DESIGN OF CORRECTOR MAGNETS FOR THE LHC

A.Ijspeert, M. Karppinen, J. Salminen
CERN, 1211 Geneva 23, Switzerland

Abstract

The Large Hadron Collider will be equipped with a large number of superconducting Dipoles and Quadrupoles. The field quality of these magnets is of primary importance as coasting particles may easily get disturbed and quit the vacuum chamber. The desired field quality can only be obtained by the introduction of a number of corrector magnets forming part of the “cold masses” of the main magnets. Many types of correctors will be necessary: dipoles, quadrupoles, sextupoles and decapoles. Their design presented a challenge to ROXIE in particular those types where several “nested” coils produce different superposed fields and where no easy symmetry exists anymore. The paper discusses several typical corrector magnets and highlights the extensive use of ROXIE for the field optimisation, the coil drawing, the definition of the coil spacers and the machining of the latter.

I. Introduction

Why do we need corrector magnets? A circular machine like the LHC where the particles pass many thousands of times through the different magnets is very sensitive to any small field disturbance. The particles meeting it in a repetitive way are easily distorted to a point where they leave the orbit and crash into the wall of the surrounding vacuum tube. Corrector magnets are necessary to cancel such distortions counteracting the field irregularities of the main magnets. There is also a need for corrector magnets to locally influence the beam orbit or the beam focusing for instance to correct for alignment errors of a main quadrupole magnet. This cannot be done with the main magnets themselves because these are powered in large families making it impossible to use them for local actions. It would be difficult to create corrector magnets with fields that are exactly the inverse of the field perturbation to be corrected. Therefore the field perturbations are subdivided in linear, quadratic etc. components, the multipoles, which can each be corrected with a corresponding multipolar corrector.

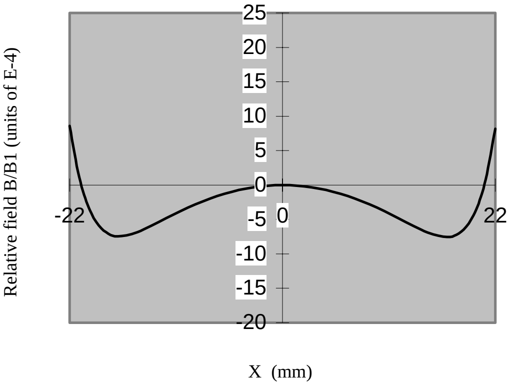

Fig.1a Field homogeneity of Main Dipole at Injection (Yellow Book)

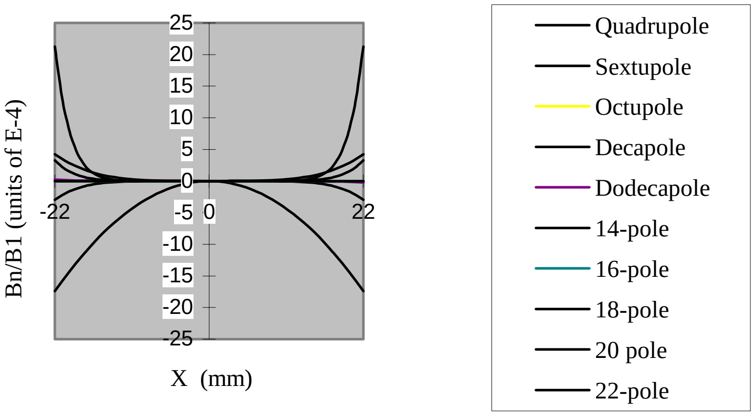

Fig. 1b The same subdivided in Field Components

Fortunately, only the most important multipoles need correction. The different types of correctors are:

- Dipoles for closed orbit corrections
- Quadrupoles to tune the focusing
- Sextupoles for chromaticity correction and for field corrections
- Octupoles for Landau damping
- Decapoles for field corrections
- Dodecapole for field corrections

Some corrector magnets, sextupoles and decapoles in particular which are used for field corrections are directly attached to the magnets concerned (the main bending magnets). The other correctors for beam steering are concentrated near the focusing and defocusing main quadrupoles. The total number is impressive, we need some 6500 superconducting corrector magnets subdivided in about 10 different types. Together they cover 1.2 km of the LHC ring. At CERN we are only a small team and therefore a non-negligible part of the design and prototype work is done outside CERN through agreements with laboratories and industries.

Table 1
Overview of Corrector Magnets (parameters are for indication only)

	Sextupole Dipole MSCH	Sextupole Dipole MCBV	Dipole MCB	Wide Dipole MCBY	Inner trip Dipole MCBX	Tuning Quad MQT/MQS	Trim Quad MQTL	Sextupole MCS	Decapole MCD	Octupole MO	**Inner trip. Correction Windings**
Strength	1500 T/m2 1.5 T	1500 T/m2 1.5 T	3 T	3 T	3.3 T	110 T/m	110 T/m	1740 T/m2	1.83 E6 T/m4	5.7E4 T/m3	
Current	400 A / 50 A	400 A / 50 A	100 A	100 A	550 A	550 A	550 A	550 A	550 A	550 A	
Aperture	56 mm	56 mm	56 mm	70 mm	90 mm	56 mm	56 mm	56 mm	56 mm	56 mm	
Outer Diam.	210 mm	210 mm	185 mm	185 mm	470 mm	160 mm	150 mm	120 mm	110 mm	115 mm	
Length	1.26 m	1.26 m	1.1 m	1.1 m	0.6 m	0.38 m	1.7 m	0.16 m	0.11 m	0.38 m	
Approx, weight	300 kg	300 kg	200 kg	200 kg	600 kg	50 kg	200 kg	10 kg	6 kg	25 kg	
Approx. number	360	360	228	8	16	288	64	2464	2464	384	

The challenge of the corrector magnets is that they must work at low currents ranging from 55 to 550 A in order to reduce the busbar and current lead sections, they must be cheap and reliable, easy to protect in case of quenches and very compact. As compared to the main magnets the principal differences are that the iron yoke touches the coil to boost the field and make the magnet as compact as possible, the coils are made from monolythic enamelled wire and not from cable and impregnated to obtain the desired mechanical strength. The use of spacers in the coils is avoided where possible and the resulting end field problems are corrected by slightly modifying the cross section in the straight part of the magnets. This allows to apply cheaper coil winding techniques.

The challenge for the field calculations and therefore the demands on ROXIE are several:

- In a number of correctors there are different coils one around the other to create combinations of fields. Therefore those correctors have no symmetry plane any more and we are obliged to model the whole magnet. This triggered ROXIE versions that could handle this.

- Several corrector magnets are truly 3-dimensional the straight part being very short. We therefore needed 3-dimensional calculations including the layer jumps and lead ends of the coils.

- With the iron of the yoke close to the coil, the saturation of the iron is an important parameter to be calculated and to be corrected by designing appropriate holes in the yoke. The new versions of ROXIE allow to do this. For the scissor laminations we also need to introduce different rim geometries and packing factors. Field trimming with iron keys is something we might want to explore.

- Finally, a not yet realised dream is the possibility to calculate the persistant current fields created by the corrector field, even for the cases where the corrector field has no symmetry and where the inner rim of the iron yoke has any optimised shape. We are curious to see if the shape of the iron can be used to minimise the persistant current fields.