IDSM 02 program and abstracts

Second international workshop on Instrumentation and Diagnostics for Superconducting Magnets

Salerno, Italy

26-28 April 2023

Wednesday April 26, 2023

Time	Author (institute)	Title
08:30 Workshop registration		
09:00	Workshop opening, Maxim Marchevsky and Gerard Willering	
Session: Key challenges - Setting the Scene		
09:15	Soren Prestemon (LBNL)	US MDP instrumentation and diagnostics needs
09:40	George Velev (FNAL)	Instrumentation and diagnostics for Test Facility Dipole at Fermilab
10:05	Gerard Willering (CERN)	CERN needs: I&D quench detection and localization
10:30	*Coffee break*	
11:00	Stephan Russenschuck (CERN)	CERN needs magnetic field sensors
11:25	Christian Fallouh (Airbus)	Electric aircraft diagnostics needs
11:50	Round table discussion: Prestemon, Siemko, Russenschuck, Velev, Marchevsky, Stoynev, Joshi	
12:30 Lunch *13:30 Bus departure, visit Fisciano Campus, University of Salerno* *14:30 Welcome from Department of Physics, Prof. Salvatore de Pasquale* *14:45 New projects in applied superconductivity* *15:00 Visit to the THOR test facility* *16:30 Coffee break* *17:00 Bus departure, return to workshop hotel*		

Thursday April 27, 2023

Time	Author (institute)	Title
Mechanical diagnostics for transients and precursors		
9:00	Michael Daly (PSI)	Development and advancement in vibration measurements using acoustics
9:20	Maxim Marchevsky (LBNL)	Analysis of mechanical transients and energy release in CCT magnets
9:40	Michael Guinchard (CERN)	Fast strain measurements in superconducting magnets
10:00	Discussion on mechanical diagnostics for transients and precursors	
10:30	*Coffee break*	
Novel diagnostic techniques and data analysis		
10:50	Óscar Sacristán (CERN)	Digital transformation / Digital twin in mechanical measurements applied to superconducting magnets
11:10	Gerard Willering (CERN)	Advanced diagnostics on precursors and motion using voltage signals and quench antenna
11:30	Ruben Keijzer (CERN/UTwente)	Advanced diagnostics for conductor damage

11:50	Antonio Esposito (Univ. of Naples)	An advanced instrumentation lab for superconducting cables and magnets
12:10	Discussion on novel diagnostic techniques and data analysis	
12:40 *Working lunch*		
Fiberoptic diagnostics for strain and quench		
13:40	Steven Krave (FNAL)	Fiber optic mesh for 2D strain characterization
14:00	Maria Baldini (FNAL)	Fiber optic sensing for strain and temperature
14:20	Shahna Haneef (Robinson)	Bragg grating based sensors for quench detection on HTS tapes
14:40	Discussion on fiberoptic techniques	
15:10 *Coffee break*		
Innovative electronics and devices, electrical diagnostics		
15:30	Mateusz Bednarek (CERN)	Methods and instrumentation for insulation defects measurements and electrical issues with superconducting magnets and circuits.
15:50	Emmanuele Ravaioli (CERN)	Classifying the electromagnetic behavior of a series of superconducting magnets
16:10	Marcos Turqueti (LBNL)	Advances in cryo-electronics
16:30	Discussion on innovative electronics and devices, electrical diagnostics	

Friday April 28, 2023

Time	Author (institute)	Title
Novel quench detection and localization methods (optical, ultrasonic, RF, etc.).		
9:00	Stoyan Stoynev (FNAL)	Quench conditioning device. Vibrational quench conditioning
9:20	Nikolay Bykovskiy (PSI)	Wire-based and thermocouple-based QD
9:40	Maxim Marchevsky (LBNL)	Ultrasonic and RF quench diagnostics
10:00	Jeseok Bang (NHMFL)	Research on no-insulation high-temperature superconductor magnet for quench simulation, imitation, protection, and detection
10:20	Peter Moore (Tufts University)	MEMS microphones for QD in fusion cables
10:40 *Coffee break*		
11:00	Geon Seok Lee (LBNL)	Impregnation damage and quench monitoring using time-domain reflectometry
11:20	Reed Teyber (LBNL)	Current Distribution Monitoring for Quench Detection and System Health Monitoring in CORC® CICC's
11:40	Discussion on novel quench detection and localization methods	
12:10 *Working lunch* - Discussion		
Magnetic measurement methods		

13:10	Lucio Fiscarelli (CERN)	Quench antenna development at CERN
13:30	Joe DiMarco (FNAL)	Quench antennas and non-rotating probe development
13:50	Discussion on magnetic measurement methods	
14:20	Closing remarks /summary Gerard Willering / Maxim Marchevsky	

Wednesday

Wednesday 09:15 **Soren Prestemon (LBNL)**

US MDP instrumentation and diagnostics needs

Soren Prestemon[1], Director, US Magnet Development Program

[1]Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Abstract – One of the primary themes of the US Magnet Development Program (MDP) is to "Investigate fundamental aspects of magnet design and technology that can lead to substantial performance improvements and magnet cost reduction". Instrumentation and diagnostics are the primary experimental elements that provide insight into magnet performance. Diagnostic data, coupled with modeling and analysis, together demonstrate a proper scientific understanding of magnet performance. Here we review driving questions that the MDP seeks to address, and provide an overview of the diagnostics needs and strategic directions being pursued by the MDP. In particular, we discuss what appear to be fundamental differences in the behavior of HTS vs LTS accelerator magnets and the implications of these differences on the operational paradigms for each magnet and on the diagnostics needed.

Wednesday 09:40 **George Velev (FNAL)**

Instrumentation and diagnostics for Test Facility Dipole at Fermilab

George Velev[1] (for Fermilab's Test and Instrumentation and R&D groups)

[1]FermiLab National Laboratory, Batavia, IL, USA

Fermi National Accelerator Laboratory (FNAL) and Lawrence Berkeley National Laboratory (LBNL) are constructing a new High Field Vertical Magnet Test Facility (HFVMTF) to test superconducting cables in high magnetic fields. The HFVMTF's background magnetic field of 15 T will be generated by a magnet provided by LBNL, referred to as the TFD. The facility will also be used to test high-field superconducting magnet models and demonstrators, including hybrid magnets, produced by the US Magnet Development Program (MDP). This talk will focus on the instrumentation needed to operate the facility, including the TFD and HTS sample holder for fusion cables, as well as the testing of hybrid magnets for the US MDP.

Wednesday 10:05 **Gerard Willering (CERN)**

CERN instrumentation and diagnostics needs

G. Willering[1], L. Fiscarelli[1], F. Mangiarotti[1], C. Petrone[1], S. Russenschuck[1]

[1]CERN, Geneva, Switzerland

Abstract – CERN has a large and versatile superconducting magnet test facility. The horizontal test benches are dedicated to testing of full-scale prototype and series magnets ready for the LHC and HL-LHC. The goal is to have a warm bore/anti-cryostat in all different type of magnets to allow rotating magnetic field measurement devices and pickup coil-based quench antenna. The main focus of research is quench localization in all magnets and particularly conductor damage investigation in Nb_3Sn coils with quench antenna, but also with precision voltage measurements. The vertical test cryostats are dedicated to short model magnets and future magnet technology, including Nb_3Sn for High Field Magnets, and HTS coils. For a large variety of magnets, a large variety of instrumentation is needed, specifically to detect quenches, localize quenches, investigate conductor issues, etc. In this talk, the main focus and main challenges foreseen for the magnet testing in the years to come.

Wednesday 11:00 **Stephan Russenschuck (CERN)**

CERN needs magnetic field sensors

S. Russenschuck[1]

[1]CERN, Geneva, Switzerland

Abstract – abstr text

Wednesday 11:25 **Christian Fallouh (Airbus)**

Electric aircraft diagnostics needs

C. Fallouh, E. Nilsson, J-F. Rouquette, L. Ybanez

[1] Airbus UpNext, Toulouse, France

Abstract – With the environment constraint that will shape the future of the aircraft industry, Airbus is working on different concepts of zero-emission commercial aircraft using hydrogen as a primary source of energy. If this energy is stored in its liquid form at cryogenic temperature, it can be used as a cold source to enable the use of cryogenic and superconducting technologies. The aim of the ASCEND (Advanced Superconducting and Cryogenic Experimental powertrain

Demonstrator) project is to develop a ground demonstrator of 500kW powertrain based on these technologies:

On top of conventional needs of superconducting instrumentation and diagnostics needs, some constraints related to the powertrain and aircraft integration need to be considered:

- AC waveforms, motor back-electromotive force, inverter electromagnetic noise can make traditional voltage-based quench detection techniques difficult to implement.

- High reliability and safety shall be achieved regardless of the airborne environmental conditions

Thursday

Thursday 09:00 Michael Daly (PSI)

Using acoustic signals with post-mortem analysis for material research & development

M. Daly[1]

[1]PSI, Villigen, Switzerland

Abstract **–** The results presented here are in the framework of the ongoing BOX program (BOnding eXperiment) at the Paul Scherrer Institute and the University of Twente. The BOX samples are designed to reproduce the failure behaviour of Nb3Sn high field magnets in realistic conditions and representative Lorentz forces. The samples enable the benchmarking of various impregnation materials and processes in order to assess their impact on performance such as training, stability and maximum current. The samples are instrumented with acoustic sensors and voltage taps and measure the complete ramp to quench. In this context, we aim to correlate acoustic and voltage signals with features identified during post-mortem analyses such as cracking, debonding and voids. The results enable us to better target improvements to manufacturing processes and impregnating materials to reduce training and improve performance of Nb3Sn superconducting magnets.

Thursday 09:20 Maxim Marchevsky (LBNL)

Analysis of mechanical transients and energy release in CCT magnets

M. Marchevsky[1]

[1]LBNL, Berkeley, CA, USA

Abstract The phenomenon of “training" has baffled superconducting magnet designers for over 60 years. A peculiar similarity of training patterns across magnets of various sizes and designs hints at a universal mechanism responsible for this phenomenon, likely associated with crack propagation and slip-stick motion events in superconducting windings. Elastic energy is released in such events as the heat would raise the conductor temperature locally and transition it to the normal state. At the same time, a gradual accumulation of structural damage would constitute the magnet training memory. Using acoustic emission (AE) diagnostics to access the micromechanics of training of superconducting Nb_3Sn canted-cosine-theta (CCT) dipoles, we analyze the release of mechanical energy during the training process and discuss the scaling of the released energy with the Lorentz force stress and its variation in the course of training. We also observe successive AE events (multiplets) exhibiting highly reproducible waveform shapes pointing to identical source locations. The evolution of multiplets through the training cycle

reveals stress concentrators that form persistent channels for energy release. Future development of AE-based magnet diagnostics and its role in understanding and eliminating training will be discussed.

Thursday 09:40 Michael Guinchard (CERN)

Fast strain measurements in superconducting magnets at CERN

M. Guinchard[1]

[1]CERN, Geneva, Switzerland

Abstract – For the High Luminosity upgrade of the Large Hadron Collider (HL-LHC) at CERN (European Organization for Nuclear Research) and for the future high-energy accelerator projects, a sustained R&D activity is required to implement advanced technologies for the development of a new generation of superconducting magnets, high-energy proton beam dumps, powerful physics detectors and cryogenic radio-frequency cavities. During the R&D phases, strain monitoring of prototype structures is paramount to validate Finite Element Analysis and understand the mechanical response of complex structures in harsh environments. After an overview of the different measurement techniques used to assess the static mechanical behaviour of superconducting magnets over their lifecycle, the presentation will describe the working principle of the fast and ultra-fast strain measurements, the recent developments performed at CERN to measure the mechanical dynamic response of sub-component systems such as coils, shell or rods and the future validation tests and roadmap in this field.

Thursday 10:50 Óscar Sacristán (CERN)

Digital transformation / Digital twin in mechanical measurements applied to superconducting magnets

O. Sacristán[1]

[1]CERN, Geneva, Switzerland

Abstract – The digital transformation is changing the world at a fast pace, and it has the potential to revolutionize the way we conduct measurements to test superconducting magnets in the laboratory in the framework of international collaborations by facilitating the task of pooling measurements from different teams to test superconducting magnets.

The presentation will provide a brief overview of the trends in the measurement industry for data streaming, followed by a description of the new solutions adopted by the EN-MME Mechanical Measurement lab to share mechanical data in real time. A few recent examples will be shown to illustrate our global interest in this technology. Those real time data streaming solutions have been an important steppingstone for an ongoing initiative at CERN for the development of digital twin technology that will be also discussed during the presentation.

Thursday 11:10 Gerard Willering (CERN)

Advanced diagnostics on precursors and motion using voltage signals and quench antenna

G. Willering[1]

[1]CERN, Geneva, Switzerland

Abstract – For a long time voltage spikes (also called precursors) were measured while ramping up magnets, sometime leading to quench, other times not. These spike precursors have been seen as movements, but no qualitative detailed description of the events has been given.

Combining measurement data from coil voltage, magnetic pick-up coils and current during the precursor transients have been acquired and analysed for the Nb_3Sn block coil and cos-Theta dipole magnets. The measurement data is compared to movement simulations that were done with the ROXIE-program, used to calculate mutual inductance change for a number of different movement types in these magnets. The study strongly suggests that the transients are caused by movements, and also indicates that the maximal length of a single slip-stick motion can be up to around 10 µm, mostly in the direction of the magnet's internal forces. The proposed instrumentation and diagnostics method proves that transients in measurement data occur due to coil movements, and propose a method to quantify conductor motion.

Thursday 11:30 Ruben Keijzer (CERN, University of Twente)

Diagnostics of Conductor Damage in Nb_3Sn Accelerator Magnets

R. Keijzer[1,2], G. Willering[1], G. Succi[1], M. Dhallé[2] and H. Ten Kate[2]

[1]CERN, Geneva, Switzerland; [2]University of Twente, Enschede, The Netherlands

Abstract –In recent years, several new 11 T class accelerator magnets that employ Nb_3Sn technology were tested at the superconducting magnet test facility at CERN. A number of these magnets exhibit performance limitations that are accompanied by anomalous signals from different types of diagnostic measurement tools, such as decaying voltage signals on the current plateaus of V-I measurements, and anomalous quench propagation observed with quench antennas. To better understand the physical phenomena underlying this anomalous magnet behavior, two kinds of modelling studies focusing on two different time scales were performed. To study how different types of conductor damage, that might be present in the Rutherford cable, affect the V-I measurements a continuum model implemented in the THEA software is used. With this model, we show that a local inhomogeneous defect, where a subset of strands is either fully or partially damaged causes a long range current redistribution process that can explain the measured anomalous decaying voltages. The predictions from this continuum model were then used as input for a coupled thermal-electric 3D network model that was newly developed to study the quench process during the first 10 ms. With this model we were

able to show that the current imbalance predicted by the continuum model can cause the quench to propagate along overloaded strands in such a way that they can cause the observed anomalous quench propagation. By using a combination of these diagnostic measurement tools and numerical simulations we increase our understanding of the underlying physical mechanisms which aids in the interpretation of test results of magnets with potentially present conductor damage.

Thursday 11:50 Antonio Esposito (Univ. of Naples)

An advanced instrumentation lab for superconducting cables and magnets

[1]University of Naples, Italy

Abstract **–** The Italian project IRIS aims at creating an innovative and distributed research infrastructure for applied superconductivity. As a part of this network, the Neapolitan pole took on the task of building an instrumentation laboratory for superconducting cables and magnets. The final objective is the establishment of a facility aimed at designing, prototyping, and validating monitoring and diagnostics systems for high-temperature superconducting devices. Such systems will be based on new electronic instruments and machine learning techniques, and the technical reference specifications are linked to a green superconducting line and an energy-saving magnet to be built.

The presentation will thus deal with a sketch of the new laboratory. This will involve instrumentation and measurement for assembly process and integrity control of cables and magnets, optical setups, cryogenic apparatus, and machine learning-based systems. The discussion will be carried on from a metrological point of view with the idea to provide a service for research and development in applied superconductivity.

Thursday 13:40 Steven Krave (FNAL)

Fiber optic mesh for 2D strain characterization

S. Krave[1]

[1]FermiLab National Laboratory, Batavia, IL, USA

Abstract **–** Fermilab has been exploring the application of fiber-optic strain and temperature sensors to fabrication and test of superconducting magnets. This presentation focuses on the novel application of the Rayleigh-type distributed system from Luna for fully characterizing the 2d strain state of a system. This system is applied to test the principles of operation on a QXFA cold mass during helium vessel welding. The data gathered can be processed and represented in a form similar to what users see in Finite Element Analysis Additional information based on considering the whole mesh area as a single large sensor is used to cross check the actual process against the design criteria. This concept has been applied to an upcoming magnet scheduled to be tested in the next few months.

Thursday 14:00 Maria Baldini (FNAL)

Optimization of distributed fiber optic sensors for strain and temperature measurements on superconducting magnets

M. Baldini[1] , L. Elementi, S. Krave, V. Marinozzi

[1]FermiLab National Laboratory, Batavia, IL, USA

Abstract –

The next generation high energy physics accelerators will require magnetic fields at ~20 T and the use of high temperature superconducting coils. In this paper, we explore the use of distributed fiber optics sensors for diagnostic and quench detection. Indeed, fiber optic sensors based on Rayleigh backscattering are promising tool for quench detection of HTS magnets and for continuous strain measurements during magnet training and quench. This work presents a series of fast turn-around experiments, recreating quench conditions in small resistive coils and superconducting wires. Strain and temperature sensors are employed. Those experiments will show that distributed fibers are very promising tool for quench detection in HTS coil.

Thursday 14:20 Shahna Haneef (Robinson Research Institute)

Quench protection in HTS magnets using Quasi-distributed array of Fiber Bragg gratings

Shahna M Haneef[1], Bart Ludbrook[1], Xiyong Huang[1], Jofferson Gonzalez[1], Dominic Mosely[1], Mike Davies[1], Owen Duke[2], Erica Salazar[2], Rod Badcock[1]

[1]Paihau- Robinson research institute, Victoria University of Wellington, Lower Hutt,5012, New Zealand

[2]Commonwealth Fusion Systems, 501 Massachusetts Ave, Cambridge, MA 02139, United States of America

Abstract – High temperature superconducting magnets (HTS) are an essential part of next generation tokomak fusion energy as it offers high current density and magnetic field at a higher temperature compared to the counterparts. In a tokomak system, the cost of the superconducting magnets covers a major portion of the overall cost, and hence the stability of superconducting magnets is crucial. This greatly relies on its capability to maintain the superconducting state in which it can conduct the high current density in a lossless manner. An open issue that hampers the stability of the magnet is a quench event which occurs when a section of the superconductor ceases the superconducting state and transitions into a resistive

state [1]. A rapid and reliable quench detection system is necessary to prevent HTS magnets traversing into a thermal runaway and protect the system from the catastrophic failure. This can be realized through spatially distributed sensing of any localized hotspot that precedes a quench event in the superconductor. High degree of induced electromagnetic noise in the magnetic fusion devices and the low quench propagation velocity of the high temperature superconductors impose significant challenges to the conventional voltage-based quench detection system. A promising alternative is the use of fiber optic sensors, which are immune to EMI and can function in harsh and extreme environments.

Our group previously presented a highly sensitive fiber optic sensor for hotspot detection using ultra-long fiber Bragg grating array (ULFBG) [2]. The ULFBG contains quasi-continuous FBGs with the same Bragg wavelength in a single optical fibre, designed to provide extremely high spatial resolution. The spatial information (e.g. location) about the hotspot may not be identified using the array of identical gratings, but rapid detection of the occurrence of a hot spot is more important than identifying the location of temperature change in the superconductor. In this talk, the advantages of the proposed techniques, key challenges arise during the sensor deployment, and the advanced signal processing methods developed to extract the temperature profile of the high-temperature superconductor will be presented [3-5]. The presentation will also include a transfer matrix fiber model introduced to design and predict the spectral response of ULFBG incorporating the statistical noise distributions of the FBG parameters such as Bragg wavelength, peak reflectivity and full-width half-max [6].

References

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[2] M. Fisser, X. Huang, D. A. Moseley, C. Bumby, and R. A. Badcock, "Evaluation of continuous fiber Bragg grating and signal processing method for hotspot detection at cryogenic temperatures," en, Superconductor Science and Technology, vol. 35, no. 5, p. 054 005, Apr. 2022, Publisher: IOP Publishing, ISSN: 0953-2048. DOI: 10.1088/1361-6668/ ac5d68.

[3] X. Huang, M. Davies, D. A. Moseley, J. T. Gonzales, H. W. Weijers, and R. A. Badcock, "Sensitive Fiber Optic Sensor for Rapid Hot-Spot Detection at Cryogenic Temperatures," IEEE Sensors Journal, vol. 22, no. 12, pp. 11 775–11 782, Jun. 2022, Conference Name: IEEE Sensors Journal, ISSN: 1558-1748. DOI: 10.1109/JSEN.2022.3174894.

Thursday 15:30 Mateusz Bednarek (CERN)

Electrical faults can lead to serious damage when powering superconducting magnets or circuits

M. Bednarek[1]

[1]CERN, Geneva, Switzerland

Abstract – Application of circuit integrity procedures gives the possibility of early detection of electrical faults before high current operation. In some cases, despite properly implemented electrical quality control system, failures can appear during high current operation, for example following high current magnet quenches.

Superconducting magnets are complex devices that operate in cryogenic environment. Coils, busbars, splices, and quench protection instrumentation are enclosed inside of a cryostat. Live parts can be electrically accessed only using V-taps and at the level of current leads.

Diagnostics and localization of electrical faults can therefore be particularly challenging. In addition, the resistivity of components of superconducting magnets at cold is extremely low, distances between available pick-ups can be large, and large thermal gradients might be present and might influence the precision of measurements.

In this presentation selected electrical faults are described and methods to diagnose and localize them are given.

Thursday 15:50 **Emmanuele Ravaioli (CERN)**

Classifying the electromagnetic behavior of a set of superconducting magnets

E. Ravaioli[1], Z. Charifoulline[1], M. Janitschke[1], C. Obermair[1], A. Verweij[1], CERN, Geneva, Switzerland

Abstract – A set of magnets are built according to the same functional specifications and design in order to generate the same static magnetic field. However, it is fairly common to observe differences in their behavior during electromagnetic transients with characteristic frequencies of a few tens of Hz and higher.

Understanding the factors that influence a magnet’s electrodynamics can bring several benefits including explaining abnormal observed transients, reducing the occurrence of spurious quench detection, predicting worst-case scenarios, and ultimately improving the design of future magnets.

A large amount of data is collected during a superconducting magnet’s design, fabrication, and testing, both at warm and cryogenic temperature. Examples of correlations between LHC main dipole magnet electromagnetic behavior and as-built magnet parameters are shown.

More generally, a brief introduction to data analysis techniques to examine superconducting magnet features, correlate them with each other, and identify outliers are presented. These methods can in principle be applied to analyze transients in a wide range of domains.

Thursday 16:10 Marcos Turqueti (LBNL)

Advances in cryo-electronics

M. Turqueti[1]

[1]Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Abstract – In this talk, we will discuss the latest developments in cryo-electronics circuits and sensor technology, with a particular focus on front-end electronics based on Field Effect Transistors (FETs), including Metal-Oxide Semiconductor FETs (MOSFETs) and Graphene FETs (GFETs). GFETs have gained significant attention as a promising platform for low-temperature electronics due to their exceptional electron mobility, low power consumption, and unique transport properties.

During this presentation, we will explore the distinct advantages of different types of MOSFETs and GFETs, such as their superior performance in low-temperature environments, and the key challenges that need to be overcome for their successful implementation in cryo-electronics. We will also discuss the latest research developments in this area, including how GFETs can be utilized as magnetic sensors and for signal amplification.

Moreover, we will examine the design and implementation of DC to DC converters for cryogenic applications, which are essential for efficient power and bias management of front-end electronics in cryogenic systems. Since these converters must operate at low temperatures while maintaining high efficiency, they are important elements of cryo-electronics systems. We will discuss the latest advancements in the design of DC to DC converters and their potential for future applications in cryogenic electronics.

Friday

Friday 09:00 Stoyan Stoynev (FNAL)

Quench conditioning device. Vibrational quench conditioning

S. Stoynev[1]

[1]FermiLab National Laboratory, Batavia, IL, USA

Abstract – Recently a new type of device, capacitor-based, aiming to eliminate or reduce superconducting magnet training was developed and tested at FNAL. I will review its main characteristics and principles of operation, make relevant comparisons and conclusions. Separately, I will discuss somewhat similar concepts based on induced vibrations in magnets, but I will extend this topic to cover both training reduction and quench protection. Those will be discussed at conceptual level, arguing about feasibility of such an approach and the need for more focused research on the topic, including simulations.

Friday 09:20 Nikolay Bykovskiy (PSI)

Temperature-based quench detection methods via integrated superconducting wires and thermocouple chains

N. Bykovskiy, H. Bajas, D. Uglietti, P. Bruzzone, and K. Sedlak[1]

École Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-5232 Villigen PSI, Switzerland.

Abstract – Quench detection in fusion magnets is challenging because of complex pulsed operation of the machines, resulting in a strong electromagnetic noise and relatively weak resistive signal from the quenching conductor section. This is even more problematic considering HTS materials in the design, because of the low quench propagation velocity (~0.1 m/s). Aiming to improve the quench detection performance, a modification of the co-wound voltage taps using superconducting wires (SQD) is proposed for fusion conductors at EPFL Swiss Plasma Center. By providing electrical insulation and sufficient thermal coupling with the main conductor, the SQD wires can be operated independently at a certain transport current (~1 A) and allow increasing the resistive signal up to ~1 V/m. Furthermore, due to their 'active' nature of the response (i.e. the detection signal is developed within the wire itself), SQD can be used as a twisted pair to completely eliminate parasitic electromagnetic signals. In this configuration, it essentially becomes an exotic distributed temperature sensor capable of detecting temperature exceeding a certain value. The critical temperature as a function of magnetic field Tc(B) and off-state resistance of the SQD wires are the key figures for their application. In case these parameters do not match specific requirements and their tuning is deemed problematic (such as tailoring the

Tc(B)), a chain of thermocouple wires can be considered as an alternative. They are similar to SQD wires in terms of the integration and cancellation of EM noises. In contrast to SQD, they provide a continuous response upon a temperature rise and a discrete spatial resolution determined by the location of the thermocouple joints. In this work, we will report the experimental demonstrations performed recently on the SQD wires and thermocouple chains and discuss prospects and main challenges of their application.

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Friday 09:40 Maxim Marchevsky (LBNL)

Ultrasonic and RF quench diagnostics

M. Marchevsky[1], G. S. Lee[1], S. Prestemon[1]

[1]Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Abstract **–** Quench protection of high-temperature superconductor (HTS)-based and hybrid magnets is one of the key standing problems in the field. Recently, various distributed sensing approaches were proposed to address the early detection of heating in HTS magnets, aiming at realizing a new protection paradigm where a magnet will be safely de-energized before experiencing thermal runaway. First, I will discuss using a thermal runaway criterion to define the required sensitivity limits for temperature-based quench diagnostics in HTS. Next, I will review recent advances made at LBNL in developing a robust and easily integrable way of implementing distributed sensing in magnets using ultrasonic and radio-frequency (RF) technologies. In particular, the Time Domain Reflectometry (TDR) approach has been realized in non-leaky acoustic fibers for temperature sensing and various RF transmission lines and coaxial cables for distributed sensing of stress, temperature, and magnetic fields. Results of cryogenic testing of our TDR sensors with HTS tape conductors and cables will be presented.

Friday 10:00 Jeseok Bang (NHMFL)

Research on no-insulation high temperature superconductor magnet for quench simulation, imitation, protection, and detection

J. Bang, K. Kim, G. Bradford, J. Lee, and D. Larbalestier[1]

[1]Applied Superconductivity Center, National High Magnetic Field Laboratory, Florida State University, Tallahassee FL 32310 USA

Abstract – No-insulation (NI) high temperature superconductor (HTS) magnet technology has provided reliable and stable magnet operation based on the current sharing feature between windings. As a result, the technology could have been sometimes considered an exceptional case from the quench. Based on this superiority, the NI HTS magnet technology has been recently applied to many fields, from laboratory to industry applications. However, as the target magnetic field intensity to be produced by an NI HTS magnet becomes immensely high and the development of various applications proceeds, the quench issues on the NI HTS magnet technology have been gradually raised. To address the relevant issues, we have studied quench simulation, imitation, protection, and detection approaches through the research endeavor. First, a numerical method for simulating quench behavior based on the partial element equivalent circuit model has been developed. Second, we have studied an NI HTS magnet consisting of coils connected in parallel to imitate the electromagnetic quench behaviors. Third, a customized electric heater to protect coil quench as mitigating screening current, named “Thermal Eraser”, has been developed and validated. Last, the use of multiple voltage taps, thermocouple wires, Hall sensors, and strain gauges to detect quench by measuring local voltages, temperatures, fields, and strains has been proposed. In this talk, we will provide the research result. Then, we would like to suggest and discuss the quench detection technique for an NI HTS coil or magnet using acoustic sensors.

Friday 10:20 **Peter Moore (Tufts University)**

MEMS microphones for Quench Detection in HTS fusion cables

P. Moore[1]

[1]Tufts University, Medford, MA. USA

Abstract – Due to their slow normal zone propagation, HTS cables need nontraditional and faster quench detection (QD) techniques compared to the technologies currently employed. This talk will summarize the work done so far to design and test an alternative method of QD that may offer advantages in detection time and ease of fabrication in HTS CICC. This method is based on the use of an array of MEMS (Micro Electro-Mechanical System) acoustic sensors which can detect pressure changes in the coolant caused by localized heating coming from a quench event. If sensors could be inserted into the coolant channel of a cable and shown to register distinct signals caused by quenches, they could offer an inexpensive and quick alternative to existing methods. We have shown that two types of MEMS chips based on off-the-shelf components can safely operate at cryogenic temperatures. The chips were then used to detect quench events for HTS conductors in both liquid nitrogen and gaseous helium and the results will be presented in this contribution. The tests done so far are significant for supporting further development of this technology and providing insight into how it may be optimized for adoption into quench detection systems.

Friday 11:00 **Geon Seok Lee (LBNL)**

Impregnation damage and quench monitoring using time-domain reflectometry

Geon Seok Lee[1]

[1]Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Abstract **–** Quench monitoring is one of the most critical aspects of high-temperature superconductor (HTS) devices and applications. A quench in large-scale HTS magnets can cause significant damage including thermal and mechanical damage to the device. However, conventional voltage-based diagnostic methods have limitations in detecting local temperature changes in large-scale HTS magnets. Therefore, new quench detection and diagnostic methods are required. One such approach is the use of acoustic reflectometry, which monitors acoustic waves transmitted along the superconductor cables. This method can provide high sensitivity and spatial resolution of up to 1 % of sample length to detect local temperature change. The performance verification of the acoustic reflectometry has been conducted on HTS conductors and the VIPER cable. Another approach is distributed electrical impedance measurements, which utilize a non-invasive electrical time-domain reflectometry method, using a vector network analyzer to apply continuous wave signals and swept frequency signals into a magnet. By measuring changes in impedance and scattering parameters, the electrical reflectometry can detect impregnation damage during magnet cool-down, training, and operation. The development and validation of new quench detection methods are crucial for their future use in complex environments such as fusion power plants and accelerators. Preliminary results suggest that these new approaches have the potential to enhance the performance and reliability of HTS devices and applications.

Friday 11:20 **Reed Teyber (LBNL)**

Current Distribution Monitoring for Quench Detection and System Health Monitoring in CORC® CICC's

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Abstract **–** A suite of quench detection methods are being developed for ReBCO cables, however several are not compatible with the fast-ramped conditions found in compact fusion reactors. In addition to measuring sample voltages and temperatures, recent work monitoring current distributions in sub-elements of CORC® Cable-In-Conduit-Conductors (CICC) has shown promise for quench detection and system health monitoring. Hall probe arrays around CICC terminations are fed into a real-time inverse Biot-Savart routine to recreate individual cable currents, which are used to extract the parameters of a predictive dynamic network model and used to look for signatures of current redistribution. While the technique has been demonstrated with short samples [1], the methodology requires substantial real-time computing, and only applies to coils of moderate length wound from cables with limited inter-strand current sharing. This talk

presents progress in addressing these limitations. First, a standalone quench detection prototype based on the current distribution monitoring framework is presented using a low-cost ARM Cortex M7 to solve the inverse Biot-Savart problem with sub-millisecond latency. Finally, the vision for a scale demountable toroidal field coil with a large-scale Hall probe matrix is presented for current distribution monitoring in a TF winding pack. The enabling feature of this configuration is the ability for current to redistribute between individual CORC® cables of a CICC at each demountable joint, bringing cable lengths to a level where our methodology can potentially be realized. Progress and anticipated challenges are presented as we mature our framework towards a practical quench detection technology.

[1] Teyber, Weiss, Marchevsky, Prestemon, van der Laan, "Current Distribution Monitoring Enables Quench and Damage Detection in Superconducting Fusion Magnets", Scientific Reports 12 (2022) 22503

Friday 13:10 Lucio Fiscarelli (CERN)

Quench antenna development at CERN

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Abstract – Many high-energy-physics laboratories, with the aim of developing accelerator magnets able to produce magnetic fields larger than state-of-the-art level, are working on the construction and test of sub-scale and prototype units based on innovative designs and materials. The full understanding of the actual performance, together with the identification of possible limitations, requires the use of advanced measurement and diagnostic tools. The so-called "quench antennas" based on pickup coils have shown to be particularly suitable for the accurate localization of quenches and for the study of the underneath mechanisms. The talk presents the instrument recently developed at CERN for the test of the new magnets for the HL-LHC. The design and the technical details of the quench antenna being used for the MQXFB magnets is presented. Examples of quench signals and localization results are as well given and discussed.

Friday 13:30 Joe DiMarco (FNAL)

Quench antennas and non-rotating harmonics probe development

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Abstract – FNAL has been developing multiple versions of flexible inductive-voltage quench antennas (flex-QA) to characterize quench events and transients during current ramping in superconducting magnets. Efforts have been focused on grid-like arrays of sensitive elements to cover coil surfaces, in order to precisely locate magnetic flux-change events. This talk presents results of QA-arrays in recent cryogenic tests, along with a design in an upcoming test which also

addresses the channel-intensive nature of these arrays. Tests of QA's in a warm scanning facility are also presented with comparison to simulation.

Part of the utility of the flex-QA designs are that they enable monitoring for quenches without an anti-cryostat, as they can be used directly in the cryogenic environment. To achieve something similar for measuring magnetic field harmonics in a cryo vessel, i.e. without anti-cryostat or warm to cryogenic transition for a rotating coil, we also present a concept for a non-rotating harmonics probe based on a torsional piezo transducer.