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Sun-Mo-PL2-01: [Plenary] Artificial Intelligence for Superconducting Magnets: Towards Smarter Magnet Technology

Sunday 6 July 2025 11:30 (45 minutes)

The field of applied superconductivity is on the brink of a transformative evolution, driven by the rapid advancements in artificial intelligence (AI). Historically rooted in physics, material engineering, and electrical engineering through experimental tests at cryogenic temperature, deterministic methods and rigorous mathematical modelling, superconductivity now face the necessity of integrating data-driven approaches to keep pace with new demands.

Superconducting magnet is one of the most advanced and commercially available applications of superconducting technology. Various types of SC magnets have been widely applied for research, MRI, NMR, accelerator and fusion magnets. These magnets are significantly contributing to healthcare, physics, materials, and energy sectors. Fusion energy is now one of the promising trends of decarbonization for curbing the existing emissions, and decelerating the global warming.

Existing analytical and finite element methods for design development and modelling of SC magnets largely focus on either their use in a general sense or their application in narrowly defined areas, leaving a critical gap in comprehensive, practical references tailored specifically to magnet technology. AI has demonstrated unprecedented capabilities in optimization, performance evaluation, predictive analytics, process automation, and real-time decision-making, all of which are becoming indispensable across magnet technology domain.

On the other hand, recent advancements in AI, such as generative models, reinforcement learning, and advanced neural networks, will enable solutions that were previously unattainable. For instance, AI-powered design optimization of superconducting magnets can drastically shortened development cycles, while machine learning will revolutionize SC magnet's, performance, manufacturing process and energy and cooling managements. Additionally, the global push toward sustainability, decarbonization, and digital transformation has created an urgent need for magnet engineers to integrate AI to address complex, and multidisciplinary challenges related to the predictive diagnostics and prognostics of such magnets especially in fusion applications.
Superconducting magnet designers, researchers, and manufacturers need guidance on adopting AI tools and methodologies to improve system efficiency, optimize designs, and address complex, interdisciplinary challenges including those related to fault, quench, deformations, sensor placement, etc. Practical examples and case studies showing real-world applications of AI in applied superconductivity are essential for translating theoretical concepts into actionable strategies. As the industry landscape evolves, the demand for SC magnet engineers proficient in AI applications has increased, but the educational infrastructure has not kept pace.

This Plenary talk provides a timely resource that bridges these gaps, offering insights into the latest AI tools, methodologies, and their potential applications in superconducting magnet technology.

The Plenary talk will provide my insights on solutions to specific problems, such as:

- AI/ML/DL/RfL introduction
- Design optimisation of SC magnets based on heuristic or meta-heuristic, or swarm-based algorithms.
- Surrogate modelling of SC magnets through machine learning and neural networks.
- Data-driven loss prediction of using machine learning techniques.
- Automating complex simulations for SC magnets.

- Quench detection using AI-enabled data-analytics.
- Mechanical defect detection using ML/DL-assisted techniques.
- AI-assisted RUL estimation for magnet cryocoolers.
- Predictive maintenance of SC magnet systems.
- Smart manufacturing of SC magnets.
- Addressing sustainability challenges through AI-enabled resource optimization, and lifecycle assessments.
- Next step: Digital twins for SC magnets.
- Future trends: GenAI for SC magnets.

Keywords: Artificial Intelligence, Digital Twins, Fault Detection, Generative AI, Machine Learning, Superconducting Magnet, Surrogate Modelling.

References:

[1] M. Yazdani-Asrami, et al. Roadmap on artificial intelligence and big data techniques for superconductivity. Superconductor Science and Technology, 36(4), 043501, 2023.
[2] M. Yazdani-Asrami, et al. Ultra-fast Surrogate Model for Magnetic Field Computation of a Superconducting Magnet Using Multi-layer Artificial Neural Networks. Journal of Superconductivity and Novel Magnetism, 36, 2023.

Author: Dr YAZDANI-ASRAMI, Mohammad (University of Glasgow)

Presenter: Dr YAZDANI-ASRAMI, Mohammad (University of Glasgow)

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