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Simulations of electromagnetic responses in superconducting magnets in the time and frequency domains using a physically derived equivalent circuit

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Coherent and accurate modelling in multiple domains of superconducting magnets is challenging as their behavior is usually the result of complex interactions of physical effects on different temporal and spatial scales. However, for example, for the performance analysis of the LHC main dipole circuits, it is important to be consistent across the time- and frequency domains.

A modelling approach is presented that allows consistent time and frequency domain simulations of electromagnetic responses in superconducting magnets. This modelling approach captures the driving physical phenomena in lumped elements within smaller electrical networks. These elements are mutually coupled to the magnet's coil inductances. The coupling parameters are analytically derived using only measured geometric and material properties of the magnets and their components. The specific features of transient responses are thus physically interpretable. As such, the model can reproduce complex transient effects within the magnets'coils, such as inter-filament and inter-strand coupling losses. It can also account for the effect of eddy currents in other metallic components of the magnet, such as the beam-screen located inside the magnets' apertures.

This paper presents the general analytical derivation and practical implementation of the coupled lumped elements, applied to the LHC main dipole magnet model. The model is validated against measurements from Fast Power Abort (FPA) tests of the LHC main dipole magnet circuits. To a good agreement, the model can reproduce frequency-dependent impedance differences of the magnet apertures, induced by different beam-screen characteristics. In addition, the model can accurately reproduce impedance measurements under various conditions in the low-frequency range.

The model can thus be used in the frequency and time domains to reproduce electromagnetic responses while relying entirely on measured parameters and physically derived components. It can therefore be used to provide insights into frequency-dependent effects in superconducting magnets.

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