



HAL
open science

Reduced Order modeling of high magnetic field magnets

Cécile Daversin, Christophe Prud'Homme, Christophe Trophime, Stéphane Veys

► **To cite this version:**

Cécile Daversin, Christophe Prud'Homme, Christophe Trophime, Stéphane Veys. Reduced Order modeling of high magnetic field magnets. 2014. hal-00955232v1

HAL Id: hal-00955232

<https://hal.science/hal-00955232v1>

Preprint submitted on 4 Mar 2014 (v1), last revised 17 Apr 2014 (v2)

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Reduced Order Modeling of High Magnetic Field Magnets

C. Daversin, Lab. Nat. des Champs Magnétiques Intenses, CNRS-UJF-UPS-INSA, cecile.daversin@lncmi.cnrs.fr
C. Prudhomme, Inst. de Recherches en Math. Appl., University of Strasbourg, Strasbourg, prudhomme@unistra.fr
C. Trophime, Lab. Nat. des Champs Magnétiques Intenses, CNRS-UJF-UPS-INSA, christophe.trophime@lncmi.cnrs.fr
S. Veys, Lab. Jean Kuntzmann, CNRS-University Joseph Fourier, stephane.veys@imag.fr

The Laboratoire National des Champs Magnétiques Intenses (LNCMI) is a French large scale facility [1] enabling researchers to perform experiments in the highest possible magnetic field (up to 35 T static field provided by water cooled resistive magnets connected with a 24 MW power supply). In the race for higher field, existing magnet technologies are pushed to the limits in terms of material properties and design methods. This is even more true for magnets where either the field profile or the field homogeneity (eg. for NMR applications) is also targeted. The design and optimization of these magnets require from

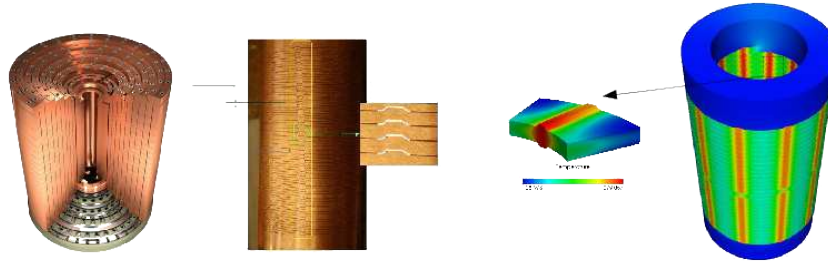


Figure 1. On the left : a view of a 35 tesla magnet; on the right a detailed view of the inner part of the magnet with a zoom on the cooling channels and insulators. Temperature field within this part is displayed on the same figure.

an engineering point of view the prediction of "quantities of interest" or performance metrics, which we shall denote outputs namely magnetic field in the center, maximum stresses, maximum and average temperatures. These outputs are expressed as functionals of field variables associated with a set of coupled parametrized PDEs which describe the physical behavior of our magnets. The parameters, which we shall denote inputs, represent characterization variables such as physical properties, heat transfer coefficients, water temperature and flowrate, and geometric variables in optimisation studies. To evaluate these implicit input/output relationships, solutions of a multi-physics model involving electro-thermal, magnetostatics, electro-thermal-mechanical and thermo-hydraulics are requested. It should be noted that this model is non-linear as the material properties depend on temperature. In practice these evaluations represent a huge computational time but they are mandatory to improve the magnet design as we can no longer rely on common physical sense.

To significantly reduce this computational time, we choose to use model order reduction strategies, and specifically to use the reduced basis method [2, 3, 4]. This method is well adapted in this context of many model evaluations for parametric studies, inverse problems and uncertainty quantification. We will present the RB method applied to our non-linear coupled models starting with the example of the

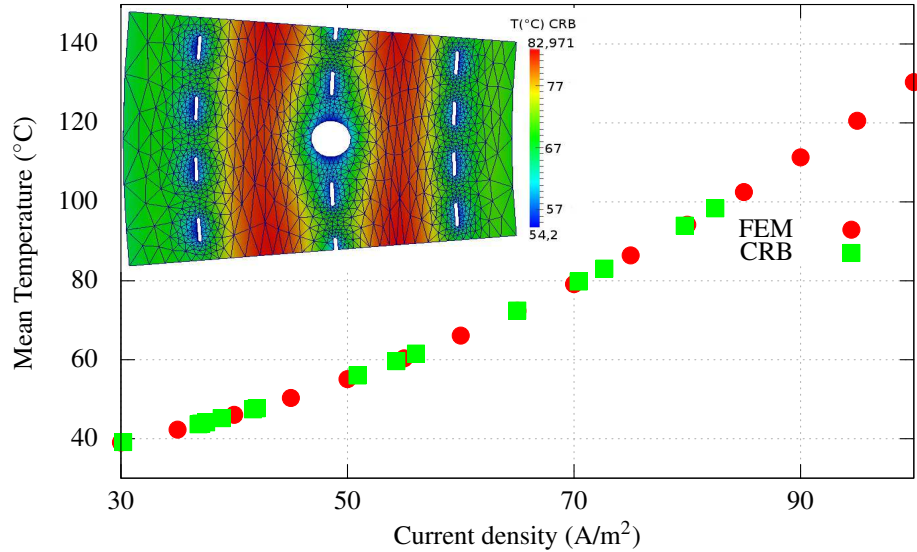


Figure 2. Parametric study of the mean temperature of a Bitter magnet sector.

electro-thermal coupled problem which is the basis of our design. We build upon the `feel++` reduced basis framework ([5, 6]) and rely on the `openturns` (<http://www.openturns.org/>) library for uncertainty quantifications. Validations and examples will be presented for small to large magnet models. Ongoing developments to include more physics in our models (eg. electro-thermal-mechanical phenomena) will be discussed.

Acknowledgments

We acknowledge PRACE for awarding us access to resource SuperMUC based in Germany at LRZ.

References

- [1] F. Debray, H. Jongbloets, W. Joss, G. Martinez, E. Mossang, P. Petmezakis, J.C. Picoche, A. Plante, P. Rub, Ph. Sala, and P. Wyder. The grenoble high magnetic field laboratory as a user facility. *IEEE transactions on applied superconductivity*, 12(1), March 2002.
- [2] C. Prud’homme, D. V. Rovas, K. Veroy, L. Machiels, Y. Maday, A. T. Patera, and G. Turinici. Reliable real-time solution of parametrized partial differential equations: Reduced-basis output bound methods. *Journal of Fluids Engineering*, 124(1):70–80, 2002.
- [3] K. Veroy, C. Prud’homme, D. V. Rovas, and A.T. Patera. *A posteriori* error bounds for reduced-basis approximation of parametrized noncoercive and nonlinear elliptic partial differential equations (AIAA Paper 2003-3847). In *Proceedings of the 16th AIAA Computational Fluid Dynamics Conference*, June 2003.
- [4] A. Quarteroni, G. Rozza, and A. Manzoni. Certified reduced basis approximation for parametrized partial differential equations and applications. *Journal of Mathematics in Industry*, 1(1):1–49, 2011.
- [5] C. Prud’homme. A domain specific embedded language in C++ for automatic differentiation, projection, integration and variational formulations. *Scientific Programming*, 14(2):81-110, 2006.
- [6] C. Daversin, S. Veys, C. Trophime, and C. Prud’Homme. A reduced basis framework: Application to large scale nonlinear multi-physics problems. *Esaim Proc.*, 43:225–254, 2013.