Intelligent Magnetic Experiment Teaching System Based on Hall Effect

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Abstract—The Hall effect experiment occupies an important position in the teaching of university physics experiments. Traditional experimental teaching instruments have problems of tedious operation and difficult data collation. The new system designed in this paper uses the STM32 series single-chip microcomputer, the main control chip VT95276L128 and the touch screen module, and adopts the configuration graphic user design software VGUS programming to intelligentize the traditional TH-H/S type Hall effect experimental instrument. In addition to retaining all the functions of the original instrument, the experimental data processing and drawing can be handed over to a single-chip computer, which improves teaching efficiency and facilitates students to think deeply about the experiment.

1. Introduction
The Hall effect has a wide range of applications in modern society, and also occupies an important position in college physics experiment teaching. The Hall effect experiment requires students to understand the principle of the experiment. At the same time, the "symmetric measurement method" is adopted in the experimental operation to reduce the side effects. Finally, the method of measuring the magnetic field using the Hall element is required[1]. In the traditional TH-H/S Hall effect experiment instrument, the data measurement and collation part of the experiment, due to the many experimental operation steps[2] and the complicated data, are prone to leaks during the manual processing, which reduces the teaching efficiency of the experimental course. Literature[3] proposes to adopt MATLAB for experimental data processing, but this improved scheme requires additional operations on the PC side. Literature[4] proposes to use a single-chip microcomputer to display data and transmit the data to the host computer, and specially design a software for data processing for this purpose. This solution requires a computer for each experiment instrument, which is very costly.

In order to improve these shortcomings and improve the efficiency of the Hall effect experiment teaching, the system uses the STM32F103 chip as the core and designs a new control detection circuit. This circuit can store the measured data and input the data to the main control chip VT95276L128 and FLASH chip W25Q64/128 integrated in the integrated serial screen. The serial port screen has a high level of intelligence, which can save the collected data, calculate and draw the corresponding curve.

The overall structure of the new experimental instrument is shown in Figure 1.
The new experimental device is powered by a power supply. The Hall effect experiment part is not different from the traditional TH-H Hall effect experimental instrument in principle. The main improvement lies in the variable working current $I_S$, excitation current $I_M$ and dependent variable $V_H$ in the experiment. The voltage $V_H$ is input to the control detection section after A/D conversion. The CPU on the serial port touch screen can calculate these data, then draw the curves of different parameters and display them on the screen, thus the whole device has a high degree of intelligence.

2. Test Experiment

2.1. Experimental principle

If a conductor carrying a current is in the magnetic field $B$, and the magnetic field $B$ (along the $z$ axis) is perpendicular to the direction of the current $I_S$ (along the $x$ axis), a transverse potential difference will appear in the conductor perpendicular to the $B$ and $I_S$ directions $V_H$, this phenomenon is called Hall effect. When the transverse electric field force $F_E$ Lorentz force $F_B$ experienced by the carriers is equal:

$$qV \times B = qE$$  \hspace{1cm} (1)

At this time, the charge is no longer deflected in the sample, and the Hall potential difference is established by this electric field. The electric field established in the N-type sample and the P-type sample is opposite, so the Hall potential difference has different signs, from which the conductivity type of the Hall element can be judged. Suppose the carrier concentration of the P-type sample is $p$, the width is $w$, and the thickness is $d$. Through the sample current $I_S = pqwd$, the hole rate $v = I_S/pqwd$, there is

$$BIKd = BIRpqwd = BIEV_H$$  \hspace{1cm} (2)

Where $R_H = 1/pq$ is called Hall coefficient, $K_H = R_H/d = 1/pqd$ is called Hall element sensitivity.

2.2. Side effect in Hall effect and its elimination method

In the actual measurement process, there will be some thermomagnetic effects, these thermomagnetic effects are Ettingshausen effect[5], Nernst effect[6], Rigi-Leduc effect[7], and the unequal potential difference due to electrodes not on the same equipotential surface. In order to eliminate side effects, we use an experimental method named "Symmetry Measurement Method". Change the direction of $I_H$ and $B$ during operation, and record the data of 4 sets of potential difference.
TABLE 1. PARAMETER SETTINGS

| Symmetry Measurement Method | Magnetic induction intensity B |
|-----------------------------|-------------------------------|
| Working current I           | positive                      |
| positive                   | V1                            |
| negative                   | V2                            |

The above four values can be averaged to eliminate the error:

$$\frac{1}{4}(V_1 - V_2 + V_3 - V_4) = V_E + V_H \approx V_H$$  \hspace{1cm} (3)

These side effects may come from different heat flow effects, for example, the contact resistance of the contact is different, the external thermal field is distributed in the Hall element to cause heat flow, the Peltier effect of the contact generates heat flow\(^{[8]}\). So it’s difficult to eliminate all the side effects but it’s possible to reduce the impact through improvements.

2.3 Measuring circuit

The experimental schematic of the Hall effect is shown in Figure 2. \(I_M\) is the excitation current, \(I_S\) is the Hall current, and \(V_H\) is the Hall voltage to be measured. According to the instructions in Part B the corresponding side effects need to be eliminated in the experiment. During the actual operation, students need to place the switches K1, K2 of \(I_S\) and \(I_M\) in the states shown above, and get the corresponding voltage value in sequence.

The test part is composed of two groups of \(I_S\) and \(I_M\) DC constant current sources and ammeters and digital voltmeters. As shown in Figure 3, the two groups of constant current sources are independent of each other, where "\(I_S\) output" is the sample working current source, "\(I_M\) output" is the excitation power supply, the two output currents are continuously adjustable and can be displayed on two screens respectively, and the "\(V_H\) output" can display the corresponding Hall voltage. The positive and negative of the Hall voltage can determine whether it is hole conduction or electron conduction.
2.4. Intelligent data display
The intelligent data display part of the new experimental device performs A/D conversion and storage of the data measured by the Hall effect experiment part, so that the measured Hall voltage value is displayed on the serial port screen, and the calculated $V_H$ and the $I_S$ and $I_M$ values input from the Hall effect control power supply are drawn into corresponding graph lines, which greatly simplifies the manual steps required for students to conduct experiments.

2.4.1. Control and detection. Figure 4(a) shows a part of the circuit schematic diagram of the control detection module, and Figure 4(b) shows a part of circuit schematic diagram of the control power supply module. All the designs (including the schematics below) are carried out in AltiumDesigner18.
The design idea of the control and detection part is to connect the $I_S$ and $I_M$ values set in the Hall effect experiment part to the control and detection circuit respectively. After the A/D conversion function of the ICL7135 chip, the measured analog signal is converted into a digital signal and input to the main control chip STM32F103. The core of the chip is ARM Cortex-M3, which has high comprehensiveness and good configurability\[9,10\]. The processor integrates modules such as reset circuit, low voltage detection, voltage regulator and RC oscillator, which is conducive to the accurate and stable operation of the system\[11\]. In the Hall effect experiment, changing the direction of $I_S$ will cause the positive and negative changes of $V_H$, but the MCU cannot recognize the negative voltage, so the control detection part uses the ICL7660 chip, which can convert this negative voltage into a positive voltage, which is convenient for the following display. In addition, basic circuit elements such as resistors and capacitors are added to the corresponding positions in the circuit, so that the circuit can work normally.

2.4.2 Display section. The main design of the display part is carried out on the serial touch screen based on the innovative main control chip platform VT95276L128. This serial port is powerful, with TTL interface, low cost and high integration\[12,13\]. The pin diagram of the built-in main control chip is shown in the reference\[12\] and \[13\] at the end of the article. The built-in CPU of the serial screen can control the display content according to the touch screen instructions. Its function is developed by the configuration graphical user interface design software VGUS (Viewtech Graphical User Software) tool implementation. After completing the interface design and development and screen parameter configuration on the PC, the configuration file can be downloaded to the serial port screen through the USB disk for display.

3. Result and Discussion
All the above work finally built an intelligent magnetic experiment teaching system based on Hall effect. Users need to click the start experiment button in the experiment start interface, and enter their number in the subsequent interface. These interfaces are basic parts of any intelligent system. In the experiment selection interface, users can choose test 1 to measure the $V_{H/I_S}$ curve, test 2 to measure the $V_{H/I_M}$ curve, and test 3 to measure the $B-X$ curve.

Figure 5, Figure 6 and Figure 7 show some user interfaces programmed by VGUS, which are parts of a more intelligent magnetic experiment teaching system.
4. Conclusion

Traditional Hall effect experiment instruments require users to record a lot of data, which can easily lead to wrong experimental results. The new experimental system has redesigned the circuit diagram of the experimental detection part. In addition to retaining the basic functions of the original VH-H/S Hall effect experimental instrument (verifying the Hall effect, measuring the solenoid and measuring the magnetic field), it is also optimized. The experimental process has been improved, and the accuracy of data collection has been improved. The data collection and calculation work required by students in traditional experimental teaching is handed over to the main control chip STM32F103. Therefore, the error that may be caused by manual operation is reduced, and the intelligent level of the experiment is improved. The drawing work is handed over to the serial touch screen based on the innovative main control chip platform VT95276L128. All the data of the experimental operations performed by the students can be displayed on this serial port screen. After the new experimental system is popularized in the experimental center, it can improve the intelligence of teaching and improve the efficiency of experimental. What’s more, the new experimental system can also be used to other areas, such as measurement of the magnetic induction intensity of Helmholtz coil.

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