U.S. MAGNET DEVELOPMENT PROGRAM

IDSM'02 workshop summary

M. Marchevsky, LBNL
G. Willering, CERN

Outline

- 2nd international Workshop on Instrumentation and Diagnostics IDSM'02: a 10 min overview

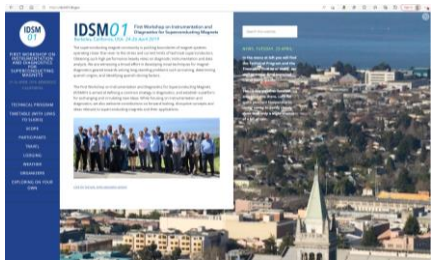
- LTS magnets: looking beyond "disturbance spectra". What we still do not know about mechanical energy releases and the origin of quenching? What diagnostics need to be developed or improved?

- HTS magnets: the "no-quenching" protection paradigm – is it feasible? What could be our "flight indicators" showing how far we are from quenching an HTS magnet at any given time?

- What is ahead in novel instrumentation, magnet protection and data analysis?

Key topics of IDSM'02

26-28 April, 2023, Paestum, Italy



A follow-up from IDSM'01 organized at Berkeley in 2019

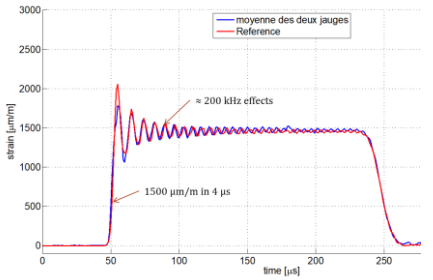
Joint with the Test Stands Workshop
Co-sponsored by CERN and INFN
- 50 participants
- 27 presentations

- Understanding of magnet training (or lack thereof). Disturbance spectra of LTS high-field magnets
- Quench detection and protection for HTS / hybrid magnet for HEP and Fusion
- Novel diagnostic instrumentation approaches and techniques
- Novel (cryo) electronics, data analysis, modeling

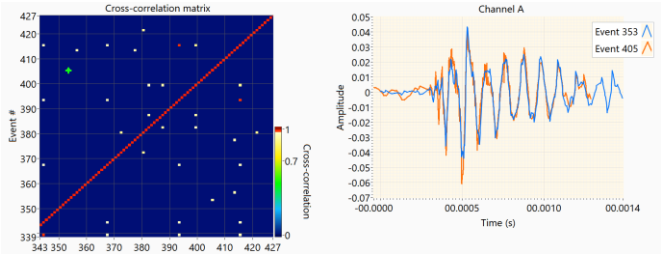
https://agenda.infn.it/event/32061/

LTS magnets: probing disturbance spectrum

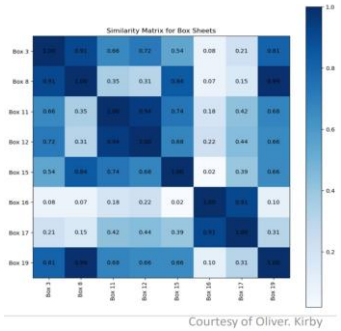
- Advances in vibration / strain measurements at high frequency **(M. Guinchard, CERN)** using regular strain gauges open a new diagnostic window into magnet mechanics

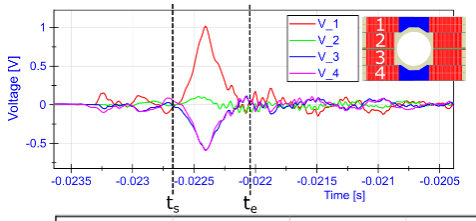


- AE data analysis using cross-correlation (**MM, LBNL**) reveals stress concentrator action

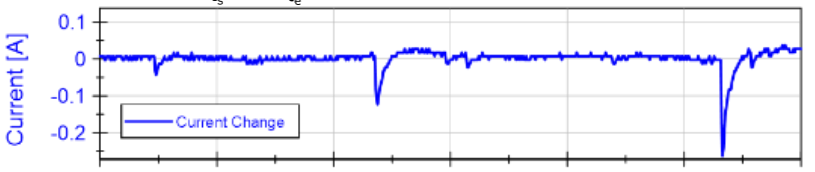


- Attempts of classifying AE precursors to quenching using well-defined “BOX” experiments (**M. Daly, PSI**)



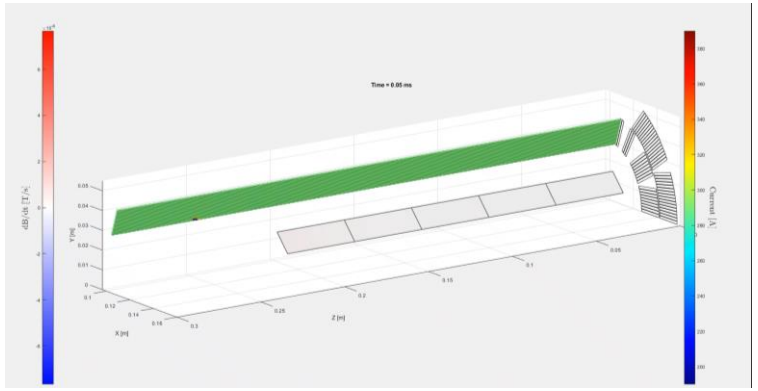


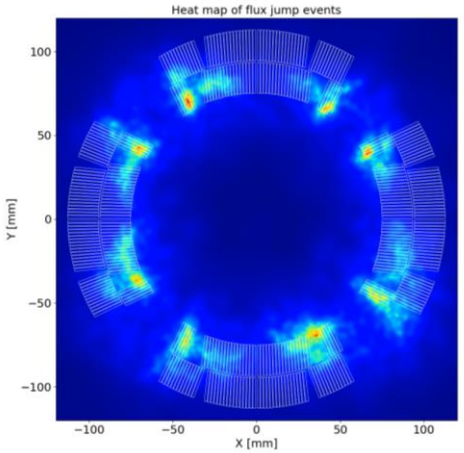
- Motion of coil blocks in accelerator magnets can be precisely quantified using current measurements / inductive response (**G. Willering, CERN**)



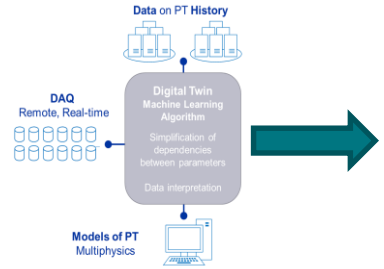
Modelling and data analysis

- Advanced modelling of quench development on Rutherford cables (**R. Keizer, U Twente/CERN**) enables a very precise way of identifying conductor degradation/damage in full scale accelerator magnets. A foundation for analysing voltage and quench antenna diagnostic data!

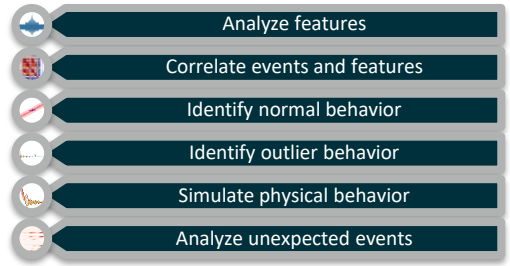




- Digital transformation technique (“digital twins”) is applied for some projects at CERN, realtime comparing test and modeling results, but also realtime sharing the data with clients through cloud services (**Ó. Sacristán, CERN**)

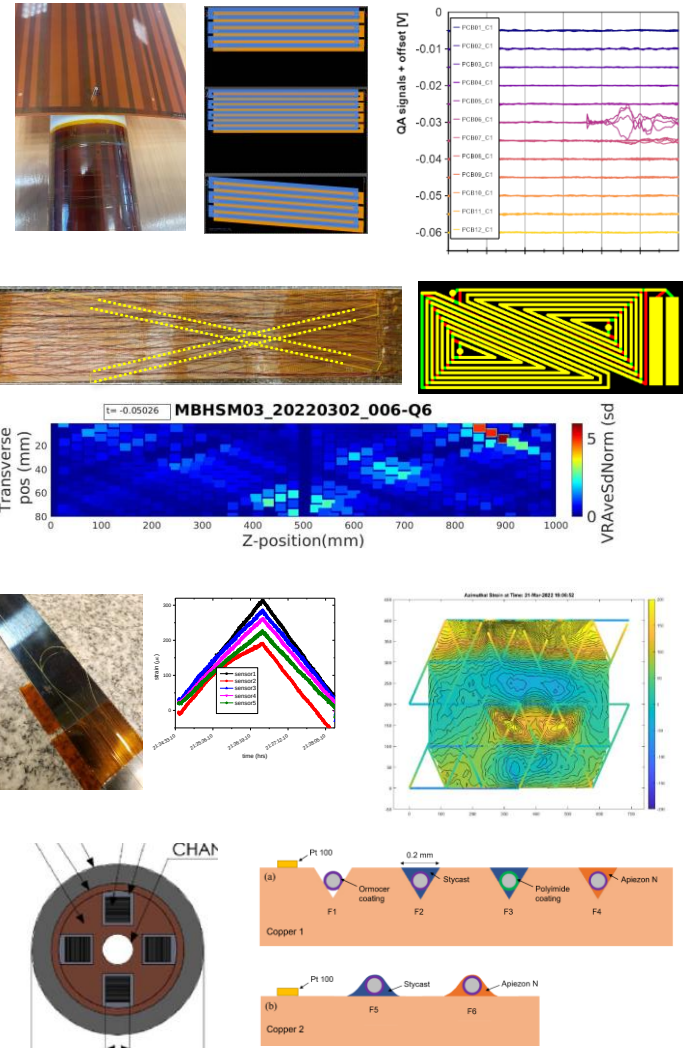


- Also at CERN a large campaign is ongoing on electromagnetic behavior of superconducting magnets to use data science on LHC magnets that are installed in the LHC to idenfity outliers that could possibly indicate issues with a magnet. (**E. Ravaioli, CERN**). Methods to look for outliers are being developed.



Quench antennas & fiber-optics

- A harmonic compensation quench array's, using flexible PCBs gives a unique solution to identify the radial and azimuthal quench location (**L. Fiscarelli, CERN**)
- Novel quench antenna designs ("slant" configuration, binary-coded QA) enable more precise and fast localization of quenches and mechanical vibrations (**J. DiMarco, FNAL**)
- Fiberoptic stain sensors are getting increasingly used for strain measurements and heating detection (**M. Baldini, FNAL**). A fiber grid was presented, which is a very powerfull tool to do strain mapping with many sensors on the mechanical structure (**S. Krave, FNAL**)
- FBG and ULFBG are integrated in VIPER cables for fusion, testing is ongoing to embed the fibers using various cryogenic adhesives and fiber coating (**S. Haneef, Robinson institute**)



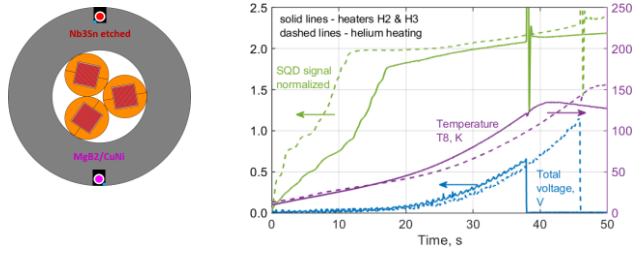
Novel quench detection

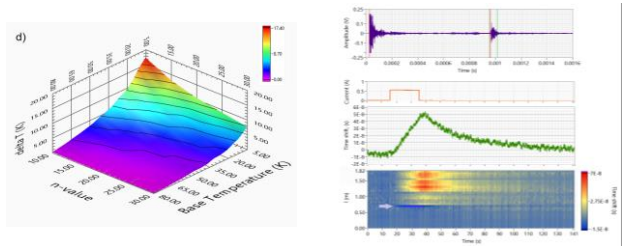
- Co-wound superconducting wires can be used for quench detection; the most suitable selection of superconducting wires and materials is being investigated. Thermocouple chains were proposed for continuous spatial temperature sensing (**N. Bykovskyi, EPFL)**

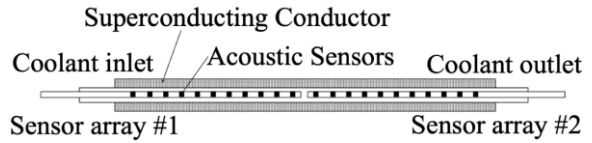
- Using thermal runaway criteria for realizing the quench-avoiding magnet protection paradigm. Demonstrated distributed temperature sensing with cladded ultrasonic waveguides and distributed sensing of temperature, strain and magnetic filed using RF reflectometry (LBNL)

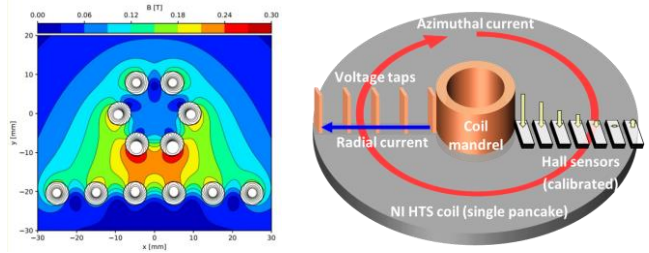
- Arrays of MEMS acoustic sensors are being developed to detect quenches in fusion cables (**P. Moore, Tufts U / MIT**)

- Hall sensors are used for early quench detection by current redistribution between the sub-elements of the HTS cable (**R. Teyber, LBNL**) and for diagnostics of high-field NI ReBCO coils (**J. Bang, NHMFL**)



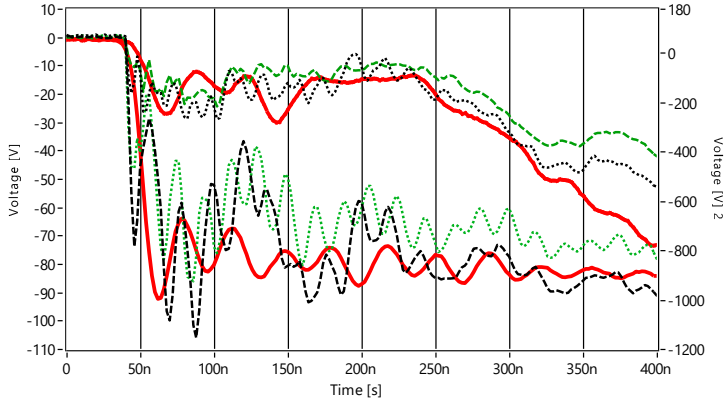




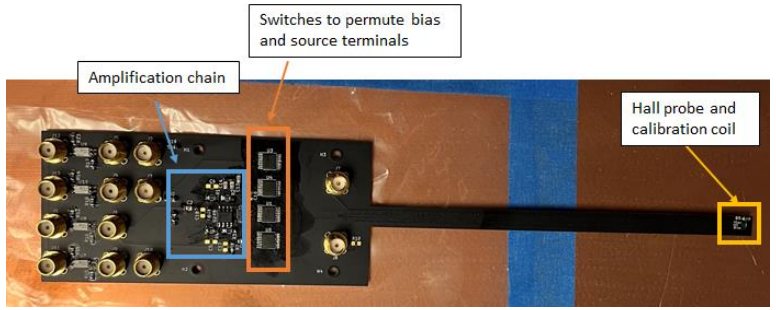


Electrical diagnostics and electronics

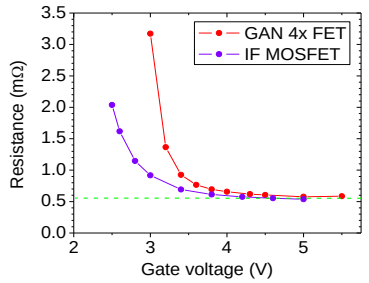
- Many methods to detect and localize electrical faults are developed and used, specifically for shorts, insulation issues, both for magnets as for a full LHC magnet circuit (**M. Bednarek, CERN**). Since those faults could easily disappear, most measurements need to be conclusive in one shot. In addition it is more complex because multiple fault scenarios could exist.



- Graphene-based GFETs are gaining attention as a promising platform for low-temperature electronics. GFETS are utilized as magnetic sensor and for signal amplification (**M. Turqueti, LBNL**)



- MOSFET-based current distribution controls for HTS quench protection (**MM, LBNL**)



IDSM'02 discussions summary

- Connecting mechanical transients with training
- Development of correlation matrices for classification of damage in different impregnation materials
- Digital twin models and use of AI for predicting magnet behavior
- Monitoring inductance variation for quantifying coil block displacements
- Current flow in a quenching cable and advanced quench antennas
- Fiberoptic detection of heat (down to 20 K and below)
- Use of fiber meshes for 2D mapping of strain
- Alternative non-voltage QD: acoustic, RF, SC wire, thermocouples, MEMS sensor, Hall sensors
- Use of strain gauges to monitor fast mechanical transients
- Cryogenic data acquisition and digital processing

All speakers acknowledged the importance and challenge for future technology in **quench detection**, understanding **performance limitations** and identifying **degradation mechanisms**.

What other advances in magnet diagnostics and instrumentation may be expected in the near future?

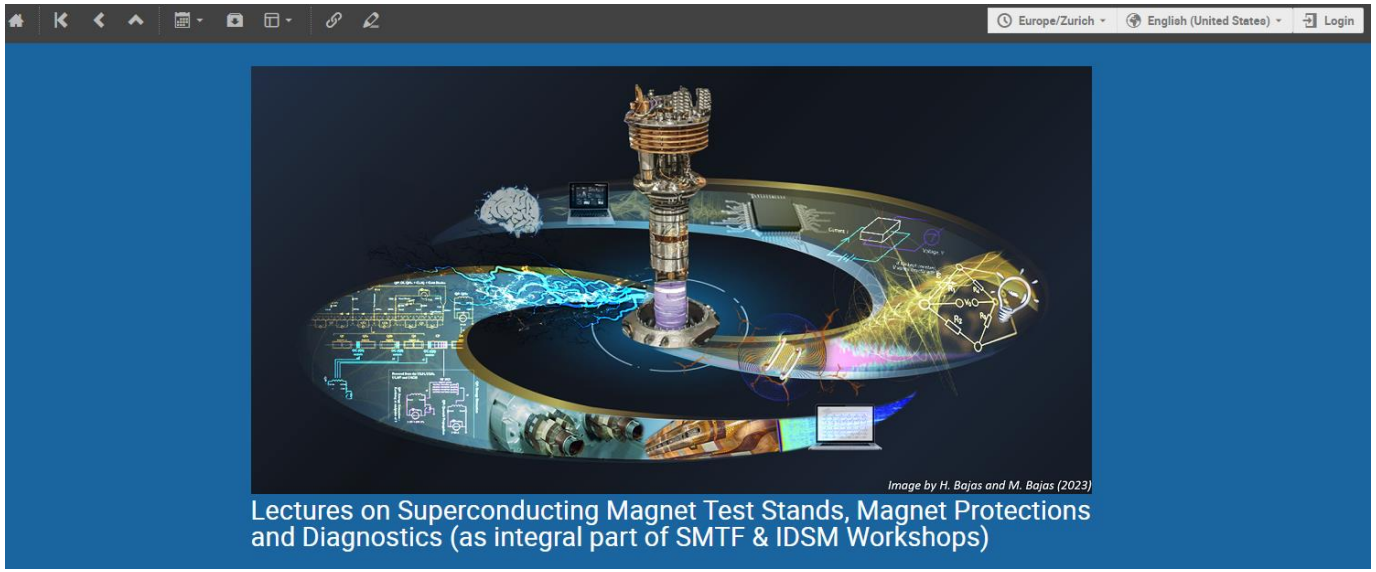
- Advanced ML models will become increasingly popular choice of analyzing large arrays of diagnostic data
- Small scale training experiments should provide a next level understanding of disturbances in LTS magnets and their classification based on diagnostics data
- Distributed sensing of temperature and strain (optical fibers, ultrasonic, RF) will become more robust and widely accepted technology and scale to longer lengths and new interesting configurations
- New approaches to detection and prevention of quenches in HTS magnets through advanced diagnostics, modeling and active current distribution controls will be demonstrated
- Cryogenic data acquisition and power electronics will amend or change the way how we diagnose, power and protect magnets

One statement (by Soren Prestemon) that came back a few times at IDSM'02:

"Diagnostics experts must interact closely with modeling experts, magnet designers, and magnet operators – communication is vital in both directions! "

Lectures

A nice cycle of educational lectures was organized by M. Bajko and H. Bajas on various aspects of magnet instrumentation and diagnostics, as a follow-up to SMTF/IDSM workshops



[Lectures on Superconducting Magnet Test Stands, Magnet Protections and Diagnostics (as integral part of SMTF & IDSM Workshops) (May 30, 2023 - June 12, 2023): Overview · Indico (cern.ch)]

https://indico.cern.ch/event/1281454/