MAGNETIC MEASUREMENTS OF THE DIPOLE, QUADRUPOLE AND SEXTUPOLE PROTOTYPES FOR THE ACCUMULATOR OF DAΦNE, THE FRASCATI Φ−FACTORY

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Abstract

DAΦNE is a Φ-Factory, presently under construction at INFN-LNF in Frascati. Injection is performed through a Linac and an intermediate damping Accumulator. The Dipole, Quadrupole and Sextupole magnets of the Accumulator have been designed at LNF. Prototypes of each kind of magnet have been built by TESLA Engineering (UK) and magnetically characterized at LNF before series production. Construction of 8 dipoles, 12 quadrupoles and 8 sextupoles has been completed and each magnet measured at LNF before complete machine assembling. The results of point by point (Hall probe system) and integrated measurements (rotating coil system) are presented.

1 INTRODUCTION

DAΦNE [1] is a Φ-factory, expected to be completely assembled in the Frascati National Laboratory (LNF) at the end of 1996. Its injector consists of a 800 MeV electron (550 MeV positron) Linac and a 32 m long damping/storage ring (Accumulator) [2].

The contract for the construction of the Accumulator Ring has been awarded to Oxford Instruments (UK) [3] in July 1993, on the basis of an international tender. TESLA Eng. has been appointed by Oxford as a subcontractor for the construction of the magnets. All the Accumulator magnets have been completely designed by LNF in order to set a sound Specification for the tender. However, the seller was responsible for the magnet performances, and therefore free to make changes to the basic design (with LNF approval). Only minor changes have been proposed by the manufacturer.

Series production of the magnets has been completed, and systematic magnetic measurements to characterize mechanical and magnetic properties of each magnet have been performed. Here we present the results obtained on the dipole, quadrupole and sextupole prototypes.

2 DIPOLE

The Accumulator dipole is an "H" type solid steel magnet with a bending radius of 1.1 m, a nominal field of 1.55 T and 0.5 field index. Its magnetic parameters are listed in Table 1.

Preliminary tests performed on the prototype showed good agreement between measured and calculated parameters. As an example, the current required to reach the nominal field was only 1.7% larger than expected. However, the harmonic analysis of the field at the magnet center showed a dominant octupole component, which is hard to correct and harmful to the beam dynamics. For this reason, the final choice for the pole profile was a simple, flat one; in this way a better field quality with a sextupole-like major high order contribution was obtained. Figure 1 is a sketch, on a vertically enlarged scale, of the shapes of the first and second pole profiles.

Table 1 - Magnetic parameters of the dipole

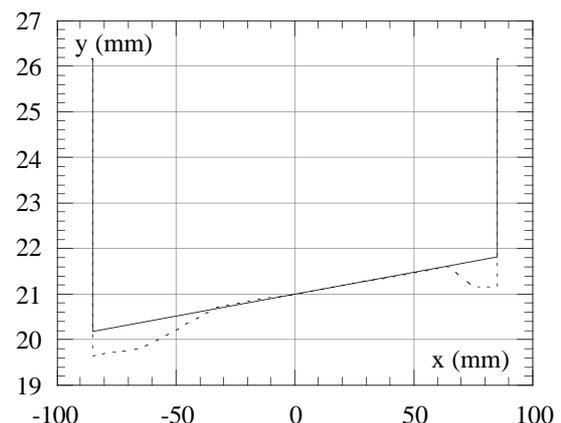| Quantity	
Quantity	8
Nominal Magnetic Field (T)	1.545
Maximum Magnetic Field (T)	1.66
Gradient (T/m)	0.657
Bending Radius (m)	1.1
Deflection Angle (deg)	45
Magnetic Arc Length (mm)	864
Magnet Gap at center (mm)	42
Good Field Region (mm)	±30
$|\Delta B/B|$ at magnet center (%)	0 ÷ -0.08
Nominal Current (A)	590
Maximum Current (A)	700

Figure 1 - Shimmed (dotted) and flat (full) pole profiles.

Figures 2 and 3 show the two measured fractional deviations from the ideal linear field. Note that the two plots have different vertical scales and that the solid vertical lines represent the limits of the good field region. Both the measured and calculated (by means of 2-D FEM) deviations are referred to an ideal linear field with the slope of the measured field at the magnet center.
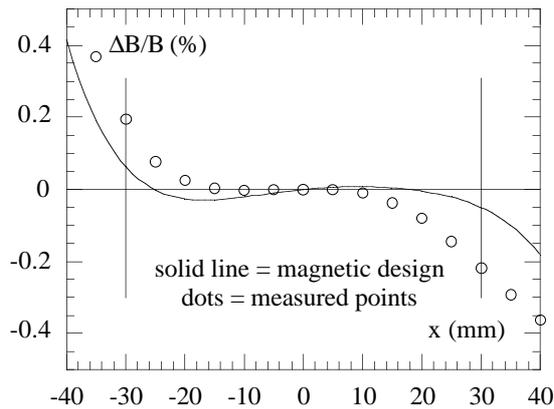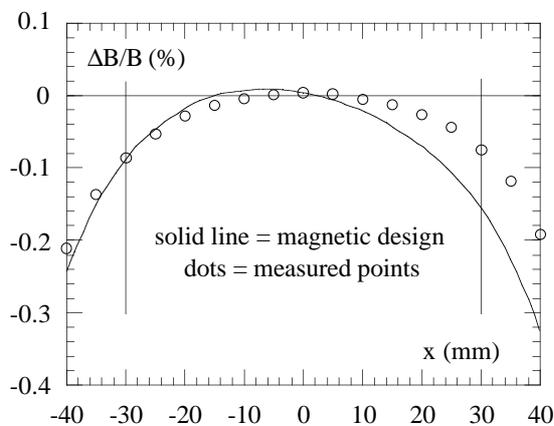
Figure 2 - Field quality with shimmed pole profile.

Figure 3 - Field quality with flat pole profile.

For such a short magnet, the contribution of nonlinear terms, mainly sextupoles, in the fringing field region is rather large, and needs to be locally corrected to keep the overall chromaticity of the machine within tolerable limits. We have therefore applied shims on the end caps, measuring the contribution of non linear terms with different geometries. Figure 4 shows the behaviour of the sextupole term along the magnet axis without shims and with two shim thicknesses.
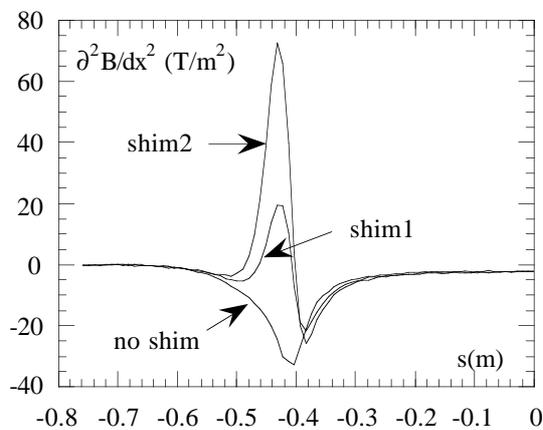

Figure 4 - Sextupole term along half magnet.

The configuration indicated as "shim1" was chosen for series production, as the result of a compromise between chromaticity correction and minimization of the 10-pole component introduced by the shims, given in Fig. 5.
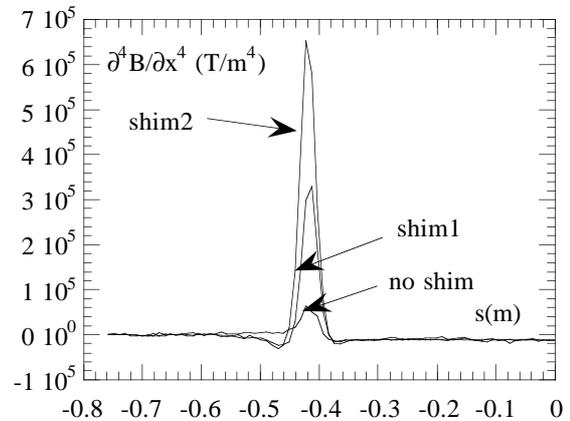

Figure 5 - Decapole term along half magnet.

3 QUADRUPOLE

The DAΦNE Accumulator Quadrupole prototype was delivered and fully tested at LNF during summer 1994. Its magnetic parameters are given in Table 2. Its pole shape is hyperbolic at the pole center with a straight line on each side.

Table 2 - Magnetic parameters of quadrupole prototype

Quantity	
Quantity	12
Nominal Gradient (T/m)	8
Maximum Gradient (T/m)	12
Magnet Bore Diameter (cm)	10
Good Field Region (mm)	±30
Integrated field quality $|\Delta B/B|$ (%)	±0.01
Magnetic Length (mm)	295.9
Nominal Current (A)	262
Maximum Current (A)	400

Also for this magnet the measurements were in good agreement with the expected values. The nominal gradient was achieved at 262 A (261 A computed by 3-D FEM). The overall high order contribution to the field, before any chamfer, defined as $\Delta B/B$ on a circle of 30 mm radius, is shown in Fig. 6. The measurement was performed by means of a rotating coil technique. The radial and azimuthal components of the error field are plotted together with their vector sum versus the azimuthal position, clearly showing a leading 12-pole term. Following a standard procedure, we have therefore chamfered the removable end caps, by applying a 45° cut of increasing depth.

Figure 7 shows the dependence of the main high order terms on the chamfer depth, demonstrating that the 12-pole contribution has been reduced by an order of magnitude, leaving the other terms almost constant.

Figure 8 shows, on an expanded scale, the final field quality: the overall high order contribution is $\approx 1 \times 10^{-4}$, well below the requirement of both the DAΦNE Accumulator and Main Rings.
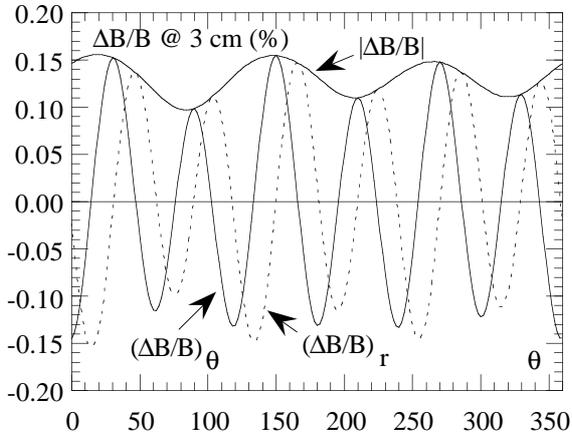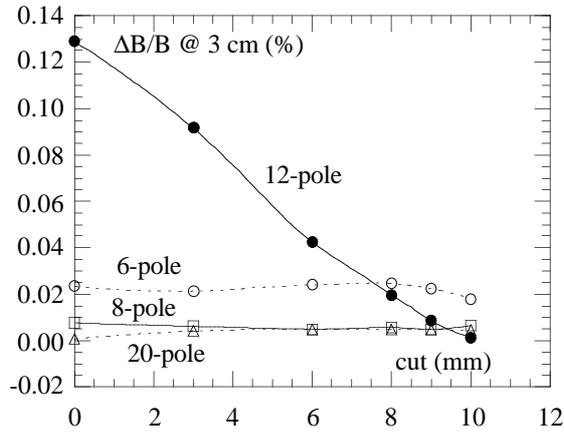

Figure 6 - Quadrupole field quality before chamfer.

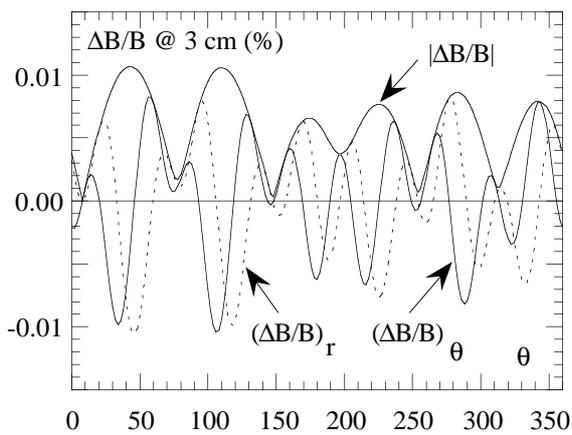Figure 7 - Multipole contributions versus chamfer.

Figure 8 - Quadrupole field quality after chamfer.

4 SEXTUPOLE

Also the DAΦNE Accumulator Sextupole magnet prototype was delivered and fully tested at LNF during summer 1994.

Its pole shape is cubic at the pole center with a straight line on each side. Its main parameters are given in Table 3.

Table 3 - Magnetic parameters of sextupole prototype

Quantity	8
Gradient ($\partial^2 B/\partial x^2$, T/m^2)	135
Maximum Gradient (T/m^2)	180
Magnet Bore Diameter (cm)	10.8
Good Field Region (mm)	±30
Integrated $|\Delta B/B|$ (%)	±0.11
Magnetic Length (mm)	104.8
Nominal Current (A)	212
Maximum Current (A)	275

The deviation from the integrated ideal sextupole field is shown in Fig. 9, its maximum value being less than $\pm 1.1 \times 10^{-3}$. Tracking simulations showed that this field quality is acceptable, in spite of the very short yoke (67 mm): the longitudinal field profile does not exhibit any "flat top", and the integrated field quality is mainly determined by the fringing field at the magnet ends.
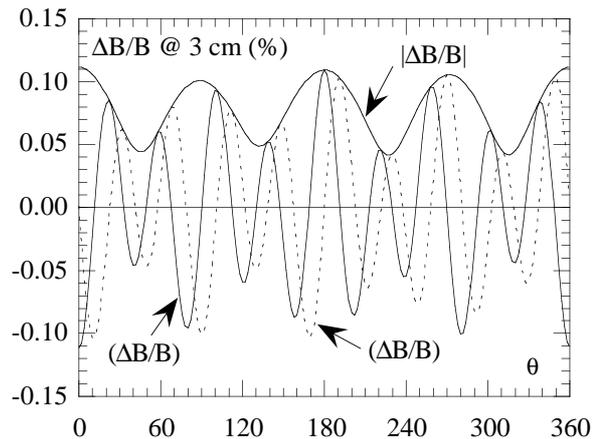

Figure 9 - Sextupole field quality.

5 CONCLUSION

Sixty quadrupoles (out of 96) and 14 sextupoles (out of 32) in the DAΦNE Main rings, where the field quality requirements are more severe than in the Accumulator, are of the same type of those described above. All these magnets have been built by TESLA and their field quality was found to be remarkably constant among the whole series production.

REFERENCES

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[2] R. Boni, S. Kulinski, M. Preger, B. Spataro, M. Vescovi and G. Vignola, "The Frascati Φ-Factory Injection System", 1991 Particle Accelerator Conf., S. Francisco, USA, p. 961.

[3] OXFORD Instruments, Accelerator Technology Group, Osney Mead, Oxford OX2 0DX, England.