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COMPARISON OF MAGNETIC AND MECHANICAL CENTER POSITIONS OF SMALL QUADRUPOLES AND SEXTUPOLES IN THE DAΦNE MAIN RINGS

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1. Introduction

The magnetic measurements on the 60 "small" quadrupoles and 14 "small" sextupoles of the DAΦNE Main Rings are described in [1,2]. These measurements included also the position of the magnetic center of each magnet, while the determination of the mechanical center positions has been performed later, directly in the Main Rings Hall. We present here the methods and results of both kinds of measurements and the comparison between them.

2. Magnetic center position

The position of the magnetic center of each quadrupole is the result of the alignment procedure performed with the rotating coil system of the magnetic measurement laboratory [3].

An alignment table is precisely positioned on top of each magnet by means of three removable supporting cylinders leaning directly on the upper lamination stacks of the quadrupoles and on a machined reference surface of the sextupoles. The table is equipped with two micrometric slits, each holding a Taylor-Hobson sphere (A and B). The sphere centers are the reference of the magnet with respect to the laser beam of the rotating coil system, placed parallel to the rotating coil axis in a vertical plane at a distance of 350 mm from it. The accuracy of the system is discussed in [4].

The magnet is placed on the movable support of the rotating coil system, and the plane of the alignment table is accurately set horizontally by means of a levelling system. In this way we make sure that the mechanical azimuthal tilt (defined as the rotation around the longitudinal symmetry axis of the magnet) and the mechanical vertical tilt (defined as the rotation around an axis perpendicular to the longitudinal one and lying in the horizontal symmetry plane of the magnet) are negligible. However, there is no way of making the mechanical horizontal tilt (defined as the rotation around an axis perpendicular to the longitudinal one and lying in the vertical symmetry plane of the magnet) negligible as well, and therefore the magnet is placed on the support by placing the poles as parallel as possible to the rotation coil.

We recall that the rotating coil system cannot give any indication on the magnetic horizontal and vertical tilts, because it measures only the position of the average magnetic center. This information can only come from the mechanical measurements, as explained in the following. On the contrary, it is capable of measuring the azimuthal rotation Φ of the magnetic horizontal symmetry axis with respect to the mechanical position set by the levelling procedure of the alignment table. A positive Φ value means that the magnet, seen from the electrical and cooling connections side, must be rotated counterclockwise by the angle Φ to have the magnetic symmetry plane coincident with the ideal horizontal plane of the ring. Of course, the plane of the alignment table will then be tilted by the corresponding amount

After the initial positioning of the magnet on the rotating coil system support, the system indicates the horizontal and vertical displacements to be applied in order to bring the magnetic center of the magnet on the axis of the rotating coil. After a few iterations it is possible to reach a situation where these displacement are of the order of few microns. At this point the sphere centers are horizontally set on the laser beam by means of the micrometric movements and their readings (XAmag and XBmag) recorded. The laser system indicates the vertical displacement of the laser beam with respect to the center of each sphere, and these values are subtracted from 350 mm to give the vertical distances (YAmag and YBmag) between the center of the spheres and the magnetic axis. It is important to remark that the system also rotates the magnet by the angle Φ azimuthally to correct the magnet rotation before performing the field quality analysis. The vertical positions of the sphere centers are practically not affected by this rotation, while their horizontal positions change by 350 mm times the rotation angle. The final horizontal readings are therefore taken including the azimuthal correction.

These four positions have been measured on the 60 small quadrupoles of the DAΦNE Main Rings using the alignment table Q3. The results of the measurements are given in Table I. The 14 sextupoles have been measured with the alignment table S1 and the results are shown in Table II.

3. Mechanical center position

The position of the mechanical axis of the magnets has been measured in the DAΦNE Main Rings Hall by means of a computer controlled equipment using two theodolites.

The mechanical axis of the magnet is simulated with an half-cylinder, leaning on the surfaces of the lower poles of magnets with two precision cylindrical ribs and having three optical targets, as shown in Figure 1. The two targets 1 and 2 are exactly on the axis of the cylinder defined by the two ribs.

The table is accurately levelled, acting on the adjustable supports of the magnets, to get a vanishing azimuthal angle; then the half-cylinder is rotated until the line parallel to the direction 2-->3 is horizontal: in this way it is also parallel to the table.

The slits are positioned in an arbitrary but fixed position, so that the sphere centers are very near to the vertical plane passing through the cylinder axis. Then the positions of the five points (1, 2, 3 and sphere centers in A and B), referred to the reference system of the measuring equipment, are measured and recorded. These measures are later computed to obtain the positions of sphere centers A and B in the reference system defined in the figure.

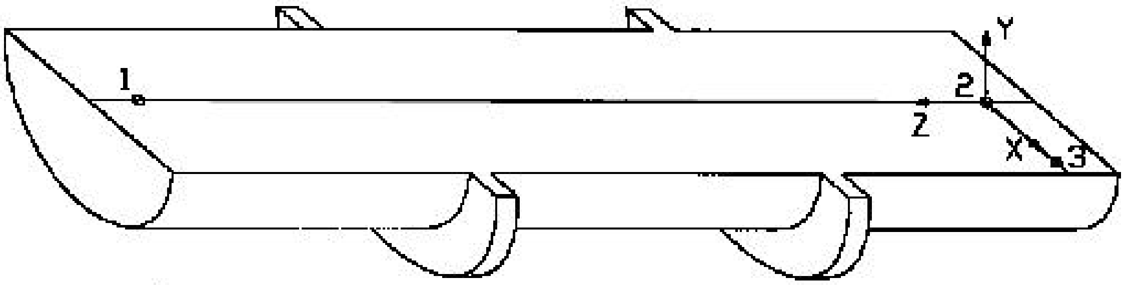

Figure 1 - Half-cylinder simulating the mechanical axis of the magnet

The readings of slits A and B, corresponding to a situation where the two sphere centers are on the vertical plane passing through the cylinder axis, are then computed and recorded as XAmec and XBmec. The distances of the sphere centers from the XY plane are recorded as YAmec and YBmec.

Each quadrupole and sextupole has been measured with three alignment tables, Q1, Q2 and Q3 for the quadrupoles, S1, S2 and S3 for the sextupoles. Table III reports the results for the quadrupoles with Q1, Table IV the sextupoles with S1, Table V the quadrupoles with Q2, Table VI the sextupoles with S2, Table VII the quadrupoles with Q3 and Table VIII the sextupoles with S3. Tables IV and VII are used for the comparison with the magnetic measurements described in the following section.

The accuracy of the measurements (maximum errors) is ±0.10 mm in the horizontal plane, ±0.05 mm in the vertical one.

4. Comparison between mechanical and magnetic center position

The magnetic measurements have been performed only with the alignment tables Q3 and S1. The results obtained for the other tables used for the mechanical measurements are useful anyway, since the tables have been calibrated against each other.

As mentioned in Section 1, the rotating coil system gives only the average position of the magnetic center along the longitudinal axis of the magnet, while the horizontal and vertical tilts are derived from the mechanical measurements.

Comparing the results in Tables I and VII for the quadrupoles, II and IV for the sextupoles, it is possible to find the average displacement of the magnetic axis from the mechanical one. Taking into account that the readings of the movable slits increase in opposite directions for the two slits, we can define two variables ΔXA and ΔXB representing the horizontal distance between the magnetic and mechanical readings of the two slits for each magnet:

$$\Delta XA = XAmag - XAmec$$

$$\Delta XB = XBmec - XBmag$$

and the distance between the magnetic and mechanical axes is the average of ΔXA and ΔXB:

$$ShiftX = \frac{\Delta XA + \Delta XB}{2}$$

Let us discuss the meaning of the sign of the variables defined above. The small quadrupoles (and sextupoles) are positioned on the movable support of the measuring system in such a way that the electrical and cooling connections are on the encoder side of the rotating coil. The A slit is on the encoder side as well and its reading increases when the Taylor-Hobson sphere moves from left to right. The B slit, as mentioned before, increases its reading when the corresponding sphere moves from right to left. Let us assume that the magnet is initially positioned with its mechanical center exactly aligned on the axis of the rotating coil, and that its magnetic center is on the right. In order to bring the magnetic center on the coil axis, the system displaces the magnet towards the left; now, our procedure is such that the slit reading is taken with the sphere centers on the laser, which is in the same horizontal position as the coil axis, and to obtain this alignment the A sphere must be moved to the right, thus increasing its reading with respect to the initial value. With our definition, therefore, a positive value for ΔXA and ShiftX indicates that the magnetic center of the magnet is on the right with respect to the mechanical one, when the magnet is observed from the electrical and cooling connection side.

From ΔXA and ΔXB it is also possible to find the horizontal projection of the angle between the mechanical axis measured with the alignment optical system and the axis of the magnet positioned on the rotating coil system. We recall that the alignment of the magnet in the horizontal plane on the magnetic measurement system is rather rough, and therefore this angle can reach large and random values. This horizontal tilt is obtained as the difference between ΔXA and ΔXB divided by the longitudinal distance L between the centers of the spheres (170 mm for the quadrupoles, 100 mm for the sextupoles).

$$\mathrm{TiltX} = \frac{\Delta XA - \Delta XB}{L}$$

The corresponding quantities for the vertical plane are defined in the same way, with the warning that the differences between the vertical positions of the two slits are taken in the same direction:

$$\Delta YA = YAmag - YAmec$$

$$\Delta YB = YBmag - YBmec$$

In addition, the distribution for TiltY is now much narrower than in the horizontal case, due to the preliminary levelling of the alignment table in the horizontal plane during the magnetic measurements.

Table IX gives the values of ShiftX, ShiftY, TiltX and TiltY for the quadrupoles. The last column (ShiftXC) takes into account the effect of the azimuthal rotation performed by the rotating coil system to bring the magnetic horizontal plane of the magnet on the horizontal plane of the machine. This rotation, which is not applied during the mechanical measurement procedure, displaces the horizontal position of the sphere centers by the vertical distance between the sphere centers and the magnetic axis of the magnet times the rotation angle. The values of ShiftXC are therefore corrected by this amount to be better compared with the mechanical results. Table X shows the same quantities for the sextupoles.

We need to discuss again on the sign of the correction, as we did before for the displacement between the mechanical and magnetic centers. When the angle Φ in Tables I and II is positive, the system rotates the magnet in the counterclockwise direction, always looking from the electrical and cooling connection side, before performing the field quality measurement. When Φ is positive, therefore, the A sphere moves towards the left, and the slit must bring it again to the right in order to reach the position of the laser. In this case the reading of slit A is further increased and the corresponding value must be subtracted from ShiftX in order to have a correct comparison between the mechanical and magnetic center positions.

Figure 2 shows in an XY plane the uncorrected distance between the magnetic and mechanical axes of the quadrupoles. It can be noticed that there is systematic displacement in both planes: in the horizontal one the average shift and its standard deviation are +0.32 mm and 0.15 mm respectively. These values are smaller in the vertical plane (-0.12 mm and 0.05 mm respectively). Figure 3 shows the same data corrected by the azimuthal rotation of the magnets: the distribution in the horizontal plane is now well centered around zero (its average is 0.05 mm) and also its width is slightly smaller (0.12 mm): the difference has been initially (see Section 5) explained by a systematic rotation of the magnetic symmetry plane with respect to the mechanical one (0.76 mrad on the average with 0.35 mrad r.m.s. width).

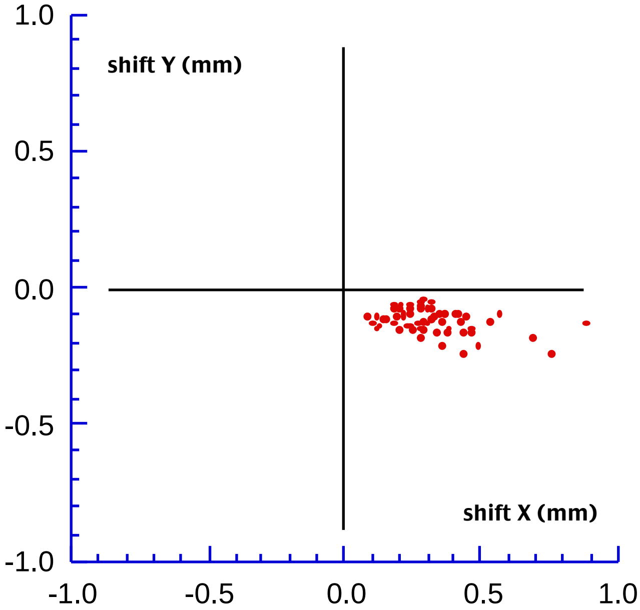

Figure 2 - Distance between magnetic and mechanical axes for the quadrupoles (not corrected for the azimuthal rotation)

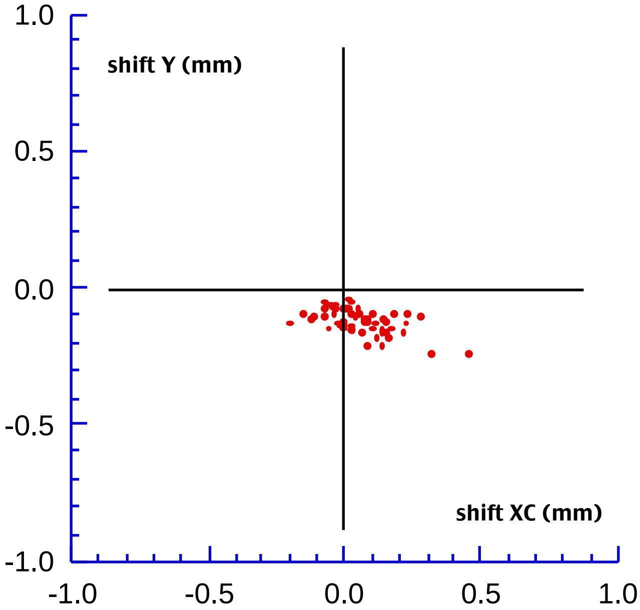

Figure 3 - Distance between magnetic and mechanical axes for the quadrupoles corrected for the azimuthal rotation

Figures 4 and 5 are the same plots for the sextupoles. Although the statistics is poorer than for the quadrupoles (14 magnets against 60), it is easy to notice that there is no vertical systematic displacement (the average is 0.01 mm, the standard deviation 0.04 mm).

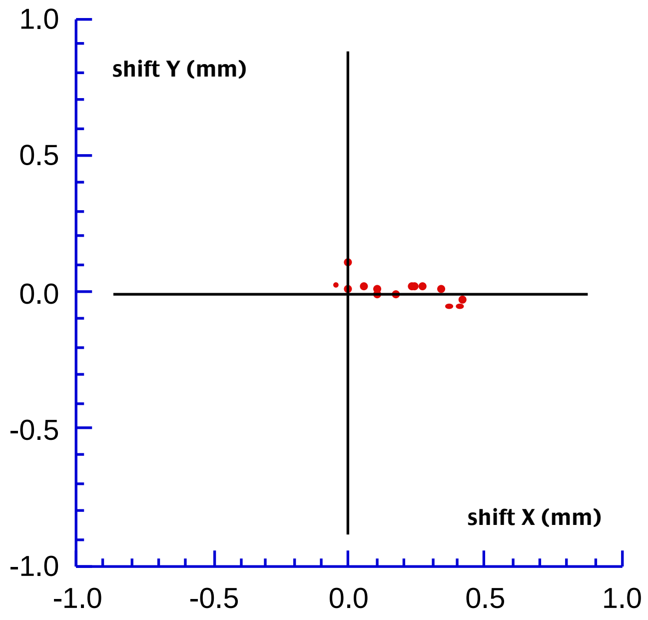

Figure 4 - Distance between magnetic and mechanical axes for the sextupoles (not corrected for the azimuthal rotation)

After correction for the azimuthal rotation (<Φ> = 0.42 ± 0.23 mrad), the average horizontal shift is 0.04 mm, with an r.m.s. width of 0.18 mm.

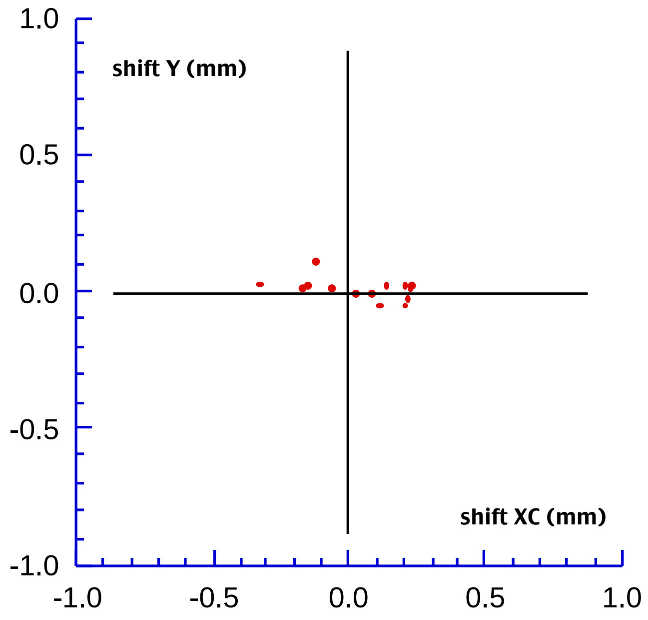

Figure 5 - Distance between magnetic and mechanical axes for the sextupoles corrected for the azimuthal rotation

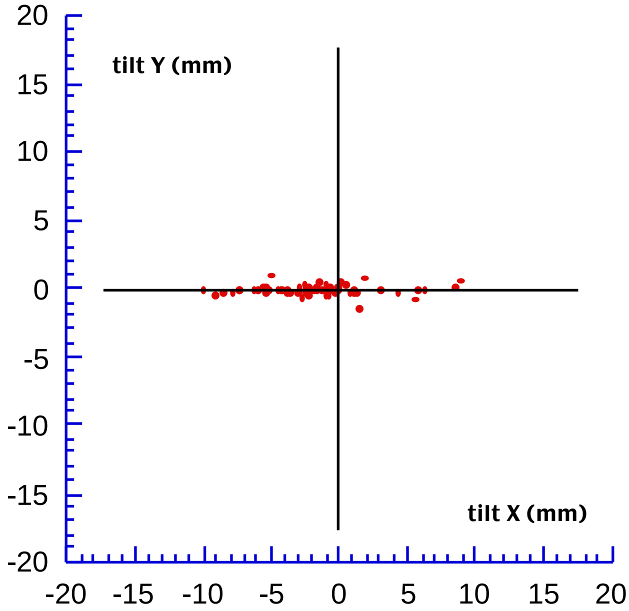

Figure 6 - Horizontal and vertical angles between measured mechanical axis of the quadrupoles and magnet axis on the rotating coil system

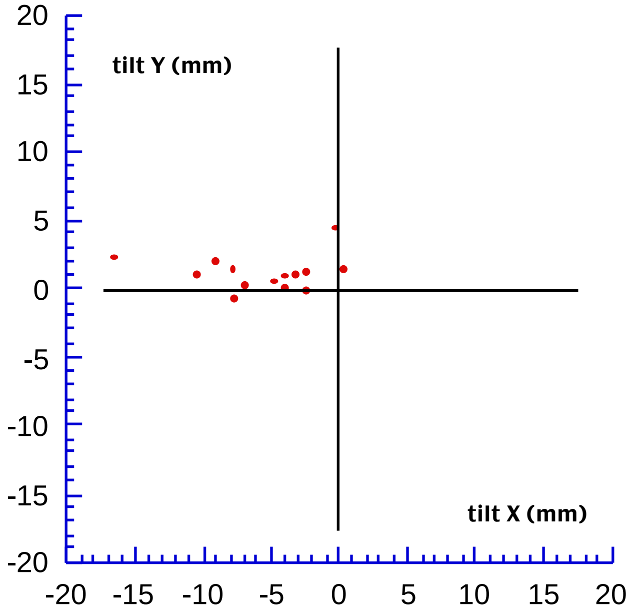

Figure 7 - Horizontal and vertical angles between measured mechanical axis of the sextupoles and magnet axis on the rotating coil system

For sake of completeness, we show in Figures 6 and 7, for the quadrupoles and sextupoles respectively, the angles in the horizontal and vertical planes between the longitudinal axis position obtained from the mechanical measurements and the position of the magnet axis during the magnetic measurement, although, as remarked in Section 1, the latter is not the tilt of the magnetic axis, which cannot be obtained from the rotating coil system. As anticipated in that Section, the tilt distribution is much larger in the horizontal than in the vertical plane, and the vertical tilt spread is smaller for the quadrupoles, due to the larger longitudinal distance between the supporting cylinders.

5. Recalibration of the azimuthal rotating coil offset

As shown in Table I, the rotation Φ of the horizontal magnetic symmetry plane with respect to the mechanical one is positive for all the small quadrupoles of the DAΦNE Main Rings. As already mentioned in Section 4, the average rotation is 0.76 mrad with an r.m.s. spread of 0.35 mrad. At the end of the measurements, we concluded that this small offset could be attributed to a systematic construction error of the quadrupoles. For the sextupoles, the average rotation is smaller (0.42±0.23 mrad), and its effect on the particle dynamics is negligible.

However, during the measurements on the "large" quadrupoles for the Main Ring achromats [5], the same behaviour was observed, In addition, due to the particular geometry of the electrical and cooling connections, half of the magnets were measured with the connections on the encoder side of the rotating coil and half of them on the opposite one. If the offset comes from a systematic construction error, the rotation of the magnet with respect to the measuring coil should change the sign of Φ, but the measured values were again positive for all the quadrupoles. It was therefore decided to check the calibration of the coil (directly performed at the factory three years ago) by measuring the same quadrupoles once with the connections on the encoder side and once on the opposite one. In addition the calibration procedure followed by the builder, consisting in rotating the coil with respect to the quadrupole, was repeated. The two procedures were found to be in agreement with an offset variation ΔΦ of 0.7±0.2 mrad. Applying this variation to the measurements performed on the quadrupoles, the average rotation is well within the accuracy of the measurement. Figure 8 shows the distribution of Φ among all the quadrupoles after applying the calibration correction. The corrected values are also given in Table XIII.

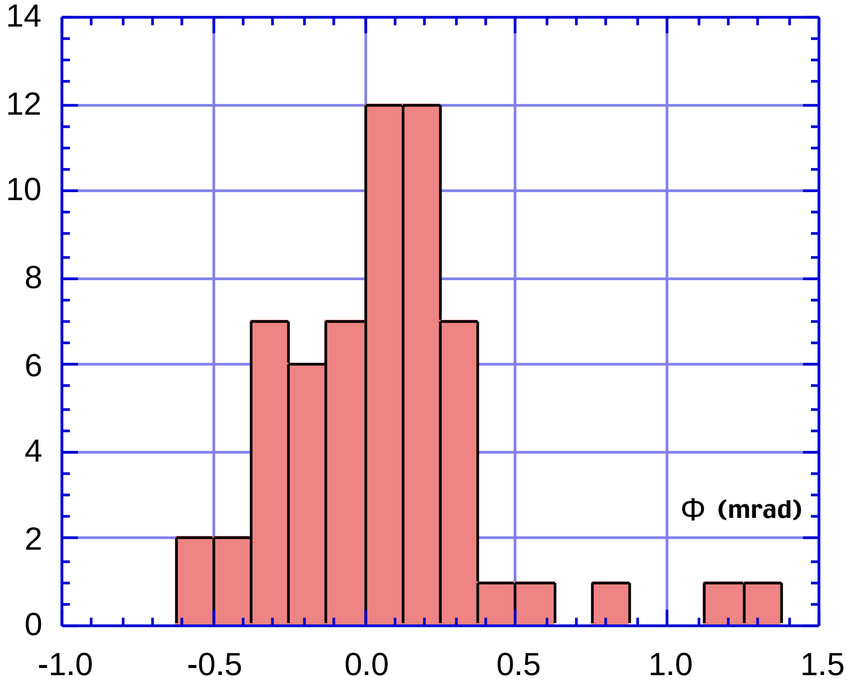

Figure 8 - Distribution of the angle between the magnetic and mechanical horizontal symmetry planes among the 60 quadrupoles

6. Operating instructions for the alignment of the magnets on the rings

From the above described measurement we extract in this Section the essential information to align the small quadrupoles and sextupoles on the DAΦNE Main Rings. We follow the general criterion, adopted throughout the whole project, of relying, as far as possible, on the results of magnetic measurements, integrating them, when necessary, with the mechanical ones. We take into account two possibilities:

a) alignment without compensation of the azimuthal rotation of the magnets

b) alignment with compensation of the azimuthal rotation to minimize the coupling between the betatron oscillations in the horizontal and vertical planes (it is a first order effect for the quadrupoles, a second order one for the sextupoles).

6a) Alignment without compensation

The average displacements in the horizontal direction between the magnetic and mechanical axes (after subtracting the effect of the rotation performed by the rotating coil system to compensate for the azimuthal rotation of the magnetic symmetry plane of the magnets) are given by ShiftXC in Tables IX (for the quadrupoles) and X (for the sextupoles), while the best estimate for the orientation of the axis is given by the mechanical measurements. Combining the two kinds of measurements, the final settings of the first slit (SlitA), corresponding to the horizontal alignment of the sphere centers on the ideal beam trajectory, are obtained by summing for each magnet the value of ShiftXC in Tables IX and X to the values of XAmec in Tables VII (for the quadrupoles) and II (for the sextupoles). For the second slit (SlitB), due to the opposite direction of the micrometric movements, ShiftXC must be subtracted from XBmec.

$$\text{SlitA} = \text{XAmec} + \text{ShiftXC}$$
$$\text{SlitB} = \text{XBmec} - \text{ShiftXC}$$

For the vertical plane we indicate with HeightA and HeightB the vertical distances from the ideal beamline at which the centers of the spheres must be set to properly align the magnets. These values are obtained by summing for each magnet the values of ShiftY in Tables IX and X to the values of YAmec and YBmec in Tables VII and II. The results are summarized in Table XI for the quadrupoles and XII for the sextupoles.

$$\text{HeightA} = \text{YAmec} + \text{ShiftY}$$
$$\text{HeightB} = \text{YBmec} + \text{ShiftY}$$

6b) Alignment with compensation of the magnet rotation

Obviously, a method of aligning the magnets taking into account the rotation of the magnets is to set them as described in 4a) and then perform an azimuthal rotation of the magnet by the angle Φ indicated in Tables XIII (after the coil recalibration) and XIV, keeping the position of the longitudinal axis fixed. However, this method may be rather unpractical in real life.

An alternative method is to perform, as a preliminary adjustment, an azimuthal rotation by the angle Φ with respect to the ideal horizontal plane of the ring, and then to adjust the positions of the sphere centers to the values indicated in Tables XIII (for the quadrupoles) and XIV (for the sextupoles). The values in this table must take into account the recalibration of the coil. We have therefore:

$$\text{SlitA} = \text{XAmec} + \text{ShiftX} - 0.35\text{x}\Delta\Phi$$
$$\text{SlitB} = \text{XBmec} - \text{ShiftX} + 0.35\text{x}\Delta\Phi$$

Of course, ΔΦ is zero for the sextupoles. For the vertical plane, HeightA and HeightB are obtained exactly as described in 4a). When the sign of the rotation is positive the magnet, observed from the elctrical and cooling connections side, must be rotated counterclockwise.

References

[1] B. Bolli, F. Iungo, F. Losciale, N. Ganlin, M. Preger, C. Sanelli, F. Sardone "Field quality of the small quadrupoles for the DAΦNE Main Rings" - DAΦNE Technical Note MM-10 (22/2/96).

[2] B. Bolli, F. Iungo, F. Losciale, N. Ganlin, M. Preger, C. Sanelli, F. Sardone "Field quality of the small sextupoles for the DAΦNE Main Rings" - DAΦNE Technical Note MM-11 (6/3/96).

[3] F. Iungo, M. Modena, Q. Qiao, C. Sanelli "DAΦNE magnetic measurement systems" - DAΦNE Technical Note MM-1 (2/12/94).

[4] B. Bolli, F. Iungo, F. Losciale, M. Paris, M. Preger, C. Sanelli, F. Sardone, F. Sgamma, M. Troiani "Field quality and alignment of the DAΦNE Accumulator quadrupoles" - DAΦNE Technical Note MM-8 (21/8/95).

[5] DAΦNE Technical Note, to be published.

Table I - Magnetic center position of the 60 quadrupoles (alignment table Q3)

Serial #	XA mag	XB mag	YA mag	YB mag	Φ (mrad)
1	13.120	11.620	350.250	350.320	0.730
2	13.130	11.630	350.220	350.320	0.700
3	13.390	11.750	350.250	350.330	0.940
4	12.970	11.770	350.260	350.300	0.530
5	12.920	11.740	350.220	350.280	0.310
6	12.900	11.430	350.240	350.300	0.560
7	13.350	12.320	350.220	350.240	0.210
8	13.100	11.770	350.200	350.270	0.710
9	12.740	12.090	350.230	350.280	0.530
10	13.360	11.980	350.180	350.240	0.770
11	12.740	11.560	350.210	350.280	0.350
12	12.990	11.930	350.190	350.260	0.790
13	13.290	11.700	350.210	350.280	0.840
14	13.020	11.830	350.210	350.270	0.600
15	12.850	11.600	350.210	350.270	0.680
16	12.480	11.270	350.180	350.260	0.660
17	13.180	11.910	350.280	350.350	0.350
18	13.860	12.410	350.380	350.440	1.890
19	12.900	11.520	350.210	350.290	0.590
20	12.720	10.880	350.190	350.270	1.150
21	12.790	11.540	350.280	350.340	0.780
22	12.370	10.980	350.250	350.320	0.880
23	12.230	10.710	350.210	350.260	1.040
24	12.160	10.850	350.210	350.270	0.460
25	13.120	11.190	350.210	350.280	1.270
26	12.730	11.070	350.280	350.230	1.010
27	12.730	11.200	350.280	350.350	0.370
28	12.720	11.040	350.210	350.260	0.960
29	12.820	11.180	350.200	350.260	1.020
30	12.980	11.760	350.250	350.300	0.790
31	12.430	11.010	350.230	350.300	0.880
32	12.940	11.430	350.210	350.270	0.980
33	12.280	11.390	350.190	350.250	0.840
34	13.080	11.425	350.190	350.240	0.880
35	12.850	11.345	350.170	350.230	0.880
36	12.730	11.210	350.200	350.250	0.520
37	13.520	12.015	350.180	350.250	1.000
38	12.955	11.600	350.200	350.260	0.430
39	12.520	11.215	350.170	350.220	0.170
40	12.915	11.680	350.170	350.240	0.370

Table I (continued)

Serial #	XA mag	XB mag	YA mag	YB mag	Φ (mrad)
41	13.080	11.705	350.170	350.230	0.650
42	12.715	11.690	350.200	350.260	0.350
43	12.495	11.125	350.190	350.220	0.830
44	12.935	11.335	350.420	350.480	2.060
45	12.380	10.955	350.200	350.260	0.690
46	12.825	11.430	350.170	350.260	0.850
47	12.665	11.525	350.220	350.290	0.440
48	12.695	11.480	350.220	350.280	0.790
49	13.065	11.595	350.190	350.260	0.810
50	13.020	11.510	350.200	350.270	0.890
51	13.925	12.260	350.210	350.280	0.890
52	13.485	11.955	350.250	350.330	0.740
53	12.900	11.395	350.240	350.300	0.850
54	12.910	11.310	350.200	350.260	0.480
55	12.560	10.960	350.290	350.350	1.530
56	12.375	10.865	350.170	350.240	0.710
57	12.760	11.565	350.310	350.380	0.150
58	12.765	11.545	350.180	350.240	0.780
59	12.925	11.470	350.210	350.290	0.780
60	13.040	11.470	350.250	350.330	1.010

Table II - Magnetic center position of the 14 sextupoles (alignment table S1)

Serial #	XA mag	XB mag	YA mag	YB mag	Φ (mrad)
1	11.73	10.99	350.38	350.18	0.59
2	12.01	11.24	350.40	350.19	0.60
3	11.96	11.20	350.39	350.18	0.02
4	12.21	11.52	350.32	350.22	0.74
5	12.30	11.60	350.38	350.19	0.80
6	11.86	11.39	350.46	350.16	0.09
7	12.01	11.57	350.36	350.18	0.22
8	12.05	11.48	350.36	350.18	0.37
9	12.23	11.75	350.41	350.19	0.24
10	12.12	11.65	350.36	350.22	0.33
11	12.25	11.62	350.38	350.15	0.58
12	11.91	11.53	350.36	350.31	0.33
13	12.06	11.44	350.37	350.14	0.47
14	12.42	11.72	350.52	350.00	0.48

Table III- Mechanical center position of the 60 quadrupoles (alignment table Q1)

Serial #	XA mec	XB mec	YA mec	YB mec
1	12.40	12.75	350.49	350.52
2	12.44	12.68	350.46	350.49
3	12.42	12.62	350.44	350.41
4	12.55	12.79	350.46	350.44
5	12.42	12.78	350.48	350.43
6	12.35	12.77	350.50	350.43
7	12.25	12.81	350.46	350.36
8	12.33	12.77	350.47	350.41
9	12.10	12.96	350.47	350.38
10	12.42	12.62	350.43	350.35
11	12.00	12.98	350.53	350.58
12	12.07	13.05	350.47	350.40
13	12.49	12.61	350.37	350.46
14	12.35	12.81	350.49	350.39
15	12.39	12.79	350.39	350.34
16	12.32	12.87	350.39	350.34
17	12.51	12.76	350.68	350.38
18	11.80	13.40	350.58	350.63
19	12.37	12.63	350.44	350.34
20	12.33	12.66	350.41	350.39
21	12.22	12.83	350.43	350.41
22	12.16	12.87	350.48	350.42
23	12.24	12.83	350.43	350.36
24	12.29	12.70	350.47	350.34
25	12.33	12.74	350.46	350.40
26	12.31	12.79	350.44	350.44
27	12.31	12.79	350.50	350.46
28	12.48	12.63	350.47	350.42
29	12.35	12.70	350.46	350.38
30	12.37	12.83	350.46	350.38
31	12.33	12.79	350.44	350.38
32	12.24	12.74	350.46	350.34
33	12.21	12.80	350.46	350.37
34	12.38	12.93	350.48	350.42
35	12.26	12.79	350.46	350.41
36	12.37	12.78	350.43	350.37
37	12.13	12.88	350.52	350.46
38	12.39	12.70	350.42	350.38
39	12.34	12.71	350.45	350.38
40	12.23	12.85	350.43	350.36

Table III (continued)

Serial #	XA mec	XB mec	YA mec	YB mec
41	12.42	12.82	350.44	350.41
42	12.06	13.00	350.50	350.43
43	12.14	12.98	350.46	350.37
44	12.27	13.08	350.66	350.57
45	12.42	12.69	350.40	350.32
46	12.16	12.92	350.49	350.40
47	12.17	12.86	350.54	350.47
48	12.17	12.95	350.54	350.51
49	12.41	12.70	350.40	350.37
50	12.43	12.69	350.39	350.34
51	12.01	13.15	350.57	350.54
52	12.32	12.62	350.52	350.35
53	12.37	12.79	350.39	350.38
54	12.46	12.83	350.42	350.36
55	11.80	12.87	350.60	350.53
56	12.36	12.77	350.43	350.34
57	12.28	13.02	350.55	350.48
58	12.26	12.85	350.42	350.39
59	12.42	12.88	350.45	350.33
60	12.35	12.62	350.42	350.40

Table IV - Mechanical center position of the 14 sextupoles (alignment table S1)

Serial #	XA mec	XB mec	YA mec	YB mec
1	12.13	12.23	350.30	350.32
2	12.30	11.65	350.38	350.18
3	12.24	11.97	350.32	350.22
4	12.04	12.09	350.33	350.31
5	12.47	11.67	350.29	350.22
6	12.08	12.08	350.34	350.24
7	12.11	11.87	350.37	350.19
8	12.03	11.99	350.31	350.19
9	12.05	11.91	350.35	350.27
10	11.90	12.11	350.36	350.21
11	12.00	12.19	350.38	350.26
12	12.29	11.91	350.29	350.17
13	12.35	11.93	350.29	350.20
14	12.43	11.73	350.29	350.21

Table V- Mechanical center position of the 60 quadrupoles (alignment table Q2)

Serial #	XA mec	XB mec	YA mec	YB mec
1	12.27	11.97	350.52	350.57
2	12.31	11.90	350.49	350.54
3	12.29	11.84	350.47	350.46
4	12.42	12.01	350.49	350.49
5	12.29	12.00	350.51	350.48
6	12.22	11.99	350.53	350.48
7	12.12	12.03	350.49	350.41
8	12.20	11.99	350.50	350.46
9	11.97	12.18	350.50	350.43
10	12.29	11.84	350.46	350.40
11	11.87	12.20	350.56	350.63
12	11.94	12.27	350.50	350.45
13	12.36	11.83	350.40	350.51
14	12.22	12.03	350.52	350.44
15	12.26	12.01	350.42	350.39
16	12.19	12.09	350.42	350.39
17	12.38	11.98	350.71	350.43
18	11.67	12.62	350.61	350.68
19	12.24	11.85	350.47	350.39
20	12.20	11.88	350.44	350.44
21	12.09	12.05	350.46	350.46
22	12.03	12.09	350.51	350.47
23	12.11	12.05	350.46	350.41
24	12.16	11.92	350.50	350.39
25	12.20	11.96	350.49	350.45
26	12.18	12.01	350.47	350.49
27	12.18	12.01	350.53	350.51
28	12.35	11.85	350.50	350.47
29	12.22	11.92	350.49	350.43
30	12.24	12.05	350.49	350.43
31	12.20	12.01	350.46	350.40
32	12.11	11.96	350.48	350.36
33	12.08	12.02	350.48	350.39
34	12.25	12.15	350.50	350.44
35	12.13	12.01	350.48	350.43
36	12.24	12.00	350.45	350.39
37	12.00	12.10	350.54	350.48
38	12.26	11.92	350.44	350.40
39	12.21	11.93	350.47	350.40
40	12.10	12.07	350.45	350.38

Table V (continued)

Serial #	**XA mec**	**XB mec**	**YA mec**	**YB mec**
41	12.29	12.04	350.46	350.43
42	11.93	12.22	350.52	350.45
43	12.01	12.20	350.48	350.39
44	12.14	12.30	350.68	350.59
45	12.29	11.91	350.42	350.34
46	12.03	12.14	350.51	350.42
47	12.04	12.08	350.56	350.49
48	12.04	12.17	350.56	350.53
49	12.28	11.92	350.42	350.39
50	12.30	11.91	350.41	350.36
51	11.88	12.37	350.59	350.56
52	12.19	11.84	350.54	350.37
53	12.24	12.01	350.41	350.40
54	12.33	12.05	350.44	350.38
55	11.67	12.09	350.62	350.55
56	12.23	11.99	350.45	350.36
57	12.15	12.24	350.57	350.50
58	12.13	12.07	350.44	350.41
59	12.29	12.10	350.47	350.35
60	12.22	11.84	350.44	350.42

Table VI - Mechanical center position of the 14 sextupoles (alignment table S2)

Serial #	**XA mec**	**XB mec**	**YA mec**	**YB mec**
1	11.80	11.92	350.40	350.30
2	11.97	11.34	350.48	350.16
3	11.91	11.66	350.42	350.20
4	11.71	11.78	350.43	350.29
5	12.14	11.36	350.39	350.20
6	11.75	11.77	350.44	350.22
7	11.78	11.56	350.47	350.17
8	11.70	11.68	350.41	350.70
9	11.72	11.60	350.45	350.25
10	11.57	11.80	350.46	350.19
11	11.67	11.88	350.48	350.24
12	11.96	11.60	350.39	350.15
13	12.02	11.62	350.39	350.18
14	12.10	11.42	350.39	350.19

Table VII- Mechanical center position of the 60 quadrupoles (alignment table Q3)

Serial #	XA mec	XB mec	YA mec	YB mec
1	12.82	11.89	350.38	350.50
2	12.86	11.82	350.35	350.47
3	12.84	11.76	350.33	350.39
4	12.97	11.93	350.35	350.42
5	12.84	11.92	350.37	350.41
6	12.77	11.91	350.39	350.41
7	12.67	11.95	350.35	350.34
8	12.75	11.91	350.36	350.39
9	12.52	12.10	350.36	350.36
10	12.84	11.76	350.32	350.33
11	12.42	12.12	350.42	350.56
12	12.49	12.19	350.36	350.38
13	12.91	11.75	350.26	350.44
14	12.77	11.95	350.38	350.37
15	12.81	11.93	350.28	350.32
16	12.74	12.01	350.28	350.32
17	12.93	11.90	350.57	350.36
18	12.22	12.54	350.47	350.61
19	12.79	11.77	350.33	350.32
20	12.75	11.80	350.30	350.37
21	12.64	11.97	350.32	350.39
22	12.58	12.01	350.37	350.40
23	12.66	11.97	350.32	350.34
24	12.71	11.84	350.36	350.32
25	12.75	11.88	350.35	350.38
26	12.73	11.93	350.33	350.42
27	12.73	11.93	350.39	350.44
28	12.90	11.77	350.36	350.40
29	12.77	11.84	350.35	350.36
30	12.79	11.97	350.35	350.36
31	12.75	11.93	350.33	350.36
32	12.66	11.88	350.35	350.32
33	12.63	11.94	350.35	350.35
34	12.80	12.07	350.37	350.40
35	12.68	11.93	350.35	350.39
36	12.79	11.92	350.32	350.35
37	12.55	12.02	350.41	350.44
38	12.81	11.84	350.31	350.36
39	12.76	11.85	350.34	350.36
40	12.65	11.99	350.32	350.34

Table VII (continued)

Serial #	XA mec	XB mec	YA mec	YB mec
41	12.84	11.96	350.33	350.39
42	12.48	12.14	350.39	350.41
43	12.56	12.12	350.35	350.35
44	12.69	12.22	350.55	350.55
45	12.84	11.83	350.29	350.30
46	12.58	12.06	350.38	350.38
47	12.59	12.00	350.43	350.45
48	12.59	12.09	350.43	350.49
49	12.83	11.84	350.29	350.35
50	12.85	11.83	350.28	350.32
51	12.43	12.29	350.46	350.52
52	12.74	11.76	350.41	350.33
53	12.79	11.93	350.28	350.36
54	12.88	11.97	350.31	350.34
55	12.22	12.01	350.49	350.51
56	12.78	11.91	350.32	350.32
57	12.70	12.16	350.44	350.46
58	12.68	11.99	350.31	350.37
59	12.84	12.02	350.34	350.31
60	12.77	11.76	350.31	350.38

Table VIII - Mechanical center position of the 14 sextupoles (alignment table S3)

Serial #	XA mec	XB mec	YA mec	YB mec
1	12.74	12.48	350.31	350.40
2	12.91	11.90	350.39	350.26
3	12.85	12.22	350.33	350.30
4	12.65	12.34	350.34	350.39
5	13.08	11.92	350.30	350.30
6	12.69	12.33	350.35	350.32
7	12.72	12.12	350.38	350.27
8	12.64	12.24	350.32	350.27
9	12.66	12.16	350.36	350.35
10	12.51	12.36	350.37	350.29
11	12.61	12.44	350.39	350.34
12	12.90	12.16	350.30	350.25
13	12.96	12.18	350.30	350.28
14	13.04	11.98	350.30	350.29

Table IX - Distance (mm) and tilt (mrad) between magnetic and mechanical axes for the quadrupoles

Serial #	Shift X	Shift Y	Tilt X	Tilt Y	Shift XC
1	0.29	-0.15	0.18	0.29	0.03
2	0.23	-0.14	0.47	0.12	-0.01
3	0.28	-0.07	3.18	-0.12	-0.05
4	0.08	-0.11	-0.94	0.18	-0.11
5	0.13	-0.14	-0.59	-0.12	0.02
6	0.30	-0.13	-2.06	-0.24	0.11
7	0.16	-0.12	6.18	-0.18	0.08
8	0.24	-0.14	1.24	-0.23	-0.00
9	0.11	-0.10	1.24	-0.29	-0.07
10	0.15	-0.12	4.35	-0.29	-0.12
11	0.44	-0.25	-1.41	0.41	0.32
12	0.38	-0.14	1.41	-0.29	0.10
13	0.22	-0.11	1.94	0.65	-0.08
14	0.18	-0.14	0.76	-0.41	-0.03
15	0.18	-0.06	-1.71	-0.12	-0.05
16	0.24	-0.08	-5.88	-0.24	0.01
17	0.12	-0.15	1.53	-1.65	-0.00
18	0.88	-0.13	8.88	0.47	0.22
19	0.18	-0.07	-0.82	-0.53	-0.03
20	0.45	-0.10	-5.59	-0.06	0.04
21	0.29	-0.05	-1.65	0.06	0.02
22	0.41	-0.10	-7.29	-0.24	0.10
23	0.41	-0.10	-9.94	-0.18	0.05
24	0.22	-0.10	-9.06	-0.59	0.06
25	0.53	-0.12	-1.88	-0.24	0.09
26	0.43	-0.12	-5.06	0.82	0.08
27	0.37	-0.10	-4.29	-0.12	0.24
28	0.28	-0.14	-5.35	-0.06	-0.06
29	0.35	-0.12	-3.59	-0.29	-0.00
30	0.20	-0.08	-0.12	-0.24	-0.08
31	0.30	-0.08	-7.29	-0.24	-0.01
32	0.36	-0.10	-1.00	-0.53	0.02
33	0.10	-0.13	-5.29	-0.35	-0.19
34	0.46	-0.17	-2.15	-0.12	0.15
35	0.38	-0.17	-2.44	-0.12	0.07
36	0.32	-0.11	-4.53	-0.12	0.14
37	0.49	-0.21	5.68	-0.24	0.14
38	0.19	-0.10	-0.56	-0.06	0.04
39	0.20	-0.15	-5.15	-0.18	0.14
40	0.29	-0.13	-0.26	-0.29	0.16

Table IX (continued)

Serial #	Shift X	Shift Y	Tilt X	Tilt Y	Shift XC
41	0.25	-0.16	-0.09	0.00	0.02
42	0.34	-0.17	-1.26	-0.24	0.22
43	0.46	-0.15	-6.24	-0.18	0.17
44	0.57	-0.10	-3.76	-0.35	-0.16
45	0.21	-0.06	-7.85	-0.29	-0.03
46	0.44	-0.16	-2.26	-0.53	0.14
47	0.28	-0.18	-2.35	-0.29	0.12
48	0.36	-0.21	-2.97	0.00	0.08
49	0.24	-0.10	-0.06	-0.06	-0.04
50	0.24	-0.07	-0.88	-0.18	-0.07
51	0.76	-0.24	8.62	-0.06	0.45
52	0.28	-0.08	5.53	-0.94	0.02
53	0.32	-0.05	-2.50	0.12	0.02
54	0.34	-0.09	-3.71	-0.18	0.18
55	0.70	-0.18	-4.18	-0.24	0.16
56	0.32	-0.12	-8.53	-0.41	0.07
57	0.33	-0.10	-3.15	-0.29	0.28
58	0.26	-0.13	-2.12	0.00	-0.01
59	0.32	-0.07	-2.74	-0.65	0.04
60	0.28	-0.06	-0.12	-0.06	-0.07

Table X - Distance (mm) and tilt (mrad) between magnetic and mechanical axes for the sextupoles

Serial #	Shift X	Shift Y	Tilt X	Tilt Y	Shift XC
1	0.42	-0.03	-16.40	2.20	0.21
2	0.06	0.01	-7.00	0.10	-0.15
3	0.25	0.01	-10.50	1.10	0.24
4	0.37	-0.05	-4.00	0.80	0.11
5	-0.05	0.03	-2.40	1.20	-0.33
6	0.23	0.02	-9.10	2.00	0.20
7	0.10	-0.01	-4.00	0.00	0.02
8	0.27	0.02	-4.90	0.60	0.14
9	0.17	-0.01	0.20	1.40	0.09
10	0.34	0.01	-2.40	-0.10	0.22
11	0.41	-0.06	-3.20	1.10	0.21
12	0.00	0.10	-7.60	-0.70	-0.12
13	0.10	0.01	-7.80	1.40	-0.06
14	-0.00	0.01	-0.20	4.36	-0.17

Table XI - Alignment values without compensation of azimuthal rotation for the 60 quadrupoles of the DAΦNE Main Rings (Method 4a)

Serial#	Slit A	Slit B	Height A	Height B
1	12.85	11.86	350.23	350.35
2	12.84	11.84	350.21	350.33
3	12.79	11.81	350.26	350.32
4	12.86	12.04	350.24	350.32
5	12.86	11.90	350.23	350.27
6	12.88	11.80	350.26	350.28
7	12.75	11.87	350.23	350.22
8	12.75	11.91	350.22	350.25
9	12.45	12.17	350.26	350.26
10	12.72	11.88	350.21	350.21
11	12.74	11.80	350.17	350.32
12	12.59	12.09	350.21	350.24
13	12.83	11.83	350.15	350.33
14	12.75	11.97	350.24	350.23
15	12.76	11.98	350.22	350.26
16	12.75	12.00	350.20	350.24
17	12.93	11.90	350.42	350.21
18	12.44	12.32	350.34	350.48
19	12.76	11.80	350.26	350.24
20	12.79	11.76	350.20	350.27
21	12.66	11.95	350.27	350.35
22	12.68	11.91	350.27	350.30
23	12.71	11.92	350.23	350.24
24	12.77	11.78	350.26	350.22
25	12.84	11.79	350.23	350.26
26	12.81	11.85	350.21	350.30
27	12.97	11.69	350.29	350.34
28	12.84	11.83	350.21	350.26
29	12.77	11.84	350.23	350.23
30	12.71	12.05	350.27	350.28
31	12.74	11.94	350.25	350.28
32	12.68	11.86	350.26	350.22
33	12.44	12.13	350.22	350.22
34	12.95	11.92	350.20	350.23
35	12.75	11.86	350.18	350.22
36	12.93	11.78	350.21	350.24
37	12.69	11.88	350.20	350.23
38	12.85	11.80	350.21	350.26
39	12.90	11.71	350.18	350.21
40	12.81	11.83	350.20	350.21

Table XI (continued)

Serial #	Slit A	Slit B	Height A	Height B
41	12.86	11.94	350.17	350.23
42	12.70	11.92	350.22	350.24
43	12.73	11.95	350.21	350.21
44	12.53	12.38	350.45	350.45
45	12.81	11.86	350.23	350.23
46	12.72	11.92	350.22	350.22
47	12.71	11.88	350.24	350.27
48	12.67	12.01	350.22	350.28
49	12.79	11.88	350.20	350.26
50	12.78	11.90	350.21	350.26
51	12.88	11.84	350.21	350.27
52	12.76	11.74	350.33	350.25
53	12.81	11.91	350.23	350.31
54	13.06	11.79	350.22	350.24
55	12.38	11.85	350.31	350.33
56	12.85	11.84	350.21	350.21
57	12.98	11.88	350.34	350.35
58	12.67	12.00	350.18	350.24
59	12.88	11.98	350.27	350.23
60	12.70	11.83	350.26	350.33

Table XII - Alignment values without compensation of azimuthal rotation for the 14 sextupoles of the DAΦNE Main Rings (Method 4a)

Serial #	Slit A	Slit B	Height A	Height B
1	12.34	12.02	350.27	350.29
2	12.15	11.80	350.40	350.20
3	12.48	11.73	350.34	350.23
4	12.15	11.98	350.28	350.26
5	12.14	12.00	350.32	350.25
6	12.28	11.88	350.36	350.26
7	12.13	11.85	350.36	350.18
8	12.17	11.85	350.33	350.21
9	12.14	11.82	350.34	350.26
10	12.12	11.89	350.36	350.21
11	12.21	11.98	350.33	350.21
12	12.17	12.03	350.39	350.27
13	12.29	11.99	350.30	350.21
14	12.26	11.90	350.30	350.22

Table XIII - Alignment values with compensation of azimuthal rotation
for the 60 quadrupoles of the DAΦNE Main Rings (Method 4b)

Serial #	Φ (mrad)	Slit A	Slit B	Height A	Height B
1	0.030	12.86	11.85	350.23	350.35
2	-0.000	12.84	11.84	350.21	350.33
3	0.240	12.88	11.73	350.26	350.32
4	-0.170	12.81	12.10	350.24	350.32
5	-0.390	12.73	12.03	350.23	350.27
6	-0.140	12.83	11.85	350.26	350.28
7	-0.490	12.58	12.04	350.23	350.22
8	0.010	12.75	11.91	350.22	350.25
9	-0.170	12.39	12.23	350.26	350.26
10	0.070	12.74	11.86	350.21	350.21
11	-0.350	12.61	11.93	350.17	350.32
12	0.090	12.62	12.06	350.21	350.24
13	0.140	12.88	11.78	350.15	350.33
14	-0.100	12.71	12.01	350.24	350.23
15	-0.020	12.75	11.99	350.22	350.26
16	-0.040	12.73	12.02	350.20	350.24
17	-0.350	12.81	12.02	350.42	350.21
18	1.190	12.86	11.90	350.34	350.48
19	-0.110	12.72	11.84	350.26	350.24
20	0.450	12.95	11.60	350.20	350.27
21	0.080	12.69	11.93	350.27	350.35
22	0.180	12.74	11.85	350.27	350.30
23	0.340	12.83	11.80	350.23	350.24
24	-0.240	12.68	11.87	350.26	350.22
25	0.570	13.03	11.60	350.23	350.26
26	0.310	12.91	11.74	350.21	350.30
27	-0.330	12.85	11.81	350.29	350.34
28	0.260	12.93	11.74	350.21	350.26
29	0.320	12.88	11.73	350.23	350.23
30	0.090	12.74	12.02	350.27	350.28
31	0.180	12.81	11.87	350.25	350.28
32	0.280	12.78	11.76	350.26	350.22
33	0.140	12.48	12.09	350.22	350.22
34	0.180	13.02	11.85	350.20	350.23
35	0.180	12.81	11.80	350.18	350.22
36	-0.180	12.87	11.84	350.21	350.24
37	0.300	12.79	11.78	350.20	350.23
38	-0.270	12.76	11.89	350.21	350.26
39	-0.530	12.71	11.90	350.18	350.21
40	-0.330	12.69	11.95	350.20	350.21

Table XIII (continued)

Serial #	**Φ (mrad)**	**Slit A**	**Slit B**	**Height A**	**Height B**
41	-0.050	12.84	11.96	350.17	350.23
42	-0.350	12.58	12.04	350.22	350.24
43	0.130	12.78	11.90	350.21	350.21
44	1.360	13.01	11.90	350.45	350.45
45	-0.010	12.80	11.87	350.23	350.23
46	0.150	12.77	11.87	350.22	350.22
47	-0.260	12.62	11.97	350.24	350.27
48	0.090	12.70	11.98	350.22	350.28
49	0.110	12.82	11.85	350.20	350.26
50	0.190	12.85	11.83	350.21	350.26
51	0.190	12.95	11.77	350.21	350.27
52	0.040	12.77	11.73	350.33	350.25
53	0.150	12.87	11.85	350.23	350.31
54	-0.220	12.98	11.87	350.22	350.24
55	0.830	12.67	11.56	350.31	350.33
56	0.010	12.85	11.84	350.21	350.21
57	-0.550	12.78	12.08	350.34	350.35
58	0.080	12.70	11.97	350.18	350.24
59	0.080	12.91	11.95	350.27	350.23
60	0.310	12.81	11.73	350.26	350.33

Table XIV - Alignment values with compensation of azimuthal rotation
for the 14 sextupoles of the DAΦNE Main Rings (Method 4b)

Serial #	**Φ (mrad)**	**Slit A**	**Slit B**	**Height A**	**Height B**
1	0.59	12.55	11.81	350.27	350.29
2	0.60	12.36	11.59	350.40	350.20
3	0.02	12.49	11.73	350.34	350.23
4	0.74	12.41	11.72	350.28	350.26
5	0.80	12.42	11.72	350.32	350.25
6	0.09	12.31	11.85	350.36	350.26
7	0.22	12.21	11.77	350.36	350.18
8	0.37	12.30	11.72	350.33	350.21
9	0.24	12.22	11.74	350.34	350.26
10	0.33	12.24	11.77	350.36	350.21
11	0.58	12.41	11.78	350.33	350.21
12	0.33	12.29	11.91	350.39	350.27
13	0.47	12.45	11.83	350.30	350.21
14	0.48	12.43	11.73	350.30	350.22