WED-PO2-116-03

Design, Manufacture and Measurement of three Permanent Magnet Dipoles for FASER Experiment

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Introduction

FASER, the ForwArd Search ExpeRiment installed in 2021 at the CERN Large Hardron Collider (LHC), 480 m from the ATLAS collision point (IP1), is an experiment designed to search for new, yet undiscovered, light and weakly-interacting particles and study the interactions of high-energy neutrinos.

Due to tight dimensional constraints, the three dipoles required to achieve sufficient separation of pairs of oppositely charged, high-energy Standard Model particles originating from decays of new physics particles are based on a Halbach array permanent magnet (PM) design. The longest, a 1.5-m-long surrounds the decay volume to start the separation of oppositely charged particles. It is followed by two 1-m-long dipoles installed along the tracking spectrometer. They produce a field of 0.57 T inside an aperture diameter of 200 mm.

FASER layout

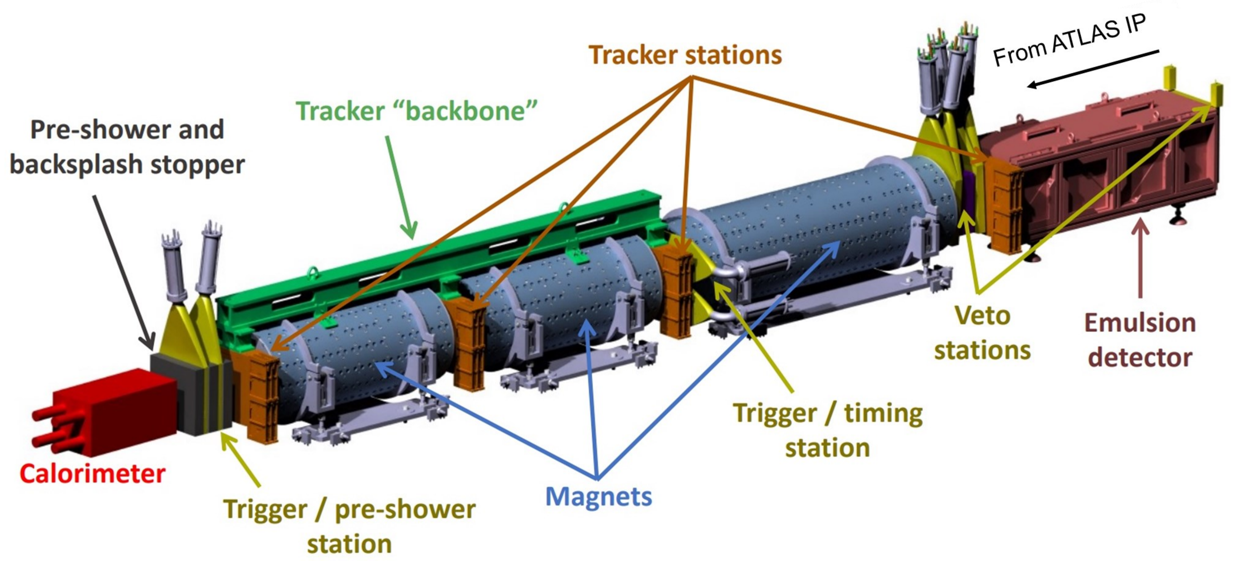

Fig. 1– FASER detector.

Fig. 2– FASER permanent magnet dipoles installed in LHC, 480 m from IP1.

TABLE I
MAIN DESIGN PARAMETERS OF THE FASER DIPOLES

Parameter	Short model	Long model	Unit
Aperture diameter	200	200	mm
Length	1000	1500	mm
Outer diameter	430	430	mm
Mass	914	1331	kg
Mass of permanent magnet	606	909	kg
Nominal field at the center	0.576	0.576	T
Good Field Region radius	100	100	mm
Field homogeneity in GFR	≤ ±3	≤ ±3	%
Permanent magnet material	Sm_2Co_{17}	Sm_2Co_{17}	

Design

The design is based on a Halbach array with 16 magnet sectors. The cross section of the dipole is identical for short and long model. The PM blocks, made of Rare Earth Samarium Cobalt Sm_2Co_{17}, have a trapezoidal shape, with five different easy axis orientations. They are installed inside a structure made of aluminium guiding profiles attached to an external steel ring. The PM blocks are locked in position with aluminium pushing plates.

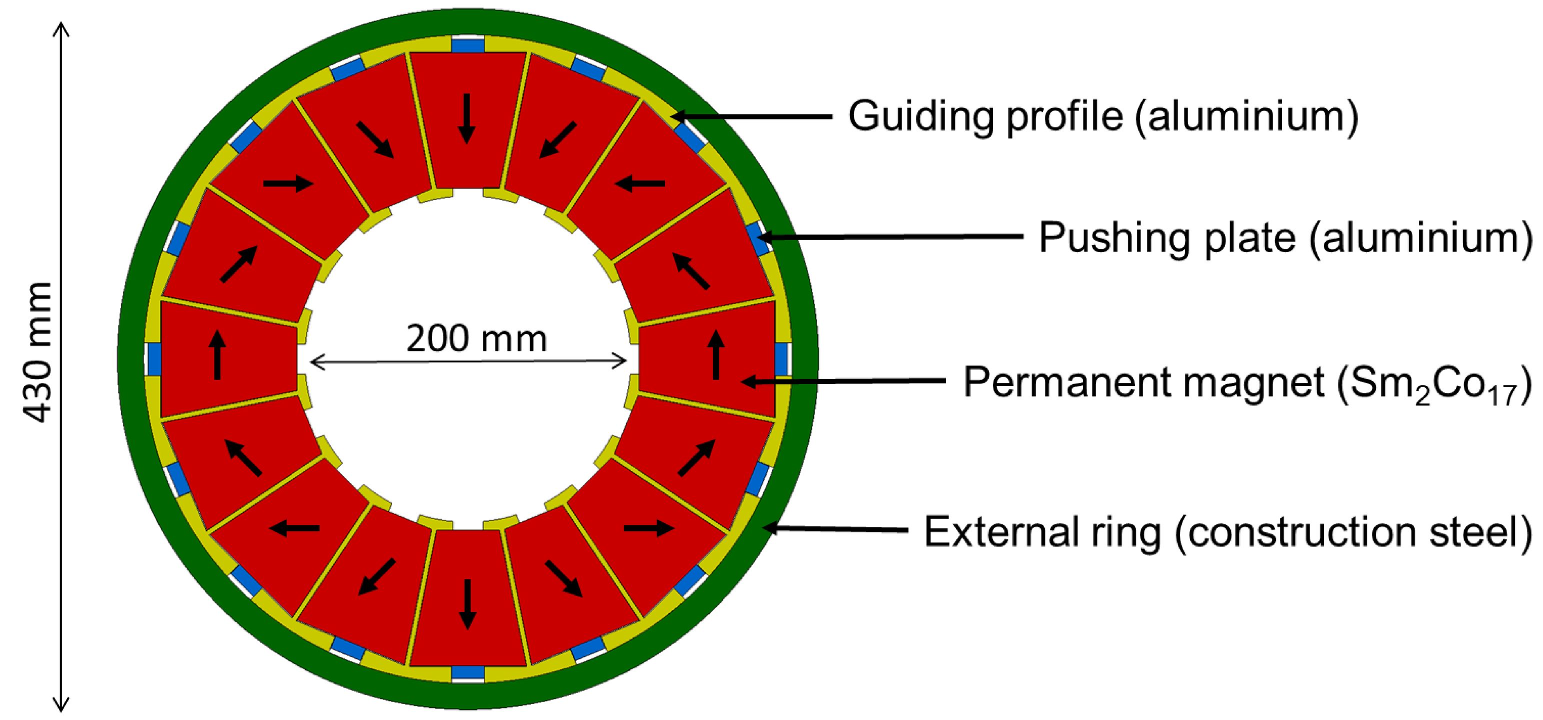

Fig. 3– Cross section of FASER dipole.

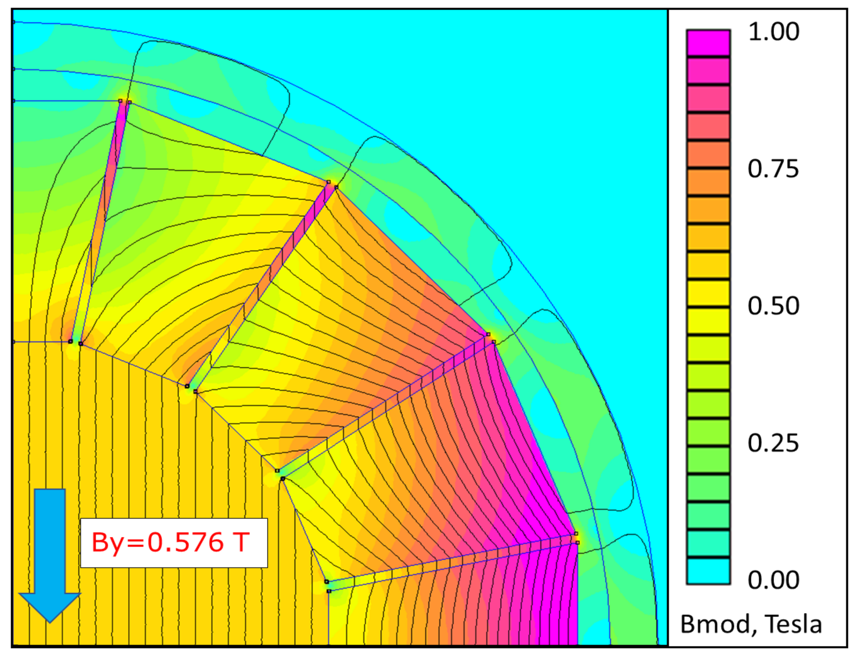

Fig. 4– 2D magnetic field distribution (T).

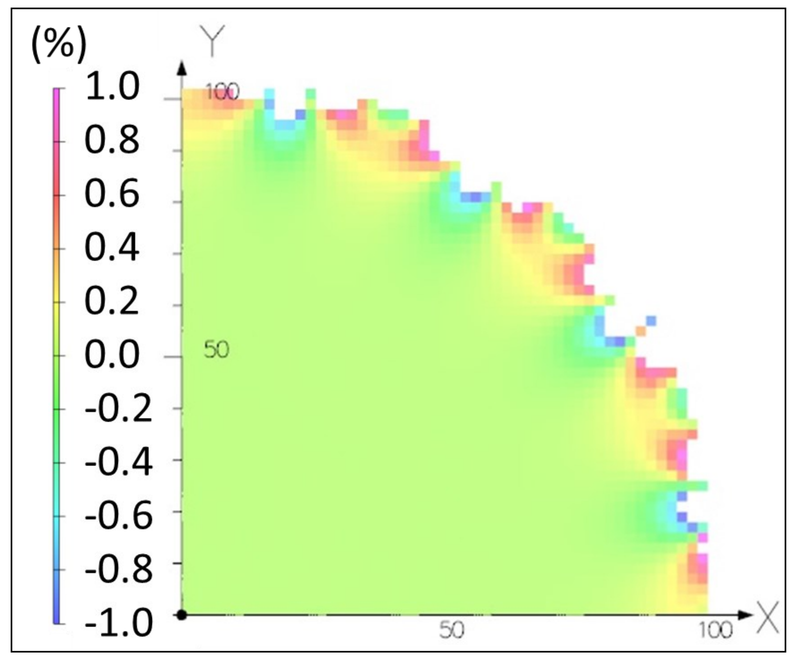

Fig. 5– Integrated field (∫Bydl) homogeneity inside the aperture (%) within the +/-3% specified value.

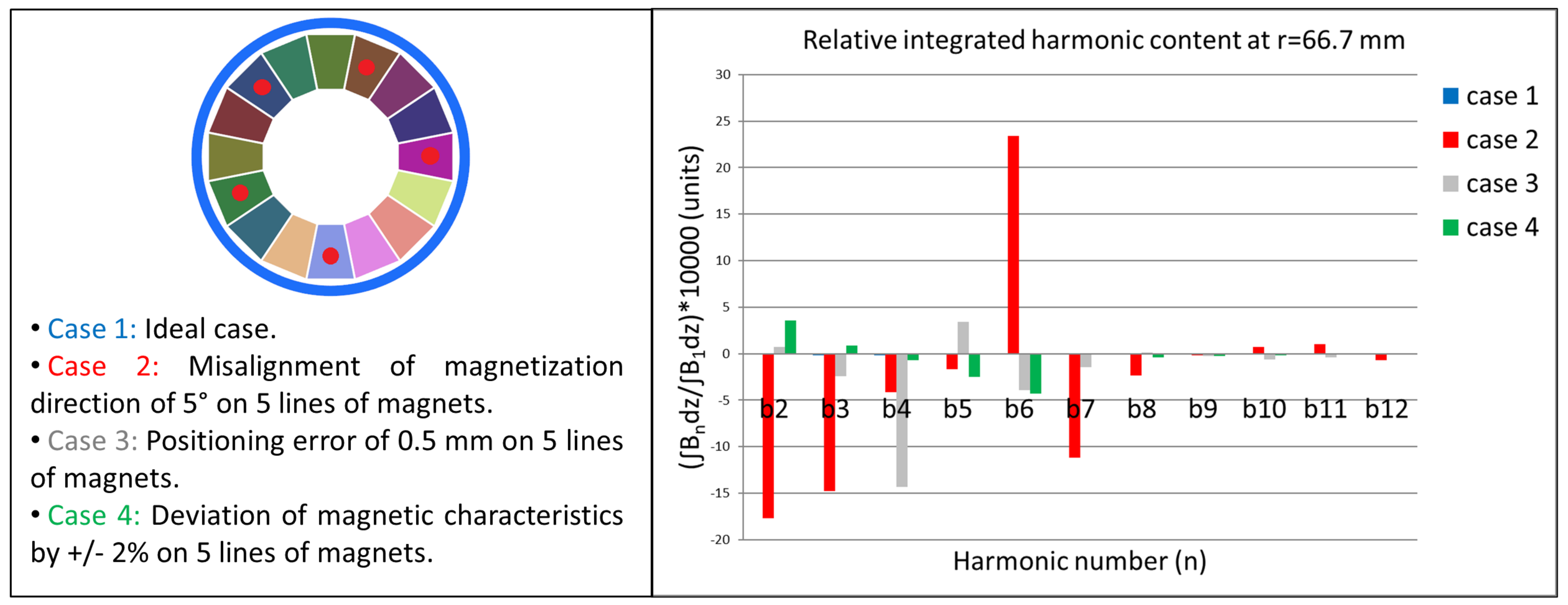

Fig. 6– Deviations applied on some magnet sectors (left); Effect of PM blocks irregularities on field quality evaluated through a harmonic analysis (right).

Assembly

The guiding profiles, manufactured 0.5 m longer than the external ring are used for the PM blocks insertion. Each 3.2 kg PM block is inserted between two profiles without external forces and pushed inside the dipole assembly with a dedicated tooling. The extra length of the guiding profile is cut at the end of the assembly.

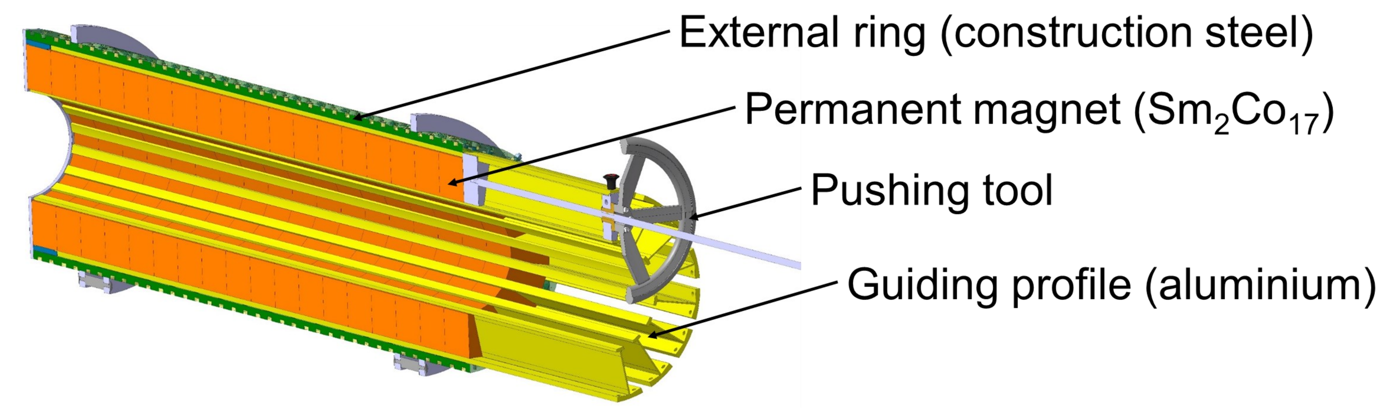

Fig. 6– Tooling for permanent magnet insertion.

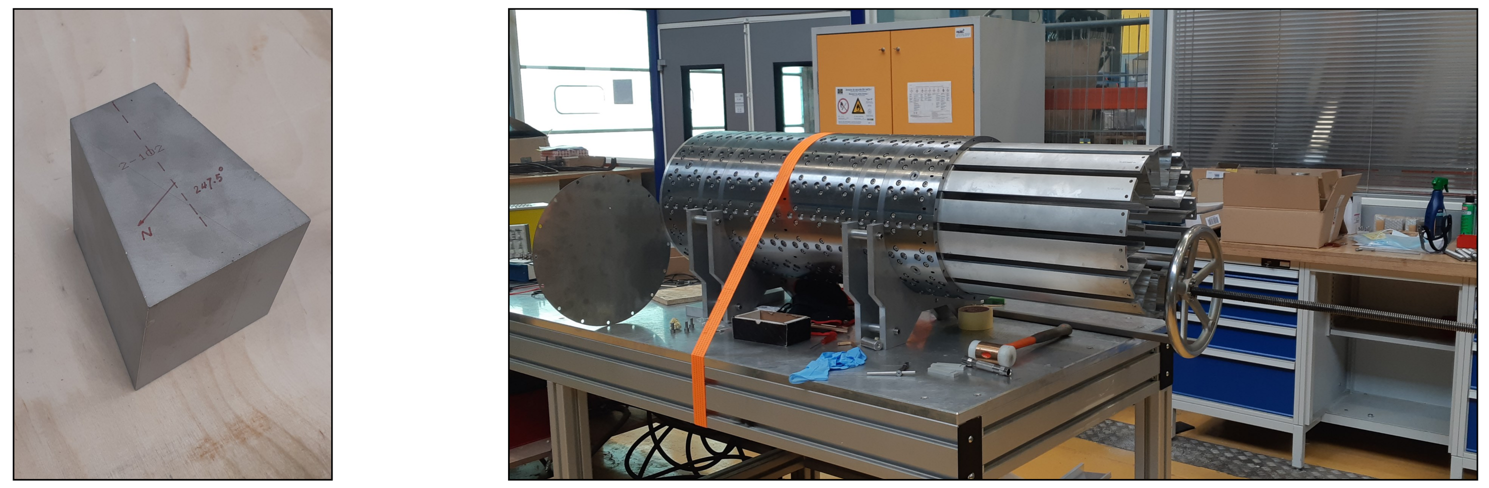

Fig. 7– Permanent magnet block (left); Insertion of a permanent magnet block (right).

Magnetic measurements

Prior to the assembly, the 672 PM blocks were characterized with a 3-D Helmholtz coil. During the assembly, the radial field (Br) was measured after each slice completion to avoid the risk of positioning or polarity error of a PM block. Finally on the assembled dipoles, the integrated field and higher order field harmonics were measured with a stretched wire and the local field homogeneity was measured with a 3-D Hall probe mapper.

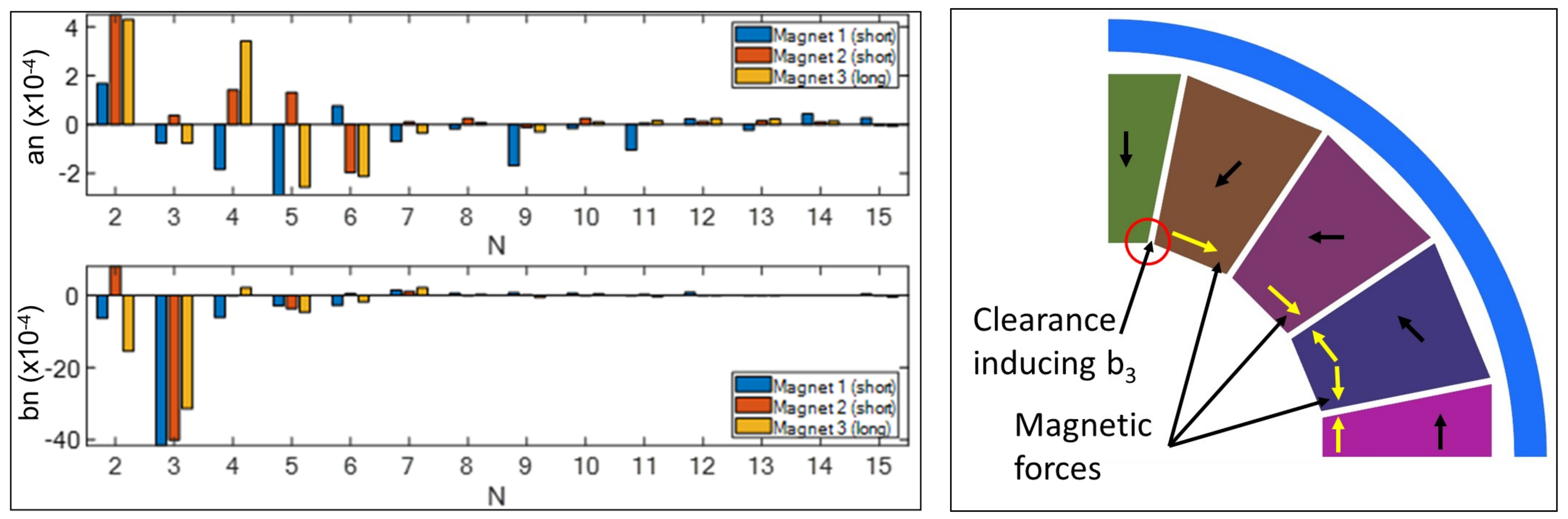

Fig. 8– Measured field harmonic with stretched wire (left); Forces inducing a clearance around top and bottom PM blocks, at the origin of systematic b_3 harmonic component (right).

Conclusion

The design of the permanent magnet dipoles for FASER meets the tight design constraints in term of available space, large aperture with significant field and the cost-effectiveness. The field strength and homogeneity inside the aperture are within specified values.

Innovative assembly technology and magnetic measurement tools were developed for manufacturing these three dipoles providing new validated method for the assembly of large Halbach arrays.