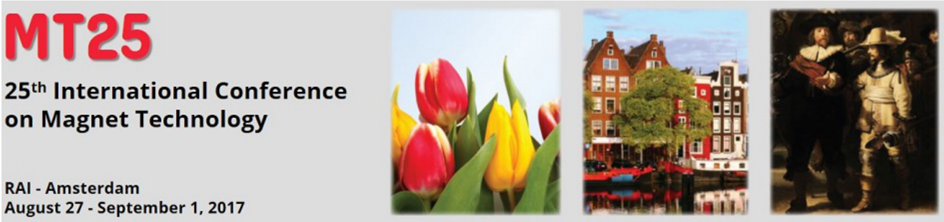

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STEAM: A Hierarchical Co-Simulation Framework for Superconducting Accelerator Magnet Circuits

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Numerical simulations play a crucial role in understanding transient phenomena occurring within circuits of superconducting accelerator magnets. Numerical methods are extensively used during both the electromagnetic and mechanic design. Furthermore, simulations support the quench protection system design, bringing insights on the quench behaviour and contributing to prevent potentially irreversible consequences.
Accelerator magnet circuits are intrinsically multi-physics, multi-scale, and multi-rate systems. The currently available multi-physics simulation tools tend to cover only a specific subset of physical domains, given that no high-performance tool can cover the full range of phenomena within a single model. Therefore, circuits are traditionally decomposed in simpler parts, represented in domain-specific models refined by expert knowledge. As a consequence, the domains' reciprocal influences are neglected, possibly leading to incorrect results.
In this paper we present STEAM, a Java-developed framework which implements a hierarchical co-simulation scheme. The key feature is a dedicated common interface which enables the exchange of information between multiple models, arranged as modular and independent sub-units. The consistency between the solutions is ensured by the convergence of the co-simulation algorithm, which applies the waveform relaxation method.
The framework implements a scalable and extendable architecture, which ensures that any new sub-unit can be easily interfaced. Then, the STEAM collaborative environment enhances the synergy between the different sub-units which can be actively used in a modular approach, depending on the required simulation scenario.
The STEAM capabilities are applied to the inner triplet circuit for the High Luminosity LHC at CERN, assuming a quench scenario in one of the low-beta Nb_3Sn quadrupole magnets (MQXF). The system is deconstructed and co-simulated by means of dedicated models which account for the quench initiation and propagation, the reaction of the quench protection system, the electro-thermal behaviour of the magnet, and the electrical transient in the external circuit. Results are analysed, and further applications are proposed.

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