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Constrained Spline-Based Everett Map for Static Hysteresis Modeling

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Aim

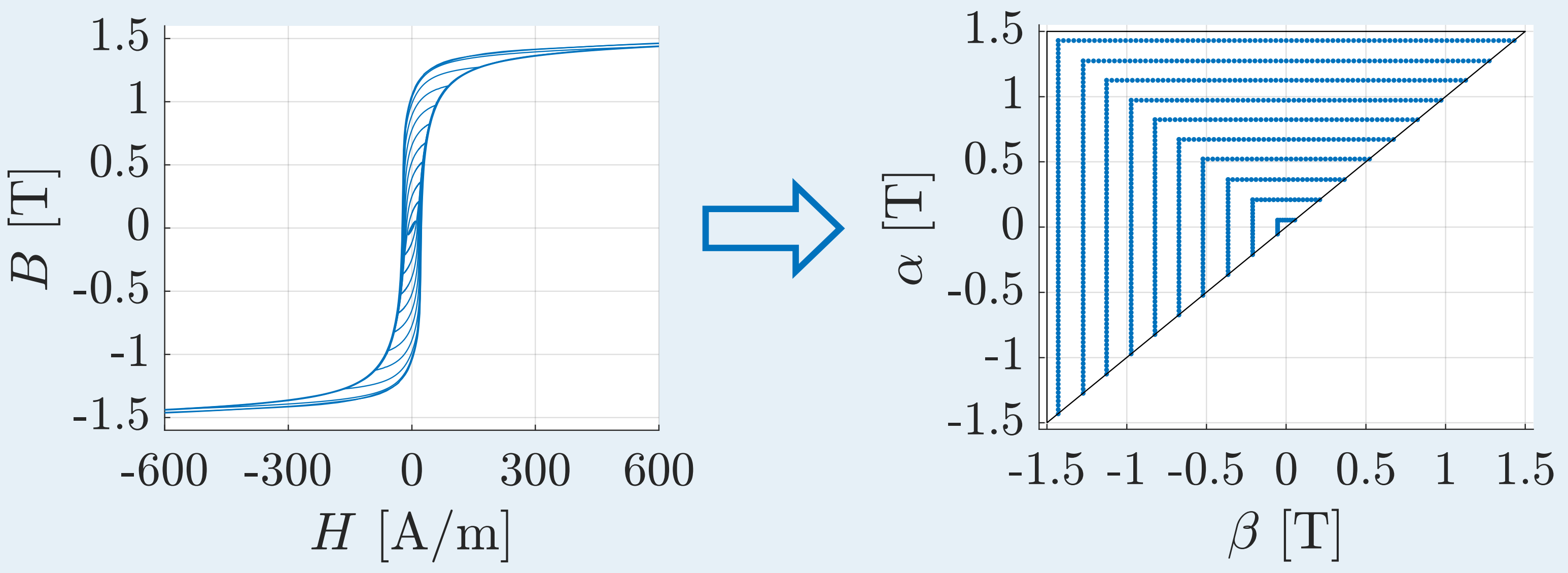
This work investigates the quality of hysteresis loops, reconstructed by the Preisach model and governed by a B-spline based Everett map, that was fitted with constraints on measured concentric hysteresis loop data, to eliminate artifacts.

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.



Measured concentric hysteresis loops and the data points on the Everett map.

These data points are captured by a B-spline surface to be applied in the Preisach model of hysteresis, in order to reconstruct hysteresis behavior with high precision, by

$$f(t) = \iint\limits_{\alpha \geq \beta} \mu(\alpha,\beta)\hat{\gamma}_{\alpha,\beta} u(t) d\alpha d\beta \,.$$

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

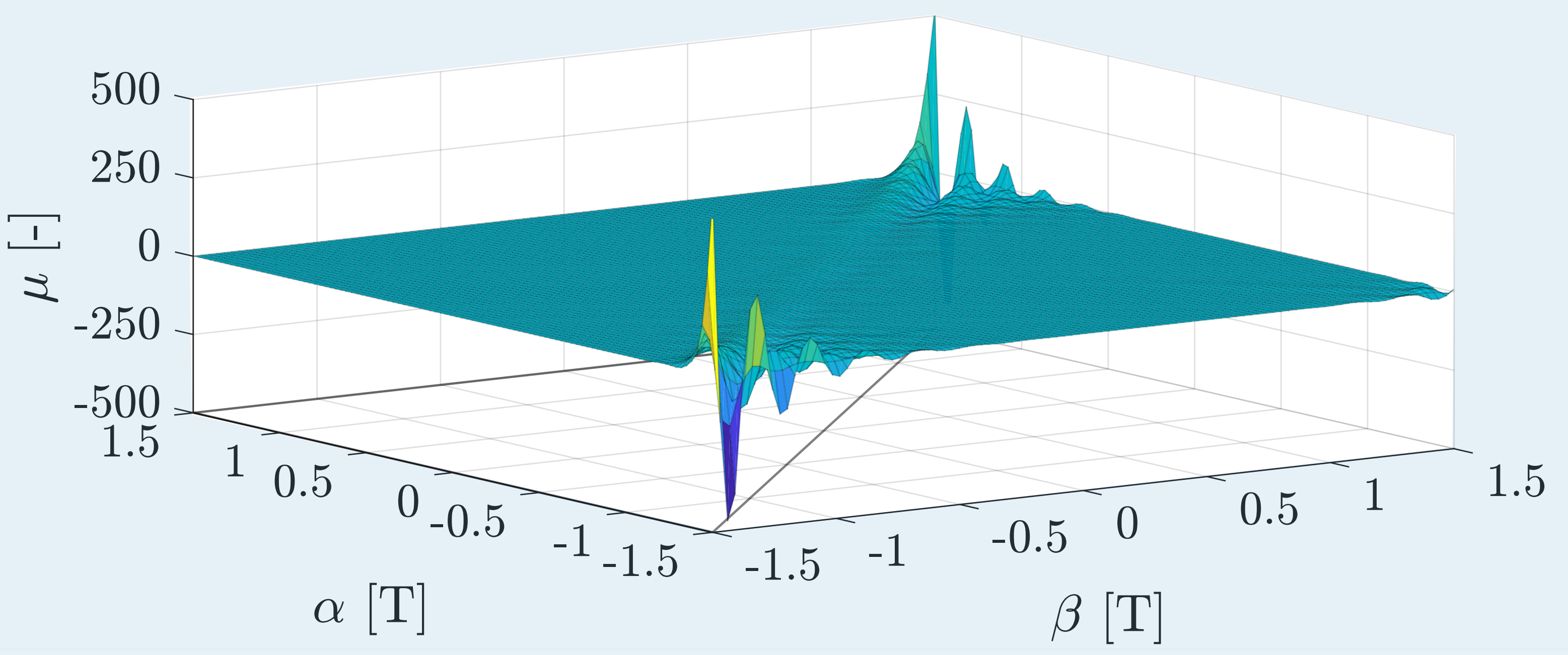
$$\mu(\alpha,\beta) = -\frac{\partial^2 \xi(\alpha,\beta)}{\partial\alpha\partial\beta}.$$

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

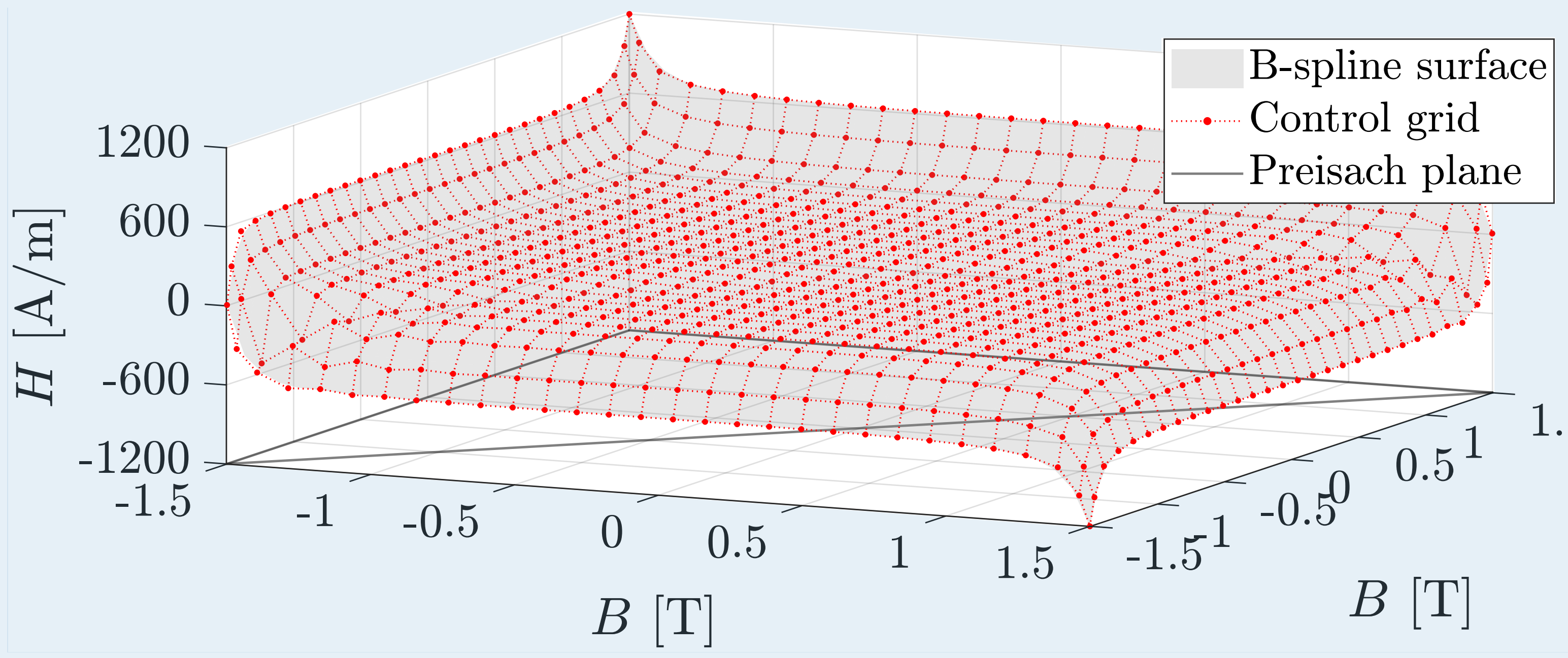
- A strictly increasing/decreasing slope, *e.g.* $\partial\xi/\partial\alpha \geq 0$,
- No negative values in the weight function, $\mu \geq 0$.



The second derivative of the surface, *i.e.* weight function; with constraints applied (left), and unconstrained fit with problematic negative values (right).

Constrained B-spline surface

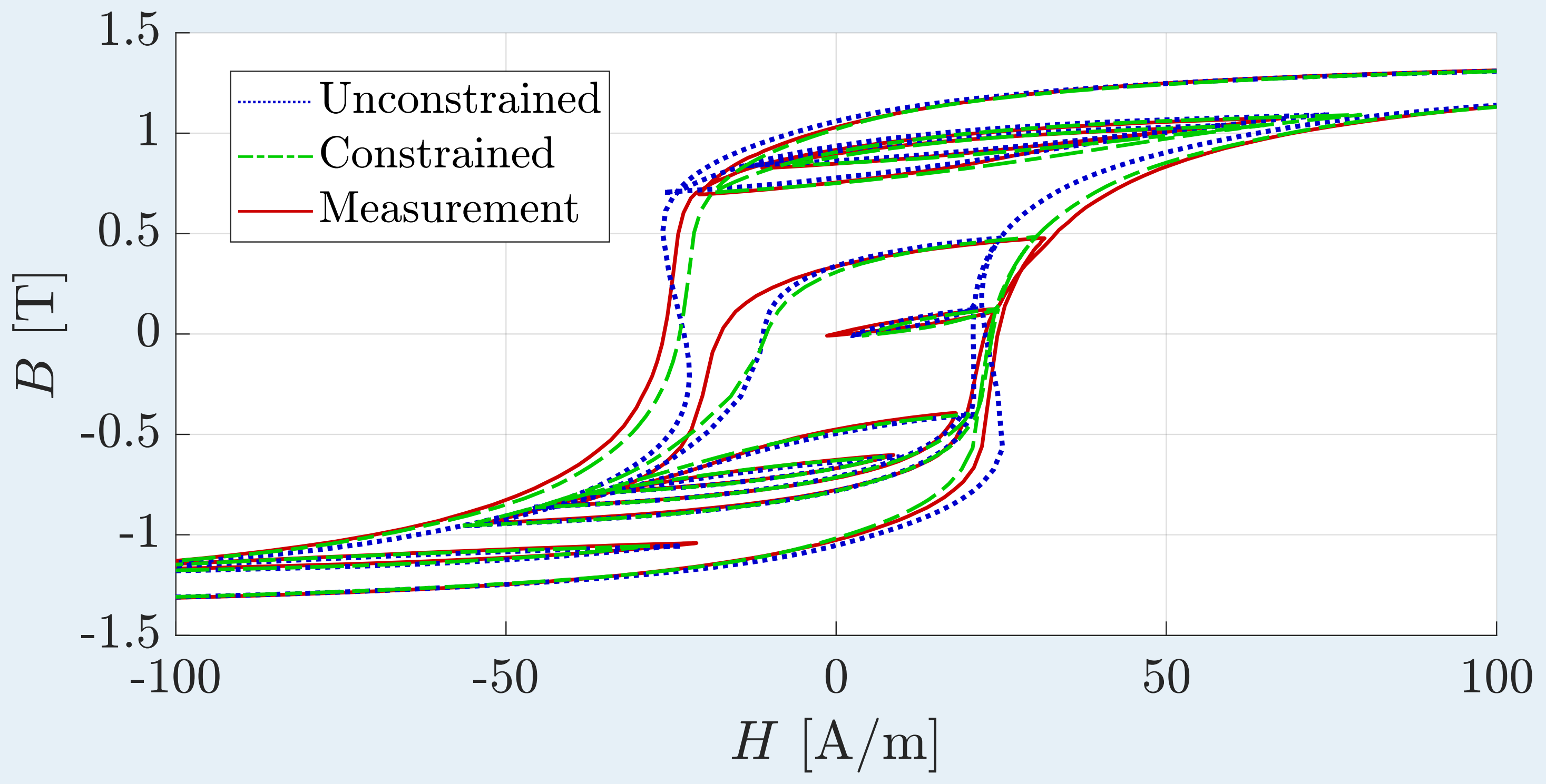
The fitting procedure yields an optimal control grid, that approximates the source data points with a closed-form B-spline surface, while adhering to the constraints.



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, 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.