Research on Degaussing Method of Ferromagnetic Materials Based on Magnetic Domain Control

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Abstract. The microscopic magnetic structure of the ferromagnetic material determines its macroscopic magnetic properties. Therefore, the arrangement of the magnetic domains inside the material affects the magnitude and direction of the magnetic properties that appear externally. In this paper, the degaussing method of ferromagnetic materials based on magnetic domain control is studied. The magnetic domain control principle is studied by analyzing the magnetization process inside the material. The permanent magnet array is used as a strong magnetic source to control the internal magnetic domain by a particular arrangement. Based on the simulation calculation, test is carried out to verify the feasibility of the method. The results show that the use of permanent magnet arrays to control the internal magnetic domains of ferromagnetic materials can effectively reduce the magnetic properties of materials.

1. Introduction

Ferromagnetic materials are widely used in many fields such as shipbuilding, and have certain requirements on their magnetic properties. At present, at home and abroad, the magnetic properties are eliminated by winding an alternating current coil around the material \cite{1-3}. This method has the disadvantages of complicated coil structure, high power and short duration of effect.

From the magnetization process of ferromagnetic materials, it can be known that the arrangement of internal magnetic domains affects the macroscopic magnetic properties of materials. Based on this, the paper proposes a method of degaussing materials by using a permanent magnet array to control internal magnetic domains. The feasibility of the method is verified by the analysis of magnetic domain control principle, the study of permanent magnet array degaussing method, simulation calculation and experiment.

2. Magnetic domain control principle

Magnetic is one of the basic properties of a material. The magnetic properties of a material are derived from the magnetic moment of an atom. Magnetic domain refers to a small magnetized area inside a ferromagnetic material \cite{4}. Each region contains a large number of atoms inside, and the magnetic moments of these atoms are arranged neatly like a small magnet, but the directions of the atomic
magnetic moments between different adjacent regions are different, as shown in Figure 1. The interface between the individual magnetic domains is called a magnetic domain wall.

Before being magnetized by an external magnetic field, the magnetic domains in the ferromagnetic material have different directions, cancel each other out, and do not exhibit magnetism. Magnetic properties are only shown when the material is magnetized.

Fig. 1. Magnetic domain under magnetic force microscope

The magnetization process of ferromagnetic materials can be roughly divided into four stages [5], as shown in Figure 2.

The first stage is the reversible displacement of the magnetic domain walls. When the external magnetic field is small, the magnetic domain is enlarged by the movement of the magnetic domain wall, causing the material to be magnetized. At this time, if the magnetic field is removed, the material will return to the demagnetized state.

The second stage is the irreversible magnetization process. As the external magnetic field increases, the magnetization curve of the material rises rapidly, its magnetization increases sharply. This is the process of domain wall jump movement, which is called the Buckhausen Jump. This kind of jump is that the magnetic domain jumps from one stable position to another, and the magnetic domain structure also mutates, which is an irreversible stage.

Fig. 2. Magnetization process of ferromagnetic material

The third stage is the rotation of the magnetic domain magnetic moment. With the further increase of the external magnetic field, the magnetic domain displacement in the material has basically been completed, and the magnetization can be increased only by the rotation of the magnetic moment in the magnetic domain.

The fourth stage is the stage of approaching saturation. At this time, if the external magnetic field is continuously increased, the increase in the magnetization is small, and this increase is caused by the reversible rotation of the magnetic moment in the magnetic domain.

It can be obtained from the magnetization process of the ferromagnetic material, by applying an external magnetic field of a certain strength and direction to the material, the size and orientation of the internal magnetic domain can be changed, thereby affecting the external magnetic properties. The
generation of the external magnetic field should use a magnetic source with good magnetic properties, and the permanent magnet can locally generate a large magnetic field strength [6].

3. Degaussing method research

Combined with the magnetic permeability change model of ferromagnetic materials, the magnetization process of ferromagnetic materials under the influence of external magnetic sources is studied, and the variation of internal magnetic domains and magnetic domain walls is analyzed. Permanent magnets are used as strong magnetic sources to control the internal magnetic domains of ferromagnetic materials, so that the localized regional magnetization tends to be saturated, thus reducing the influence of external environmental magnetic fields. At the same time, the arrangement of the permanent magnet arrays is carefully designed to reduce the influence of the array itself on the magnetic properties of the material [7].

According to the basic magnetization curve of the ferromagnetic material, the magnetic permeability \( \mu = B/H \) can be approximately determined. Since \( B \) and \( H \) are nonlinear, the \( \mu \) of the ferromagnetic material is not constant, but varies with \( H \), as shown in Figure 3.

![Fig. 3. Ferromagnetic material \( \mu \) and \( H \) curve](image)

It can be seen from the magnetic permeability change curve that the magnetic permeability rapidly rises when the external field increases initially, and the magnetic permeability reaches a maximum when the external field reaches a certain value, and then the magnetic permeability decreases as the external field increases. For ferromagnetic materials, the external field of the geomagnetic field strength generally falls within the rising edge of the curve, that is to say, the magnetic properties of the material change greatly in the geomagnetic field.

By attaching a permanent magnet array to the ferromagnetic material, the magnetic domain of the material is controlled by the strong field strength of the array, and the magnetic permeability is controlled in a small area, thereby effectively reducing the influence of external magnetic field changes on the magnetic properties.

In order to minimize the influence of the permanent magnet array itself on the magnetic properties of the material, precise control of the arrangement of the array is required.

Its arrangement mainly follows the following principles:

1. Equivalent central symmetry principle, as shown in Figure 4
4. Simulation and test verification

On the basis of theoretical analysis, the electromagnetic simulation calculation and test verification work were carried out.

First, the CST electromagnetic studio is used to simulate permanent magnets of different shapes, volumes and magnetic moments attached to the ferromagnetic material with certain regularity. Then, analyze its influence range and size on the internal magnetic domain of the material, and calculate the influence of the external field change on the magnetic properties of the material. On the basis of
simulation, the test verification work is carried out. The simulation results are shown in Figure 7 and Figure 8.

![Fig. 7. Additional magnetic source and magnetic field distribution of flat material](image)

For the flat material (10 cm in length, 3 cm in width, 1 cm in thickness, the magnetic parameters are obtained by a certain type of steel), when the external environmental magnetic field changes from 1000 nT to 4000 nT along the longitudinal direction of the flat plate, the change value of the magnetic properties of the material is calculated.

The results show when the additional magnetic source to material volume ratio is 1/100, its magnetic change under the external field is reduced by 25%, and when the additional magnetic source to material volume ratio is 1/50, its magnetic change under the external field is reduced by 40%.

![Fig. 8. Additional magnetic source and magnetic field distribution of cylindrical material](image)

For the cylindrical material (30 cm in inner diameter, 78 cm in length, and 3 cm in thickness, the magnetic parameters are obtained by a certain type of steel), when the external environmental magnetic field changes from 1000 nT to 4000 nT along the long axis direction of the cylinder, the change value of the magnetic properties of the material is calculated.

The results show when 12 magnetic sources were attached, its magnetic change under the external field was reduced by 30%.

The test is verified by using a ferromagnetic cylinder material of the same size as the simulation model, and the same form of magnetic source attachment is performed with a permanent magnet array, as shown in Figure 9. This experiment is performed in the CM2 magnetic field simulation system.
The measurement results show that under the geomagnetic field, the magnetic properties of the material can be reduced by more than 30% by this degaussing method, which verifies the feasibility of the method.

5. Conclusion
In this paper, the magnetic domain control principle is studied by analyzing the magnetization process of ferromagnetic materials. The method of using permanent magnet array as a strong magnetic source to control internal magnetic domains by a certain arrangement to reduce the magnetic properties of materials is studied. On the basis of theoretical analysis, the feasibility of the degaussing method is verified by simulation and experiment, which is conducive to the next research and application.

The method has the following characteristics: (1) high efficiency, low energy consumption; (2) long duration of effect; (3) simple operation and low cost.

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