

THE INJECTION AND EXTRACTION KICKER MAGNETS OF THE ELETTRA BOOSTER

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Abstract

The design, realization and performance of the injection and extraction Kicker magnets of the Booster of Elettra are presented. A window-frame geometry has been chosen due to its transverse symmetry. A suitable layout for in vacuum operation has been developed. The magnetic core is made by CMD 5005 ferrite blocks, assembled in a stainless steel case, obtaining a single module; one module has been used for the injection Kicker and two such modules, connected in parallel, have been used for the extraction Kicker. In both cases the magnet modules have been installed in stainless steel vacuum chambers. The design of the magnetic core has been checked using the well known 2D code POISSON, thanks to the fact that the magnet's gap is narrow compared to its length.

MAGNET DESIGN

Booster injection and extraction processes are performed by the combined action of Septum and Kicker magnets, in combination with four bumper magnets. The optics requirements for the Booster extraction, reported in tab. 1, are the most demanding; they have been taken into account to design a magnet module adopted, for standardization reasons, both for the injection and extraction Kickers. In the latter case two such modules have been connected in parallel in order to optimize the performance of the system.

Table 1: Main extraction optics parameters

Extraction energy	2.5 GeV
Total deflection	2.24 mrad
Transv. aperture (hor. x ver.)	44 x 18 mm

Other important factors that have driven the design of the magnets are:

- the free space available for the chamber installation
- the maximum charging voltage of the circuit
- the rise-time of the excitation current pulse

The specific requirement for the latter ones was that the current pulse rise-time of the extraction Kicker should have been in the range of 100 ns [xxx]. Concerning the maximum charging voltage, a safe value of 25 kV has been considered [xxx].

The analytical study of the magnet module has been performed neglecting border effects and assuming a permeability of the core equal to infinity. A window-frame geometry has been chosen due to its symmetry in the transverse plane and the module has been designed to operate in vacuum. In this way the transverse dimensions of the gap (i. e. the vertical and horizontal aperture) have

been set at the minimum values allowed by the optics, i. e. the values of the transverse aperture (18 x 44 mm), optimizing the global performance of the system.

The Kicker magnets will be driven by square current pulses with rise-time and fall-time in the range of 100 ns and with a flat-top duration in the range of 350 ns; thus the choice of the material for the magnetic core must satisfy the following criteria:

- high permeability at the foreseen operating field
- narrow hysteresis cycle (will minimize losses)
- high electric resistivity (will minimize eddy current losses)
- material suitable for high vacuum applications

The CMD 5005 ferrite, provided by Ceramics Magnetics, has been the final choice and its relevant parameters are summarized as follows.

- Initial permeability 1600
- Max. permeability 4500
- Max. flux density 300 mT
- Residual flux density 1800 Gauss max.
- Coercitive strength 0.23 Oersted max.
- Curie temperature 130 deg C
- Electric resistivity (dc) $10^7 \Omega \text{ m}$

Taking into account the extraction energy and the deflection required by a single module (half the total deflection) we have:

$$Bl = \frac{E}{c} \sin \alpha = 9.34 \text{ mT m}$$

where

B = Magnetic field

l = core length

E = extraction energy

c = speed of light

α = deflection of a single magnet module (i. e. 1.12 mrad)

Fixing a core length $l = 350$ mm we have the required magnetic field in the gap $B = 26.7$ mT. The field inside the ferrite B_{fe} has been estimated, once again, assuming infinite permeability and imposing a core thickness of 15 mm; the resulted value $B_{fe} = 39.2$ mT is well within the specified limit of 300 mT.

The geometry developed for the module's core is shown in fig. 1.

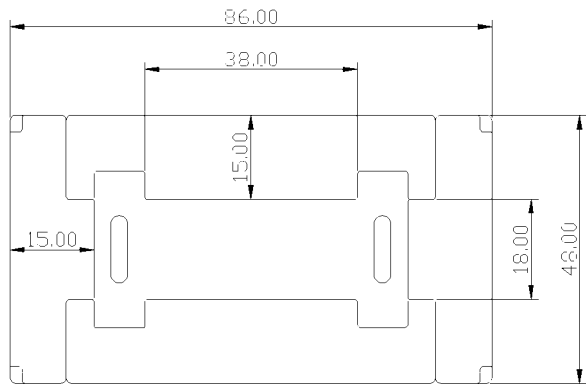


Figure 1: Geometry of the magnetic module.

This geometry has been analysed with the 2D code POISSON and, in order to have a better evaluation of the magnetic behaviour of the magnetic core, the B-H curves of the CMD 5005 ferrite have been adopted in the analysis. Fig. 2 shows the lines of the B field both in the air-gap and in the magnetic core.

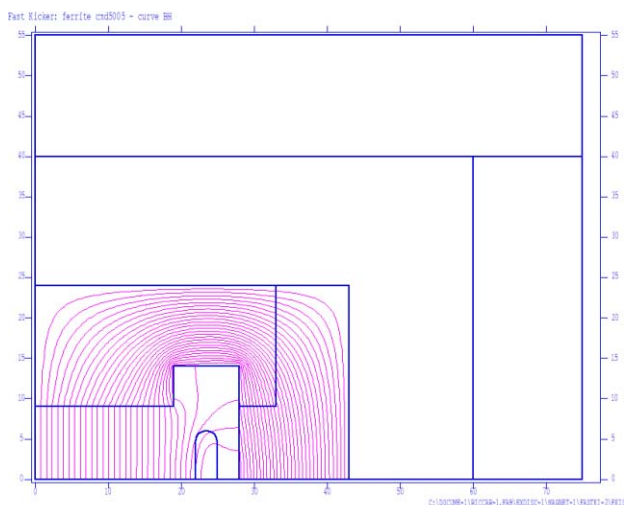


Fig. 2: Lines of B

The field analysis along the middle plane evidences that the deviation between the field at the center and the field off center remains well within 0.5 % in a region of $x = \pm 12$ mm with respect to the longitudinal axis of the magnet, as reported in fig. 3.

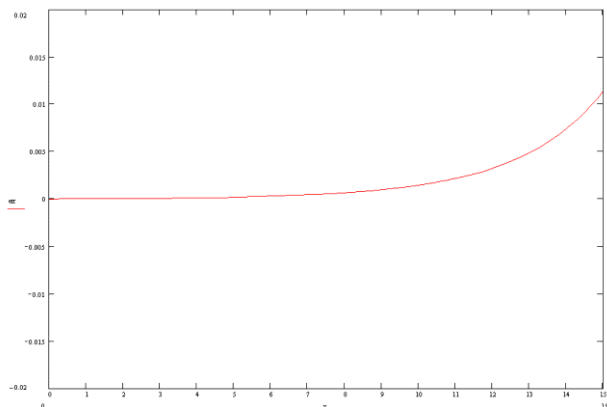


Figure 3: Deviation of B along the x-axis.

MODULE CONSTRUCTION AND INSTALLATION

The ferrite blocks, which compose the magnetic core, have been machined and provided by Ceramics Magnetics; then the blocks have been assembled and kept in position by means of a spring loaded slides system, each slide being composed by an insulator made by alumina (see fig. 4).



Figure 4: Assembly of the magnet module.

A suitable stainless steel case encloses the block assembly; at the bottom, alumina insulators separate the ferrite blocks from the stainless steel plate (see fig. 5).

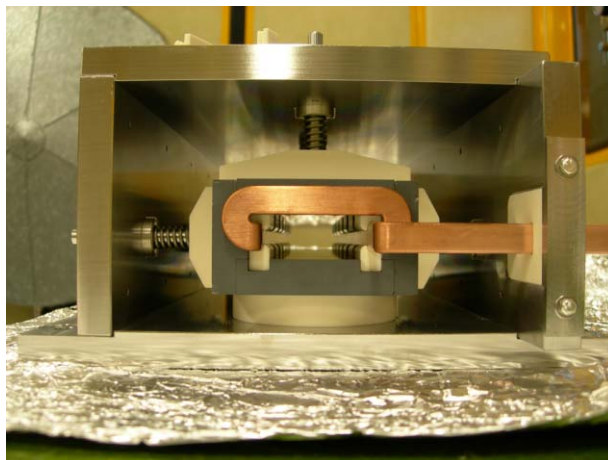


Figure 5: Magnet module assembled.

In this way the magnetic core is completely separated from the steel case; this aspect of the layout is quite important, since high voltage circuits will power the Kicker magnets. The conductor is made by OFHC copper and it is kept in position inside the module gap by means, once again, of suitable alumina insulators.

Once assembled, the modules have been installed in a suitable vacuum chamber, a big cylindrical vessel with an external diameter of 400 mm. The alignment of the modules inside the vessel has been performed by a 3D machine using, as reference, two calibrated holes realized on two reference plates outside the vessel.

MAGNETS TEST

As mentioned before, the modules have been designed in order to have the working point of the magnetic core well far away from its saturation. This assured a linear correspondence between current and magnetic field pulses. Furthermore, the waveform of the current pulse is not distorted adjusting the flat-top amplitude within the operational range. Operatively, the required flat-top level will be controlled by setting the charging voltage of the power circuit from the control room. A scan, giving the response curve of the flat-top vs. charging voltage, has been performed, with voltages ranging from 19 kV up to 21 kV (maximum nominal voltage is 20 kV; maximum operating voltage is 22 kV). The resulting linear fit has been used for converting the required flat-top values into voltage settings. The following instrumentation was adopted for the scan:

- FUG HCK 2500 M 50000 power supply
- Pearson 110A current transformer
- Digital oscilloscope LeCroy 9354 L

Data have been acquired interfacing the oscilloscope with a PC; fig. 6 shows the graph of the acquired data (red diamonds) and the linear fit (blue line).

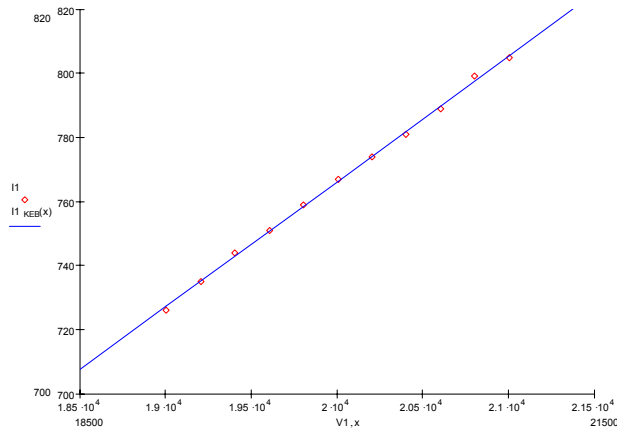


Figure 6: Extr. Kicker voltage – current response.

Fig. 7 shows a typical waveform of the current pulse of the extraction Kicker at a charging voltage of 20 kV; in particular the rise-time of 120 ns is the expected value for a calculated total inductance of about 1.0 μ H [1]. This datum, taking into account the additional inductances introduced by the electrical connections, validates the analytical model assumed for the core design and for the calculation of the magnet inductance.

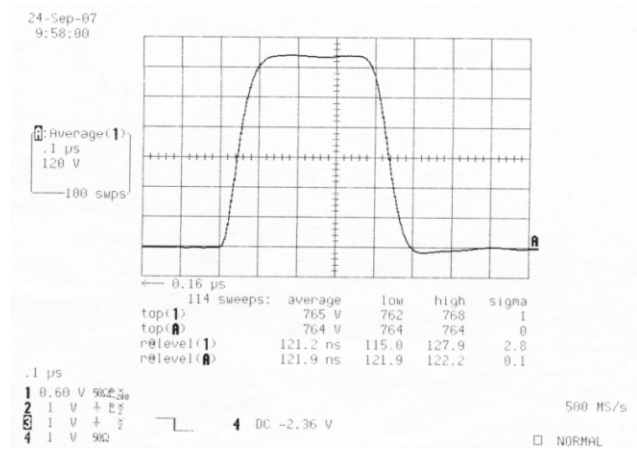


Figure 7: Extr. Kicker current waveform, hor. scale: 100 ns/div, vert. scale: 120 A/div.

Thanks to the MCD 5005 material, vacuum performances were also good; this ferrite has a very low outgassing rate and a pressure in the order of 10^{-8} mbar was easily achieved. This pressure level remained stable during all the routine tests duration, i. e. 5 days of continuous operations at maximum charging voltage (22 kV) and 5 pps repetition rate.

CONCLUSIONS

This design has been challenging concerning both the mechanical and the electrical point of view.

Mechanically the design has been developed focussing most of the efforts on the correct way to assemble the ferrite blocks, which are extremely fragile, in order to realize a compact magnetic core.

On the other side, being the magnet modules supplied by high voltage circuits, the insulation between metallic parts was a big issue. Once again, the POISSON 2D code was of great help in estimating the potential differences between the various components of a single module, i. e. excitation winding, ferrite blocks, external stainless steel case. Another help, concerning the insulation between components, came from the in-vacuum installation layout that has been chosen appositely for this application.

REFERENCES

- [1] R. Fabris, P. Tosolini, "The injection and extraction Kicker circuits for the Elettra Booster", these Proceedings.