Generalized Superconducting Hysteresis Model for the MgB_2 Based on the Preiasach Model

Kun. Dong, Haitao. Yu, Minqiang. Hu, and Rong. Guo

School of electrical engineering, Southeast University, Nanjing, 210096 China

I. Introduction

Although heat generated by the power losses of superconductors are near zero. But the extremely low temperature, the precondition of maintaining superconductivity, makes local generated heat require a large amount of refrigerator power for the removal of thermal effect according to the Carnot-cycle theory. The superconducting hysteresis loss is the leading cause for the power losses. The superconducting hysteresis is a phenomenological model of interaction between flux pinning force and Lorentz force resulting in an electromagnetic memory in the MgB_2. Superconducting hysteresis losses in whether the applied fields or self-field generated by the carrying current cables are described and modeled based on the bean critical state. The analytical expressions are available for simple geometries. However, those expressions cannot be subject to the varying amplitude of magnetic field and frequency accurately.

the macroscopic and phenomenological hysteresis models and their partial different equations such as Preisach, Relay operator, Preisach density function, and the time-integral equations are well-known to be used to describe the hysteresis property and employed extensively as fundamental tools to calculate the hysteresis loss and embedded components easily coupled with the magnetic field numerical computation. In the recent decades, the typical Priesach model is modified to accustom the superconducting hysteresis in the name of simplified Priesach model, Preisach-type model, parameterized Priesach model and the new Priesach model. However, the practical superconducting hysteresis is complicated. the classical Preisach model cannot account for reversible components of hysteresis nonlinearities but irreversible components. More, the viscous damping effects are neglected in these Preisach mathematical models.

To remove the above limitations of Preisach models, the The paper presents the generalized superconducting hysteresis model (GSHM) consisting of rate-independent and rate-dependent components for superconductor based on the classical Preisach model. The GSHM is presented in the paper requiring the only one whole *M-H* loop first-order transition data as the input parameters. The paper is organized as follows: First, that the Preisach model and the superconducting magnetization process is summarized laying the foundation for GSHM. Then, the magnetization versus applied field loop is divided into two the separate parts: the rate-independent and the rate-dependent, and that the GSHM is described in details. Finally, the experimental data verifies the GSHM.

II. Classical Preisach Model and its Derivatives

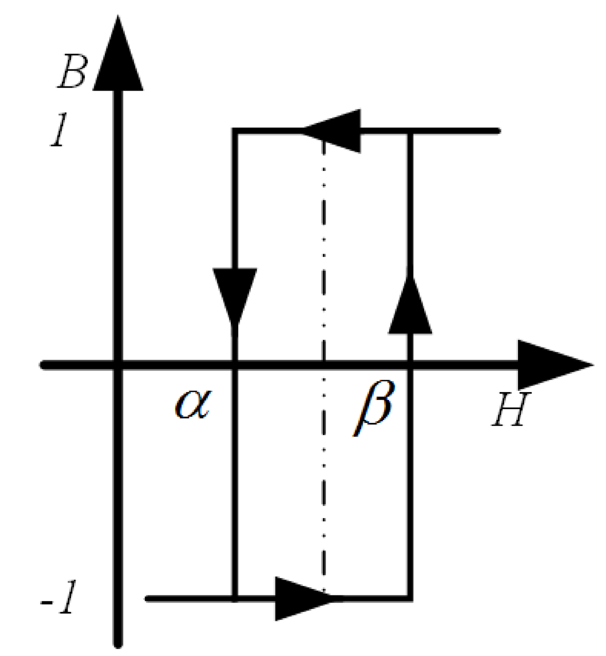

Fig.1. The simplest hysteresis operator in the Preisach model

The unit relay hysteresis operator, as shown in Fig.1, is characterized by the input H and the output B at each cycle determining the width of the hysteresis operator.

Under the assumption of (α, β) plane and $\alpha \leq \beta$,there exists the triangle range which is be specific by the inequalities $\alpha_0 \leq \alpha \leq \beta \leq \beta_0$. With the inputs of variations, when $H(t)$ exists the range [α, β], the hysteresis operator can be modified in the figure 2 and as follows.

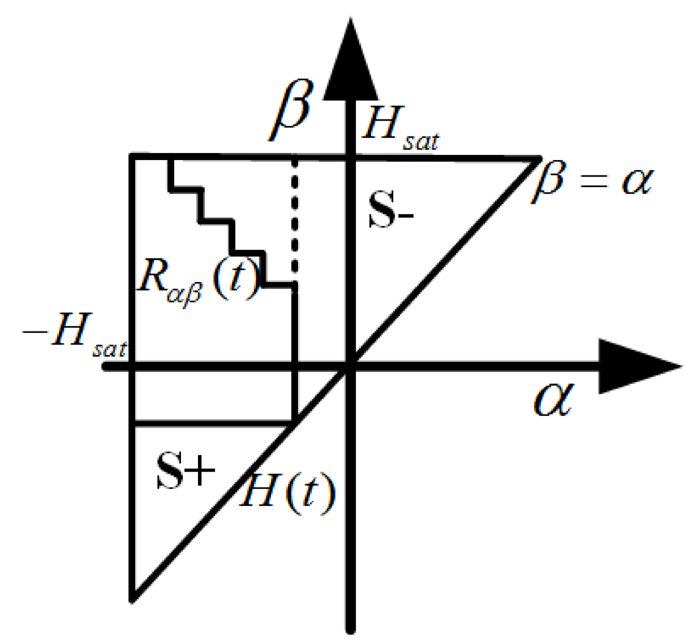

Fig.2. The modified hysteresis operator (H_{sat} is the saturated magnetic field intensity).

$$R_{\alpha\beta}[H(t)] = \begin{cases} +1 & H(\mathrm{t}) \geq \beta \\ -1 & \alpha \leq H(\mathrm{t}) \end{cases}$$

$$R_{\alpha\beta}[H(t)] = \begin{cases} +1 & \beta_0 \geq H(\mathrm{t}) \geq \beta \\ R_{\alpha\beta}(t) & \alpha \leq H(\mathrm{t}) \leq \beta \\ -1 & \alpha_0 \leq \alpha \leq H(\mathrm{t}) \end{cases}$$

III. Superconducting Hysteresis

The superconducting back-and-forth magnetization processes includes irreversible components and reversible components of the wipe-out property and congruency property. It is important to emphasize here that the irreversible superconducting hysteresis is caused by the motion of flux pinning in the various defects.

The reversible part: at the instant time, the magnetic field will completely be variable with the change in the external field $B_{app}(t)$. $dB_{app}(t)$ is the change of $B_{app}(t)$, $B_{ind}(t)$ is the corresponding field created by the interior superconducting currents. It is clear that $dB_{app}(t)>0$ when $B_{app}(t)$ is monotonically increased until the saturated magnetic density, and $dB_{app}(t)<0$ when $B_{app}(t)$ is monotonically decreased until the reversed magnetic point. At the same time, when the moving fluxion meet the defects in the superconductors, the flux tubes are pinned by the pinning potential and cannot move until they can overcome an energy barrier and jump irreversibly to a new pinning potential. This is the irreversible fluxoid motion.

IV. Generalized Superconducting Hysteresis Model

The irreversible superconducting hysteresis is the process of fairly complicated magnetization behavior. A large number of experiments on magnetization properties is generally presented in the form of hysteresis loop in the *M-H* plane. The complex magnetization and demagnetization in nature is due to the intrinsic reason that the electrodynamic and magnetic behavior of a superconductor depend largely on how the applied magnetic field works and distribution of various defects in the specific specimen. And that it is good method to use the Preisach model which is purely phenomenological mathematical tool to describe the M-H loop. However, the classical Preisach, just have the rate-independent components, needed to modified to adjust the rate-independent and rate-dependent property of superconducting hysteresis.

The proposed generalized superconducting hysteresis model mainly includes three parts:

1:Modeling the Generalized Mathematical Hysteresis Model;

2:Modelling the Rate-independent Considering the Irreversible parts and Reversible parts;

3:The Initial Magnetization Process

V. Comparisons & Conclusions

The program for the generalized superconducting hysteresis model is coded via the python to approximatively forcast the hysteresis behavior curve of MgB_2. The result by calculation is compared with the experiments which is shown in the fig 3.

The Preisach model of hysteresis is in this paper applied to the case of Mgb_2, where it relates the hysteretic behavior of the magnetic density $B(t)$ as a function of magnetic intensity $H(t)$. It is demonstrated that the critical state model complies to the necessary and sufficient conditions to be described of the Preisach model. the rate-independent, rate-dependent, and viscous damping coefficient makes up the whole phycial superconducting hysteresis behavor.

This paper focuses on the more efficient hysteresis model for superconductors, and that the generalized superconducting model is proposed and verified by the experiments.

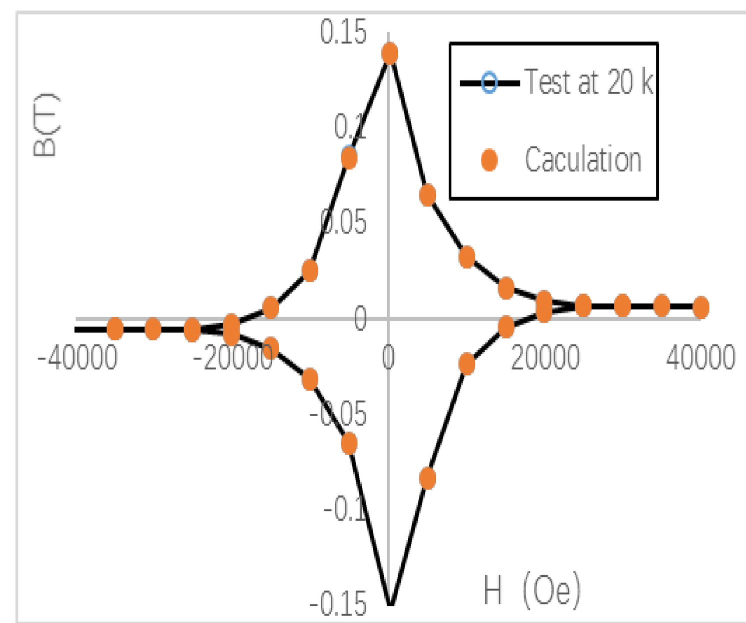

Fig.3. Result comparisons of MgB2 hysteresis loop at 20 k based on test and calculation