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Two Methods of Measuring Curie Temperature Based on PID Temperature Control

Bowen Wu

School of Electrical and Control Engineering, North China University of Technology, Beijing, China

2667307038@qq.com

Abstract: To explore the Curie temperature of a magnetic object and accurately measure its Curie temperature, this paper selects solid and powdered Mn-Zn ferrite to measure it by two different methods. Method 1 uses a method similar to a magnetic balance to measure the Curie temperature, and method 2 uses an AC bridge method to measure the Curie temperature. At the same time, this project uses STM32 single chip microcomputer and PID algorithm to control the temperature, so that a reasonable result can be obtained last. The two sets of devices used in this project can accurately measure the Curie temperature of the materials used, and the measured Curie temperature is not much different from the theoretical Curie temperature of the materials.

Keywords: Curie temperature, PID control, magnetic, Mn-Zn ferrite solid.

1. Introduction

Curie temperature is the temperature at which the internal magnetic moment of ferromagnetic materials changes from order to disorder, that is, the temperature at which ferromagnetism and paramagnetism change from each other. It is one of the basic characteristics of ferromagnetic materials. The Curie temperature of the material reflects the chemical composition and crystal structure of the material, and also directly determines its working temperature. Therefore, the accurate measurement of Curie temperature is an extremely important work in the research of magnetic materials.

Commonly used in industry, Curie temperature is determined by measuring the relation curve between magnetization M or specific saturation magnetization and temperature T.[1]

At present, in the teaching of college physics experiments in China, the Curie temperature is generally measured by observing the dynamic hysteresis loop of ferromagnetic materials changing with temperature with an oscilloscope. The advantage of this method is relatively intuitive, but the measurement accuracy is low because the annular sample size is too large and the temperature inside the sample is uneven, which leads to the variation of the output induced voltage with temperature, and the rising and falling curves near Curie temperature are not coincident.[2]

In our study, two different methods are used to measure Curie temperature. One method is similar to a magnetic balance to obtain the temperature-mass curve of the object to be measured, and then the Curie temperature is obtained from the curve. The other method is an AC bridge to obtain the voltage-temperature curve, and the Curie temperature is obtained from the curve. The results show that the two methods have no requirements for measuring the state and shape of objects, which can be solid or powder. In addition, both methods can accurately measure Curie temperature, and the measurement accuracy is high.

2. Principle

We measured Curie temperature with a self-made device in two ways:

Method 1:

By measuring the relationship between mass m and temperature t, the Curie temperature is obtained. When the temperature rises, the balance indicator increases to reflect the magnetic change of the sample. When the balance indicator is about equal to the original weight of the sample, the sample temperature reaches Curie temperature.

Method 2:

By measuring the relationship between voltage V and temperature T, the Curie temperature is obtained. The change in sample magnetism is reflected by the increase in temperature and the decrease in sample voltage. When the voltage indicator becomes about zero, the sample temperature reaches Curie temperature.

2.1 Magnetization law and Curie temperature of ferromagnetic materials.

Due to the action of the external magnetic field, the state of a substance changes, and the phenomenon of generating a new magnetic field is called magnetism. The magnetism of a substance can be divided into three types: antiferromagnetism (diamagnetism), paramagnetism, and ferromagnetism. All substances that can be magnetized are called magnetic media. In an unmagnetized ferromagnetic substance, although each magnetic domain has a definite spontaneous magnetization direction and great magnetism, a large number of magnetic domains have different magnetization directions, so the whole ferromagnetic substance does not show magnetism. As shown in Figure 1, the schematic diagram of the polycrystalline magnetic domain structure is given. When the ferromagnetic substance is in an external magnetic field, the volume of those magnetic domains whose spontaneous magnetization direction is at a small angle with the external magnetic field direction expands with the increase of the external magnetic field, and the magnetization direction of the magnetic domains is further turned to the external magnetic field direction. The volume of other magnetic domains whose spontaneous magnetization direction is at a large angle with the external magnetic field direction is gradually reduced, at which time ferromagnetic materials show macroscopic magnetism. When the external magnetic field increases, the above-mentioned effect increases correspondingly, until all magnetic domains are aligned along the external magnetic field, and the magnetization of the medium reaches saturation.

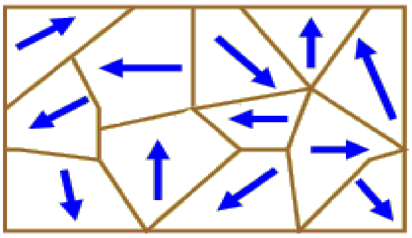

Fig. 1 Polycrystalline magnetic domain structure without magnetic field

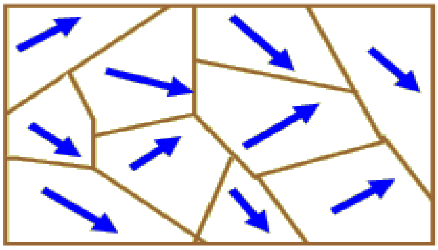

Fig. 2 Polycrystalline magnetic domain structure with the magnetic field

Because the magnetic moments of elements in each magnetic domain are completely arranged in order, it has strong magnetism. When the ferromagnetic body is subjected to strong vibration or under the influence of violent movement at a high temperature, the magnetic domain will collapse, and then a series of ferromagnetic properties (such as high permeability, hysteresis, etc.) associated with the magnetic domain will all disappear. There is such a critical temperature for any ferromagnetic substance, above which ferromagnetism disappears and becomes paramagnetism. This critical temperature is called the d Curie point of ferromagnetic substances.

The magnetization law of the magnetic medium can be described by the magnetic induction intensity B, the magnetization intensity M and the magnetic field intensity H, which satisfy the following relationship

$$\mathrm{B} = \mu_0(\mathrm{H}+\mathrm{M}) = (\chi_m + 1)\mu_0\mathrm{H} = \mu_r\mu_0\mathrm{H} = \mu\mathrm{H} \quad (1)$$

where μ=4p×10-7H/mis the vacuum permeability, χ_m is the magnetic susceptibility, and μ_r is the relative permeability, which is a dimensionless coefficient. μ is the absolute permeability. For paramagnetic media, the magnetic susceptibility $\chi_m > 0$ and μ_r are slightly greater than 1; for diamagnetic media, $\chi_m < 0$, the absolute value of χ_m is generally between 10^{-4} and 10^{-5}, and μ_r is slightly less than 1; and for ferromagnetic media, $\chi_m >> 1$, so $\mu_r >> 1$.

For non-ferromagnetic isotropic magnetic media, the linear relationship between H and B is satisfied: $B = \mu H$,while there is a complex nonlinear relationship between μ, B, and H in ferromagnetic media. In general, there is a spontaneous magnetization in the ferromagnetic substance, and spontaneous magnetization is larger when the temperature is lower. Figure 3 is a typical magnetization curve (B-H curve), which reflects the common magnetization characteristics of ferromagnetic substances: with the increase of H, B increases slowly at the beginning, and μ is small at this time; then B sharply increases with the increase of H increases, μ also increases rapidly; finally, with the increase of H, B tends to be saturated, and the value of μ at this time decreases sharply after reaching the maximum value. Figure 3 shows that the permeability μ is a function of the magnetic field H. As can be seen from Figure 4, the permeability μ is also a function of temperature. When the temperature rises to a certain value, the ferromagnetic substance changes from a ferromagnetic state to a paramagnetic state , and the temperature corresponding to the sudden change of the curve is the Curie temperature T_C.

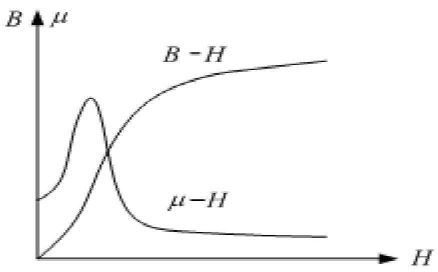

Fig. 3 magnetization curve and curve

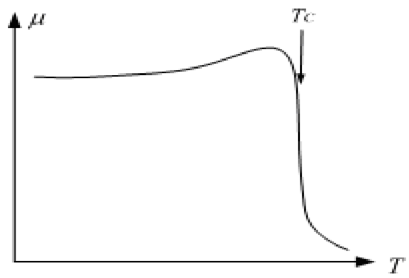

Fig.4 $\mu \sim H$ curve

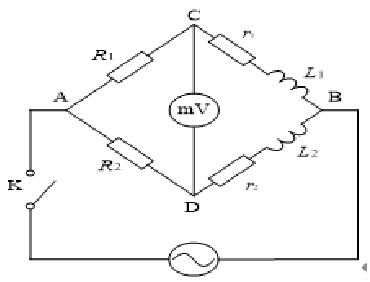

Fig. 5 AC bridge

2.2 Measuring Curie temperature by AC bridge

As shown in the figure, it is an RL AC bridge. The input power in the bridge is provided by the signal generator. In the experiment, a higher output frequency should be appropriately selected, and ω is the angular frequency of the signal generator. Among them, Z_1 and Z_2 are pure resistance, Z_3 and Z_4 are inductance (including the linear resistance r_1 and r_2 of the inductance, and an adjustable resistance r is also connected to the FD-FMCT-A type ferromagnetic material Curie temperature test instrument), Its complex impedance is

$$Z_1 = R_1,\ Z_2 = R_2,\ Z_3 = r_1 + j\omega L_1,\ \ Z_4 = r_2 + j\omega L_2 \quad (2)$$

When the bridge is balanced, there is

$$R_1(r_2 + j\omega L_2) = R_2(r_1 + j\omega L_1) \quad (3)$$

The real part and the imaginary part are not equal, so

$$r_2 = \frac{R_2}{R_1} r_1, \quad L_2 = \frac{R_2}{R_1} L_1 \quad (4)$$

Choosing appropriate electronic components to match can directly balance the bridge when ferrite is not put in, but when one of the inductors is put in ferrite, the inductance changes, causing the bridge to be unbalanced. As the temperature rises to a certain value, the ferromagnetism of ferrite changes to paramagnetism, and the potential difference between two points of CD suddenly changes and tends to zero, and the bridge tends to be balanced. The temperature corresponding to this abrupt point is Curie temperature.

3. Experimental design

3.1 Basic experimental device

Manganese-zinc ferrite was used in the experiment, and two states were used: solid and powder. Put the powder in a test tube and seal it.

The first device is based on balance, and a heating dish connected with the temperature control circuit of the single chip microcomputer is placed above the balance. The heating dish is filled with silicone oil so that it can be heated evenly during heating. After heating, the balance can be sealed with a glass cover. Next to the balance is an iron frame with a permanent magnet hanging. At the beginning of the experiment, the Mn-Zn ferrite solid or sealed powder is placed in a heating dish, and the mass m_0 of the material to be measured in the absence of a magnetic field is measured first. Then move the suspended magnet directly above it, so that the magnet and the manganese-zinc ferrite are in a state where they are about to attract each other. After regularly reading the external magnetic field, measure the mass reading m_1 of the balance. When the mass of the substance to be measured does not change, the Curie temperature is reached. When it reaches the Curie temperature, the measured mass will be labeled M, then M = m_0.

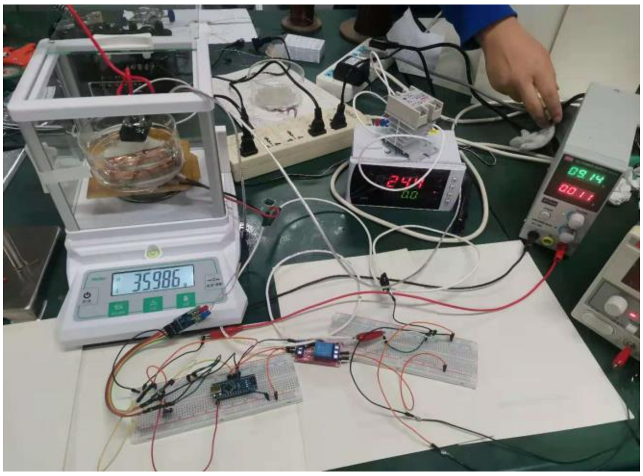

Fig. 6 The first device

The second device adopts a method similar to the AC bridge. The material to be measured is wrapped with self-made copper foil, and a coil with a certain number of turns is wound on its outer end. The coil leads out of the input end and the output end, and resistors and capacitors with corresponding sizes are connected to the input end and connected to the input end by a signal generator. The output voltage signal is measured by a millivoltmeter at the output end. When the material to be measured is wrapped with copper foil, it can be observed that the voltage signal at the output terminal decreases slowly. When it decreases to zero, the corresponding temperature is the Curie temperature of the material to be measured.

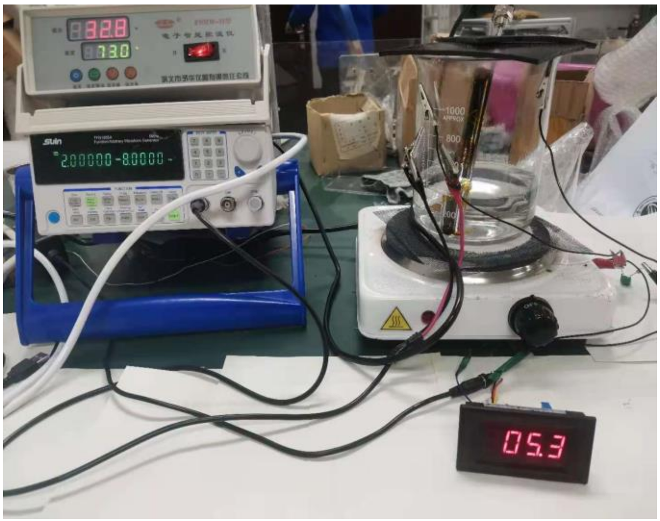

Fig. 7 The second device

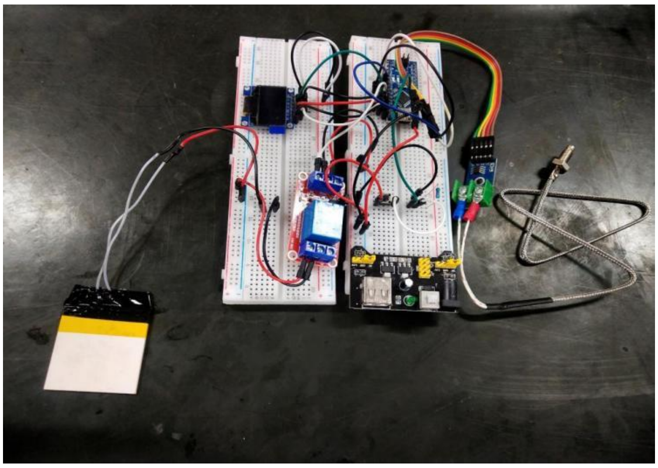

Fig. 8 Control part

3.2 Control part

To obtain reasonable data, the heating rate must be controlled during heating, so that the temperature of the copper rod can slowly rise to the target temperature, so that reasonable data can be collected. In this paper, the PID control algorithm is selected for temperature control.

PID algorithm involves three parts: proportion, integration, and differentiation. Proportional control is the response to the current deviation, and integral control is to adjust PID controller parameters so that the system can quickly achieve a stable response. e(t) is the difference between the given value and the measured value. Increasing the proportional gain K_P can adjust the proportional band, which directly affects the current error signal. When the proportional coefficient is small, the adjustment strength is insufficient, the system output changes slowly, the proportional coefficient is too large, the system deviation value changes too much after adjustment, and the adjustment strength is too strong, resulting in a large change in the output value, which will lead to system instability. The integral link is the cumulative compensation of the previous error signals, and the integral control can eliminate the static error of the system. Increasing K_i will increase the overshoot of the system, making the system oscillate, and reducing K_i system oscillation will be small but the stabilization time will be longer. The differential value K_d is related to the rate of change of the system error signal, and the differential link can predict the trend of error change. Increasing K_d can speed up the response speed of the system.

In this paper, STM32F103 based on ARM Cortex-M3 architecture is selected as the main controller of the PID control system, a ceramic heating plate is selected in the heating part, and PT100 is selected as the front-end temperature sensor. The temperature information is converted into a voltage signal by constant current source excitation, which is then converted into a digital signal by MAX6675 digital-to-analog conversion module and transmitted to STM32F103, where the PID algorithm is executed. [3]The OLED screen will display the temperature information in real-time. The whole control circuit is mounted on the breadboard.

In the process of temperature control, STM32F103 will adjust the duty cycle of PWM(Pulse Width Modulation) according to the error increment of PID output, and PWM will be used as the signal source for driving the heating circuit to realize high-precision constant temperature control.

4. Experiment and result analysis

In the mass-temperature curve obtained by the first method, the Curie temperature is reached when the measured mass is equal to the original mass. The Curie temperature of Mn-Zn ferrite solid is 143.1°C, and that of powder Mn-Zn ferrite is 105.8°C.

In the voltage-temperature curve measured by the second method, the Curie temperature is considered to be reached when the voltage drops to zero. Methods The Curie temperature of Mn-Zn ferrite solid is 143.0°C and that of powder Mn-Zn ferrite is 100.2°C.

The Curie temperatures of two different states measured by the two methods are the same. Moreover, referring to the relevant data, the measured data is consistent with the Curie temperature range of Mn-Zn ferrite given in the data.

Because of the limited space, only the mass-temperature curve of solid manganese-zinc ferrite measured by method 1 and the voltage-temperature curve of solid manganese-zinc ferrite measured by method 2 is given here, as shown in the figure:

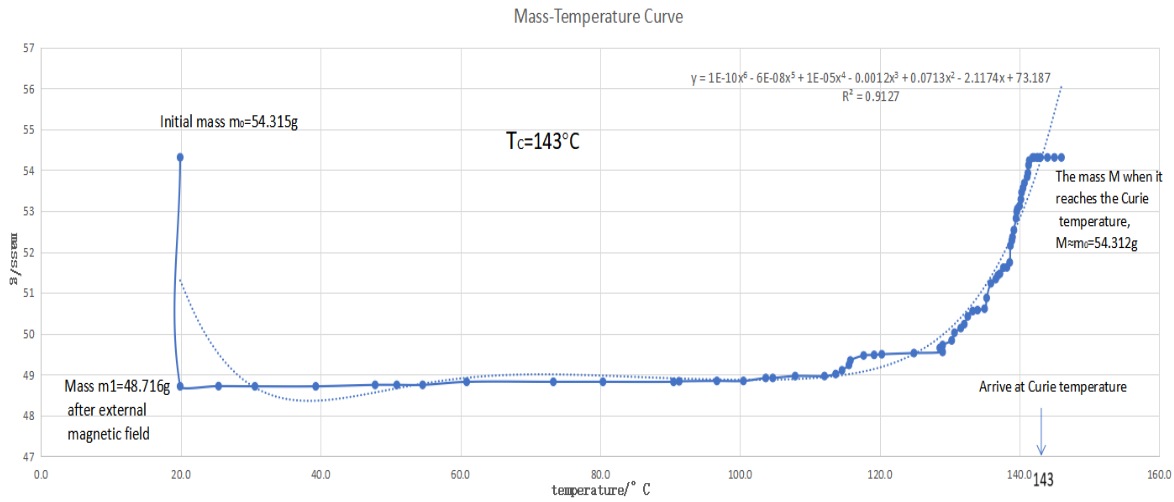

Fig. 9 Mass-temperature curve

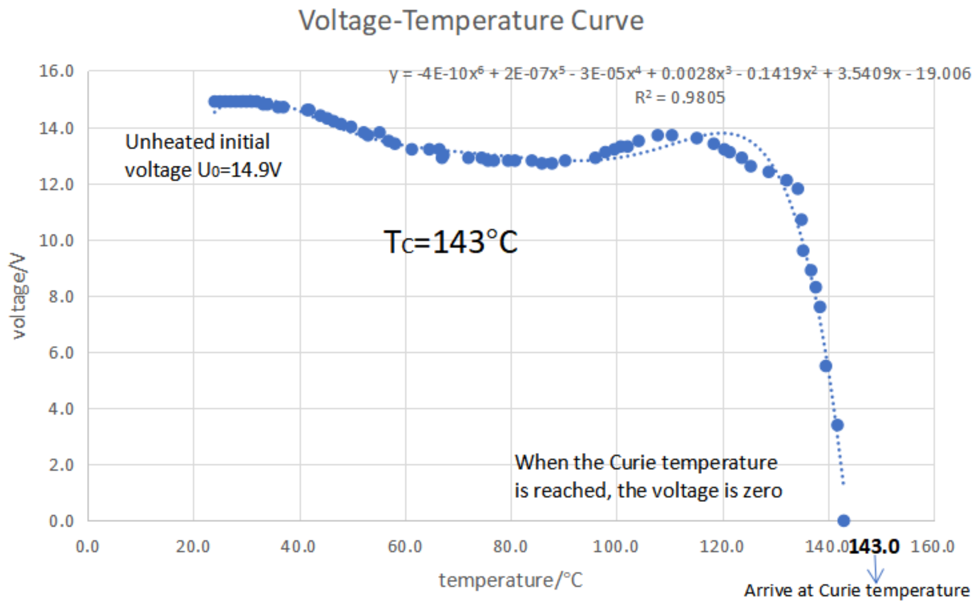

Fig. 10 Voltage-temperature curve

5. Project innovation and features:

This method can measure both solid and powder.

This method can measure both materials with regular shapes and materials with irregular shapes.

The phenomenon is obvious; Accurate and reliable data;

Using a single chip microcomputer to control the temperature makes the measurement result more accurate;

Compared with the devices and methods used in traditional experimental teaching, the two devices designed in this experiment have lower costs and certain teaching practicability.

6. Summary

This project adopts two sets of devices to measure the Curie temperature of solid magnetic ring and Mn-Zn ferrite magnetic powder respectively. The two sets of devices used in this project can accurately measure the Curie temperature of the materials used, and the measured Curie temperature is not much different from the theoretical Curie temperature of the materials.

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