HFM

High Field Magnets Programme

WP5.5
Transducers, instrumentation and measurement equipment needs for the HFM R&D programme

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Date: 19.09.2024

Scope of the Work Package

“Transducers, instrumentation and measurement equipment needs for the HFM R&D programme”

- Identify the measurement needs
- Define the measurement strategy
- Design, procure, and assemble the required sensors, instruments, and equipment
- Validate and calibrate the instruments
- Develop the software for the acquisition and processing
- Contribute to the interpretation of results

Basic concepts

- Full exploitation of known techniques
- Selection of promising new methods and development of the related instruments
- For HTS magnets, more focus on new possibilities with sensors for various quantities and integrated in the magnet coils (quench detection/localization, current distribution, field transients, temperature profiles,...)

Plan

Three groups of tasks:

- General-purpose instruments
- Instrumentation for Nb_3Sn magnets
- Instrumentation for HTS magnets

General-purpose instruments

- Data acquisition with on-line processing
  - Fast and long acquisitions with on-line processing for identification of events (e.g. mechanical or magnetic transients)

- Data acquisition and setup for small-amplitude signals
  - Insulated channels for precise measurement of small signals (e.g. VI transitions)

- Control and postprocessing for new acquisition systems
  - Postprocessing using filters, transforms, patter recognition (e.g. Fourier, wavelets) and more complex identification techniques

Instrumentation for Nb_3Sn magnets

- Measurement systems for short models both at ambient and cryogenic temperature
  - Standard magnetic measurement systems adapted to the new magnet geometries
  - Integration of rotating coils, quench localization, and other sensors

- Measurement system for long prototypes both at ambient and cryogenic temperature
  - New designs and new materials for long shafts

- Instrumentation for the racetrack coils
  - Sensors integrated in the magnet structure with effort on quench localization

Instrumentation for HTS magnets

- Review of instrumentation needs for HTS magnets
  - In collaboration with cable and magnet experts, identification of the measurement challenges and selection of most appropriate instrument

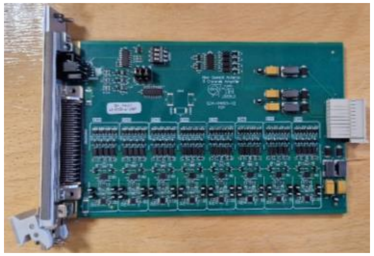
- New sensors, amplifiers, electronics, and calibration
  - Development of techniques based on multipole sensors integrated in the magnet coils and structure. Study of the use of active electronic components at cryogenics temperatures to improve precision, to allow integration, and to reduce complexity (cabling).

Progress: Acquisition and signal conditioning

- High-performance data acquisition system
  - Multiple channels (~100)
  - High sample-rate (2 MS/s)
  - High precision (16 bit)
  - Real-time processing (on board FPGA)

Commercial acquisition system with real-time processing procured in 2023

- Multi-channel signal conditioning
  - Differential input/output
  - 8 channels/card.
  - 10 cards/chassis
  - 2 output per channel
  - Gain of 1, 100, 200, 500, 1000 can be set on all cards or individually
  - Antialiasing filter



Credits:
U. Martinez Hernandez
V. Di Capua
D. Giloteaux

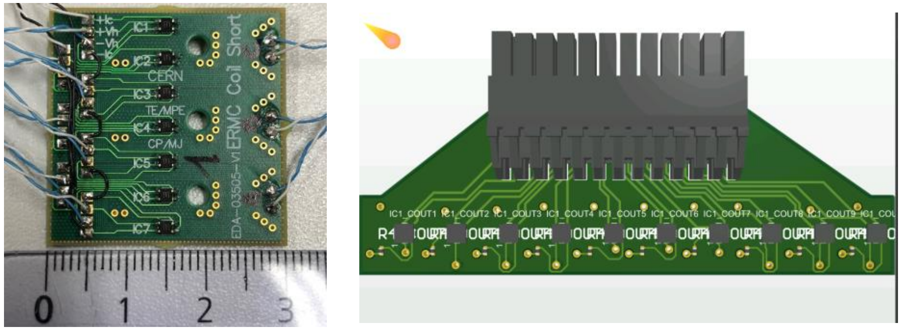
Custom design of amplifier cards and crates. First unit produced in 2024 and now under validation.

Progress: Sensors, amplifiers, electronics, and calibration

- Explore new possibilities of small sensors embedded in the magnet coils or structure

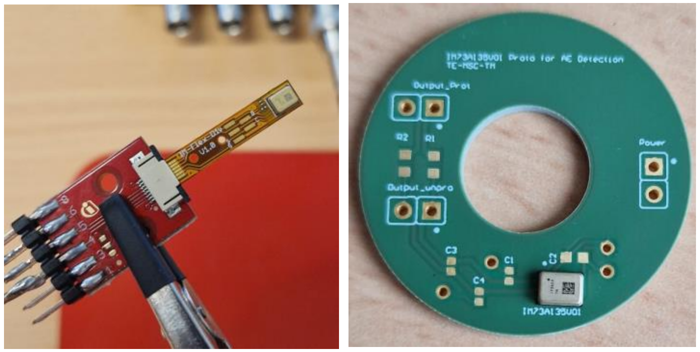
- First studies already on going for:
  - Hall probe arrays
  - Acoustic-emission sensors

- Envisaged for the future:
  - Optical fibers
  - Co-wound and distributed sensor



Hall probe sensors already in use on racetrack magnets (left) and new design for test and validation at cryogenic temperature (right).

Credits: C. Petrone, V. Di Capua



Commercial MEMS microphones (left) and PCB board for integration in the magnet structure (right).

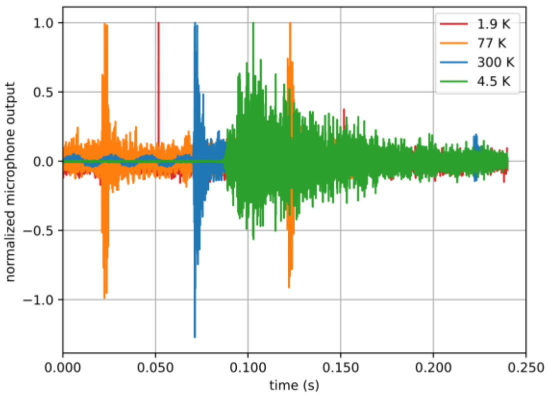
Credits: V. Di Capua

Progress: Sensors, amplifiers, electronics, and calibration

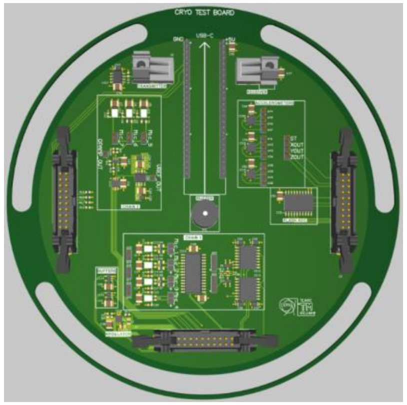
- Selection, test, and calibration of different electronic components and sensors for use at cryogenic temperature

- First results are available (1st campaign) for
  - MEMS microphones
  - Piezoelectric transducers
  - Amplifiers
  - Analog multiplexer

- Other components will be tested (2nd and 3rd campaign in 2025):
  - Fiber optic transmitters and receivers
  - Integrated circuits (FPGA, ADC)



V. Di Capua, Cryogenic tests of electronic components and sensors for superconducting magnet instrumentation, IMEKO2024

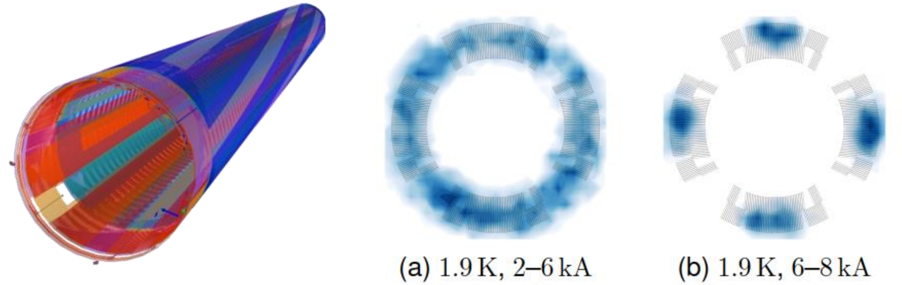


Credits:
U. Martinez Hernandez
V. Di Capua

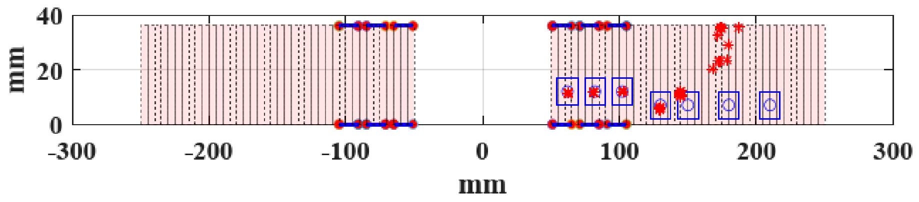
PCB for 2nd campaign of tests of sensor and electronic components at cryogenic temperature

Progress: Non-invasive quench localization

- Precise localization of quench by means of less-invasive methods
- Recent developments:
  - Combined transverse and longitudinal localization
  - Characterization of flux jumps
  - Study of a quench antenna for racetrack coils
- In the future
  - Integrated rotating coil and quench antenna for short models tested in vertical (2025)



Sensor for transversal and longitudinal quench localization for round apertures (left) and characterization of flux jumps (right).
P. Rogacki, Measurement of fast transients in Nb3Sn magnets by using a static harmonic-coil, ASC2024



M. Ferrini, Design and Test of a Flat Quench Antenna for Superconducting High-Field Magnets at CERN, Master thesis, Università di Pisa

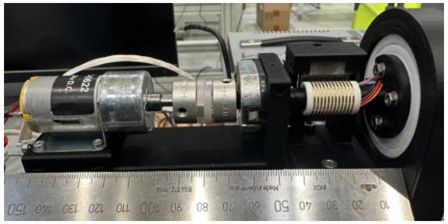
Progress: Magnetic measurements

- Full exploitation of well-known techniques for both magnetic measurement at ambient and cryogenic temperature

- Recent developments for HL-LHC:
  - Improved accuracy (printed circuits, new calibration methods)
  - Improved time and spatial resolution (multi-segment fast rotating coils)
  - Scanning systems (mechatronic for positioning, optical targets for precise alignment)

- In the future
  - Design (early 2025) and construction (second half 2025) of specific instruments adapted to the new magnet geometries

Rotating-coil scanner ⌀90-140 mm for HL-LHC



Prototype of a miniaturized motor-encoder unit for 50-mm magnets
Credits: P. Rogacki

Rotating-coil segment ⌀70 mm for HL-LHC D2 (bottom) and the one ⌀40 mm for the STAARQ collaboration (top).
Credits: R. Beltron, C. Petrone

Schedule for next two years

	2024	2025				2026			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
MM for 12/14 T at amb. temperature	Design		Procur.	Assembly and valid.		First real measurements			
MM & quench loc. for 12/14 T at cryo. temperature		Design		Procur.	Assembly and valid.		First real measurements		
Quench loc. for SMC and eRMC	Design	Procur.		Integration in real magnets			Test		
Sensors and components at cryo. temp.	Test of 2nd set		New PCB	Test of 3rd set		Application in real magnet tests			
Acquisition and amplifiers	Test and validation of proto			Production of new units		Use for real tests			

Remarks

- Activities are ramping up
- Till now strong synergy with other projects
- Priority on readiness of instruments for 12/14 T
- More R&D effort required, for HTS in particular
- More interaction with other WP's

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Programme

Measurement infrastructure

- Easy access to the magnet aperture at ambient temperature
- Flexibility of changing sensor type or position during test run
- On-going work for developing
  - 50-mm anti-cryostats
  - Positioning system

Anti-cryostats for 50-mm aperture magnets