DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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Note: **MM-35**

MEASUREMENTS AND MODELING OF THE OFF-AXIS PERMANENT MAGNET QUADRUPOLES FOR THE DAFNE UPGRADE

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1. Introduction

The two first horizontally defocusing quadrupoles QD0 around the Interaction Point (IP) of the modified lattice of DAΦNE have been built by Aster Enterprises. The magnets have been measured with the rotating coil system at the factory, and the measurement has not been repeated at LNF, as done in the past for the quadrupoles used in the interaction regions of KLOE and FINUDA [1, 2, 3], because a sufficiently small coil is not available. The quadrupoles have instead been measured with the Hall probe system, with a rough alignment because of the lack of manpower during the machine shutdown. However, the measurements are accurate enough to calculate an optical model, following the method described in [4].

2. Magnet parameters and magnetic measurements

A picture of the permanent magnet quadrupole is shown in Fig. 1 and its specifications are listed in Table 1. The results of the magnetic measurements with the rotating coil performed at the factory are given in Table 2.

Table 1 – Specifications for the QD0 permanent magnet quadrupole.

Quantity	2
Minimum clear inside radius (mm)	33
PM inside radius (mm)	34
Maximum outside radius (mm)	100
Magnetic length (mm)	230
REM physical length (mm)	230
Maximum mechanical length (mm)	240
Nominal gradient (T/m)	29.17
Integrated field strength (T)	6.71±2%
Good field region radius (mm)	20
Integrated field quality |dB/B|	$5.00E^{-4}$
Maximum allowable mismatch of Integrated gradient between magnets	$1.00E^{-3}$
REM stabilization temperature (°C)	150
Magnet material type	SmCo2:17
Magnet construction	2 half – split

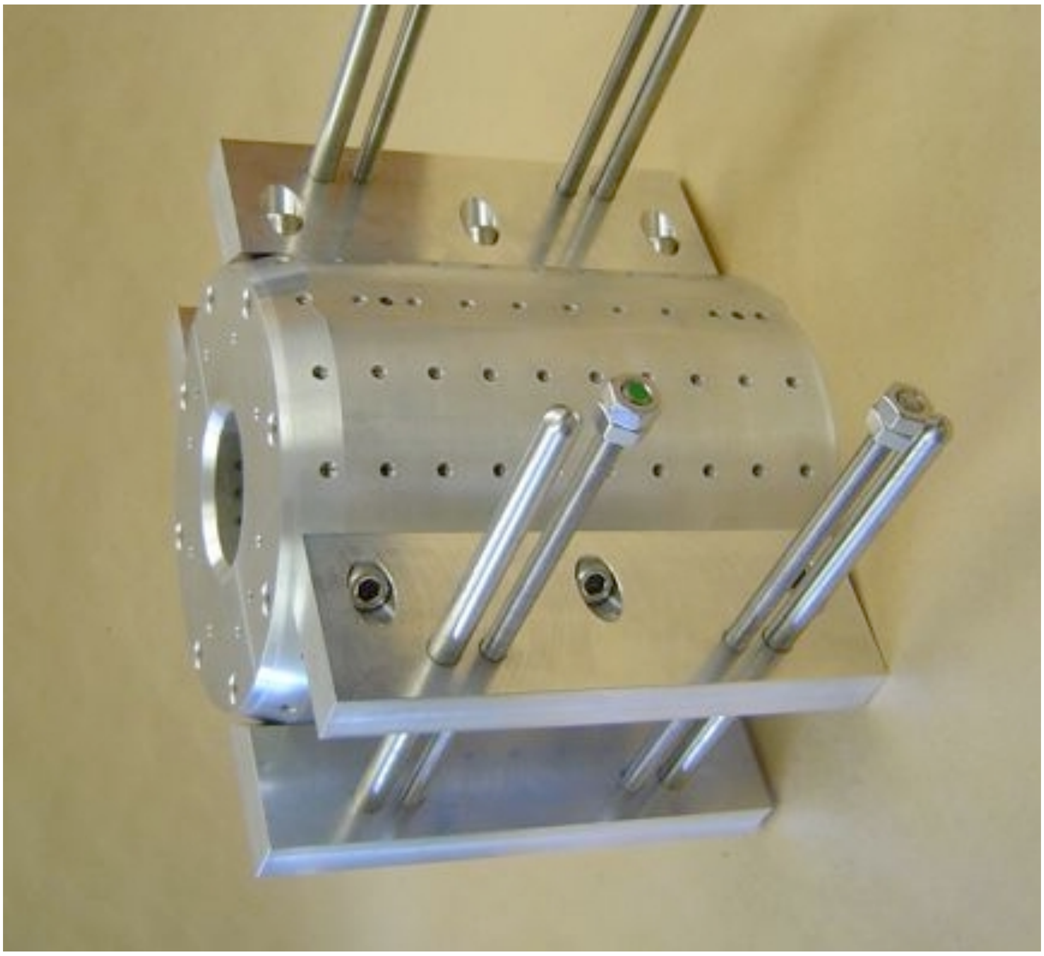

Figure 1 – The permanent magnet quadrupole QD0 with its opening tool.

Table 2 – Results of the measurements at the factory.

	Units	**Sn 1**	**Sn 2**
Integrated gradient	T	6.722	6.722
B_3/B_2 @ 20 mm	%	0.0464	0.0155
B_4/B_2 @ 20 mm	%	0.0424	0.0433
B_5/B_2 @ 20 mm	%	0.0252	0.0305
B_6/B_2 @ 20 mm	%	0.0413	0.0615
B_3 relative phase	deg	140.7	123.8
B_4 relative phase	deg	113.8	-29.2
B_5 relative phase	deg	-65.1	-87.9
B_6 relative phase	deg	-72.0	-106.2

All specifications are met, but for the 12-pole component of serial n. 2, which exceeds the tolerance by ≈20%.

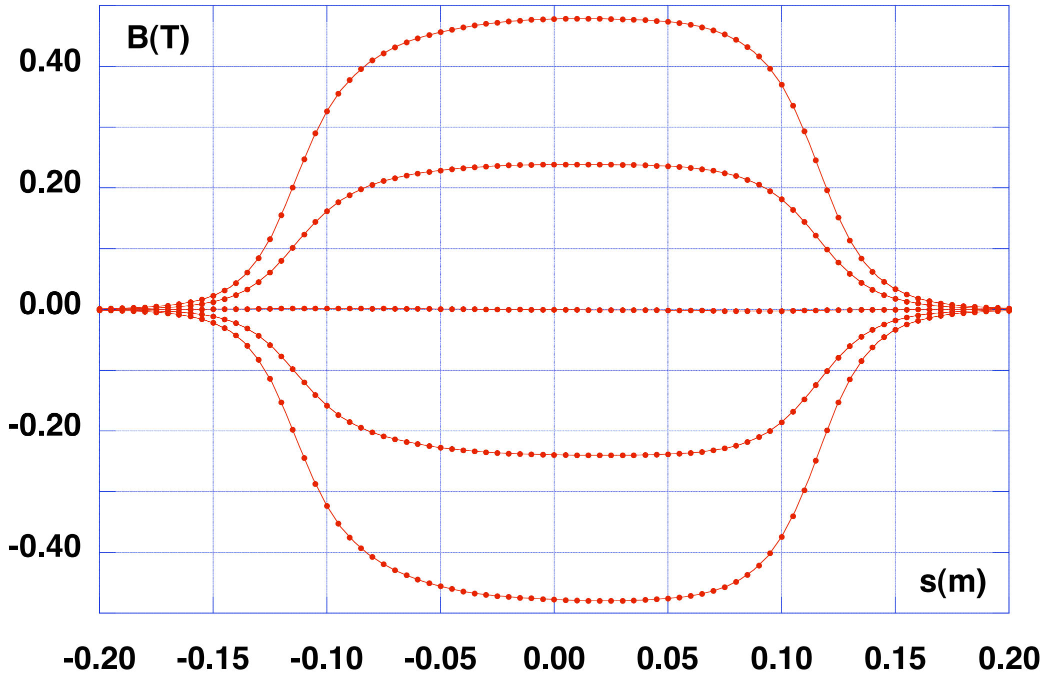

Figure 2 – Vertical field component on the horizontal symmetry plane at -16 mm, -8 mm, 0, +8 mm, +16 mm from the quadrupole axis for quadrupole serial n. 1.

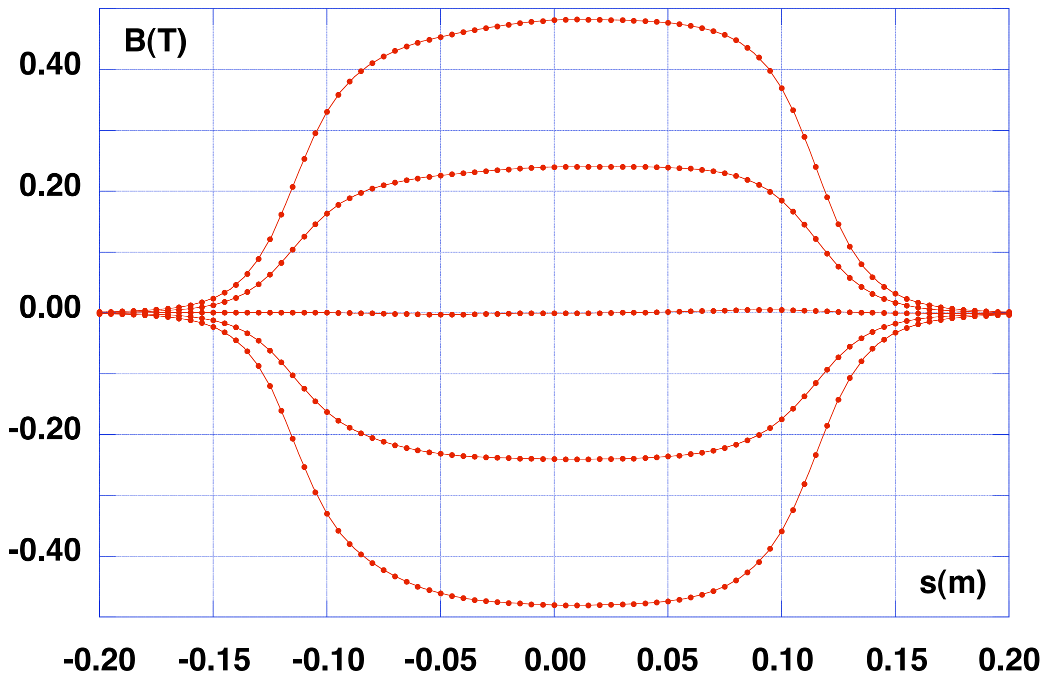

Figure 3 – Vertical field component on the horizontal symmetry plane at -16 mm, -8 mm, 0, +8 mm, +16 mm from the quadrupole axis for quadrupole serial n. 2.

Measurements with the Hall probe system have also been performed at LNF to check the longitudinal behaviour of the field and to calculate a magnetic model to be inserted in the machine lattice [4]. Due to lack of manpower, the magnets were not aligned with the optical system, as done in the past with the other magnets: only a rough alignment has been performed by placing the quadrupole parallel to the Hall probe support. Figures 2 and 3 show the longitudinal scans of the vertical field component. Fig. 4 is an expanded view of the measurement taken on the quadrupole axis, showing that the alignment of the magnet with respect to its longitudinal axis is correct to better than 1 mrad.

Thanks to the excellent linearity of the field measured at the factory, the gradient of the quadrupole can simply be obtained by the difference between the measurements at -16 mm and +16 mm, divided by their distance. In this way, under the approximation of perfect linearity of the field in this range, the gradient does not depend on the alignment error. Figures 5 and 6 show the gradient as a function of the longitudinal position for the two magnets. A slight longitudinal asymmetry can be noticed: the steeper slope is in the region of positive longitudinal positions s, and corresponds to the conical side of the magnet (see Fig. 1). The integrated gradient from the measurement with the Hall probe is 6.678 T for sn.1, 6.685T for sn.2, ≈0.6% smaller than the value obtained at the factory with the rotating coil system.

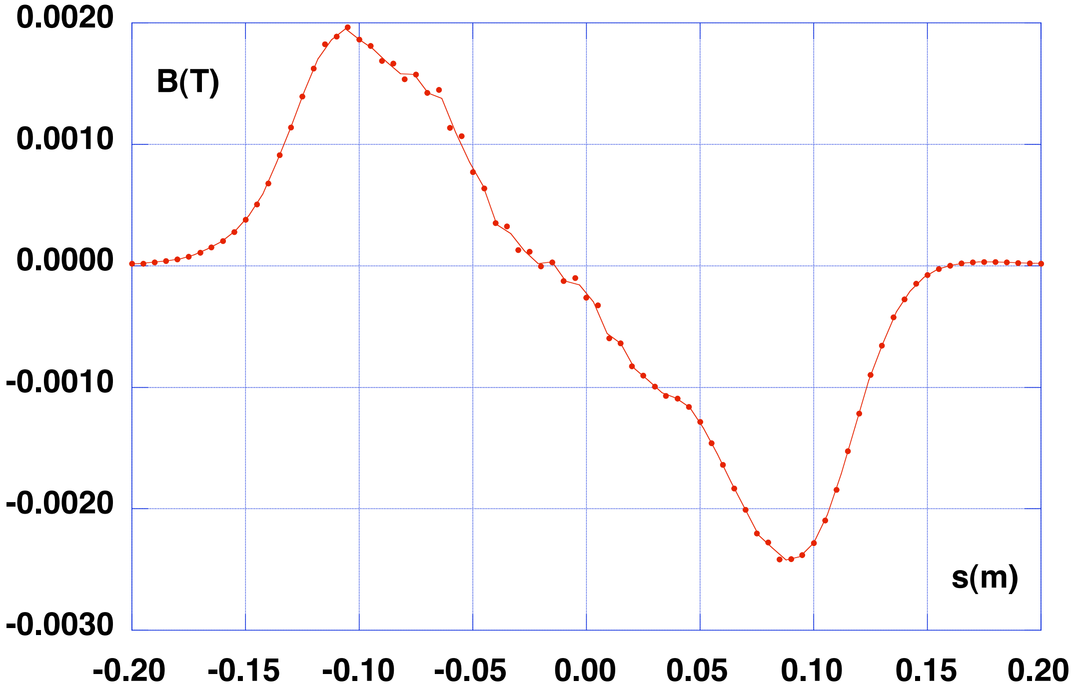

Figure 4 – Vertical field component on the quadrupole axis (sn. 1).

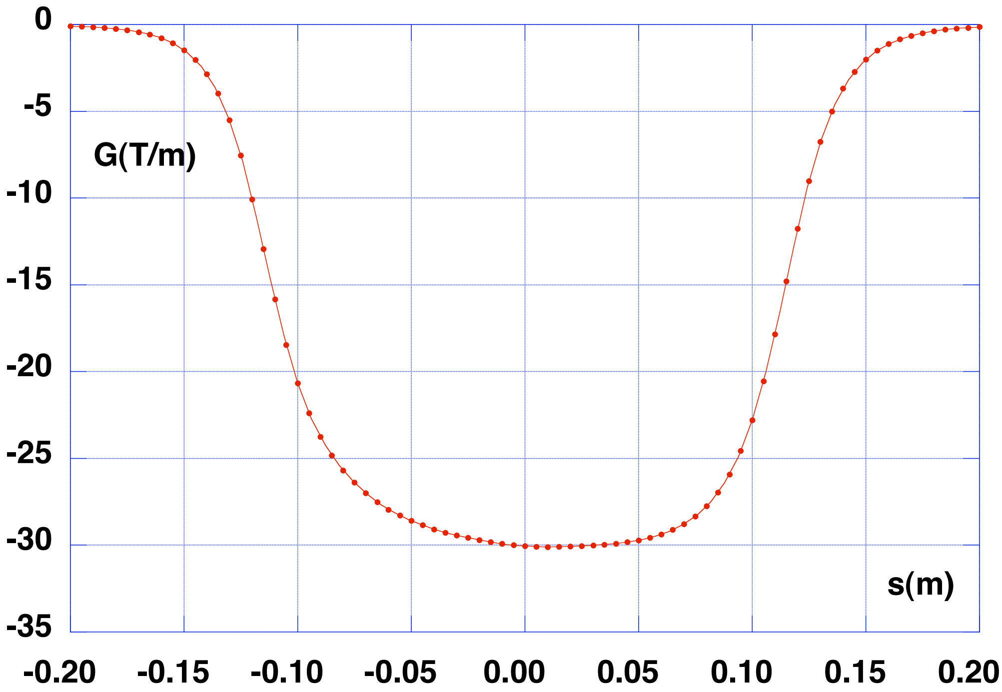

Figure 5 – Field gradient of quadrupole sn. 1.

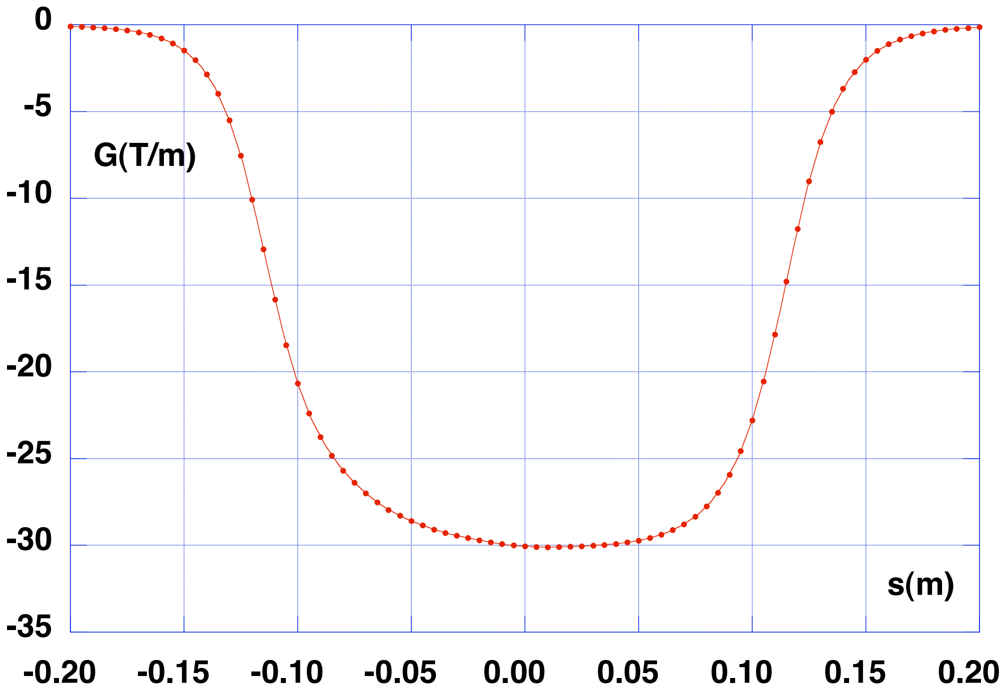

Figure 6 – Field gradient of quadrupole sn. 2.

4. Optical model of QD0

The procedure described in [4] has been applied to the field map measurements shown in the previous sections, to find a transfer matrix describing the off-axis passage of the beam in the first quadrupole after the IP. The design crossing angle between the two beams is 50 mrad and the measured distance of the quadrupole center from the IP is 414 mm. The field values in the map have been multiplied by 1.006 to compensate the difference between the integrated gradient measured with the rotating coil and that measured with the Hall probe. Tracking through the map the nominal beam trajectory and trajectories with slightly different initial conditions (1 mm, 1 mrad, and $\Delta p/p = 0.001$) yields the following matrix:

$$M^t = \begin{vmatrix} 2.85816 & 1.57268 & -0.02002 & 0.00050 & 0.00061 \\ 4.62482 & 2.89461 & -0.05333 & -0.00010 & -0.00007 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -0.41707 & 0.24222 \\ 0 & 0 & 0 & -3.37248 & -0.43710 \end{vmatrix}$$

the determinant of the horizontal part is 0.9999, the corresponding one for the vertical 1.0026 (let me remind that the vertical field component which determines the motion in the horizontal plane is obtained from the measured field, while the horizontal field component, which drives the vertical motion, has not been measured, and is obtained from the derivative of the vertical one). The length of the nominal trajectory starting at the IP and ending at 828 mm from it along the longitudinal symmetry axis of the interaction region is 0.8291 m, the horizontal distance from this axis is 39.25 mm and the final angle 72.17 mrad. Taking into account the initial angle of 25 mrad, the beam is bent by 47.17 mrad in the quadrupole. The matrix is fitted with a first straight section, a sector magnet with gradient and a second straight section; the approximation (n-1)≈n [4] has not been applied, so that the difference between horizontal and vertical focusing is here taken into account. The parameters of these magnetic elements are:

$$L_1 = 0.29824 \text{ m}$$

$$L_2 = 0.29010 \text{ m}$$

$$L_{dip} = 0.23991 \text{ m}$$

$$\rho_{dip} = 5.08550 \text{ m}$$

$$\alpha_{dip} = 0.04717 \text{ rad}$$

$$K_{dip} = -16.5677 \text{ m}^{-2}$$

And the optical matrix is:

$$M^o = \begin{vmatrix} 2.85629 & 1.57104 & -0.02208 & 0 & 0 \\ 4.62485 & 2.89391 & -0.05502 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -0.41846 & 0.24119 \\ 0 & 0 & 0 & -3.37250 & -0.44589 \end{vmatrix}$$

The differences between the matrix elements are quite small:

$$M^o - M^t = \begin{vmatrix} -0.00187 & -0.00164 & -0.00206 & -0.00050 & -0.00061 \\ 0.00003 & -0.00070 & -0.00169 & 0.00010 & 0.00007 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0.00139 & -0.00103 \\ 0 & 0 & 0 & -0.0002 & -0.00054 \end{vmatrix}$$

The total length of the optical matrix elements is 0.8282 m, 0.85 mm shorter than the tracked trajectory, the position along the longitudinal axis of the final point is 0.8271 m, 0.90 mm less than the tracked position and the transverse coordinate is 40.0 mm, 0.75 mm above the tracked one.

REFERENCES

[1] B. Bolli, F. Iungo, M. Modena, M. Preger, C. Sanelli, M. Sardone, F. Sgamma, M. Troiani: "Magnetic Measurements on the First Permanent Magnet Quadrupoles (Q1) of the KLOE Interaction Region", MM-3, 8/11/1994.

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[4] M. Preger: "An Optical Model for Off-Axis Quadrupoles", L-37, 11/10/2006.