Motor

TMB 0140-030

Rotor inertia: 0.00099 $Kg.m^2$

Continuous torque : 7.26 Nm

Number of poles : 22

Theoretically, sinusoidal brushless torque motor will not bring about torque of electromagnetic wave when back EMF and phase current of permanent magnet synchronous motor(PMSM) are sinusoid. But in practice, the current and back EMF are not real sinusoid because of technics level.

The mathematic expression of the torque fluctuation is presented as below.

$$T = \sum_{\gamma=1}^{\infty} \delta T_\gamma \sin(\gamma p \theta + \Delta\varphi_\gamma) \qquad (1)$$

T : torque fluctuation

δT_γ : amplitude of γ-order torque fluctuation

2p: number of poles

θ : angle of movement

$\Delta\varphi_\gamma$: phase of of γ-order torque fluctuation

In the experiment, the turntable moves in a uniform circular movement.

$$f = \frac{\gamma p \omega}{2\pi} \quad (\theta = \omega t) \qquad (2)$$

From the formula above ,we can see there is a position relevant periodical disturbance. To improve the low speed function of the turntable, we must choose the motor carefully and suppress the disturbance with proper control algorithm.

A motor with excellent low speed stability and pindling torque ripple is important to ultra_low speed and high accuracy turntable.

Another important factor that influence on the stability of ultra-low speed of friction drive is imbalanced load torque which is caused by the mass asymmetry of turntable and inconstant friction torque .

PID （proportional–integral–derivative）control is a generic control loop feedback mechanism widely used in industrial control systems. However, classical PID control cannot entirely satisfy the needs of the system because the parameters of classical PID controller are constant. Due to linear model, classical PID control could not regulate the overshoot and the response time to an ideal state at the same time. Non-linear PID control by online regulating PID parameters could realize a better performance. Meanwhile, this control method retains the virtues of the linear PID control, such as simple in structure, easy to be realized and strong robustness.

3. SOFTWARE

The software of control system consists of two parts. One is written by Visual C++6.0 and runs on an industrial PC (IPC) with Windows XP OS. The other is Real-time PLC program which runs on PMAC.IPC-embedded software is object-oriented Design and easy for development and debug. Three major tasks are involved, namely send commands to PMAC, exchange data with PMAC through DPRAM, provide a human-machine interface for easy manipulating the whole system.

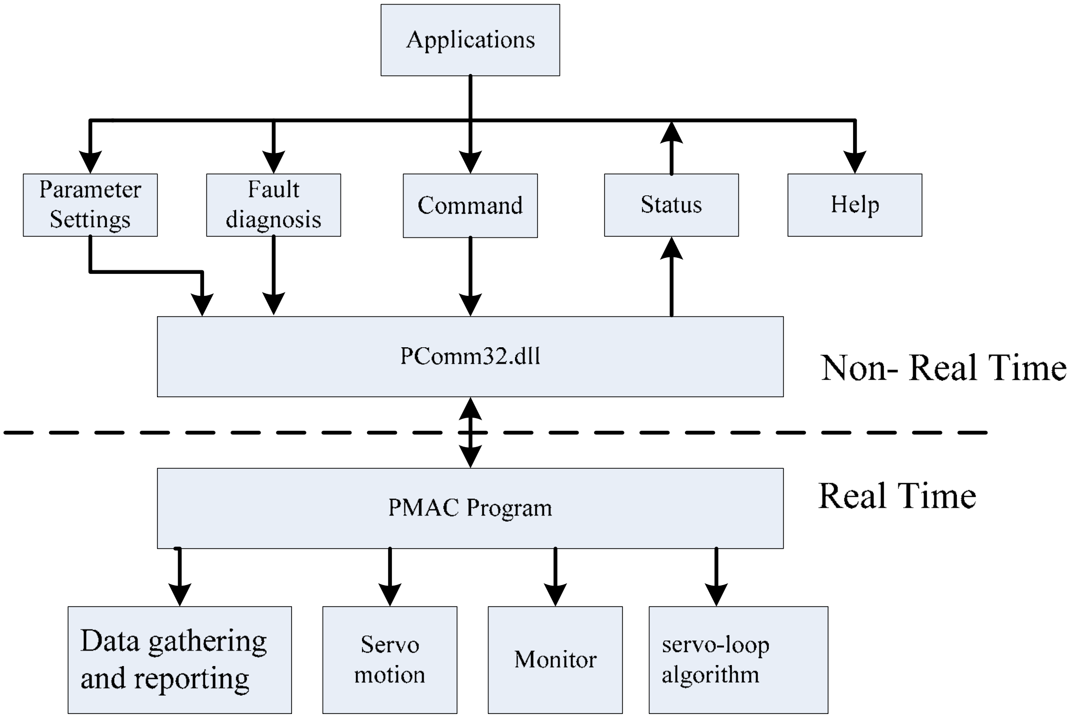

Fig. 5: Software structure

Real-time PLC program conduct real-time interpolation, servo parameter update, error calculation, compensation estimation, motor motion control and process the data from I/O ports. We use a dynamic link library PCOMM32.DLL to communicate with PMAC.

The software structure is shown in Figure 3. It is can be seen that it is a distribution control system. Windows XP is not a real-time OS. But Windows XP is friendly and familiar to many people. So IPC-embedded software based on Windows XP is employed but it just fulfills non-real time tasks. Hard real-time control tasks are fulfilled by PLC program on PMAC.

Indeed, there are several real time OS which can meet the real time task requirements for friction drive system such as VxWorks, QNX and RTLinux. But some of them are too expensive. RTLinux is low cost high performance but device driver for linux isn’t enough. For example, there is no official PMAC driver for linux. The software structure is shown in Fig. 5.

4. CONCLUSION

The friction drive system study is facing an enormous challenge because many cutting edge techniques are involved. The study is not fulfilled yet.

5. ACKNOWLEDGEMENT

The author would like to thank Mr. Christophe Daugny. The discussion with him in this regard is beneficial and interesting. Many thanks also to prof. Daxing Wang and Dr. Guomin Wang for their help. The author is grateful to LAMOST project and National Natural Science Foundation of China for the financial support.

6. REFERENCES

1. Guomin Wang, Lisheng Ma, Zhengqiu Yao, Guoping Li, “Experiment study on friction drive”, Proc. of SPIE Vol. 5495, ed. by Joseph Antebi, Dietrich Lemke, pp.419- 428, 2004.
2. Xinqi Xu, Shihai Yang, “Motion control for LAMOST focal plane”, Proc. of SPIE Vol. 6052 , ed. by Farrokh Janabi-Sharifi, pp 60520N-1 - 60520N-8，2005
3. Xu Xinqi， Xu Lingzhe， Luo Qiufeng，“Novel Control Technologies for Optical Astronomical Telescopes of Contemporary Era”， Progress in Astronomy，Vo1．21， No．3，Sep.，pp195－205, 2003
4. Huo Xin， Yao Yu, “Suppression of moment fluctuation in high precision rate table servosystem”, Electric Machines And Control, Vo1．11, No．2, pp207-210, March 2007
5. DELTA TAU Date Systems, Inc., PMAC2A-PC/104 hardware manual, 2004