Research on Closed-loop Control of Step Motor Based on Magnetic Encoder

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Abstract. Stepper motor is an actuator for converting electric pulse signal into angular displacement, which is characterized by no cumulative error, low mature price and good stability, which is widely used in various industrial environments. However, its disadvantage is also very obvious, that is, can only open loop control, the motor can only passively rotate according to the signal and cannot effectively feedback control. If closed-loop control is required, servo motors with higher price and larger volume are required. In order to solve this problem, this paper refits the stepping motor with the help of the characteristics of the magnetic encoder, so as to realize the closed-loop control of the stepping motor.

Keywords: Stepper motor, magnetic encoder, closed-loop control.

1. Introduction

With the rapid development of the Chinese economy, China has gradually become the world's processing center. With the emergence of the step motor and the servo motor, the accuracy of the control circuit is greatly improved. The step motor rotates step by step at a fixed angle (known as the "step angle"). When the motor drive of the step motor receives a pulse signal, the driver drives the step motor to rotate at a fixed angle, that is, the step angle. It is characterized by no accumulation error, and the process mature price is low, good stability, so it is widely used in various open loop control [1]. However, its disadvantages are also obvious, unable closed loop control. When low speed is easy to block rotation, high speed is easy to lose steps and other bad phenomena, cannot carry out feedback adjustment, thus affecting the work accuracy [2]. To solve this problem, the common solution is to use the servo motor that can conduct closed-loop control instead of the stepping motor, but the servo motor also has the problem of large volume and high cost. Therefore, in order to improve the control precision of stepping motor and realize the closed-loop control of step motor, the method of combining stepping motor with the magnetic encoder is designed to solve this problem.

2. The principle of the magnetic encoder

2.1 The principle of the magnetic encoder

Magnetic encoder is a new type of non-contact position detection sensors, using magnetically sensitive elements to sense the magnetic field movement changes caused by the magnetoresistance effect [3], magnetic material angle or displacement changes will cause a certain resistance or voltage changes, so as to measure the angle or displacement changes of the moving object changes. The magnetic encoder is simple, compact, with strong interference resistance, fast response speed, small volume and low cost. In the field of high-precision measurement and control, magnetic encoders have become an indispensable part, and are widely used in military, mechanical and electrical, information, aviation, construction, medical and other fields [4].

Depending on the magnetic sensitive elements used, the magnetic encoder can be divided into a magnetized magnetic encoder and a Hall magnetic encoder [5].

The magnetoresistor magnetic encoder detects position information according to the magnetoresistance effect of the magnetoresistance element at different magnetic field strengths, that is, the characteristics that the element resistance value changes with the magnetic field. Magnetic
resistance type magnetic encoder has the advantages of high sensitivity, good temperature characteristics, and wide detectable spatial magnetic field range. As the main representative of the traditional magnetic encoder, it has been widely used in many fields related to engineering technology. Although the technological development of magnetoresistance magnetic encoder is relatively mature, it limits its wider application in the industrial field due to its complex manufacturing process and high cost.

The Hall magnetic encoder uses the Hall element as the magnetic sensitive element by sensing the magnetic field changing with the movement of the detected object [6, 7], that is, the position information uses the Hall element to produce the potential difference with the magnetic field. The Hall element component assembly is mounted in the axial direction of the magnetic pole, and the voltage value of the element changes with the sensing magnetic field. Recently, the Hall magnetic encoder became popular for its simple structure, small volume and low production cost.

3. The design plan

In this paper, the magnetic sensitive elements of magnetic encoder choose a magnetic sensitive chip based on Hall effect, using the design scheme of AS5600 magnetic encoder and 42-stepper motor produced by AMS. The AS5600 is a magnetic rotation position sensor based on the Hall sensor principle, which can detect the absolute angular value of the magnetic magnet radial magnetic axis rotation in a non-contact way, and has a 12-bit high-resolution analog or PWM output and industrial-level IIC interface that can adapt to the vast majority of applications.

The accuracy, resolution and other performance indexes of magnetic encoder are determined by the factors such as the uniformity of magnetic pole magnetization, the number of magnetic poles with different tracks, the number of magnetic poles and the number of magnetic poles under non-contact conditions. The magnetization directions of magnetic poles can be divided into radial and axial directions, and the corresponding installation positions of magnetic sensing elements are also different. Taking the cylindrical magnet as an example, the radial magnet divides the cylinder into left and right N poles and S poles with the diameter of the center section of the cylinder as the dividing line, while the axial magnet divides the cylinder into upper and lower N poles and S poles with half of the height of the cylinder as the dividing line. The axial magnetization structure and radial magnetization structure of the magnetic pole are shown in Fig.1 and Fig.3.

3.1 The circuit design

The AS5600 adopts the SOIC-8 package, as shown in Fig.3, and is integrated with an LDO voltage stabilization module circuit for voltage stabilization, reducing the interference of the power ripple, and can be powered with 5V (actually 4.5V–5.5V) or 3.3V (actually 3.0V–3.6V), providing necessary conditions for low power consumption and long operation. The chip has a working temperature range of -40°C to 125°C, which is well adaptable and can be applied in fields such as automotive electronics, aerospace and petrochemical industry [8].

The design principle is shown in Fig.4, the radially charged magnets and the transfer shaft to be tested stick together, the magnetic sensitive element and the matching drive circuit module are welded on the circuit board, the shaft rotation drives the magnet to form an angular magnetic field signal above the sensitive element, the changing magnetic field is detected by the magnetic chip and the digital information to read for the MCU is stored in the register.
The measurement accuracy formula of the encoder is (1), where \( n \) is the number of the encoder, AS5600 is the 12-bit magnetic encoder, and the default detection angle is 360°. From the formula, the default measurement accuracy is 0.087890625°. At the same time, the chip is a programmable device with an adjustable angle range from 18° to 360°, so the minimum measurement accuracy is 0.00439453125°, and the measurement accuracy is very exact. The default step angle of the 42-stepper motor is 1.8° and the precision after segmentation is shown in the Table 1. According to the data analysis in the table, the AS5600 chip can fully meet the motion accuracy measurement of the stepping motor. This paper performs data acquisition and analysis using the default accuracy of AS5600 and 42-stepper motor 16 segmentation.

### Table 1. Relations between step motor subdivision and step distance angle

<table>
<thead>
<tr>
<th>Fine score</th>
<th>Step distance angle (unit: degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td>4</td>
<td>0.45</td>
</tr>
<tr>
<td>8</td>
<td>0.225</td>
</tr>
<tr>
<td>16</td>
<td>0.1125</td>
</tr>
<tr>
<td>32</td>
<td>0.05625</td>
</tr>
</tbody>
</table>

The measurement accuracy formula of the encoder is:

\[
P = \frac{2\pi}{2^n}
\]  

(1)
The communication between AS5600 and MCU adopts IIC interface, and the circuit design is shown in Fig.5.

3.2 Installation design

The installation diagram is shown in Fig.6 and Fig.7. AS5600 requires the Bz component of the magnetic field to be perpendicular to the sensitive area on the chip. Along the circumferential direction of the hall element, the Bz component of the magnetic field is sinusoidal. The magnetic field gradient of Bz along the circular radius should be within the linear range of the magnet, and the displacement error should be eliminated by the principle of differential measurement. The typical value of the air gap is between 0.5mm and 3 mm, depending on the selected magnetic field. A larger and stronger magnetic field allows a larger air gap. Guided by the AGC value, by adjusting the distance between the magnet and AS5600, the AGC value is in the center of its range to find the best air gap. The actual test uses a magnet with a diameter of 6mm and an air gap of 2.85mm, which can well meet the requirements of the chip for magnetic field. Using a magnet with a diameter of 6mm, the maximum allowable displacement from the rotation axis of the reference magnet to the package center is 0.25mm.

Figure 6. Installation schematic diagram1.

Figure 7. Installation schematic diagram2.

4. Actual installation and performance test

4.1 Actual installation

Install according to the design scheme. As shown in the Fig.8 and Fig.9, the driver uses DRV8825 drive module, the main control chip is STM32F103RCT6, and the pulse generation mode is the comparison output mode of timer. This paper collects and analyzes the data under the condition of using the default accuracy of AS5600 and 16 subdivision of 42-stepper motors.

Figure 8. Physical map1

Figure 9. Physical map2
4.2 Data acquisition and error analysis

The collected data are divided into two types. One is the randomly collected data group starting from 1.8° and increasing to 360° with 1.8° as an integer multiple. The other is a data group starting from the minimum step angle of 0.1125° subdivided by the stepper motor 16 and increasing by an integer multiple of 0.1125° to 1.8°.

After testing, the encoder error rate is 0% when the number of motions turns of the stepping motor is an integer, and the encoder will produce accuracy error only when it is 0°~360°. After the analysis of a large amount of data, the average sampling accuracy error of AS5600 magnetic coding is 0.3258% between 1.8° and 360°. For the data between 0.1125° and 1.8°, because the value is too small to be suitable for the error analysis method, the curve fitting analysis is carried out, as shown in Fig.10, and its error has been less than the minimum step angle under the subdivision of stepping motor 16, which has fully met the use requirements for stepping motor. There are two reasons for the error of the two groups of data:

1. The value stored in the register of AS5600 magnetic encoder chip is an integer value between 0-4095, which is a digital signal rather than a continuous analog signal, so it will jump within the accuracy range;
2. The precision of AS5600 magnetic encoder chip is 0.087890625°, while the stepping angle of 42-stepper motor is 0.1125° under 16 subdivision. The relationship between them is not an integer multiple, but a 32:25 ratio.

![Figure 10. Fitting curve](image)

5. Conclusion

Through data analysis, although the 12-bit sampling accuracy of AS5600 is lower than that of 17 bit or even higher encoder of advanced servo system, it is better than some servo system encoders, such as 2500-line incremental encoder. AS5600 is cheap and has a wide range of application, and can fully meet the application requirements of closed-loop control of stepper motor. AS5600 magnetic encoder has the advantages of high precision, small volume, low price and wide application range. It can be used in the closed-loop feedback control system of stepping motor.

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