AS5048 Magnetic Encoder for the Application in DC Motor Position Control of Portable Spectrometer

Jie Liu[1] ,Zekun Liu[1] ,Zhihong Wang[1] ,Junyi Cao[1]
1.College of Instrumentation & Electrical Engineering, Jilin University
Changchun, China
l_jie@jlu.edu.cn, 936205432@qq.com, zhwang@jlu.edu.cn, 547256533@qq.com

***Abstract*—The AS5048 is applied in high precision and small Angle position control system of scanning mechanism in portable raster scan type spectrum analyzer with dc torque motor. This paper expounds the working principle, main features of AS5048, installation and using, and implementation method in position control. The design of permanent magnet dc torque motor position control system adopts the special motor control chip TMS320F2812.It cooperates with software control method and motor drive module, realizing the motor's forward-reversing, start-stop, small angle control. The experimental results show that AS5048 work reliablly, servo system moves highly precious and basically meets the application of spectral instrument.**

***Keywords*—DC torque motor,DSP, magnetic encoder, grubbs criteria, angle position control,fuzzy control**

1 INTRODUCTION

The main function of scanning mechanism in portable raster-scan near infrared spectrum analyzer is driving grating. Then, the optical institution can produce different wavelengths of light. DC servo system is the most critical driving part to scan institution. Driving part adopts DC torque motor and magnetic encoder, realizing const angular displacement 3.6°, namely the increase of wavelength of 1 nm. Extension end of DC torque motor shaft is coupled with lead screw by coupler. Non-extension end is applied to install magnetic encoder composing a motor position feedback system. Because the absolute encoders are obviously better than incremental encoders in positioning, and increasingly used in positioning of industrial control, so we choose the absolute type magnetic rotary encoder AS5048 of AUMS. Servo control system requires a shorter response time, good low-speed crawling, so choose the middle moment of inertia dc torque motor as driving source, precipitating superior dynamic response characteristics of the system.

2 MAGNETIC ROTARY ENCODER

Portable near infrared spectrum analyzer puts forward very high requirements to portability, weight, volume, etc., so this article chose the convenient installation, small volume, low environment requirements application-specific integrated circuit AS5048 type magnetic encoder. The AS5048 is an easy to use 360° angle position sensor with a 14-bit high resolution output. The maximum system accuracy is 0.05° assuming linearization and averaging is done by the external microcontroller [2]. The IC measures the absolute position of the magnet's rotation angle and consists of Hall sensors, analog digital converter and digital signal processing. The zero position can be programmed via SPI or I²C command. Each position encoder has uniqueness, it does not need memory, don't need to find a reference point, the anti-interference characteristics and date reliability is greatly increased. This simplifies the assembly of the complete system because the zero position of the magnet does not need to be mechanically aligned. It helps developers to shorten their developing time. The sensor tolerates misalignment, air gap variations, temperature variations and as well external magnetic fields. This robustness and wide temperature range (-40°C up to +150°C) of the AS5048 makes the IC ideal for rotation angle sensing in harsh industrial and medical environments. Several AS5048 ICs can be connected in daisy chain for serial date read out. The absolute position information of the magnet is directly accessible over a PWM output whose duty cycle is proportional to the measured angle and can be read out over a standard SPI or a high speed I²C interface. [2]

2.1 Internal structure and pin configuration

The AS5048 is a magnetic Hall sensor system manufactured in a CMOS process. A lateral Hall sensor array is used to measure the magnetic field components perpendicular to the surface of the chip. Internal principle diagram is shown in figure 1.

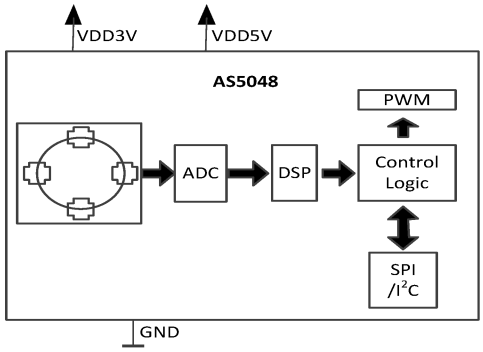

Fig. 1. Internal structure

The AS5048 is uses self-calibration methods to eliminate signal offset and sensitivity drifts. The internal structure of AS5048: Hall sensor array, ADC module, DSP module, Control logic, PWM output and standard SPI, I2C interface. Through Sigma-Delta Analog-to-Digital Converter (ADC) and Digital Signal-Processing (DSP) algorithms, the AS5048 provides accurate high-resolution absolute angular position information with a small diametrically magnetized (two-pole)

978-1-4673-9613-4/16/$31.00 ©2016 IEEE

standard magnet. The AS5048 provides a 14-bit binary code representing the angular position of the magnet.

2.2 SPI hardware connection

The AS5048A only supports slave operation mode. Therefore CLK for the communication as well as the CSn signal has to be provided by the test equipment. The following picture , figure 2, shows a basic interconnection diagram with one master and an AS5048A device and a principle schematic of the interface core. [2]

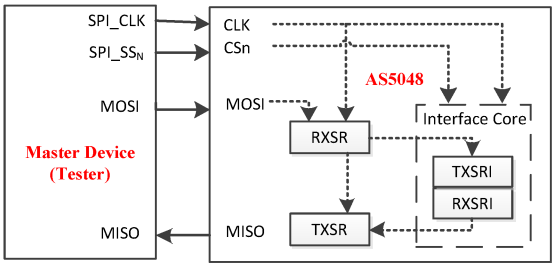

Fig. 2. SPI Connection AS5048A with uC

Because the interface has to decode the sent command before it can react and provide date the response of the chip to a specific command applied at a time T can be accessed in the next transmission cycle ending at T + TCOM. [2] So if you want to read the feedback date for the last time, you need send a command word again. Figure 3 is SPI sequence diagram of AS5048.

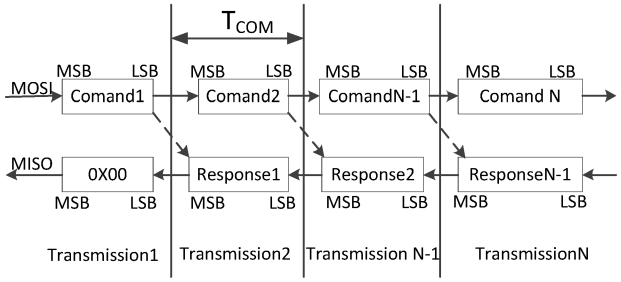

Fig. 3. AS5048 SPI sequence diagram

3 POSITION CONTROL STRATEGY OF SERVO SYSTEM BASED ON AS5048

DSP is used as the main controller for permanent magnet dc servo system control circuit. The software control part is mainly based on TI Company's CCS3.3 development platform, and use standard cprogramming language to develop motor angle control system. Development steps follow the principle of modular design, then we completed the designs of sub modules: the main program and motor drive module, acquisition module, signal processing and control module. The main program function is to initialize the various registers, open the interrupt of DSP, and set the interrupt, implementing the task scheduling and state management for the whole closed loop system as a background process. Through the control instruction, motor drive module realizes start-stop, initialization of position and continuous scanning, and multiple angle control of 3.6°.

3.1 Acquisition of position signal

To economize DSP resources, SPI adopts the query method to send command word, interrupt way to receive the angle signal. Angle of Motor control is small, only 3.6 °, and motor are not allowed to return (reverse) in the scan cycle, so motor's practical value must be refreshed and acquired at a higher frequency. Finally, when the actual angle enters the threshold range, motor is braked immediately.

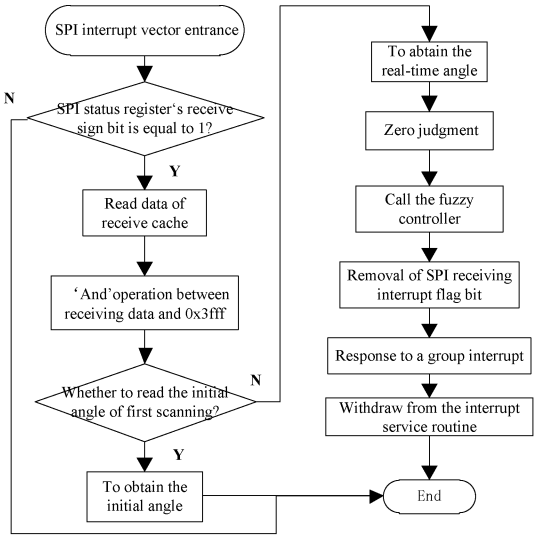

Fig. 4. Acquisition program block diagram

At the same time, the motor's brake eventually will produce a small angle jitter. The tiny wobble will affect the accuracy of stop position, resulting in a random error. If every start angle of the motor is read from encoder, then the random error will be accumulated in continuous angle control. Therefore, the angle jitter error must be compensated. Compensation method is every start angle of the motor is not read again, on the contrary, the last braking angle is used as the starting angle to eliminate jitter error in the aspects of software. Acquisition program block diagram is shown in figure 4.

3.2date processing

Portable spectrograph works in complex and changeful magnetic field conditions of outdoor environment, while the magnetic encoder is not sensitive to external magnetic field disturbance, but because for a long time magnet is fixed on the rotor shaft and environmental temperature is always changing, the encoder output linearity may fall. If the magnetic field of magnet is enough weak, all kinds of noise is doped into angle signals, resulting in fluctuation of the angle information of the SPI interface. In addition, nonstandard operation of the hardware circuit will also cause bad points. Therefore, we need to identify the date collected by DSP, whether it is true value. Adopting Grubbs criteria to process dates: the absolute value of the residual error of measured value satisfy the followed condition: [5]

$$|V_i| > G_g \qquad (1)$$

Then, we judge the measured value is gross error, and it should be removed. According to the error theory, in the process of date processing, we saved previous ten right values to judge whether the 11th date is true. After the judgment, dates

will be numerically shift in order to generate new previous ten right values.

When we adopt the absolute encoder, every position point corresponds to the fixed value, so that in the process of signals reading, there is a zero (peak) judgment problem. For example, when two adjacent absolute angle values range from 5 to 16383 (14 encoder 16384 = 2^{14}) or 16383 to 10, how to judge whether the rotation angle value (rotation angle value =current value－initial value) meets the required control set value 3.6 °.This paper recommends two ways, the first is we use software to detect the changed symbols of the above subtraction value; The second is we use acquisition mode to detect the sudden change of duty ratio of PWM output pin of encoder. This paper uses the first way to realize the zero judgment. Date processing block diagram is shown in figure 5.

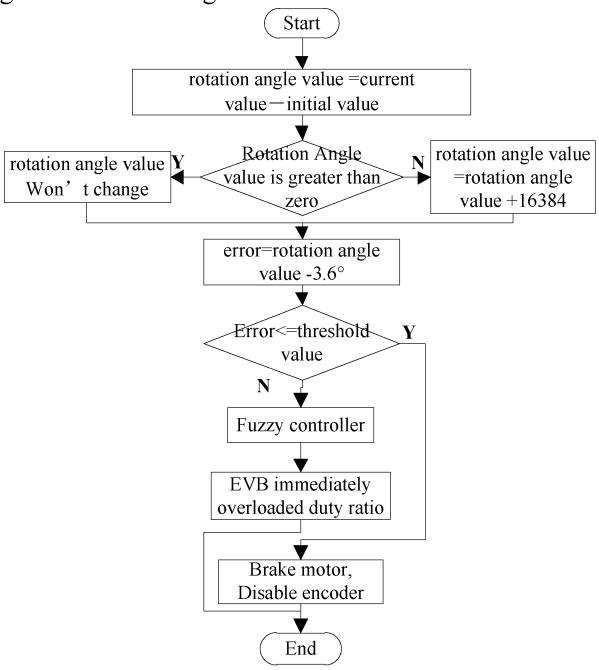

Fig. 5. Date processing block diagram

3.3 Control Strategy

The output sample rate of the encoder SPI is 11.25 KHz (0.089 MS), which means that if we want to completely collect all 16384 absolute positions without omissions, we need 1457 MS at l east. Namely, the m otor needs 1.457 s , and correspondingly maximum rotation rate of rotor is 41 RPM. If the speed i s m ore than 4 1RPM, surely we won't be a ble t o collect all 163 84 absolute position from encoder. In that way, the necessary r otation an gle 3.6°, the number N of corresponding a bsolute angle of rotation angle is s hown as follows:

$$N=\frac{3.6^{\circ}}{360^{\circ}}\times 2^{14}=163.84 \quad (2)$$

From the above formula it can be obtained that 3.6 °corresponds to 164 absolute angles of encoder. Shown as table Ⅰ.

TABLE I. ABSOLUTE ANGLE AND THE CIRCUMFERENTIAL ANGLE CORRESPONDING TO THE TABLE

Absolute angle	Circumferential angle
1	0.0219°
……	……
160	3.5156°
161	3.5376°
162	3.5596°
163	3.5815°
164	3.6035°
165	3.6254°
166	3.6474°
167	3.6694°
168	3.6914°
169	3.7134°
170	3.7354°
……	……
16384	360.0000°

At the beginning of the system design, the system precision is set to 0.15. In the whole control process of 3.6°, the encoder doesn't miss anyone absolute angle, it needs at least 15 MS. If you want to a chieve the hi ghest accuracy o f 0.05 ° i n t he technical date, and the encoder resolution of 0.0219 °,encoder can't miss anyone location, in this case the demand of motor's low speed crawl ability and quickening of whole control system are extremely higher. The encoder can read the angle signal every six absolute angles. At this time, the rotor speed can reach 246 RPM, therefore the encoder can fully meet the precision of the accuracy of the system.

Mechanical p arts and o ptical p ath parts of spectral instrument a re motor's load. Their transfer fu nction i s not difficult t o determine, therefore it adopted fuzzy-PID control strategy.

PI controller is used in the DC system, because the system demands the less system response speed and the high precision. Simulink gives the transfer function diagram of PI controller, motor a nd t he l oader. Then, in t he F uzzy-PI c ontroller, th e system output error e , e rror derivative d e/dt a re used a s Fuzzy-PI controller i nput, t he output of F uzzy-PI c ontroller input:

$$u(t) = K_u Fuzzy\left(K_e, K_d \frac{de}{dt}\right) - K_i \int e dt \quad (3)$$

Wherein t he i nput s ignal e rror $e\in[0,10]$, error d erivative $\frac{de}{dt} \in [0,10]$ and the output signal, duty cycle of PWM wave, $u \in[20,98]$, the above all are blurred into four ranks: ZO, PS, PM, PL. Control rules as shown in table Ⅱ.

TABLE Ⅱ. FUZZY CONTROL RULES

de/dt	e			
	ZO	PS	PM	PL
ZO	ZO	ZO	ZO	ZO
PS	PS	PS	PM	PM
PM	PM	PM	PL	PL
PL	PL	PL	PL	PL

In this paper, Fuzzy-PI switch control algorithm is adapted. And bidirectional switching control algorithm principle is shown in Figure 6. The basic idea of that is PI controller will be used to control the system in a wide range of errors, but, the PI

controller will be converted into Fuzzy-PI hybrid controller within a small margin of error.[7] The Fuzzy-PI hybrid controller can reduce the overshoot of the system and the settling time. The conversion between them will be automatically controlled by the DSP chip based on the error range.

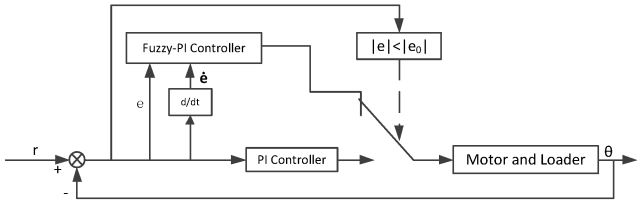

Fig. 6. bidirectional switching control algorithm principle

Generally, the more pointed curve shape of the membership function is, the higher resolution of fuzzy subset is, the more sensitive system control; Membership function curve shape is more smooth, which should indicating that the control characteristic is relatively flat, and stable performance is also better[8]. This paper uses the nonlinear membership function that has sensitive response, short adjusting time. Fuzzy inference system input-output characteristic curve is shown in the following figure 7.

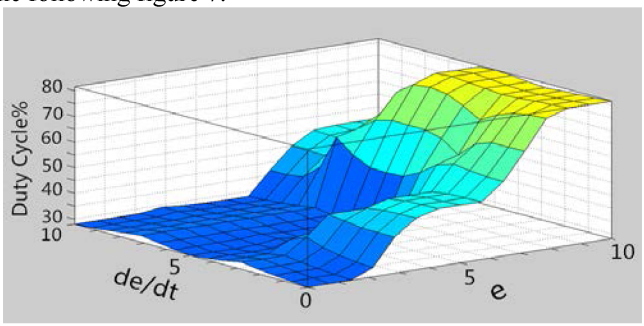

Fig. 7. Fuzzy inference system input-output characteristic curve

4 Analysis Experimental Date

Finally, install the location control system to the spectrum instrument for debugging and inspection, spectrum instrument scanning mechanism completes all specified actions: initializing light zero position, 1200-2500nm wavelength scanning, stop scanning. Testing experiment needs that control system have to complete 1300 times consecutive 3.6 ° feed at least, and anyone start-stop angle should be controlled between 3.55 to 3.75 degrees. In the experiments, sample randomly 1000 angle date points. Its scatter diagram is shown in figure8.

The results show that the magnetic encoder works reliably, stably in position control system. In addition, the scanning process of the small angle control system control have high precision and operate smoothly, and more than 97.20% of the angle date points are between 3.58 to 3.66 degrees. The other parameters: average of 1000 points reach 3.6096 °, the mean square value reach 0.0296 °.

For larger error numerical point, analyze the reasons as follow: because the coaxiality between the drive screw and motor rotor shaft is lower, the motor load changes dramatically and motor speed will be in frequent fluctuations irregularly. All of above can cause motor position angle is prone to appearing bigger error without standard speed closed loop.

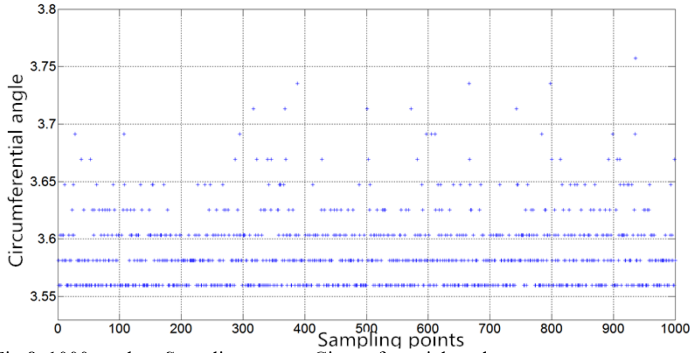

Fig.8. 1000 random Sampling ponts - Circumferential angle curve

5 Summary

This paper introduces the principle of AS5048 encoder and its application in servo system. The experimental results show that the AS5048 can achieve high precision and small angle motion control excellently. The overall servo system runs smoothly, efficiently. Angle acquisition module and control processing module enables the system with the characteristics of the rapid and high precision accurately moves to the specified location. In addition, considering the transfer function is hard to calculate and running angle is too small, so under the premise of satisfying precision, choose fuzzy control strategy, and greatly shorten the development cycle. The whole control system has high integration level, small volume, low environmental requirements, is suitable for portable spectrum analyzer.

863 National Fund: SS2013AA063903.
Component Name: Development of geophysical and special heavy load intelligent unmanned helicopter.

References

[1] Z. Wu, X.M. Lü, "Design of Angular Velocity and Position Observer for Servo Motors With Magnetic Encoders," Proceeding of the CSEE, vol. 3, issue 9, pp1, 2011.

[2] Austriamicrosystems, AS5048A/AS5048B Magnetic Rotary Encoder 14-bit Angular Position Sensor, Datasheet, pp 1-28,2012.

[3] Austriamicrosystems, AS5040 10-bit Programmable Magnetic Rotary Encoder, Datasheet, pp1-28. 2007

[4] X.M. Wang, DSP control of motor: the application of TI DSP (2th version), Beijing University of Aeronautics and Astronautics Press, pp76-92, 2009.

[5] L.F. Lin, H. Xiao, X, Q, Wu, "Compare Chauvenet criteria and guidelines Grubbs," University Physics Experiment,vol 12, issue 6, pp 1-2, 2012

[6] Y, Fang, H, P, Yang, "DC speed regulation system based on fuzzy-PID control with Kalman filter, " Journal of Mechanical & Electrical Engneering, vol 4. Issue 27, pp 42-43, 2010.

[7] Y, H, Tao, New PID Controller and Its Application, CHANA MACHIN PRESS, pp 119-120, 2002.

[8] X. F. Lin, Z. W. Liao, H. F ang, " The Action and Influence of Membership Function on the Performance of the Fuzzy Control, " ELECTRIC MACHINES AND CONTROL, vol 12, issue 4, pp 199-200, 1998.