

Constrained Spline-Based Everett Map for Static Hysteresis Modeling

Citation for published version (APA): Daniels, B., Zeinali, R., Overboom, T., Curti, M., & Lomonova, E. A. (2023). *Constrained Spline-Based Everett Map for Static Hysteresis Modeling*. Poster session presented at 24th International Conference on the Computation of Electromagnetic Fields, COMPUMAG 2023, Kyoto, Japan.

Document status and date: Published: 25/05/2023

Document Version:

Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.

• The final author version and the galley proof are versions of the publication after peer review.

• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- · Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
 You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.





PC-M2: 11 *b.daniels@tue.n **Constrained Spline-Based Everett Map** for Static Hysteresis Modeling Bram Daniels^{1,*}, Reza Zeinali¹, Timo T. Overboom², Mitrofan Curti¹, Elena A. Lomonova¹ ¹Eindhoven University of Technology, Eindhoven, The Netherlands; ²Royal SMIT Transformers (SGB-SMIT Group), Nijmegen, The Netherlands

Aim

This work investigates the quality of hysteresis loops, reconstructed by the Preisach model and governed by a B-spline based Everett map, that was fitted with constraints on measured concentric hysteresis loop data, to eliminate artifacts.

Summary

Many electromechanical devices contain soft-magnetic materials with complex hysteresis behavior. This behavior is often described by the Preisach model and an Everett map. This map, fitted on measured hysteresis data points, must be constructed properly, to enable interpolation of the data and ensure accurate and artifact-free modeled hysteresis loops.

Problem statement

The Everett map in this work is constructed from, easy to measure, concentric hysteresis loops, laid out on a plane.



Constrained B-spline surface

The fitting procedure yields an optimal control grid, that approximates the source data points with a closed-form B-spline surface, while adhering to the constraints.



be applied in the Preisach model of hysteresis, in order to reconstruct hysteresis behavior with high precision, by

$$f(t) = \iint_{\alpha \ge \beta} \mu(\alpha, \beta) \hat{\gamma}_{\alpha, \beta} u(t) d\alpha d\beta.$$

Here, μ is the Preisach weight function, given by the second derivative of the Everett map, ξ , as follows

$$\mu(\alpha,\beta) = -\frac{\partial^2 \xi(\alpha,\beta)}{\partial \alpha \partial \beta}.$$

Any inaccuracies in the data points are easily reflected in the surface fit and the reconstructed hysteresis behavior, observed as the crossing of hysteresis branches. Therefore, constrains must be applied during fitting.

Applied constraints

The constraints applied during fitting, to the B-spline based Everett map as well as its second derivate, are

Fitted B-spline surface and its optimal control grid.

Results

A benchmark input with nested minor loops, very different from the concentric source data, is reconstructed by the two fitted maps, and compared with measurement data.



The reconstructed benchmark hysteresis loops and reference measurement. The unconstrained loops contain noticeable artifacts,

- A strictly increasing/decreasing slope, e.g. $\partial \xi / \partial \alpha \ge 0$,
- No negative values in the weight function, $\mu \ge 0$.



The second derivative of the surface, *i.e.* weight function; with constraints applied (left), and unconstrained fit with problematic negative values (right). while the constrained loops manage to describe the complicated benchmark input properly, albeit at the cost of deviating slightly from the measured reference data.

Conclusions

- The unconstrained Everett map introduces noticeable artifacts in the modeled hysteresis branches,
- Constraining the fit procedure is a necessary step to reliably eliminate any problematic negative values,
- The constrained Everett map properly reproduces a benchmark input notably different from its source data.