SPARC-MM-05/001
1 July 2005

MEASUREMENTS ON COS(θ) STEERING MAGNET PROTOTYPE FOR THE EMITTANCE-METER DEVICE

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Abstract

The electrical and magnetic measurements on the emittance-meter horizontal/vertical steering magnet, in comparison with the results of the 3D simulations, are reported.

1. Introduction

The first prototype of the SPARC Project Steering Magnet, to be used with the emittance-meter device, has been built and measured to verify the magnetic simulation made by means of the 3D code OPERA.

The steering magnet was designed by LNF staff and fig. 1 shows a picture of the prototype. Table I gives its main parameters.

This magnet was designed following the so called “cos(θ)” current distribution and combining in a unique structure both the horizontal and vertical correction.

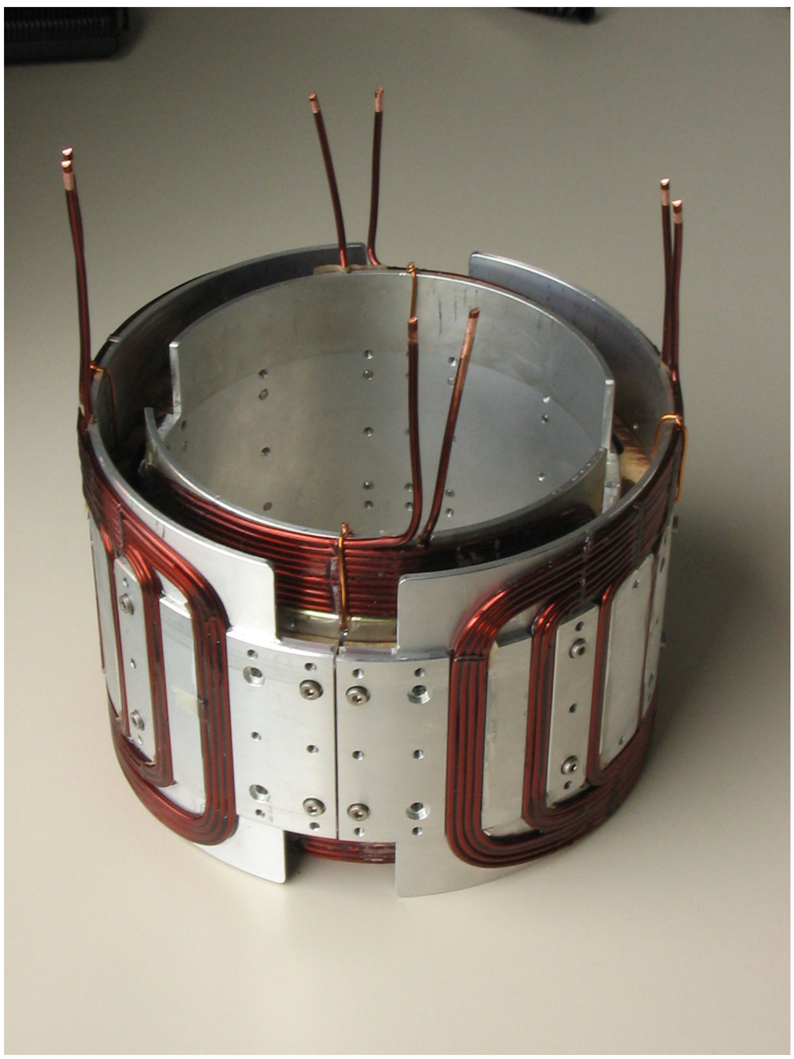

Fig. 1 – *Pictorial view of the cos (θ) steering magnet*

Tab. I – *Steering Magnet prototype design parameters*

Cos(θ) Steering H/V	Units	Hor. Steering (outer)	Ver. Steering (inner)
Energy (max)	MeV	5	5
Deflection angle (max)	mrad	6.9	8.2
Nominal Field	Gauss	8.98	12.33
Magnet Radius	mm	106.5	86.5
Magnetic Length	mm	129	112
Nominal Current	A	20	20
Copper Wire Diameter	mm	3	3
Field Homogeneity	ΔB/B @ ±10 mm	$1.7*10^{-3}$	$1.2*10^{-3}$

2. Electrical Measurements

The resistance of the cos(θ) steering magnet was measured by means of the Volt-Ampere method at room temperature using the following instrumentation:

Power supply: FUG NLB 700-20
Voltmeter: Fluke mod. 77

The following values were measured:

Inner Coils: ΔV = 0.554 V @ Inom = 20 A Tin = 21 °C
Outer Coils: ΔV = 0.598 V @ Inom = 20 A Tin = 21 °C

Corresponding to:

Inner Coil Resistance: 0.0277 Ω
Outer Coil Resistance. 0.0299 Ω

The inductance and resistance of the two combined steering magnets were also measured by means of a LCR meter, HP mod. 4284 A, at different frequencies. The results are shown in fig. 2. The corresponding dc values can be extrapolated from these data. Table II and III list the measured values. They are consistent with the design data.

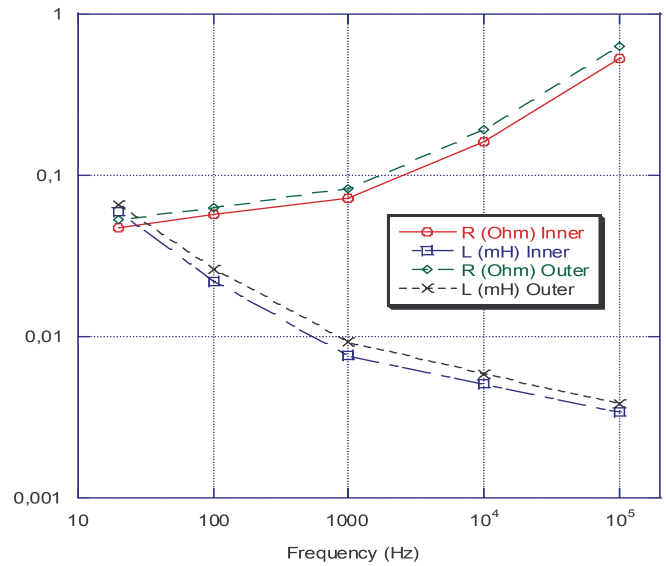

Fig. 2 – *Resistance and Inductance versus frequency for the cos(θ) steering magnets*

Table II – *Resistance and Inductance versus frequency. Inner coils*

Frequency (Hz)	**R (Ω)**	**L (μH)**
20	0.047	60
100	0.057	22
1 k	0.072	7.78
10 k	0.162	5.11
100 k	0.532	3.41

Table III – *Resistance and Inductance versus frequency. Outer coils*

Frequency (Hz)	**R (Ω)**	**L (μH)**
20	0.0529	66
100	0.0627	26
1 k	0.0827	9.18
10 k	0.192	5.79
100 k	0.633	3.76

Thermal measurements were also accomplished and figures 3, 4 and 5 show the temperature increase on the aluminium support, inner coils and outer coils respectively.

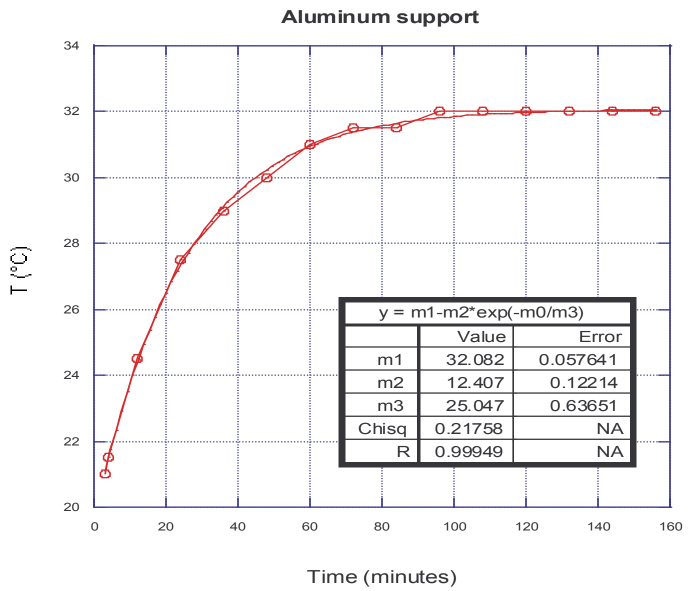

Fig. 3 – *Temperature increase on the Aluminum support*

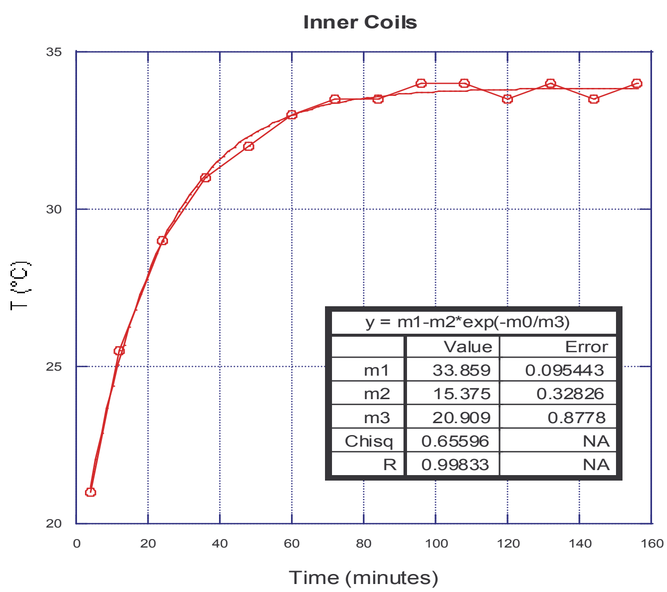

Fig. 4 – *Temperature increase on the inner coils*

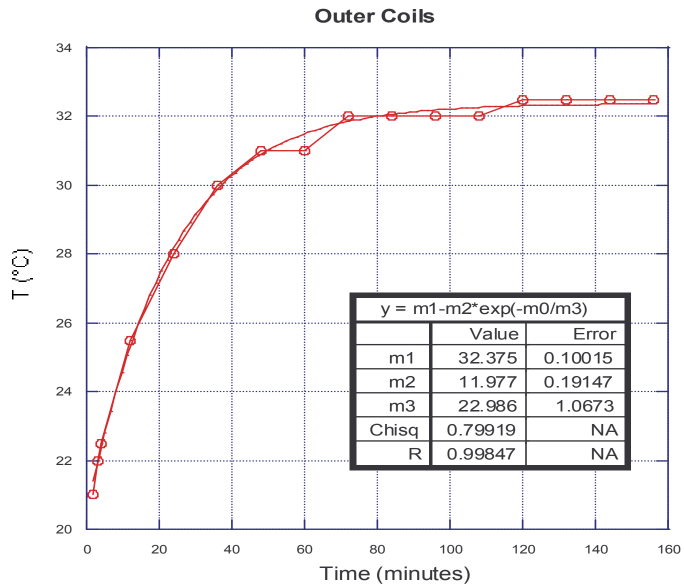

Fig. 5 – *Temperature increase on the outer coils*

3. Magnetic Measurements

The horizontal and vertical components of the magnetic field at the magnet centre have been separately measured as function of the current in the corresponding coils (in the following we indicate with CH the horizontal steering coil, which generates the vertical magnetic field component, and with CV the other one).

Since the power supplies for the steering magnets will be bipolar ones, fig. 6 and fig. 7 show the value of the magnetic field at the magnet centre respectively for the inner and outer coils in the complete current span, that means from 0 to +20 to -20 to 0 A. These kind of steering magnets are of ironless type, then the field-current curve is absolutely linear, with the only exception due to the earth magnetic field that is added in one case and subtracted in the other one. The earth magnetic field components have been measured to be about 0.5 Gauss for the vertical component and about 0.3 Gauss for the horizontal component. These components have not been subtracted to the measured values reported in the following.

The behaviour of the field has been measured in steps of 10 mm along straight lines parallel to the magnet axis at horizontal and vertical distances from it in steps of 10 mm. We remind here that the good field region was limited to ± 10 mm, see table I, but the measurements have been extended till ± 30 mm, for completeness.

The measured magnetic field values are higher than the expected ones obtained simulating the steering magnets by means of the 3D code OPERA. More precisely, the horizontal component of the field generated by the vertical steering magnet is 5.0 % higher and the vertical component generated by the horizontal steering magnet is 7.5 % higher than the calculated one.

The resolution of the Hall plate used to measure the magnetic fields is 0.05 Gauss, then we can only affirm that the field homogeneity inside the good field region is less than the resolution of measurement devices, that means $4*10^{-3}$ for the vertical steering magnet and $5.2*10^{-3}$ for the horizontal one.

In the following, the z coordinate corresponds to the vertical axis, the y coordinate to the longitudinal axis, the beam direction, and the x coordinate to the transverse coordinate.

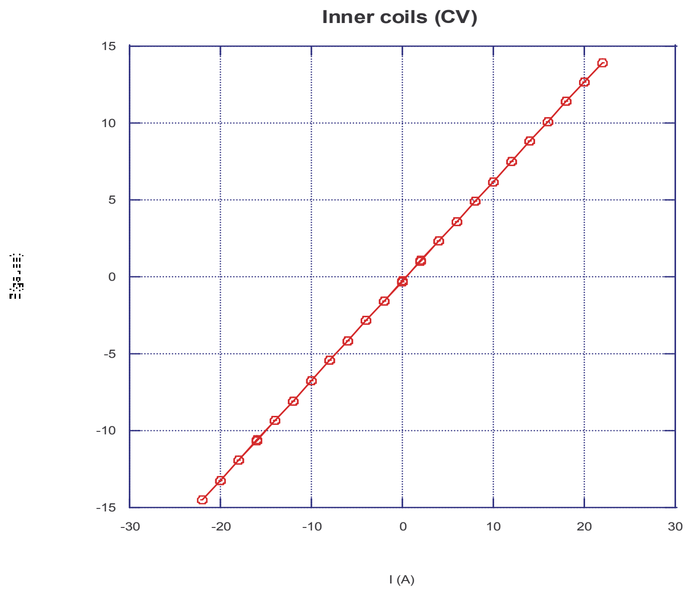

Fig. 6 - *Magnetic field component at the magnet centre versus current for the inner coils (CV)*

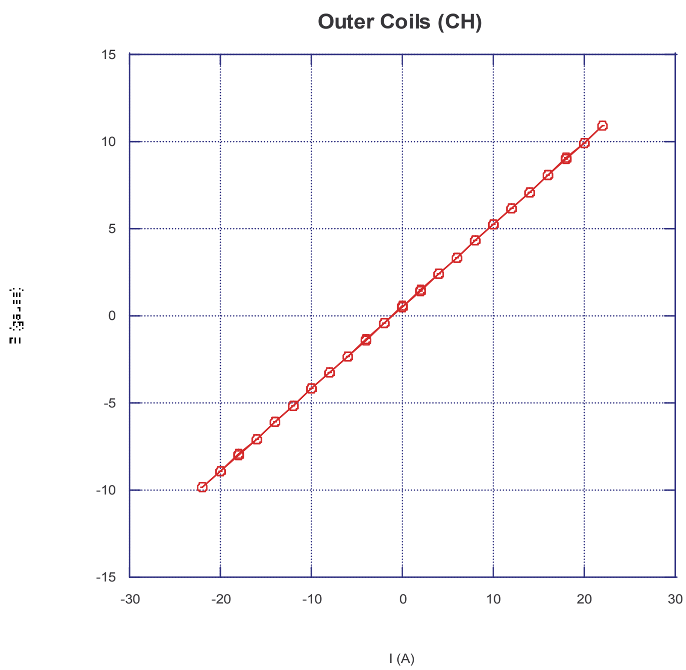

Fig. 7 - *Magnetic field component at the magnet centre versus current for the outer coils (CH)*

Figures 8 and 9 show the vertical magnetic field component measured at the centre of the magnet created by the outer (CH) coils, at the maximum current value, 20 A, with the inner coils (CV) switched off and on, respectively, at different vertical positions.

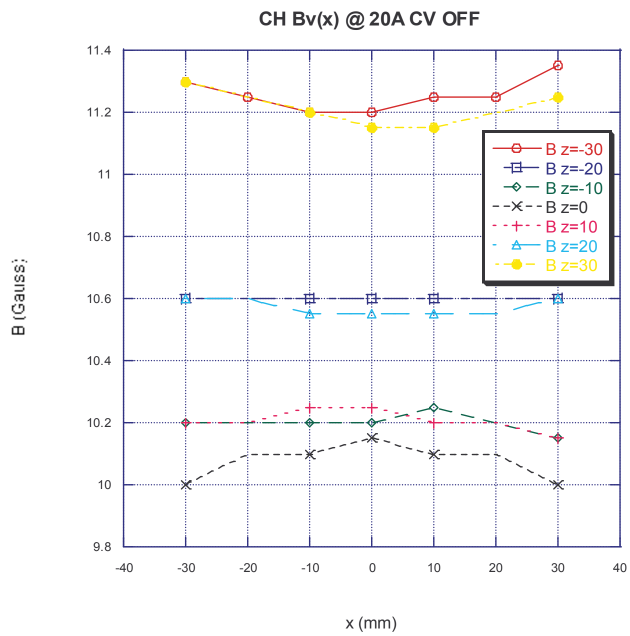

Fig. 8 – *Vertical component of the magnetic field at different radial positions generated by the outer coils (CH) with the other coils (CV) switched off, for different vertical positions*

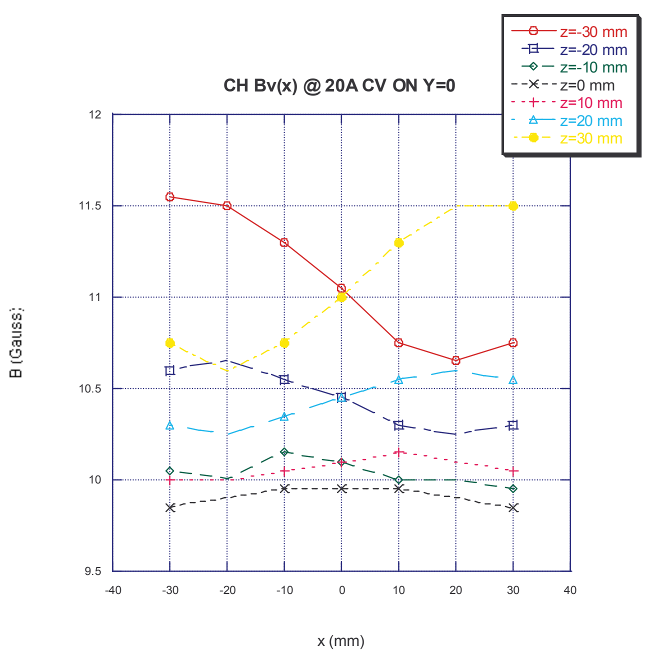

Fig. 9 – *Vertical component of the magnetic field at different radial positions generated by the outer coils (CH) with the other coils (CV) switched on, for different vertical positions*

In the following, figures 10 and 11 show the horizontal component of the magnetic field at different vertical positions generated by the inner coils (CV) with the other coils (CH) switched off and on respectively, for different horizontal position.

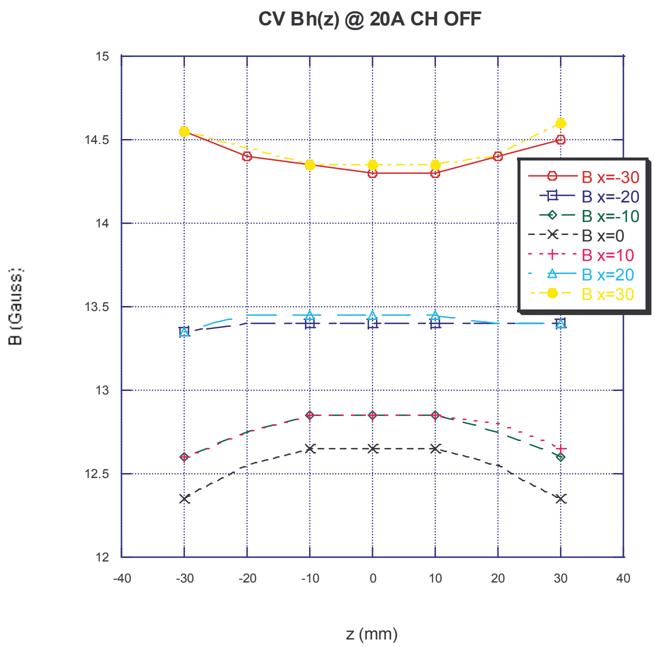

Figure 10 – *Horizontal component of the magnetic field at different vertical positions generated by the inner coils (CV) with the other coils (CH) switched off, for different horizontal positions*

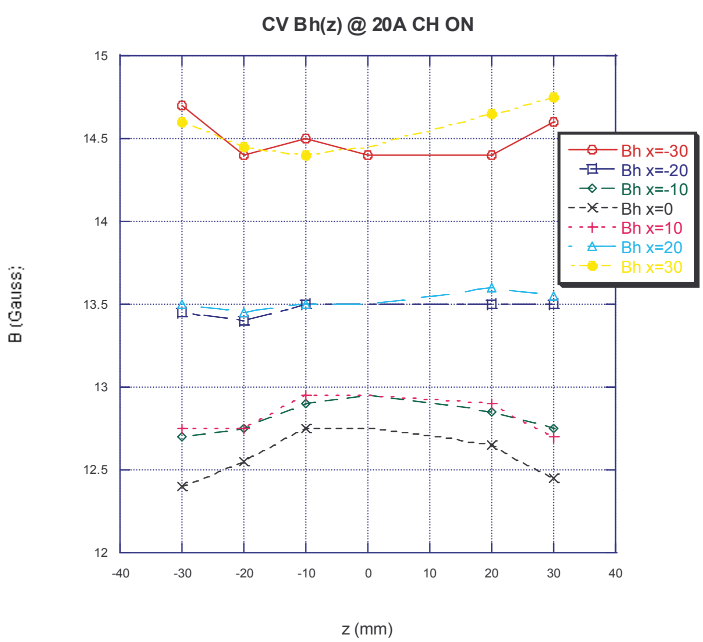

Figure 11 – *Horizontal component of the magnetic field at different vertical positions generated by the inner coils (CV) with the other coils (CH) switched on, for different horizontal positions*

In the following, figures 12 and 13 show the horizontal component of the magnetic field at different radial positions generated by the inner coils (CV) with the other coils (CH) switched off and on respectively, for different vertical position.

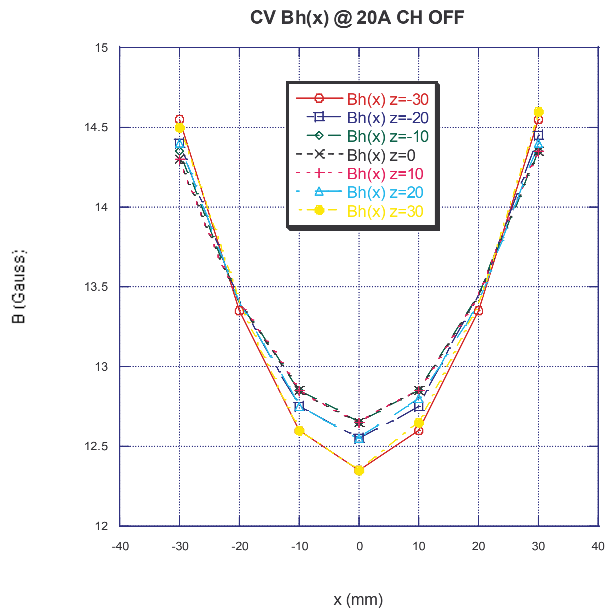

Figure 12 – *Horizontal component of the magnetic field at different radial positions generated by the inner coils (CV) with the other coils (CH) switched off, for different vertical positions*

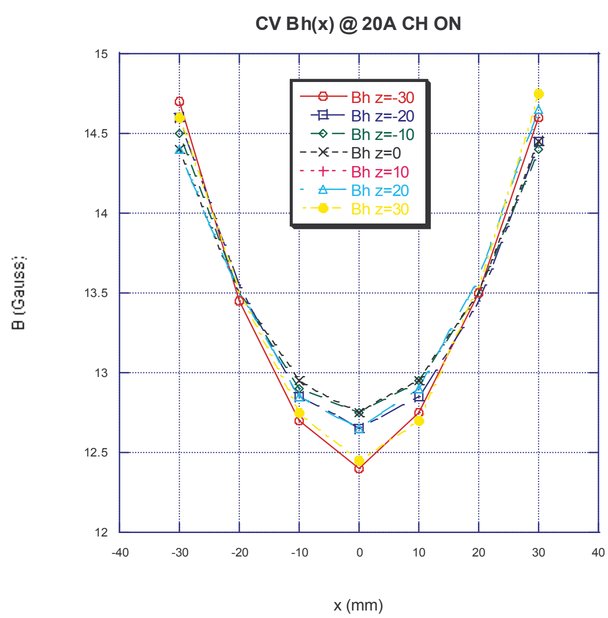

Figure 13 – *Horizontal component of the magnetic field at different radial positions generated by the inner coils (CV) with the other coils (CH) switched on, for different vertical positions*

The field on the central axis is shown in figure 14 for the vertical component (CH) and in figure 15 for the horizontal component (CV) of the magnetic field. The full width at half maximum is 151.6 mm for the horizontal steering magnet (CH) and 131.7 mm for the vertical steering magnet (CV). However, it must be observed that there are long tails and must be kept in mind that when installed near other magnetic elements, the calibration can change significantly due to the absorption of the field lines by the yokes of the neighbouring magnets.

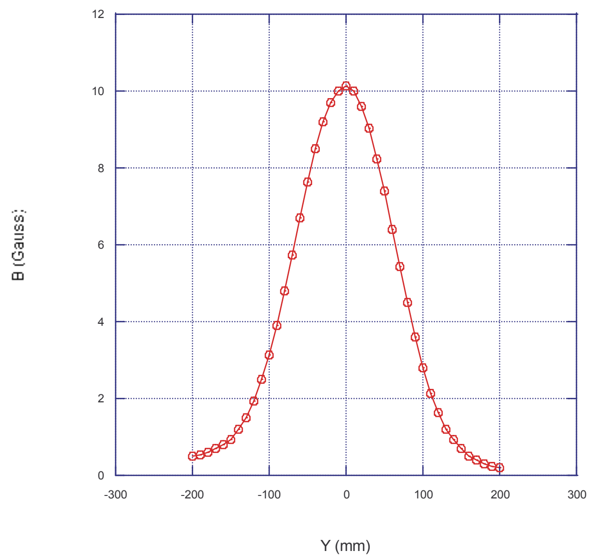

Figure 14 – *Vertical component of the Horizontal steering magnet (CH) along a line parallel to the magnet axis at the centre of the magnet itself*

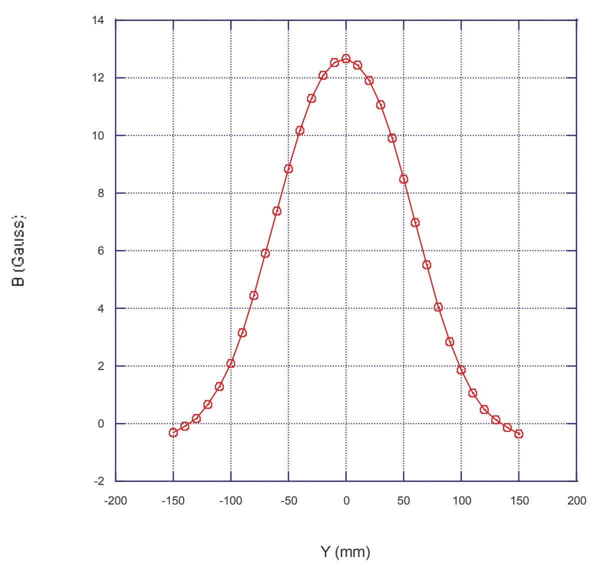

Figure 15 – *Horizontal component of the Vertical steering magnet (CV) along a line parallel to the magnet axis at the centre of the magnet itself*

Figures 14 and 15 show a small right-left asymmetry that is probably due to connections to the power supply even if a lot of accuracy has been taken putting the cables carrying the input and output current one near the other.

The values of the field integral taken along lines parallel to the magnet axis at different horizontal and vertical positions are given in figures 16 and 17 for the vertical and horizontal component respectively.

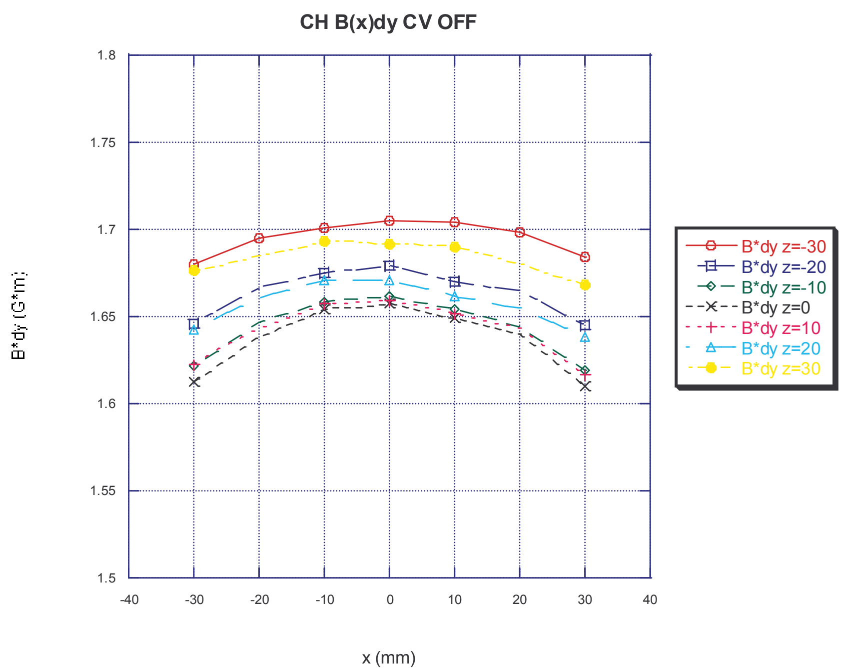

Figure 16 – *Integrated vertical component with CH @ 20A and CV switched off*

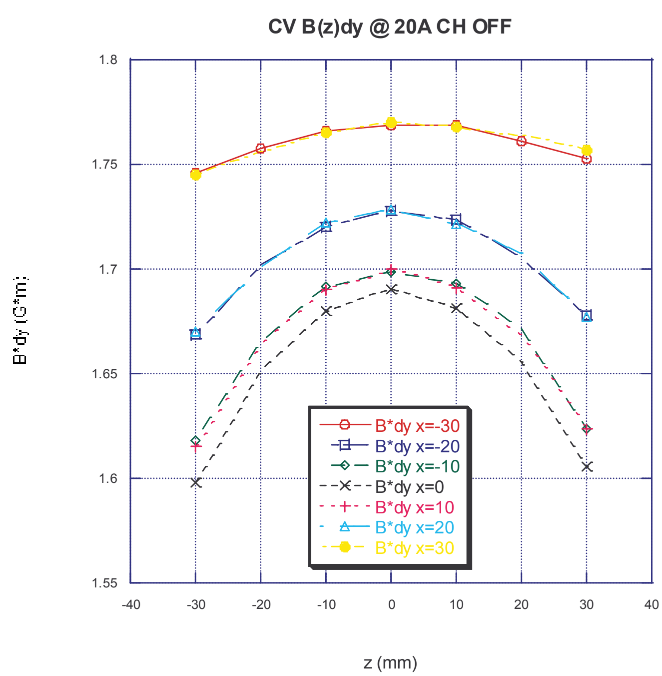

Figure 17 – *Integrated horizontal component with CV @ 20A and CH switched off*

Taking the average value of the integrated vertical field component in the good field region for the horizontal steering CH, see fig. 16, the angular kick α can be expressed as a function of the beam energy and the excitation current as:

$$\alpha \text{ (mrad)} = 2.49*10^{-3} * I \text{ (A)}/E\text{(GeV)}.$$

The same can be done for the horizontal field component of the horizontal steering CV, see fig. 17, obtaining the following expression:

$$\alpha \text{ (mrad)} = 2.53*10^{-3} * I \text{ (A)}/E\text{(GeV)}.$$

A more general expression can be obtained averaging the two values obtaining:

$$\alpha \text{ (mrad)} = 2.51*10^{-3} * I \text{ (A)}/E\text{(GeV)}.$$

4. Conclusions

The steering magnet prototype has been fully characterised at LNF. The measurements confirmed the reliability of its magnetic design. The measured absolute and integrated values are higher than expected from the magnetic simulations. The linearity of the magnetic field with the excitation current, being the magnet ironless, ensures a very good control of the overall orbit correction procedure.

The interference of the field tails with the yoke of other magnetic components must be taken in mind and carefully checked during commissioning by calibrating the steering magnet with the beam itself.