Aalborg Universitet



Enabling Real-Time Impedance Measurements of Operational Superconducting Circuits of Accelerator Magnets

Christensen, Magnus Bøgh Borregaard; Bednarek, Mateusz; Denz, Reiner; Koch, Peter; Ludwin, Jaromir; Rodriguez-Mateos, Felix; Podzorny, Tomasz; Ravaioli, Emmanuele; Steckert, Jens; Verweij, Arjan; Wozniak, Mariusz; Østergaard, Jan

Creative Commons License CC BY 4.0

Publication date: 2023

Document Version Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):

Christensen, M. B. B., Bednarek, M., Denz, R., Koch, P., Ludwin, J., Rodriguez-Mateos, F., Podzorny, T., Ravaioli, E., Steckert, J., Verweij, A., Wozniak, M., & Østergaard, J. (2023). *Enabling Real-Time Impedance Measurements of Operational Superconducting Circuits of Accelerator Magnets*. Poster presented at International Conference on Magnet Technology, Aix-en-Provence, France.

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 -

Take down policy

If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

Enabling Real-Time Impedance Measurements of Operational Superconducting Circuits of Accelerator Magnets

> M. B. B. Christensen^{1,2}, M. J. Bednarek¹, R. Denz¹, P. Koch², J. Ludwin^{1,3}, F. R. Mateos¹, T. Podzorny¹, E. Ravaioli¹, J. Steckert¹, A. Verweij¹, M. Wozniak¹, J. Østergaard² ¹European Organization for Nuclear Research, Geneva, Switzerland ²Aalborg University, Aalborg, Denmark ³Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland



Motivation & Research Goals

The goal of this research is to develop a new platform to safely inject electrical stimuli into a powered superconducting magnet circuit, and subsequently measure the response. Specifically using it for impedance estimation of a magnet is demonstrated. This research paves the way for continuous electrical integrity measurements of live circuits. Additionally, if the platform can be further developed to demonstrate high quality results for narrow measurement windows, it can enable research into quench analysis and detection.





We have designed a platform to safely inject stimuli into a magnet.

• **The hardware** is based on CERN's universal quench detection platform [1]. It has been extended with a DAC output stage.



- The stimuli signal is composed of an arbitrary amount of sinusoids. This allows us to probe multiple frequencies simultaneously.
- The response signals represent the injected current and voltage across the magnet. These parameters are set by the magnet's impedance.
- Estimating the complex amplitude of the current and voltage amplitudes is done by solving a minimization problem that fits the input sinusoids to the observed responses [2].
- Magnet impedance is found by dividing the terms of the estimated voltage and current specta.

We tested the system on a D2 prototype magnet [3].

- The magnet was measured when unpowered and powered (50 A).
- We made reference measurements using an industrial impedance analyzer [4].
- Impedance estimate based on 1.28 s (2^{19} samples) of data acquisition.
- Results show good correspondence between the powered, unpowered, and reference measurements.

Impedance









We analyse the methods merit for estimating impedance at short time scales.

• For this we split our acquisition into smaller windows and and find the relative error with respect to our reference measurements.



Mean Squared Relative Error

References and Acknowledgements

The authors would like to thank the staff at CERN's SM18 magnet test facility for their invaluable assistance and support in conducting the measurements presented in the MT28 conference. We also thank the High Field Magnet program for funding this research.

- [1] Jens Steckert et al. "Application of the Universal Quench Detection System to the Protection of the High-Luminosity LHC Magnets at CERN".
- [2] Petre Stoica, Hongbin Li, and Jian Li. 'Amplitude estimation of sinusoidal signals: Survey, new results, and an application".

[3] Barbara Caiffi et al. "The development of the superconducting dipoles D2 for the high luminosity upgrade of LHC".



MSRE ()-1020 10 40 80 320 1280 160 640 Window size (ms)

Conclusion

- We demonstrate that we can measure impedance of powered superconducting circuits accurately.
- More work is needed to obtain high quality short window impedance estimates.