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Design of the 16 T bending dipole for the Future Circular Collider

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Summary. — The EuroCirCol project is part of the Future Circular Collider (FCC) study, a 100 km post-LHC accelerator, which will allow achieving about 100 TeV energy in the center of mass. The INFN sections of Genoa and Milan (LASA) developed the baseline design of the 16 T bending dipole for the hadron collider (FCC-hh). This work is part of the Conceptual Design Report (CDR), which has been published at the beginning of 2019.

1. – Electromagnetic design

In the colliders, two particle beams are counter-rotating and require two separate channels with opposite magnetic fields. The available space in the FCC tunnel does not allow two separate storage rings. Thus, the main dipoles (MD) have been designed with the two beam pipes surrounded by the coils inside a common iron yoke (LHC style).

The main dipoles, bending the particle beams, must generate a 16 T field in each aperture (see fig. 1). The intermetallic Nb_3Sn compound is the only functional material which can generate such a high field with affordable costs on an industrial scale. However, it is a brittle material, whose superconductivity may be reduced or destroyed from too high strains [1].

The magnetic field inside the apertures must be as close as possible to a perfect dipole ($B_y = 16\,\text{T}, B_x = 0$). So, away from the heads to be able to neglect the axial component ($B_z = 0$), the field can be described in terms of harmonics,

$$B = B_y + iB_x = 10^{-4}\, B_1 \sum_{n=1}^{\infty} (b_n + ia_n) \left(\frac{x+iy}{R_{\text{ref}}}\right)^{n-1}, \tag{1}$$

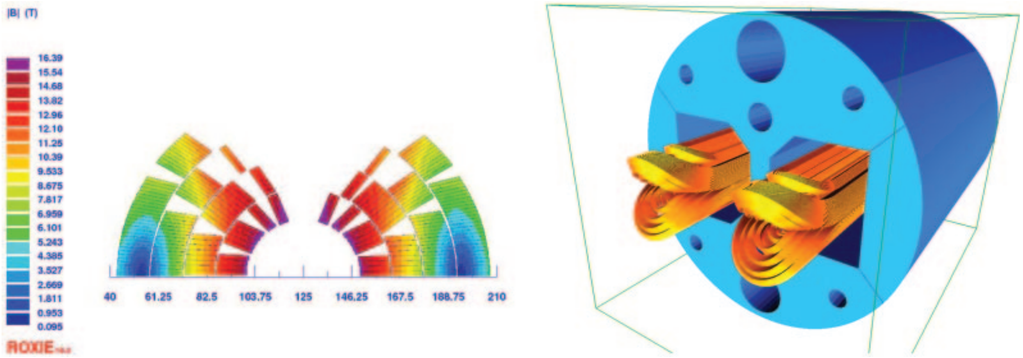

Fig. 1. – Cross-section of one coil (left) and 3D short model of the magnet (right), with the two coils (in yellow) surrounded by the iron yoke (in blue).

where R_{ref} is a reference radius, usually chosen as 2/3 of the aperture radius, B_1 is the main field component, equal to 16 T, and the dimensionless coefficients a_n and b_n are called skew and normal cylindrical harmonics, respectively. Each term of order n represents the $2n$-pole component. The perfect dipole field can be obtained by finding the conductor arrangements, which set to zero the integrated harmonics over the magnetic length.

2. – Results

The EuroCirCol Collaboration studied different designs for the 16 T bending dipole [2]. These studies led to choose as baseline the $\cos\theta$-type layout, designed by the INFN sections of Genoa and Milan (LASA) [3].

Figure 1 shows the cross-section of one coil (left) and the 3D short model of the magnet (right), with the two coils (in yellow) surrounded by the iron yoke (in blue). Each aperture has a 50 mm diameter and the distance between the apertures is 250 mm. The outer radius of the iron yoke is 330 mm. The magnet must operate at the temperature of 1.9 K. The operating current is 11.44 kA and the peak field on the conductors is about 16.4 T. The magnetic length is 14.3 m.

Table I shows the normal harmonics, integrated over the magnetic length at the nominal current. The skew harmonics are zero due to the symmetry with respect to the x-axis. The dipole field in the apertures is near-perfect.

TABLE I. – *Normal harmonics, integrated over the magnetic length at the nominal current.*

$\bar{b}_2$	$\bar{b}_3$	$\bar{b}_4$	$\bar{b}_5$	$\bar{b}_6$	$\bar{b}_7$	$\bar{b}_8$	$\bar{b}_9$	$\bar{b}_{10}$	$\bar{b}_{11}$	$\bar{b}_{12}$
−0.87	−0.75	0.32	0.17	0.35	0.18	0.37	0.56	0.13	1.09	0.09

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