INTEGRATED APPROACHES TO THE DESIGN OF RESISTIVE LARGE MAGNETS FOR CERN EXPERIMENTS

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The present contribution introduces some large magnet design activities on which a stable collaboration has been established between CERN and a number of Research Units of National Group of Electrotechnics [1-2], with reference to the approved SHiP (Search for Hidden Particles) experiment [3] and the upgrade of the SND@LHC (Scattering and Neutrino Detector at the Large Hadron Collider) [4]. They foresee, in fact, large magnetized regions which provides, respectively, muon shielding and/or muon charge and momentum measurement.

Quite a lot of engineering challenges arise from the design of such large magnets, and new models and methods are needed to their optimal design. Besides the consolidated design process to balance performance and cost at fixed performance, given some physical constraints, any modern design approach includes, within the fundamental goals, minimizing the use of energy/power and more in general material resources for sustainability, which is reflected in new guidelines at CERN. Moreover, for magnets with large iron active regions, the issue of field distribution uniformity and predictability are challenging. Finally, for efficiency and field preferred direction reasons, Grain Oriented (GO) steel can be considered, for a use quite far from their main application in large power transformers, requiring new modelling and characterization effort.

The research work herein described aims at considering, possibly in a unified analytical and numerical modelling framework, new the design procedures for resistive large magnets addressing the new challenges, at the same time providing support to real cases study and design in the framework of the above-mentioned collaborations.

In the following we mention our recent results in three areas, namely the optimization of an air core magnet for the SHiP experiment magnetic detector, the engineering design of the magnet for the SND@LHC experiment upgrade, and the preliminary studies for integrating a detector into the Muon Shield for SHiP, possibly based on the deployment of GO steel.

For the SHiP detector, an air core magnet has been considered as an alternative option to the iron core magnet baseline, with a corresponding large increase of required power at the same magnetized volume and field level (roughly three orders of magnitude). An optimization procedure has been defined, based on a semi-analytical approach, following and improving what considered in [5].When applied to a realistic experimental parameters' set, it gives some interesting and counterintuitive result, as for example that, at assigned detection performance, the minimum of electrical power and the minimum of the nominal magnetic field are not attained at the same point. This clearly shows the importance of the multi-optimization design approach. After the relevant minima are determined in the parameter's space (basically with analytical tools), full 3-D FEM validation analysis follows.

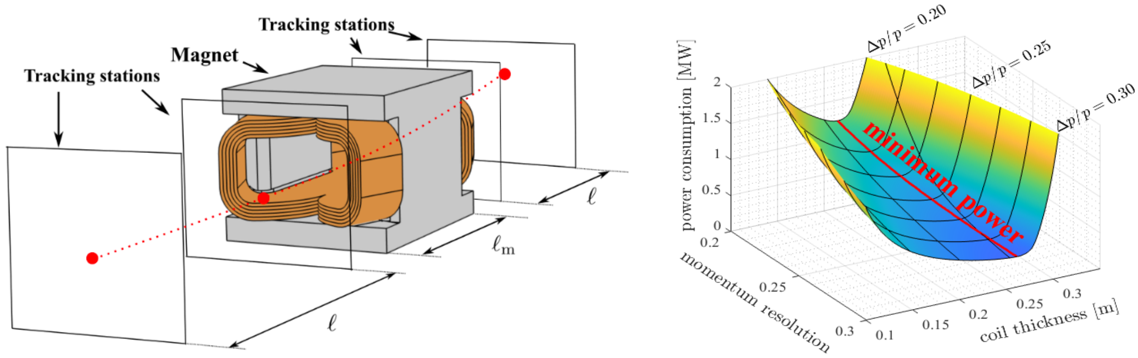
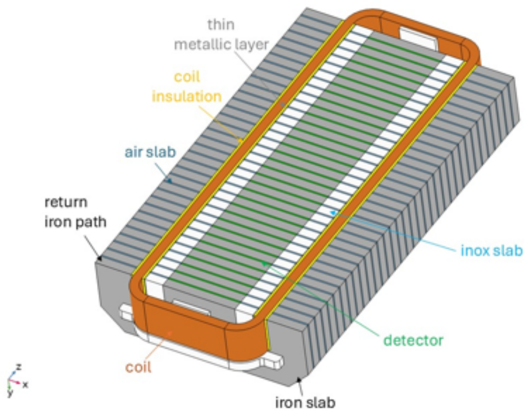


Figure 1: left) schematic structure of the magnetic detector; right) dependence of required electrical power as a function of the detector resolution and the coil thickness (@ total thickness fixed)

With respect to the magnet for the SND@LHC experiment upgrade, after a preliminary study [2], a strong constraint arose due to limitations in available space, that led to a "compact" solution. A preliminary sizing of the iron core magnets suggests defining a reference field of about 1.75 T, close to the iron saturation point. Parameters dependencies are not particularly critical for the iron core magnet. With reference to standard AISI 1010 iron, we get the results shown in figure 1 and the values in table 1. More details are given in [6].



Description	Unit	Value
Total longitudinal length (iron + gaps + coil)	[m]	2.267
Total magnetized longitudinal iron core length	[m]	1.70
Total cross-section	[m^2]	1.15×0.80
Core cross-section	[m^2]	0.40×0.40
Reference flux density (magnetized core)	[T]	1.75
$\Delta B/B$ @ 98% volume	[%]	≤ 3
Stray field [@ iron surface, @ d >2m]	[mT]	[$\lesssim 40$, $\lesssim 1$]
Current density	[A/mm^2]	0.89
Magnetomotive force	[kA]	13.0
Electrical power	[kW]	1.19
Total conductor mass	[t]	0.86
Total iron mass + s. steel	[t]	11.12

Figure 2: half structure of the detector magnet and basic design parameters

Still within the SHiP experiment, we are investigating the possibility to integrate a detector, conceptually similar to the one designed for SND@LHC, inside one of the warm magnets of the so-called "Muon Shield". In order to guarantee an effective integration of the detector, ensuring at the same time a proper shielding of the muons, a possible deployment of grain-oriented steel is under analysis.

References

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