A coaxial thickness measuring device for full-width banknote based on hall effect

Yang weisong¹², wang shukun¹ and song wei²

¹College of Mechanical and Electric Engineering, Changchun University of Science and Technology, Changchun, China, 130022
²Eastern communications co., LTD, Hangzhou, China, 310053

Abstract. In this paper, a multi-channel banknote thickness measurement mechanism based on hall effect is designed to meet the demand of banknote identification for the cash circulation module of financial instruments. It uses coaxial type rocker mechanism to mechanical amplification of the thickness of the banknote, translates the magnetic steel with hall sensor location change into money thickness signal, and the signal is amplified, filtered and calibrated to form a banknote thickness image. Finally, the detection results of the whole paper currency are obtained through calculation, so as to realize the detection and identification of the whole paper currency tape, folding and partial damage.

1. Introduction
With the development of financial tools and technology, more and more banknote deposit and withdrawal modules have put forward the request of counterfeit detection. At the same time the banknote also must be detected such as tape, ruffled and local damage, but tape, ruffled, damage may be in any position on the banknote, so the thickness of the test must be able to cover the range of the note, and it is necessary to set up closely arranged multi-channel thickness sensors for testing. Similarly, each thickness sensor must have the same result for the same thickness. In this paper, a coaxial multi-channel banknote thickness measuring mechanism is introduced. Based on hall effect, the thickness image is formed by means of mechanical and electronic coordination, and the thickness image is processed and calculated in the later stage to obtain the thickness distribution of banknote, so as to realize the full thickness detection of banknote.

2. Mathematical modeling based on hall effect thickness measurement

2.1 Hall effect
As shown in figure 1, an n-type semiconductor wafer, of length L and width is b, thickness of d, in the plane perpendicular to the semiconductor wafer on the direction of applying magnetic induction intensity for magnetic field b, if I to current on the length direction, according to the motor, the mechanism of n-type semiconductor free electrons along with the current in the opposite direction, I free electrons in the magnetic field due to the effect of lorentz force PL, positive and negative charges respectively along the direction perpendicular to the magnetic field and electric current to move on both ends of the conductor, and gathering on both ends of semi-conducting conductor to form a stable electromotive force V_H, this is the hall electromotive force (or called the hall voltage).This phenomenon is called the hall effect of semiconductor materials.
Figure 1. Hall effect

Hall voltage:

\[ V_H = \frac{I}{d\text{ne}} = \frac{R_H d B}{d} \]  

(1)

In the above equation, \( R_H = \frac{1}{ne} \) is called hall coefficient (also known as the sensitivity of hall devices), which is an important parameter reflecting the hall effect strength of materials. When the semiconductor current \( I \), thickness \( d \) and hall coefficient \( R_H \) are determined, hall voltage is proportional to magnetic induction intensity.

2.2 Magnetic field distribution of cylindrical magnetic steel

The magnetic induction intensity \( B \) along the axis of the magnetic field of a cylindrical permanent magnet can be expressed in equation 2.\(^\text{(2,3)}\)

\[ B = B_r \left( \frac{d+1}{\sqrt{(d+1)^2+r^2}} - \frac{d}{\sqrt{d^2+r^2}} \right) \]  

(2)

In the formula, \( B_r \) is remanence, \( r \) is cylindrical radius, \( l \) is cylindrical height, \( d \) is the distance from the working point to the cylindrical surface, and the magnetic induction intensity varies with the distance from the working point as shown in figure 2.

Figure 2. Magnetic induction intensity varies with distance

Formulas 1, 2 and figure 2 show that the magnetic induction intensity is proportional to the distance of the working point in a certain range, which can be expressed by Formula 3.

\[ B = A - K d \]  

(3)

\( K \) is the comprehensive coefficient. Formula 3 shows that the hall voltage of the hall sensor above the cylindrical surface of the cylindrical magnet steel in a certain range is proportional to the distance of the working point. The distance can be obtained by the change of the hall voltage.
3. Working Principle and Composition of Coaxial Multichannel Paper Money Thickness Measuring Mechanism

The principle block diagram of a thickness identification device consisting of a coaxial rocker arm mechanism and a hall sensor is shown in Figure 3. Working principle is that the checked banknotes are transmitted by the money delivery mechanism, and the loaded rollers of rollers and axle center are quickly detected by the coaxial rocker arm mechanism. The thickness of the banknotes causes a slight change in the direction of the checked rollers of the coaxial rocker arm mechanism relative to the loaded rollers. After the enlargement of the enlarged arm, the distance between the magnet on the rocker arm and the hall sensor occurs. The change causes the change of the inductive magnetic field of the Hall sensor, and produces a corresponding voltage change at the output end of the hall sensor. The voltage change is amplified by the Hall amplifier and sent to a processing circuit composed of a microprocessor or hardware circuit for processing to form a thickness image. The multi-channel thickness images are synthesized to form the whole thickness image of banknotes and distinguished by corresponding algorithms, so as to achieve the purpose of banknote thickness sorting and recognition.

The thickness identification system is mainly composed of three parts: coaxial rocker arm mechanism; Hall sensor detection circuit; signal processing and control system.

![Diagram of multi-channel banknote thickness checking mechanism](image)

Figure 3. Principle block diagram of multi-channel banknote thickness checking mechanism

3.1 Coaxial rocker arm mechanism

The coaxial rocker arm mechanism is shown in figure 4, which is composed of mechanical transmission roller detection and hall sensor. The mechanical transmission includes the superstructure and the substructure. The upper structure consists of a thickness measuring frame, which is provided with a rocker arm shaft along the width, and a number of rocker arms are rotated and connected on the rocker arm. The rocker arm is provided with rollers whose axis direction is parallel to the axis direction of the rocker arm shaft. The substructure includes a bearing roller and a scraper; The cylinder of the bearing roller and the cylinder of the roller are fitted; The rocker arm is provided with magnetic steel and hall sensor corresponding to the thickness measuring frame. Thickness recognition is a combination of mechanical transmission detection and hall sensor thickness detection to detect the thickness of banknotes.
In order to prevent the ink from affecting the thickness measurement accuracy, a scraper is designed in the rocker arm mechanism. When the roller or bearing roller rotates, the dirt stains on the cylinder surface will be scraped off by the scraper. The sleeve of each rocker arm of the thickness measuring mechanism is arranged in a line on the rocker arm axis to realize the full thickness measurement of banknote.

### 3.2 Hall sensor detection circuit

Hall sensor is a new type of magnetic detection device based on hall effect. It is composed of a linear integrated circuit and a waterproof shell applying hall effect, which is used to convert magnetic signal into electrical signal output. This system uses Linear Hall Effect Sensor IC with Unilateral Output SC4012, output state is shown in figure 5, the application circuit is shown in figure 6.

![Figure 5. SC4012 hall sensor output state](image)

**Figure 5.** SC4012 hall sensor output state

![Figure 6. SC4012 hall sensor application circuit](image)

**Figure 6.** SC4012 hall sensor application circuit

### 3.3 Signal processing and control system

As this system is multi-channel system, due to machining errors, the acquisition signals of the same thickness of each sensor will be different, and the system signals need to be calibrated before use.

Calibration process: two pieces of media of 100um+30um and 100um-30um were collected respectively, and the corresponding value of unit thickness (1um) was calculated as the calibration coefficient. Output value Voltage = K(Vsmp-V0), where Vsmp is the sampling value, V0 is the sampling value of thin media during calibration, K=(V1-V0)/(thick paper thickness - thin paper thickness). The output value after sample calibration is synthesized into a full-thickness image as shown in figure 7 and figure 8. The system can accurately identify the banknote according to the thickness image and judgment criteria.
4. Conclusion
In this paper, the thickness detection system described has the characteristics of simple structure, high sensitivity and reliable operation. It can fully reflect the comprehensive thickness characteristics of paper money and realize the thickness recognition of paper money by detecting the full width image of paper money.

By adopting the coaxial method, the thickness detection system described in this paper can ensure the concentricity of each detection rocker mechanism, improve the consistency of hall's output signal, and improve the detection accuracy.

In this paper, the rocker arm in the rocker arm mechanism of the thickness detection system described is processed by mold to ensure the consistency of processing, so as to improve the consistency of hall's output signal and improve the detection accuracy.

The supporting roller is a one-pass shaft and manufactured by precision machining, thus ensuring that the detection accuracy of the system can reach the micron level.

References
[1] Kappenman J G, Albert V D 1990 Bracing for the geomagnetic storms IEEE Spectrum Magazine 27(3):27-33.
[2] Marcio Barata, Urbano Nunes and et al 2004 Data fusion of wheel encoders and magnetic sensors for autonomous vehicles navigation In Proc. Of the 6th Portuguese Conference on Automatic Control(CONTROLO), Faro, Portugal: 31-37.
[3] Xu Haigui, Yang Ruqing and Wang Chunxiang 2005 An experimental study of the magnetic sensing system for autonomous vehicles guidance 12 15.
[4] Liu Zhancun and Zheng Yumei 2007 The Discovery of Hall Effect[J] College Physic 26(11): 51-55.
[5] Tian Hulin, Jia Rong and Yang Guoqing and etc 2008 Magnetic field and magnetic force of permanent magnet magnet assembly Transactions of China Electrotechnical Society 23 6
[6] Zhou Enquan, Zheng Zhongqiao, Zhang Yanhong and Wang Qirui 2017 Modeling and simulation of cylindrical permanent magnet Henan Science and Technology. issue 11: November.