Study on an angle measuring device based on mechanical gyroscope

Zilin Zhang\textsuperscript{1}, Huimin Zhao\textsuperscript{1}, Xiyuan Li\textsuperscript{1} and Xu Zhao\textsuperscript{1}, Jingchao Sun\textsuperscript{2}, ZhouYan\textsuperscript{3,*}

\textsuperscript{1} Shenyang Aerospace University, Shenyang, China
\textsuperscript{2} Science College of Shenyang Aerospace University, Shenyang, China
\textsuperscript{3} Engineering Training Center of Shenyang Aerospace University, Shenyang, China

*Corresponding author e-mail: sdyanzhou16888@163.com

Abstract. The circular staggered magnetic field is studied and built. Then combining with the mechanical structure of the mechanical gyroscope, a tilt angle measurement instrument which cannot be interfered by the external conditions is designed. A stable working magnetic field is generated in the system itself. Based on the principle of electromagnetic induction, the tilt angle change is transformed into the electrical signal change output, and then the tilt angle is measured.

1. Introduction

The measurement of tilt angle plays an important role in many fields, such as landslide monitoring \[1\], building tilt, navigation system \[2\], etc. In war or in life, we can easily get the geographical coordinate position and find the direction accurately by compass, modern radar or electronic gyroscope. But in some strong magnetic field or entirely blocked environment, radio communication and electronic gyroscope will be weaken or even lose function, which will make measurement get in trouble. \[3\]

In order to deal with the situation, this paper presents a real-time measuring device \[6-7\] of direction and angle, which is based on the principle of electromagnetic induction and mechanical gyroscope \[4\] \[5\], and can be free from external interference.

2. Principle and Design Scheme

2.1. Principle of Electromagnetic Induction

Electromagnetic induction method is based on Faraday’s law of electromagnetic induction. Place a circular coil with \(n\) turns and \(s\) cross-section in an alternating magnetic field with

\[
B = B_m \sin(\alpha x)
\]

Magnetic field strength. If the angle between the normal of the coil and the magnetic induction line is \(\theta\), the induced electromotive force generated in the coil is \[8-9\]:

\[
E = n s B_m \sin(\alpha x) \sin(\theta)
\]
\[ \varepsilon = -\frac{d\Phi}{dt} \]
\[ = -NS\omega B_m \cos \theta \cos (\omega t) \]
\[ = -\varepsilon_m \cos (\omega t) \]

Where: \( \varepsilon_m = NS\omega B_m \cos \theta \) is the amplitude of induced electromotive force.

It can be seen from the formula that the alternating magnetic field is established and the induced potential is obtained through the electromagnetic induction coil, and then the electrical signal change is obtained. The device mainly uses the electromagnetic induction law to convert the angle change of any surface into the current pulse output, and obtains the angle change through Arduino microprocessor processing. At the same time, the gyroscope is combined with the above principles to determine the reference plane in the early stage of measurement and play an auxiliary role in measuring the angle.

The measurement of the change of the angle is transformed into the measurement of the change of the magnetic flux, which produces the induced potential, and then causes the change of the current. The current signal is amplified, and the final angle value is obtained after the program processing.

![Figure 1. Principle of angle measurement.](image)

2.2. Establishment of Circular Alternating Magnetic Field

An annular alternating magnetic field is established by fixing 358 micro strong magnetic fields on the annular device, as shown in Figure 2.

![Figure 2. Cyclic alternating magnetic field.](image)

The internal magnetic field is similar to the sine curve, and the specific situation should be obtained through MATLAB analysis and fitting after experimental measurement, as shown in Figure 3, the maximum value of the magnetic field is about 180mT.
Combining the function of magnetic field with the movement of measuring arm, the accuracy of measuring angle can be adjusted by program according to the change of induced potential.

2.3. Principle of Measuring Machinery

The measurement part of the instrument is simplified as follows, and its function diagram is as follows:

As shown in Figure 4, the blue part divides a space into four areas, as shown in Figure 5; therefore, any angle change in the space can be represented by using the two mutually perpendicular planes where the two blue circles in Figure 4 are located.

In Figure 6, using the principle of gyroscope, the measuring arm is in the position of line 2 on one side, but the external magnet rotates with the different plane. After analysis, assuming that the external magnet does not move, the measuring arm has two degrees of freedom in three-dimensional coordinates, that is, the shell where the magnet is located can rotate freely in 360 plane. Only angle measurements in one of the directions are analyzed below.

When the outer shell rotates, the position of the measuring arm moves from 2 to 1. In this process, the two ends of the measuring arm will experience the same number of magnets in turn, and the two sides will generate reverse current of equal times. This is to eliminate the error and make the measurement more accurate.
When the two ends of the measuring arm are relatively static with the last magnet, the last electrical signal is generated. After being processed by the processor, the corresponding angle of the coil is displayed on the display screen.

The overall instrument measurement process is shown in figure 8.

2.4. Signal Processing and Algorithm Processing

In the process of signal processing, the current generated by the coil under the action of the induced potential is processed, and the current is transmitted to the processor through the amplification circuit in the middle after the current is equal to that of the example amplifier. The process is as follows.
value of each point, use the Evievs software to establish the database, so as to get the corresponding different angle value of each coil. We can think of this process as a mapping.

Figure 10. Diagram of data operation process.

The module structure of electronic part is as follows

Figure 11. Module composition diagram.

3. Data processing design
The whole idea of angle measurement system is to decompose any angle in the space into the virtual space coordinate system. After measuring the angle in three coordinate planes, the space angle is given through the calculation of the system.

The measurement results are shown in Table 1. Compared with the measurement results of dxl360s level meter, it can be seen that when measuring the horizontal inclination angle of 3-10 degrees, the absolute error of measurement with large angle is smaller, and the measurement error with small angle is larger, which is related to the fact that the device is larger and the bottom surface cannot be completely flat. And the overall average error is 0.02875 degrees, which can meet the standards in construction, civil engineering and daily life.

| Inclination angle measured by instrument | Dxl360s level measurement results | absolute error |
|-----------------|-------------------------------|----------------|
| 9.98            | 10.00                         | 0.02           |
| 8.99            | 9.01                          | 0.02           |
| 7.98            | 8.00                          | 0.02           |
| 6.99            | 7.00                          | 0.01           |
| 5.98            | 6.01                          | 0.03           |
| 4.97            | 5.01                          | 0.04           |
| 3.98            | 4.00                          | 0.02           |
| 2.95            | 3.02                          | 0.07           |
4. Conclusion
In this paper, a new horizontal angle measuring device based on electromagnetic induction principle and mechanical gyroscope is designed and implemented. The system structure and working principle are described in detail, and the calibration, contrast experiment, repeatability experiment and error analysis of the instrument are carried out. The experimental results show that the system has good repeatability and accuracy. Compared with dxl360s level, the average absolute error of measurement is within 0.05 degree, which can be used in construction, civil engineering and daily life. The main advantage of the device is that it is not interfered by the external environment, and the algorithm analysis of the angle measurement data is simple, which provides a widely used scheme for measuring the angle of inclination.

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First author: Zilin Zhang (2000.01--), female, sophomore, the main research direction is mechanical design, manufacturing and automation.

Corresponding author: Zhou Yan (1982.12--), male, engineer, main research direction is the application of numerical control technology and mechanical design research.

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