DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

Frascati, August 21, 1995

Note: **MM-8**

FIELD QUALITY AND ALIGNMENT OF THE DAΦNE ACCUMULATOR QUADRUPOLES

B. Bolli, F. Iungo, F. Losciale, M. Paris, M. Preger,
C. Sanelli, F. Sardone, F. Sgamma, M. Troiani

1. Introduction

The prototype of the DAΦNE Accumulator quadrupole, built by TESLA Engineering, was delivered to LNF in June 1994. Electrical, mechanical, thermal and magnetic tests on the prototype are described in [1]. For sake of completeness, we recall here the specified pole profile, shown in Figure 1. The coordinates of the reference points are also given in Table I. A picture of the quadrupole, placed on the rotating coil system, is also shown in Figure 2.

The prototype has been chamfered to correct the systematic 12-pole component [1], and the other 11 quadrupoles have been realized accordingly. The magnets have been assembled by grouping quadrants of similar measured length, and delivered to LNF in April 95.

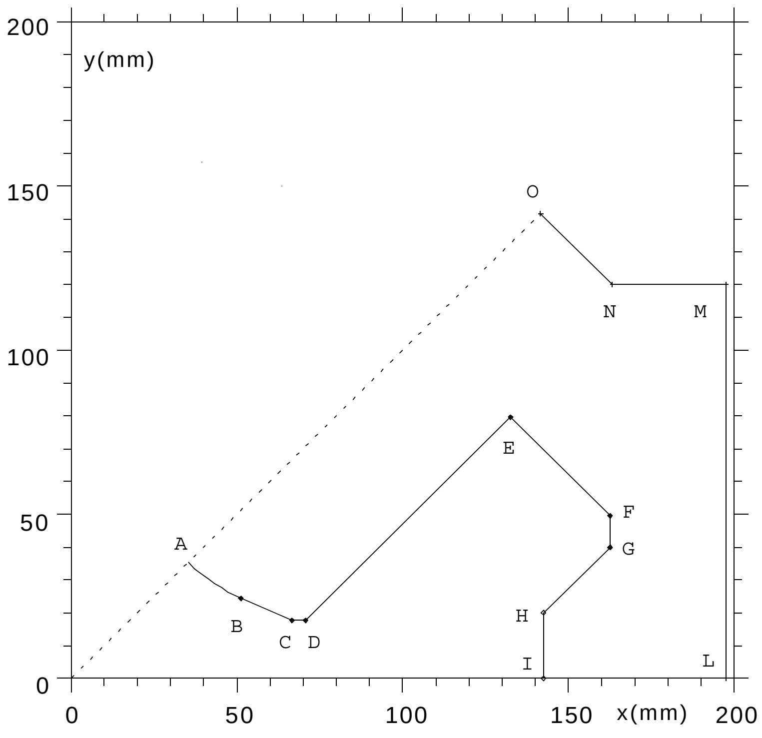

Figure 1 - Half-lamination profile - The pole profile is hyperbolic from point A to point B. All other segments are straight lines.

Table I - Pole Profile coordinates

Point	x(mm)	y(mm)
A	35.36	35.36
Hyperbolic from A to B x*y=1250		
B	51.20	24.40
C	66.68	17.68
D	70.68	17.68
E	132.50	79.50
F	162.50	49.50
G	162.50	40.00
H	142.50	20.00
I	142.50	0.00
L	197.50	0.00
M	197.50	120.00
N	163.20	120.00
O	141.60	141.60

2. Integrated gradient

The 12 quadrupoles of the Accumulator ring are divided into 3 families [2]; the 4 quads of each family are powered in series. It is therefore important that the integrated gradients of the quadrupoles pertaining to the same family are as similar as possible. The 4 quadrants of each quadrupole have been measured a first time at the factory before assembling and the length of each quadrant reported in a Quality Assurance sheet. We have therefore grouped the quadrants in order to minimise the difference within single quadrupoles and families, requiring TESLA to machine or scrape several quadrants to achieve the best result. Table II shows the final arrangement of the quadrants together with their length measured after assembling. From inspection of the last column, one can see that, if quads 1-2-3-4 are grouped in the first family, 5-6-7-8 in the second and 9-10-11-12 in the third, the spread in average mechanical length within quadrupoles in the same family is in the order of ±0.1 mm. The spread within the lengths of the quadrants in a single quadrupole is of the same order, but for quadrupole #11, where quadrant A313-04 is ≈ 0.6 mm shorter than the others. The reason is that the measurement made by TESLA for this quadrant changed by that amount after assembling although no modification had been required by LNF. The corresponding data sheet have been corrected without any notification to LNF. The same happened to quadrants A312/12 and A314-12, where the measurement changed by 0.2 mm. The consequence of this deviation in the mechanical length of one quadrant in quad #11 is a 0.1 mm displacement of the magnetic centre, as explained in $ 4.

Figure 3 shows the distribution of the integrated gradients measured with the Danfysik rotating coil system [3]. The correlation between the average mechanical length and integrated gradient follows the expectations rather well. Following the results of the measurement of integrated gradient of quadrupoles and sextupoles [4], we have arranged the magnets in the ring as shown in Fig. 9.

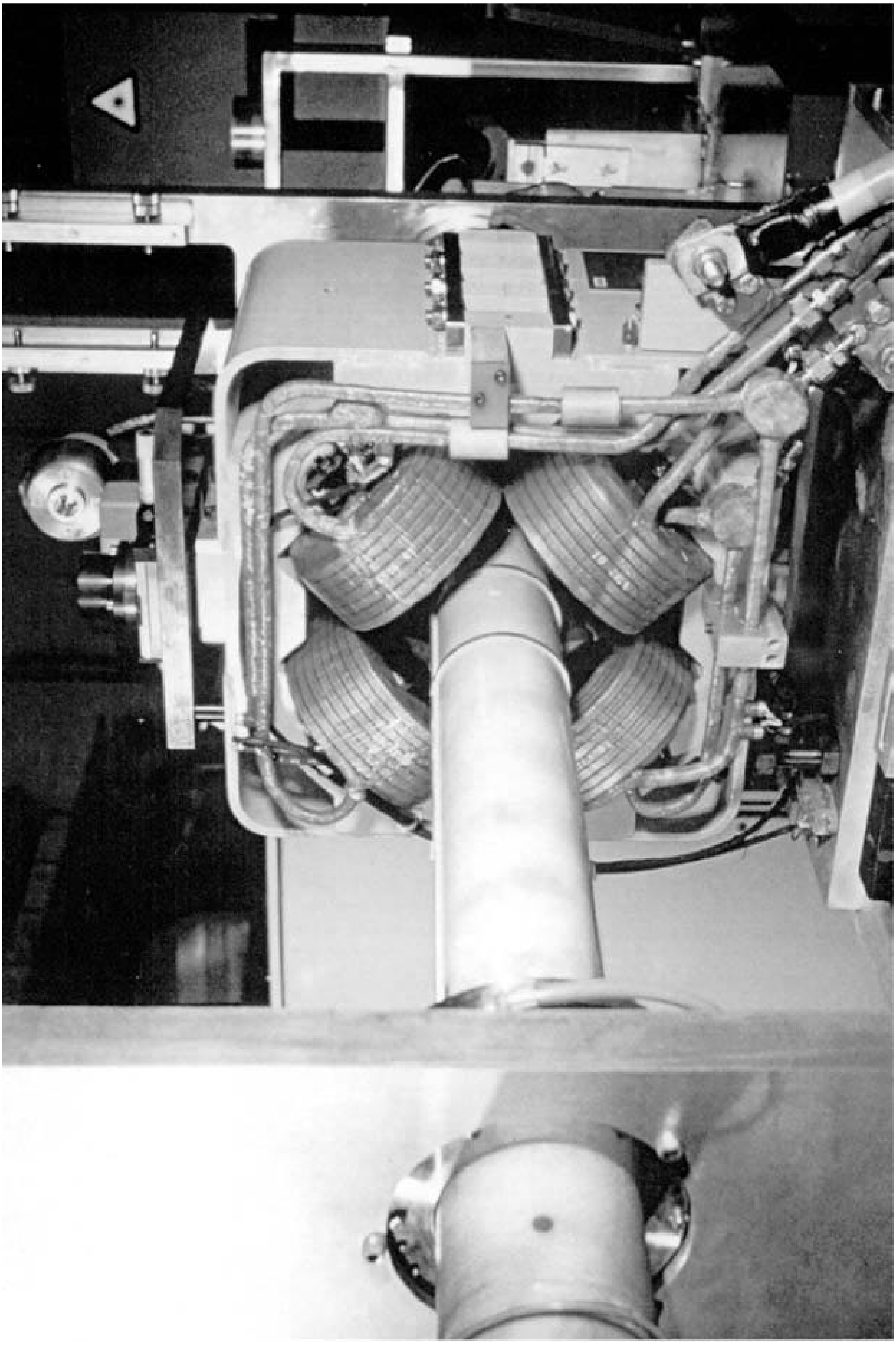

Figure 2 - The Accumulator quadrupole on the rotating coil system.

Table II - Mechanical length of quadrants

Serial number	First quadrant	Second quadrant	Third quadrant	Fourth quadrant	Average length
1	A311-01 253.10	A312-01 253.25	A313-01 253.25	A314-01 253.10	253.18 ±0.09
2	A311-11 253.00	A312-03 253.00	A313-02 252.98	A314-03 252.88	252.97 ±0.06
3	A311-06 253.10	A312.04 253.00	A313-08 253.15	A314-07 253.13	253.10 ±0.07
4	A311-04 253.06	A312-11 253.09	A313-11 253.09	A314-02 253.07	253.08 ±0.02
5	A311-07 253.23	A312-12 253.35	A313-12 253.35	A314-08 253.29	253.31 ±0.06
6	A311-12 253.31	A312-05 253.38	A313-10 253.38	A314-11 253.34	253.35 ±0.03
7	A311-03 253.35	A312-08 253.47	A313-03 253.45	A314-04 253.38	253.41 ±0.06
8	A311-02 253.40	A312-07 253.50	A313-09 253.49	A314-10 253.39	253.45 ±0.06
9	A311-10 253.55	A312-06 253.53	A313-06 253.53	A314-05 253.55	253.54 ±0.01
10	A311-08 253.48	A312-12 253.35	A313-07 253.56	A314-12 253.36	253.44 ±0.10
11	A311-05 253.60	A312-09 253.62	A313-04 253.00	A314-06 253.66	253.47 ±0.31
12	A311-09 253.75	A312-10 253.68	A313-05 253.66	A314-09 253.74	253.71 ±0.04

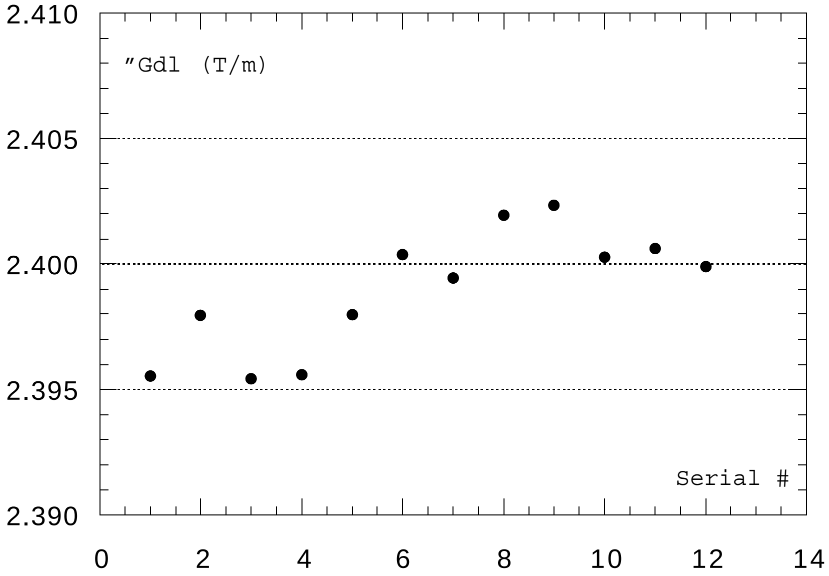

Figure 3 - Distribution of measured integrated gradients @ 262.3A

2. Field quality

The field quality of all the magnets has been measured with the rotating coil system.

Figure 4 shows the distribution of the fractional deviation from the ideal field averaged over a circle of 30 mm diameter from the axis, together with the sextupole contribution extracted from the harmonic analysis. It is clear that in all the quads this is the main contribution to the measured deviation. However, the nominal sensitivity of the rotating coil system, when operated in the 'compensated' mode, is $3x10^{-4}$ for the first term above the fundamental, and improves rapidly for the higher order ones (the signal is proportional to the periodicity of the field over 2π, while the background coming from the noise in the electronics is constant).

We can conclude that the large fluctuations in both the sextupole component and the overall field error between different quadrupoles comes from the measuring system, and can be neglected, because the integrated sextupole, in the worst case, is only 0.4% of that coming from each lumped sextupole used for chromaticity control in the lattice and can therefore be easily corrected.

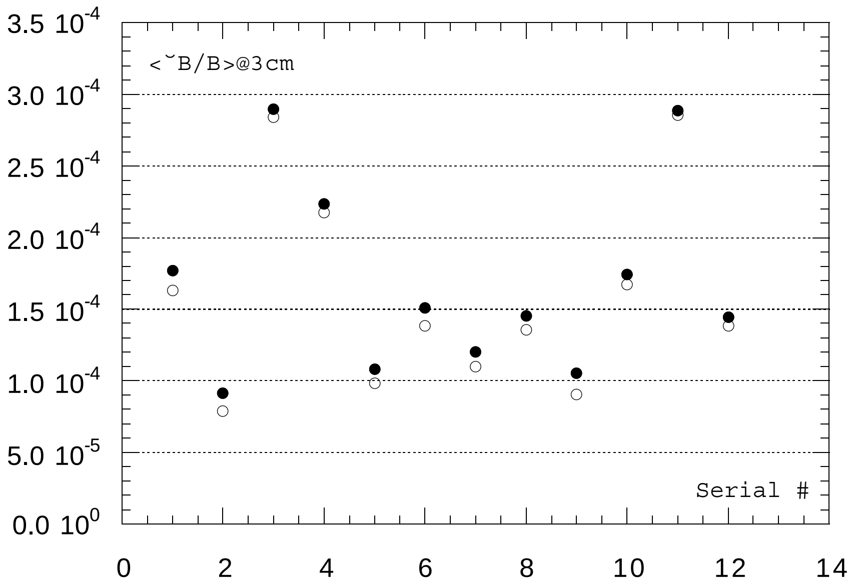

Figure 4 - Average fractional field deviation at 30 mm from quadrupole axis (full dots) and sextupole contribution (empty dots).

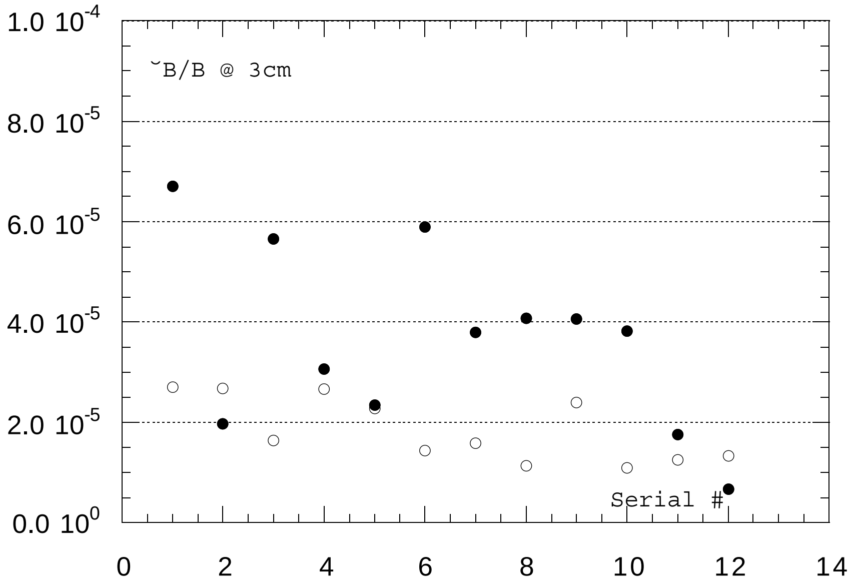

Figure 5 - Octupole (full dots) and 10-pole (empty dots) components of field deviation at 30 mm from quadrupole axis.

Figure 5 shows the measured data from the rotating coil system for the octupole and decapole components of the field scaled at a distance of 30 mm from the quadrupole axis (the border of the specified good field region). Due to the very low value of the contributions (less than 0.01%), the results seems to be dominated by the sensitivity of the measuring system. In fact there is a rather large fluctuation in the octupole term, while for the decapole the measured values for the different quadrupoles are more concentrated around $\approx 2x10^{-5}$.

Figure 6 gives finally the results for the systematic 12-pole and 20-pole components.

The 12-pole contribution is the result of the chamfering procedure performed on the prototype [1]. The small fluctuation (≈±1.5x10^{-5}) between the different quads can be explained by the tolerance on the 45° cut on the end caps of the poles.

The 20-pole is instead almost the same for all quadrupoles (≈ 4.5x10^{-5}).

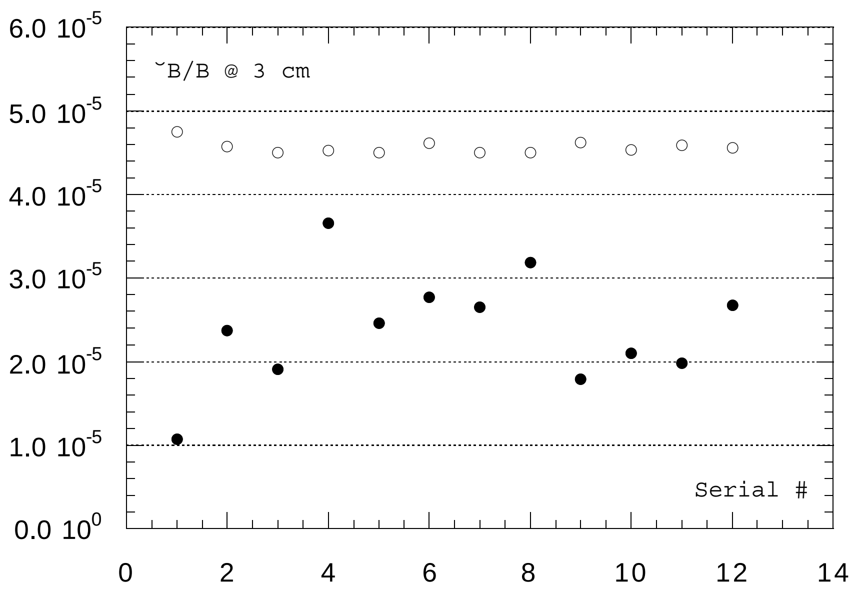

Figure 6 - 12-pole (full dots) and 20-pole (empty dots) components of field deviation at 30 mm from quadrupole axis.

2. Alignment

In order to find the position of the magnetic centre of the quadrupoles, we have followed the same procedure as for the sextupoles, described in detail in [4]. However, the holes in the magnets machined on the iron plates welded on the laminations were found to be not precise and deep enough to support the locating pins of the alignment tables reliably. We have therefore built 3 stainless steel 10 mm thick plates for each magnet with a precision machined hole (tolerance of -0, +10μ on the nominal 20 mm diameter). The plates have been welded on each hole with the locating pin in place, increasing the total hole depth from 8 to 18 mm. After this operation the overall stability of the system was satisfactory.

We have measured the first three quadrupoles with three alignment tables (called Q1, Q2 and Q3). The result of the measurements (the meaning of the symbols is clearly explained in [4]) is given in Tables III through V. While in the case of the sextupole this measurement (performed only on the first sextupole) gave a satisfactory result (the overall spreads ΔX and ΔY between the three tables of the shift between magnetic and mechanical axis were <±15μ), for the quadrupoles these spreads among all the three measurements are of the order of ±50μ. This value can be taken as the overall uncertainty on the distance between mechanical and magnetic axis and is consistent with the uncertainties of the mechanical prealignment and of the rotating coil system. However, since the mechanical axis position is used only to initialize the rotating coil system, the error on the magnetic axis position, used to align the magnets on the ring, should be lower, its best estimate being the specified accuracy of the rotating coil system only (±30μ).

Table III - Alignment parameters of Quadrupole #1 with the three tables

	Q1	Q2	Q3
XAmec	12.290	12.410	12.800
XBmec	12.580	12.020	11.890
YAmec (mm)	350.460	350.470	350.350
YBmec (mm)	350.420	350.440	350.360
ΔX (mm)	-0.140	-0.080	-0.060
ΔY (mm)	-0.177	-0.245	-0.151
Φ (mrad)	1.140	0.790	0.520
XAmag	12.430	12.490	12.860
XBmag	12.440	11.940	11.830
YAmag (mm)	350.285	350.225	350.200
YBmag (mm)	350.245	350.195	350.210

Table IV - Alignment parameters of Quadrupole #2 with the three tables

	Q1	Q2	Q3
XAmec	12.200	12.320	12.710
XBmec	12.610	12.050	11.920
YAmec (mm)	350.480	350.490	350.370
YBmec (mm)	350.480	350.490	350.410
ΔX (mm)	-0.120	-0.070	-0.050
ΔY (mm)	-0.210	-0.187	-0.235
Φ (mrad)	0.810	0.790	0.990
XAmag	12.320	12.390	12.760
XBmag	12.490	11.980	11.870
YAmag (mm)	350.270	350.305	350.135
YBmag (mm)	350.270	350.305	350.175

Table V - Alignment parameters of Quadrupole #3 with the three tables

	Q1	Q2	Q3
XAmec	11.970	12.090	12.480
XBmec	12.820	12.260	12.130
YAmec (mm)	350.540	350.550	350.430
YBmec (mm)	350.570	350.580	350.500
ΔX (mm)	-0.085	-0.110	-0.080
ΔY (mm)	-0.255	-0.252	-0.254
Φ (mrad)	0.960	0.760	1.170
XAmag	12.055	12.200	12.560
XBmag	12.735	12.150	12.050
YAmag (mm)	350.285	350.300	350.175
YBmag (mm)	350.315	350.330	350.245

All quadrupoles have been measured with the alignment table Q1. The result is shown in Tables VI and VII. The last four rows in each Table contain the alignment information transmitted to Oxford Instruments for the alignment of the magnets on their girders.

Figure 7 shows the distribution of the angle between the magnetic horizontal plane and the mechanical one measured by the rotating coil system: there is a systematic rotation of the order of 1 mrad, which will not be corrected, because it does not affect the performance of the Accumulator.

Figure 8 shows the displacement of the magnetic centre with respect to the mechanical one for all the quadrupoles. The error bars are obtained by summing up the accuracy of the rotating coil system (±30µ both in horizontal and vertical) and that of the mechanical prealignment system (±40µ in horizontal and ±20µ in vertical). From this figure one can notice that all quadrupoles but the serial #11 are clustered within the measurement accuracy around a systematic displacement of ≈-0.1 mm in the horizontal plane and ≈-0.2 mm in the vertical. We cannot establish if this displacement comes from a systematic error in our measurement system (mechanical and magnetic) or from a systematic deviation in the construction of the magnets. Quadrupole #11 is shifted from the others by ≈-0.1 mm in the horizontal plane and by ≈+0.1 mm in the vertical, thus demonstrating the effect of the shorter quadrant mentioned in $ 2.

Table VI - Alignment parameters of quadrupoles #1 through #6 with table Q1

Serial	#1	#2	#3	#4	#5	#6
XAmec	12.290	12.200	11.970	11.960	12.150	12.260
XBmec	12.580	12.610	12.820	12.720	12.740	12.630
YAmec (mm)	350.460	350.480	350.540	350.510	350.440	350.570
YBmec (mm)	350.420	350.480	350.570	350.490	350.480	350.590
ΔX (mm)	-0.140	-0.120	-0.085	-0.110	-0.130	-0.140
ΔY (mm)	-0.177	-0.210	-0.255	-0.262	-0.244	-0.259
Φ (mrad)	1.140	0.810	1.160	1.630	1.550	0.700
XAmag	12.430	12.320	12.055	12.070	12.280	12.400
XBmag	12.440	12.490	12.735	12.610	12.610	12.490
YAmag (mm)	350.285	350.270	350.285	350.250	350.195	350.310
YBmag (mm)	350.245	350.270	350.315	350.230	350.235	350.330

Table VII - Alignment parameters of quadrupoles #7 through #12 with table Q1

Serial	#7	#8	#9	#10	#11	#12
XAmec	12.170	12.310	12.150	12.130	12.270	12.130
XBmec	12.660	12.570	12.730	12.700	12.690	12.720
YAmec (mm)	350.520	350.460	350.500	350.470	350.400	350.500
YBmec (mm)	350.550	350.560	350.460	350.490	350.350	350.520
ΔX (mm)	-0.100	-0.110	-0.080	-0.120	-0.220	-0.110
ΔY (mm)	-0.248	-0.216	-0.194	-0.253	-0.112	-0.257
Φ (mrad)	1.360	1.310	0.970	1.140	1.280	1.460
XAmag	12.270	12.420	12.230	12.250	12.490	12.240
XBmag	12.560	12.460	12.650	12.580	12.470	12.610
YAmag (mm)	350.270	350.245	350.305	350.215	350.290	350.245
YBmag (mm)	350.300	350.345	350.265	350.235	350.240	350.265

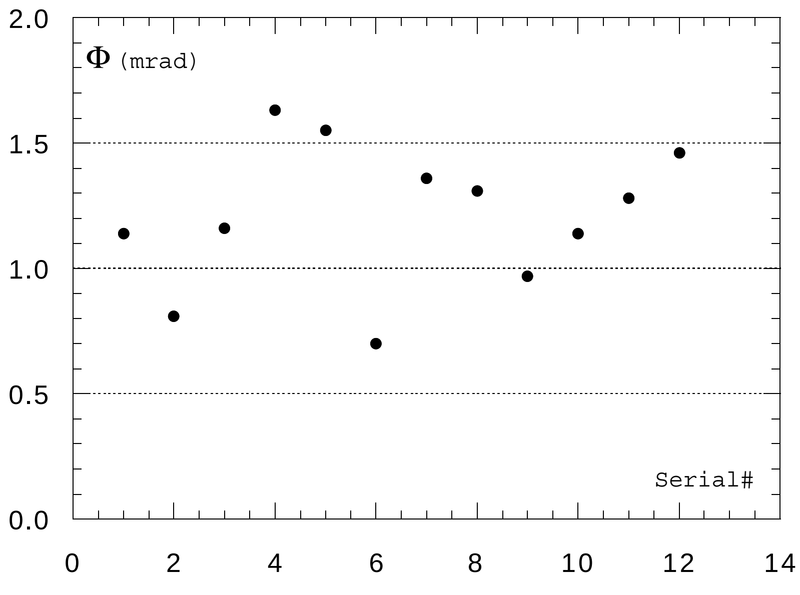

Figure 7 - Distribution of the tilt between the magnetic horizontal plane and the mechanical one.

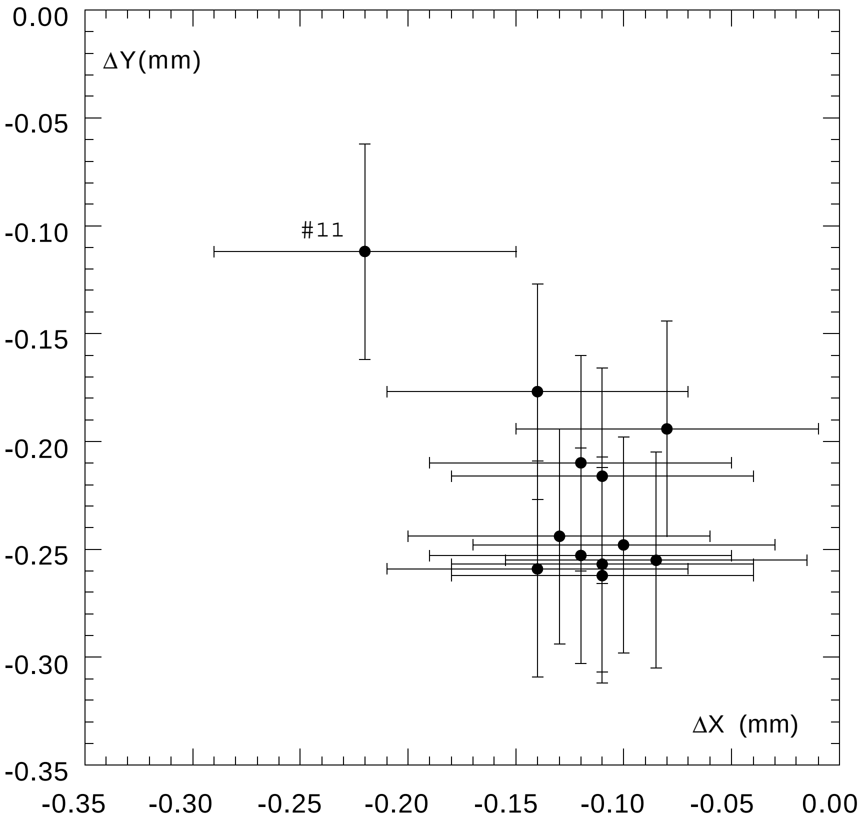

Figure 8 - Distance between magnetic and mechanical centres.

REFERENCES

[1] B. Bolli, F. Iungo, M.Modena, M. Preger, C. Sanelli, F. Sgamma, M. Troiani, S. Vescovi - "Measurements on Tesla quadrupole prototype for the DAΦNE Accumulator and Main Rings" - DAΦNE Technical Note MM-4 (2/12/1994)

[2] M. Masullo, C. Milardi, M. Preger - "DAΦNE Accumulator update-3" - DAΦNE Technical Note I-9 (13/5/1992)

[3] F. Iungo, M. Modena, Q. Qiao, C. Sanelli - "DAΦNE magnetic measurement systems" - DAΦNE Technical Note MM-1 (4/11/1993)

[4] B. Bolli, F. Iungo, M. Modena, M. Preger, C. Sanelli, F. Sgamma, M. Troiani - "The DAΦNE Accumulator sextupoles" - DAΦNE Technical Note MM-6 (10/5/1995)

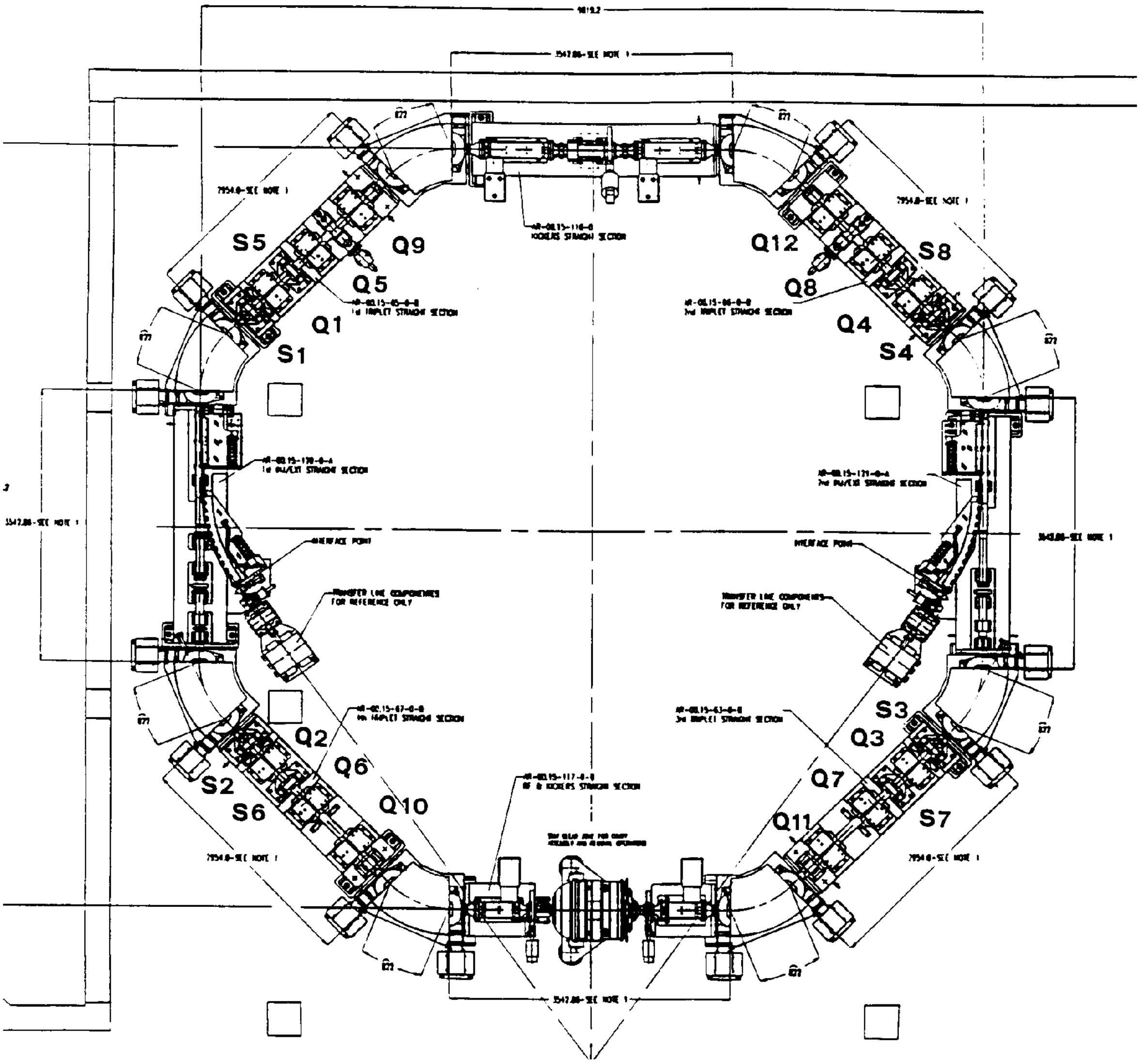

Figure 9 - Position of multipoles in the Accumulator Ring. Quadrupoles are indicated by a "Q" followed by the serial number, sextupoles by an "S" followed by the serial number.