U.S. MAGNET DEVELOPMENT PROGRAM

Performance Analysis and Enhancement (status)

MDP Meeting

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Reminder

Topics of interest:

- Exploring the QCD (and CLIQ) capabilities to learn more about underlying coil training mechanisms and possibly other performance drivers/limitations — QCD
- Investigating and establishing friction as a tunable parameter to affect (magnet) performance — Mechanical oscillations
- Determining performance dependencies on loading parameters (reproducibility) — Magnet assembly and loading
- Emulating magnet conditions by a dedicated device /together with Materials and Conductors/ (a tool for exploration and testing with broad application) — Magnet conditions emulator

The Area will also be a (non-exclusive) forum to discuss analyses and results from various testing campaigns

- magnets and non-magnets
- LTS and HTS

It is crucial to explore inter-Area connections.

"Live" MDP milestones: https://docs.google.com/spreadsheets/d/1SW1r3z0vKv8bkSPEb9bw51HyIMRt7YtO/edit?gid=2122620354#gid=2122620354

Roadmap overview (reminder)

2025 — 2030 — 2035

QCD

- Training elimination through QCD – more data
- Exploration of overcurrent dependencies with QCD
- Mini-QCD implementations and effects in bifilar coil designs
- Dedicated magnet tests using coils with no training memory, effect on retraining, detraining
- QCD and conditions limits exploration
- Physics simulation improvements: force evolution and observable parameters

Mechanical Oscillations

- Vibration and friction - establishing research
- Reproducible sample tests
- Mechanical oscillations and performance
- Design/Procurement of practical mechanical oscillation-based devices
- Demonstrating efficient mechanical oscillation transfer in LN and LHe
- Studies on magnet-design-dependent applications

Magnet/coil training

- Reproducibility in coil reloading/reassembly
- Single- vs Multi-coil phenomena

Magn. Cond. Emulator (MConE) with Materials

- Small prototype
- Samples and procedures development
- **MConE** - design and fabrication
- Optimization of testing conditions
- Tunable sample performance and simulations
- **MConE** - establishing it as a core development tool

Milestones

Performance Analysis and Enhancement

Milestone #	Description	Target	Status *	Updated Target	Requestor
III.c.M1.1	QCD testing with two (more) untrained magnet models, different designs	Mar-26	Started	**08/31/2026**	S. Stoynev
III.c.M1.2	QCD Testing with two magnet models of no/bad training memory, different designs	Mar-27	not started		S. Stoynev
III.c.M1.3	Suggest relation limitations between QCD and CLIQ regarding coil training	Dec-27	not started		S. Stoynev
III.c.M1.4	Determine main training relations to “overcurrent” parameters using reproducible “samples”/magnets	Dec-27	not started		S. Stoynev
III.c.M1.5	Determine main training relations to “overcurrent” at varying application conditions (temperature,	Dec-28	not started		S. Stoynev
III.c.M1.6	Demonstrate transient simulations can describe observations with QCD/CLIQ (make improvements)	Jun-29	not started		S. Stoynev
III.c.M2.1	Determining friction coefficients at interfaces relevant for SC magnets and their dependences on	Aug-25	Started	**05/01/2026**	M. Kifarkis
III.c.M2.2	Introducing vibration techniques to mitigate frictional contact between superconducting magnet	Jul-26	not started		M. Kifarkis
III.c.M2.3	Determining relevant vibrational parameters to mitigate friction such as amplitude, power, frequency,	Mar-27	not started		M. Kifarkis
III.c.M2.4	Developing a method to effectively transfer mechanical oscillations in cryogenic environments	May-28	not started		M. Kifarkis
III.c.M2.5	Conducting first test involving induced mechanical vibrations in a magnet (model)	Nov-30	not started		M. Kifarkis
III.c.M3.1	Establish full testing cycles for coil reloading, characterize observations	Dec-26	not started		S. Stoynev
III.c.M3.2	Establish full testing cycles for magnet reassembly, characterize observations	Dec-28	not started		S. Stoynev
III.c.M3.3	Explore available data and/or additional testing to conclude on training dependencies	Dec-30	not started		S. Stoynev
III.c.M3.4	Repeat studies with multi-coil magnets and conclude on coil vs magnet training	Dec-32	not started		S. Stoynev
III.c.M4.1	Small-scale MConE at FNAL/Stand3 –MConE.0.1	Dec-25	not started	**12/31/2026**	S. Krave
III.c.M4.2	First comparative results from the small-scale MConE	Jul-26	not started		S. Krave
III.c.M4.3	Demonstrate “identical” sample testing in controllable temperature/current/magnetic field/stress	Mar-27	not started		S. Stoynev
III.c.M4.4	Creating the basis of simulation software to explore data from tested samples –electro-mechanical,	Jul-27	not started		S. Stoynev
III.c.M4.5	Design and procurement of main components for MConE	Dec-27	not started		S. Krave
III.c.M4.6	Fabrication and commissioning of MConE (at HF-VMTF)	Dec-28	not started		S. Krave
III.c.M4.7	Demonstrate “identical” sample testing in controllable temperature/current/magnetic field/stress	Aug-29	not started		S. Stoynev
III.c.M4.8	Demonstrate controllable sample performance	Dec-29	not started		S. Stoynev
III.c.M4.9	Establish limitations of testing conditions and relevant options for expanding the phase space	Jun-30	not started		S. Stoynev
III.c.M4.10	Demonstrate simulation software quality given accumulated data	Dec-30	not started		S. Stoynev

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Milestones

Materials and Conductors

Milestone #	Description	Target (Still fixing	Status *	Updated Target	Requestor
III.d.M1.1	Establishment of a Standard Test naming scheme and conductor property database	???			Ian/ Et al.
III.d.M1.2	Establish test standards base on cryogenic load probes				All…
III.d.M2.1	Development of a 0th generation general purpose load probe for multiparameter characterization	Jul-25 ●			S. Krave
III.d.M2.2	Development of a 1st generation general purpose load probe for multiparameter characterization with	Jul-25 ●			S. Krave
III.d.M2.3	Design 2nd Generation general purpose load probe for operation in HFVTF	Dec-25 ●			
III.d.M2.4	Commission 2nd Generation general purpose load probe	Dec-28			
III.d.M3	Continued Evaluation of Materials in composites as required (onogoing task)Evalualtion		Ongoing task		
III.d.M3.1	Evaluation of Telene Mechanical properties in Nb3Sn Composite	Apr-25	Not Started		S. Krave
III.d.M3.2	(Characterization of low strength materials for reduced training)Wax???	Jun-25	Not Started		Jose-luis, S. Krave
III.d.M3.3	1st impregnation of cable sample using low complexity thermoplastic (PS)				S. Krave
III.d.M4.1	Fabrication and test of coil with Telene	Aug-25			S. Krave, D. Turrioni, LBNL
III.d.M4.2	Fabrication and test of coil with de-sized glass				S.Krave, LBNL
III.d.M5	AI/ML On image analysis of materials	Dec-25			JF. Croteau, N. Menon
III.d.M6.1	Transverse pressure tests of ReBCO cables				Xingchen, Giorgio V
III.d.M6.2	Test bare ReBCO cables without impregnation				Xingchen
III.d.M6.3	Test ReBCO cables with various imprenation materials				X. Xu G. Vallone
III.d.M6.4	Test of scalable transposed REBCO Cable				S. Krave
III.d.M6.5	Characterization of irradiated REBCO tapes	Dec-25			JF. Croteau, X. Xu
III.d.M7	Standardization of critical current measurements between the different labs			~1 year	JF. Croteau, JL. Rudeiros
III.d.M8	Development and performance evaluation of 19-strand (with central copper conductor) NbTi cable for [	Dec-25	Not started		Vikas Teotia

Short-term plans

- AUP (short) “mirror” magnet – QCD, quench analysis, dedicated instrumentation, diagnostics, ML data
- Friction experiments – establishing the basics, acquiring skills and know-how, introducing those to our field
- Developing the <u>initial setup</u> for testing of samples in cryo conditions in variable I, B, S (with Materials area)

Mechanical oscillations - milestones

Mike K.

Performance Analysis and Enhancement

Mechanical Oscillations

Current progress

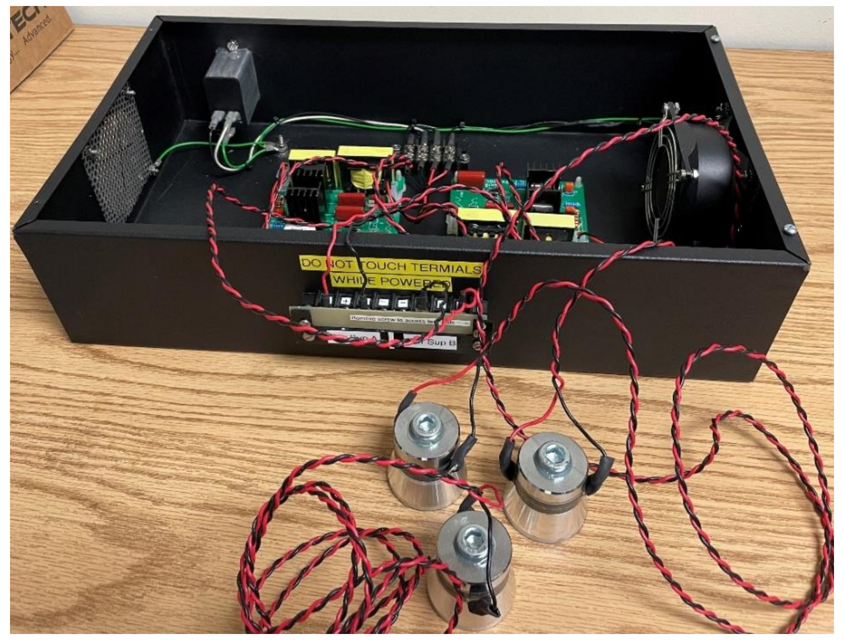
Slowly integrating effect of vibrations

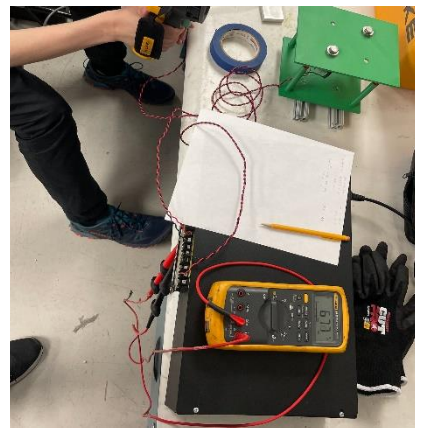
#	Milestone title	Date	
M1	Determining friction coefficients at interfaces relevant for SC magnets and their dependences on different environments	~~8/01/2025~~ ~~12/01/2025~~	Need to be pushed back 05/01/2026
M2	Introducing vibration techniques to mitigate frictional contact between superconducting magnet materials	~~7/01/2026~~	12/01/2026
M3	Determining relevant vibrational parameters to mitigate friction such as amplitude, power, frequency, damping ratio, mass, etc	3/01/2027	
M4	Developing a method to effectively transfer mechanical oscillations in cryogenic environments	5/01/2028	
M5	Conducting first test involving induced mechanical vibrations in a small magnet (model)	11/01/2030	

LTS, HTS

Student assisting on this project – Alexander Jakopin

Status: Friction Measurements & Mechanical Oscillations





Mike K.

I. **Material Characterization and Friction studies**
   - Ongoing friction measurements are being performed on a range of materials.
   - Analysis is focused on understanding how frictional behavior varies with environmental conditions.

II. **Ultrasonic Vibrations – Calibration and Integration**
   - **Transducer Calibration:** Efforts are currently focused on the precise calibration of ultrasonic transducers to ensure accurate and repeatable performance.
   - **Impedance Characterization:** Measuring the impedance of the transducers as a function of frequency.
   - **Power Drive Characterization:** Assessing the voltage and current output of the ultrasonic power drive unit and correlating it with the resulting transducer performance.
   - **Thermal Load Evaluation:** Evaluating the heat generation during transducers operation.
     - Cryogenic-environment testing is planned for future phases.
   - **Vibration Transfer Calibration:** Calibrating the transmitted vibration power delivered to contact surfaces and quantifying energy loss as waves propagate through the medium.

General purpose load probe for multiparameter characterization
General purpose load probe for multiparameter characterization

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MConE

- "MConE.0.1" (magnet conditions emulator, initial version) has multiple steps to complete
  - The topic is in coordination with Materials Area
  - Essentially – a pressure device for powered "samples" in LHe, in external magnetic field

- MConE is aimed to be a test-bed (tool) for variety of magnet-related research (that is, a non-magnet setting for magnet development)

- Current step: General purpose load probe for multiparameter characterization
  - Update by Steve K.

- Current step: Test Stand 3 upgrade
  - Update by Rosalyn Beckwith (working with Vlad N.)

General purpose load probe for multiparameter characterization
General purpose load probe for multiparameter characterization

Spare

Broader goals

QCD: Accumulate test/training statistics with QCD, including from magnets with bad training memory;
Explore potential differences on coil action between QCD and CLIQ;
Parametrize and study the effect of "overcurrent", explore the fundamentals driving dependencies, improve simulations of current transients in magnets

Mechanical oscillations: Explore mechanical oscillation to mitigate friction-dependent magnet performance drivers.
Design and commission devices able to affect magnet performance (training, stability, protection).

Magnet assembly and loading: Explore training and training control, performance in coils by magnet reassembly and reloading;
Investigate differences between single-coil and multi-coil training (in dedicated magnet structures)

Magnet conditions emulator: Enable magnet performance exploration through sustainable means:
satisfying Reproducibility, Statistics, Timing, Simplicity, Cost requirements;
establish unique in the world test-capabilities (including vector-force manipulation in external magnetic field);
explore fundamental and underlying phenomena in magnets through their proxies