DOE/ER/13846-5

MATHEMATICAL MODELS OF HYSTERESIS

DOE/ER/13846--5

DE93 001837

Progress Report

January 1992-December 1992

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September 1992

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY

UNDER GRANT NUMBER DEFG0588ER13846

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The research undertaken under the No. DEFG0588ER13846, during the past year of the project has been in complete compliance with the work statement of the grant. The main results obtained during this period can be briefly summarized as follows.

1. A thorough theoretical study has been carried out for the "superposition" (average) Preisach-type model of hysteresis. This model has consistently proven, through experimental testing, to have remarkable accuracy in comparison with other models. We have found out that the origin of this remarkable accuracy is its far reaching generalization of the congruency property of the classical Preisach model. Moreover, the necessary conditions for the representation of actual hysteresis nonlinearities by this model has been determined. We have also investigated the classical feedback Preisach model and developed a numerical technique for its implementation. An important feature of this technique is that it is not iterative in nature. As a result, its implementation is straightforward. This feedback model can be easily

applied to simulate magnetostrictive or piezoelectric micropositioners with feedback controllers. As far as vector hysteresis models are concerned, we have extended the nonlinear (input-dependent) and restricted models to the vector case. Both models have demonstrated similar performance to that of the previously developed vector model. In addition, a new generalized vector Preisach-type model has been developed. Preliminary results indicate that this model is capable, from a quantitative point of view, to match experimental results much more accurately.

2. Investigation of the Preisach model with stochastic input as a model for viscosity has been performed. A formulation for the time evolution of the expected value of the output process has been derived. This approach has been compared with the classical thermal activation-type models and with some known experimental facts. It has been demonstrated that this approach leads to more general "interacting particle" type model, as well as their vector extensions. Another potential advantage of this approach is that its stochastic nature of thermal noise is explicitly accounted for in the

model structure. In addition, the Stoner-Wohlfarth hysteresis model with stochastic input as another approach to model viscosity in magnetic materials has also been investigated.

3. Work is currently being carried out to generalize the superconductivity critical state-type model by analyzing the penetration of magnetic fields into superconductors with broad resistive transitions. This requires the solution of nonlinear PDE of parabolic types. For this reason, efforts are also being made to develop analytical techniques for the solution of these PDE's. We are also investigating the development of vector critical state-type models for superconducting hysteresis. Other cases involving the penetration of electromagnetic fields into magnetically nonlinear and even hysteretic media are also being studied.

4. Extensive experimental testing of hysteresis models has been carried out. This testing has been performed by means of the vibrating sample magnetometer (VSM) provided by the NSA researchers who have expressed interest in our work. Initially, this VSM was only equipped to measure scalar hysteresis. However, we managed , with the help of the engineers from

LDJ Company (which is the VSM manufacturer) to upgrade its capabilities to include vector hysteresis measurements as well. Intensive experimental testing has been done to assess the accuracy of the "superposition" scalar Preisach model of hysteresis. Other testing has also been performed for the classical, nonlinear (input-dependent), and restricted models. This testing has confirmed the remarkable accuracy of the "superposition" model in comparison with other Preisach-type models. The vector nonlinear (input-dependent) and restricted models have also been experimentally tested and compared to the newly developed generalized vector model. Experimental results have demonstrated that while all models are in qualitative agreement with our measurements, the new generalized vector model is much more accurate from a quantitative point of view. Additional experimental work has also been performed to test the developed numerical implementation of the feedback hysteresis model. This testing has revealed that this implementation is accurate for moderately small feedback factors (i.e. feedback factors less than 0.3). For higher feedback factors, this model can provide good initial guesses for other iterative techniques.

5. Currently, we are considering to carry out some experimental work in order to test the Preisach-type models for viscosity in hysteretic materials. It is believed that this experimental work is within the capabilities of our VSM.

6. Substantial effort has been made to numerically implement Preisach-type models of hysteresis in software form. Digital codes have been developed to implement numerous Preisach-type models. Namely, these models are: 2-D and 3-D vector nonlinear (input-dependent) model, 2-D and 3-D vector restricted model, 2-D and 3-D new vector generalized model, and the feedback model. Digital control codes have also been developed to automate the data acquisition by the VSM during experimental tests.

7. In addition to this research, we are considering the integration of 3-D vector hysteresis models in a software package simulating various magnetic recording processes.

The detailed discussion of many results described above can be found in our papers already published or submitted for publications. Copies of these papers are attached to this report.

The funds supplied for the last year of the project have been completely utilized to carry out the research summarized above.

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