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The problem of mathematical description for the hysteresis loop of ferromagnetic materials has been studied for a long time but unsolved until the present. Some models as particularly the Preisach model of general characters of hysteresis and the Jiles – Atherton model of ferromagnetic phenomenology, used in a wide range. But these can describe only some part of hysteresis. The eddy current generates heat in nanomagnetic materials because of hysteresis loss. Nowadays, the necessity to study hysteresis increases by nanomagnetic properties, but it is described only by magnetic domains and their changes. In this paper, the opening of the ferromagnetic hysteresis loop is shown firstly based on the trigonometric model. Finally, its confirmation is indicated by the experimental results of the $CuFe_2O_4$ compound.

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I. INTRODUCTION

Hysteresis can be found everywhere as in physics, astronomy, chemistry, engineering, biology, and economics.

Sir James Alfred Ewing studied firstly the hysteresis of magnetic materials around 1890. M. Krasnosel'skii turned his attention increasingly to discontinuous processes and operators, in connection firstly with nonlinear control systems and then with a mathematically rigorous formulation of hysteresis which encompasses most classical models of hysteresis and is now standard [1].

One of the most common magnetic phenomena is magnetic hysteresis, which shows the relationship between the magnetization of the ferromagnetic material and the magnetic field [2-3]. Many years of theoretical research have provided detailed theories, mathematical expressions, and models to explain the physical mechanism of the phenomenon of hysteresis [4-6].

Of these, the Preisach model [7], which determines the general characteristics of hysteresis, and the Giles-Atherton model [8], a theory of ferromagnetic phenomenology, are widely used. Theoretical physicists and mathematicians have been working for many years to understand the physical mechanism of hysteresis and to create sufficient mathematical expressions to describe it. Many experimental studies of hysteresis carried out in modern techniques and technologies. For example, only the types of Hall effects include the Quantum Hall effect [9], the quantum anomaly Hall effect [10], and the spin Hall effect [11-12]. For each topic involving hysteresis, there are appropriate models, indicating the need for a unified model.

All modern magnetic materials, from the soft Fe-Ni alloy to the hard magnetic Nd-Fe-B permanent magnet used in electronic circuits, are all associated with hysteresis. It is necessary to model the hysteresis phenomenon and create the conditions with the highest efficiency by selecting the optimal parameters.

Saturation of the magnetic hysteresis loop, coercive force, and residual magnetism are the main parameters that determine the properties of ferromagnetism (Figure 1).

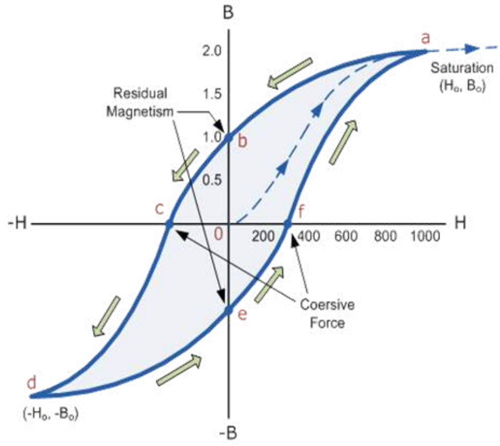

Figure 1: Ferromagnetic hysteresis loop

The Phenomenon of Electromagnetic energy into thermal energy by the action of some magnetic nanoparticles is widely studied. The amount of heat emitted depends on two types: the loss of ferromagnetic hysteresis and magnetic susceptibility of superparamagnetic nanoparticles [13].

This paper focused on opening the hysteresis of magnetic materials and on explaining the characteristics of the hysteresis loop using a mathematical model (The Supreme Theory of Everything) based on the transformation of trigonometric formulas [14-16].

II. MATHEMATICAL MODEL OF HYSTERESIS

Hysteresis is the most complicated of all the nonlinearities presented because y is not simply a function of x, as it has been in the other cases. Rather, y is also a function of $\dot{x}$. Unlike the other nonlinearities, there is no single mathematical expression for hysteresis. It is typically expressed graphically. The first thing to note about the relationship between x and y is that for a given x, there may be two possible values for y. The way to interpret the relationship is as follows. Consider a specific value for x shown in Figure 2 as $x0$. The question is whether y value will take on value $y1$ or $y2$. Just knowing $x0$ is not enough information. The value of y depends on where x came from. If x is increasing, then $y = y2$. If x is decreasing, then $y = y1$. The curve is followed in the direction given by the arrows and indicates whether to use the upper or lower part.

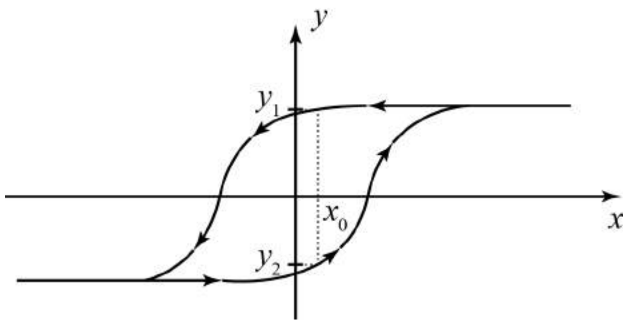

Figure 2: Demonstrating how to interpret a hysteresis curve

A system with hysteresis is one that has memory. Its output depends on where it came from". For this reason, leading scientists worked hard to express the mathematical formulations of the magnetic hysteresis, but generally experimental. [17].

The hysteresis loop has two directions: upward and downward. Since the question is whether y value will take on value y1 or y2 [17]. To avoid this problem and open the hysteresis y only must take one y value. To do this, we need to transform the function B(H) into H(B) (Figure 3b), and then it is possible to convert the left or right direction of the function by the mirror method at the saturation point (Ms). Depending on which saturation point, it may be called left or right open hysteresis (Figure 3).

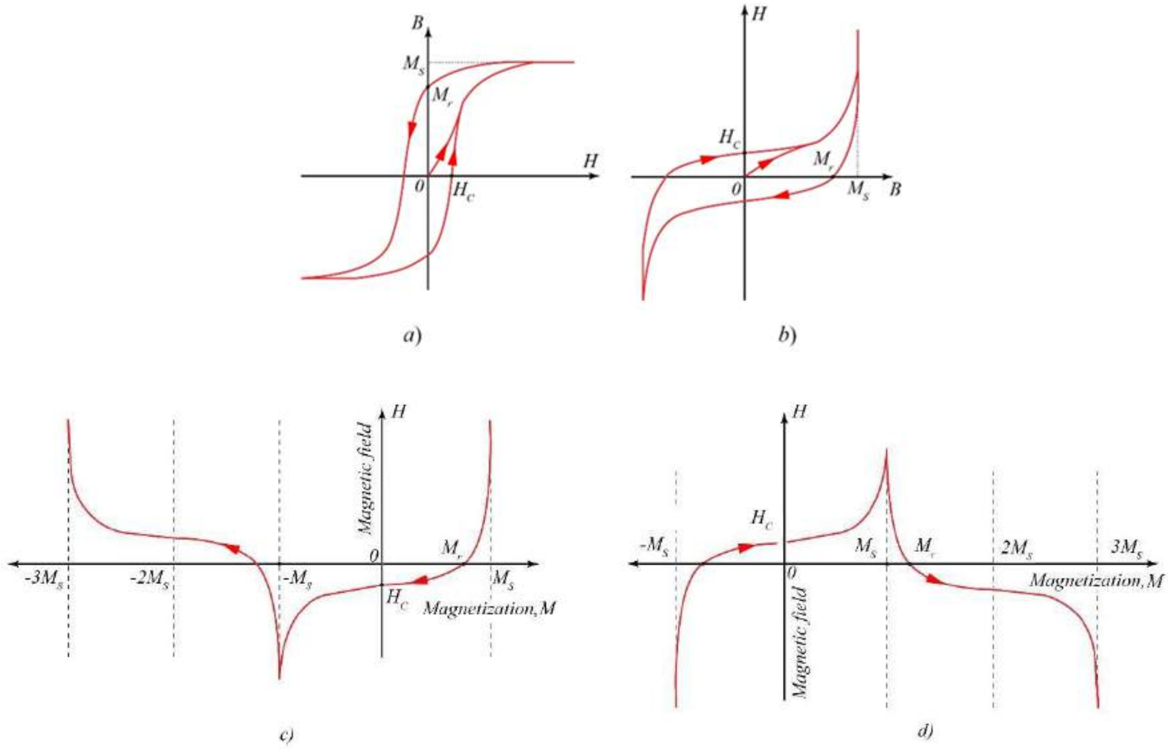

Figure 3: Algorithm for the opening of ferromagnetic hysteresis a) Traditional hysteresis, b) Reverse hysteresis, c) Left open hysteresis d) Right open hysteresis

For magnetic hysteresis, the magnetization B is a function of the magnetic field, $B = B(H)$. It is not possible to open hysteresis because the quantity H, which directly controls the process, varies in all numerical regions. However, since the dependent variable B is changed in the interval [–Ms, Ms], it is possible to open the inverse hysteresis $H = H(B)$. To construct a mathematical model, let us move on to the dimensions that do not depend on (1).

$$x = \frac{\pi}{2}\frac{B}{M_s}, \quad x \in \left[-\frac{\pi}{2}, \frac{3\pi}{2}\right]$$
$$y = \frac{H}{H_c}, \quad y \in [-\infty, \infty] \tag{1}$$

The mathematical expression for open hysteresis is described by Formula (2) [14-16] shown in Figure 3 c.

$$y = \frac{a \cdot sin(x-\theta)}{|cos(x)|} \tag{2}$$

Where x is the value of the angle along the circle, θ is the parameter that determines the phase shift or residual magnetization value, and a is the parameter that determines the amplitude or coercive force.

Thus, by replacing the two axes of the hysteresis graph, the design becomes clear and easier to use. It indicates that the x-axis seems to take on the plus and minus infinity and trigonometric transformation from a time-domain function to a frequency domain. We understand the partial frequency interval as time. The vertical axis represents the magnetic field (electric field), and the horizontal x-axis represents the magnetization (polarization) (Figure 3b). Formula (2) looks like the ratio of the upper and lower axes of an ellipse. If the amplitude of the sine function is greater than the cosine ($a > 1$ $a > 1$), the ellipse is vertically oval, and if the amplitudes are equal ($a = 1$ $a = 1$), it is circular. At $a > 1$ $a > 1$ itis a horizontal oval ellipse. Since Formula (2) has the form cosine function 1/0, two large singulars appear to be monotonically increasing and decreasing functions. The positive singular is π/2, and the negative singular is -π/2. One complete turn of a circle consists of two parts: the left-wing is in the interval [-3π /2, -π/2] and the right-wing is between [-π / 2, π/2].

While the magnetic field (*H*) can increase infinitely, the magnetization (*M*) is finite or saturated at a certain *Ms*-point. When *H* equals 0, the residual magnetization (*Mr*) is determined. The magnetic field then becomes negative and appears as infinite at 270^0, and the magnetization reaches saturation point again at *Ms*.

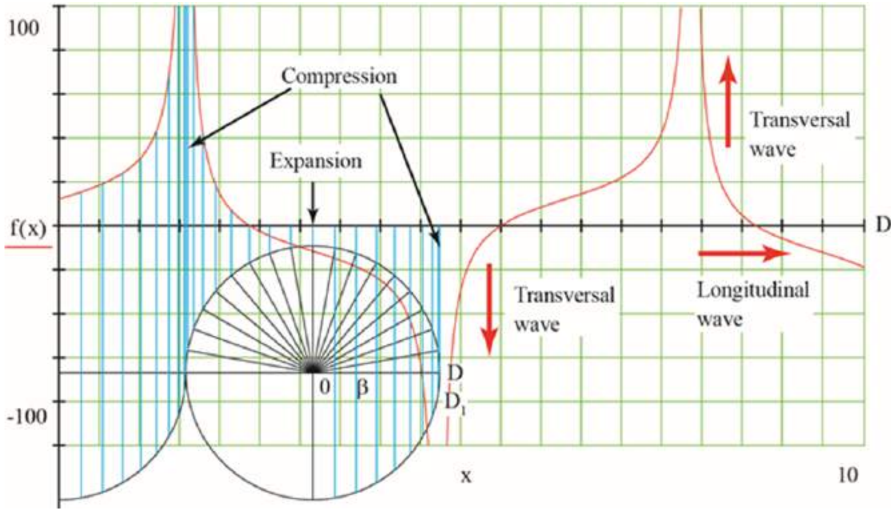

Figure 4: Open hysteresis defined by Formula (2) (For simplicity, a = 0.5 and $\theta = -\pi / 4$ are calculated)

Figure 4 shows the projection on the x-axis of the y function [14] and the magnetic state of open hysteresis.

The function y (optically, the distance of light transition in the transmitting medium) is directly proportional to the amplitude (thickness of the light-transmitting medium) and is inverse proportional to the cosine of the difference of incident and refraction angles [14]. Thus, the Supreme Theory of Everything shows no space or time, but that it is by expressions such as amplitude, frequency, and phase shift.

$$c(x) = \frac{10\sin\left(x - \frac{\pi}{4}\right)}{|\cos(x)|}; \qquad c1(x) = \frac{10\sin\left(x + \frac{\pi}{4}\right)}{|\cos(x)|}; \qquad c2(x) = \frac{15\sin(x)}{|\cos(x)|} \qquad (3)$$

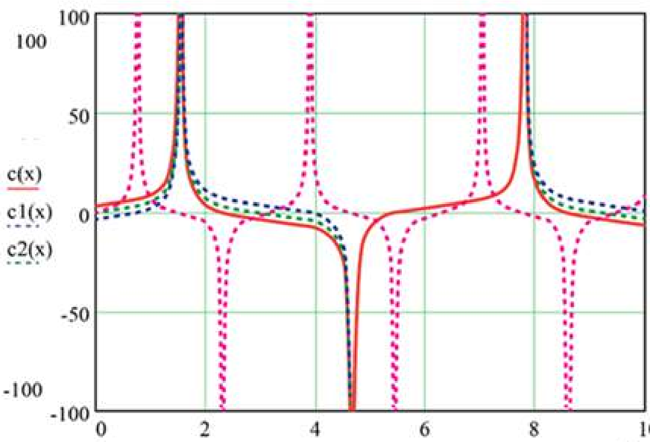

Figure 5: Behaviors of open hysteresis

Let us consider some features of open hysteresis based on equations (3):

- When the phase shift is negative (c (x)), the right-wing is higher than the left-wing. If the phase shift is positive (c1 (x)), the left-wing of the hysteresis is higher than the right-wing.
- If the formula has no phase shift (c2 (x)), the two wings are symmetrical.

The characteristics of open hysteresis compared with the experimental results.

III. HYSTERESIS OF MAGNETIC $CuFe_2O_4$ COMPOUNDS

The measured values of the magnetic properties of the $CuFe_2O_4$ magnetic material cited from the work [17] (Figures 6, 7, 8).

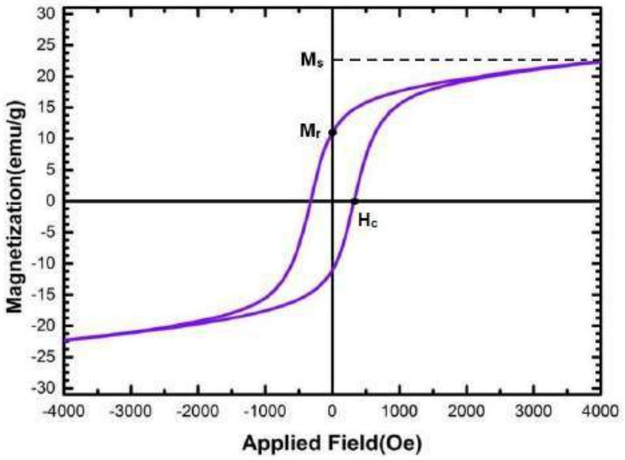

Figure 6: The hysteresis loop of $CuFe_2O_4$ nanoparticles fired at 850°C

The results of the hysteresis measurements are analyzed using the methods described above. To approximate, transfer the physical quantity to the normally non-dimensional dependent quantity according to Formula (2). *Ms* = 22 *emus*/g, and *Hc* =325 *Oe* were obtained from the measurement results [18]. To do this, use the values of Ms = 22 emus/g and Hc = 325 Oe obtained from the measurements, normalize them according to Equation (2), and convert them to non-dimensional quantities.

Since the opening point is $x_{open} = -\frac{\pi}{2}$ $x_{open} = -\frac{\pi}{2}$, the lower curve of the hysteresis loop conversion leads to an open hysteresis curve (Figure 7 and Figure 8).

$$\bar{x}_i = -\pi - x_i \; \bar{x}_i = -\pi - x_i, \quad \bar{y}_i = y_i \; \bar{y}_i = y_i$$

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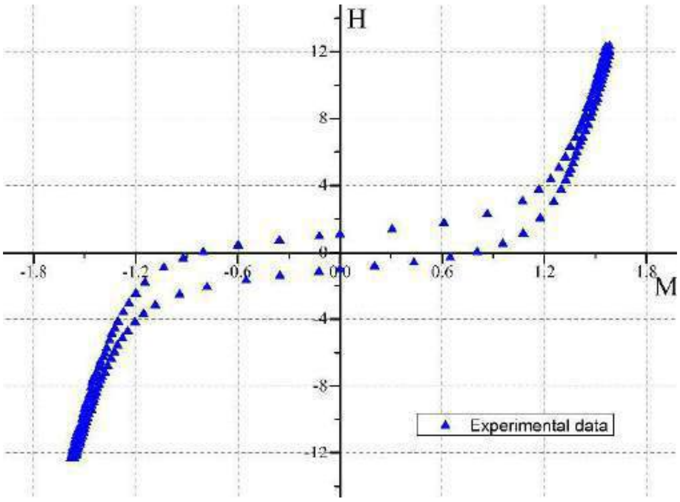

Figure 7: Reverse hysteresis of $CuFe_2O_4$ nanomagnetic compounds

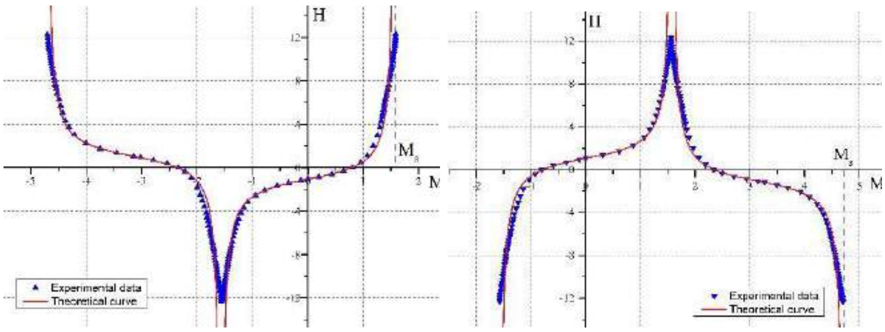

Figure 8: Fitting of the theoretical and experimental curves of the open hysteresis
a) left open hysteresis, b) right open hysteresis

The results show that the mathematical model of The Supreme Theory of Everything can approach the magnetic hysteresis curve with high accuracy and to explain the physical process.

There are the values of the approximate parameters a and θ and the standard errors shown in Table 1.

Table 1: Standard deviations of the theory and measurement curves

	a	Standard error	θ	Standard error
Left open hysteresis	1.48395	0.02339	0.79116	0.01557
Right open hysteresis	1.49068	0.02091	-0.78845	0.01359

The standard approach error was found to be 1.57% for the parameter a and 1.97% for phase transition θ.

The results show that the mathematical model of The Supreme Theory of Everything can approach the magnetic hysteresis curve with high accuracy and explain the physical process.

III. CONCLUSION

1. The experimental values are converted to non-standardized units by Formula (2). Subsequently, the hysteresis opens successfully after the transformation.
2. It is possible to explain the hysteresis of the magnetic material determined experimentally with the help of Formula (2). It is possible to extend the formula by adding physical parameters in the future.
3. With the help of the open hysteresis formula of the magnetic materials, it is possible to express many properties of the magnetic materials, such as ferromagnetic, Paramagne -tic, ferrimagnetic, antiferromagnetic.

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