AΦNE TECHNICAL NOTE

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EFFECT OF MAGNETS MISALIGNMENT IN THE KLOE IR

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1. Introduction

The KLOE detector has a solenoid with 2.4 Tm longitudinal integrated field with permanent magnet low-beta quadrupoles inside; a description of the KLOE IR is given in Ref. [1]. This field is a strong perturbation for a 510 MeV beam and gives a large contribution to the beam coupling. In DAΦNE, to achieve high luminosity, very flat beams are required, and therefore the machine coupling has to be kept very low ($\kappa \leq .01$). A sophisticated scheme, proposed by M. Bassetti [2], uses two compensating solenoids and a rotation of the low-β quadrupoles to cancel the coupling in the IR.

For an exact cancellation of the coupling introduced by the solenoid four parameters are needed: three rotation angles of the quadrupoles and the current of the compensator solenoid. For KLOE IR the three angles of the low-β quadrupoles are carefully adjusted and fixed during the installation and they cannot be moved independently: a cam system allows a rigid rotation (±1˚) of each triplet on both sides of the IP. If there is a residual coupling it can be corrected by using 8 skew quadrupoles placed out of the IRs in each ring.

The alignment of the magnetic elements of the IRs is more critical with respect to the other machine elements. The magnetic axis of the solenoid has to be determined with good precision and aligned with the machine axis. Each triplet of the low-β quadrupoles has to be aligned before insertion inside the detector, then only a rigid movement of the axis inside ± 1 mm is allowed by the cam system. Out of the IRs there is a large number of dipole correctors in each ring to correct the closed orbit.

A study of the effect of misalignment errors of the IRs magnetic elements on the closed orbit and coupling factor of the machine is presented in the following. The effect of each element is considered separately, and then the combined effect of the measured alignment errors of the detector, the two compensating solenoids and of the permanent magnet quadrupoles are simulated.

2. Error closed orbit

In this section the effects of misalignments of the IRs magnets on the closed orbit are considered. Due to the horizontal crossing angle and the presence of the solenoids, the reference beam trajectory in the KLOE IR is displaced with respect to the quadrupole axis both in x and y directions. This trajectory, between the two splitter magnets, is shown in Fig. 1 at the design crossing angle $\theta = 12.5$ mrad. The machine closed orbit is calculated as a displacement from the reference trajectory; a lattice with DEAR on the other IR and working point $Q_x = 5.15$, $Q_y = 5.21$ has been used.

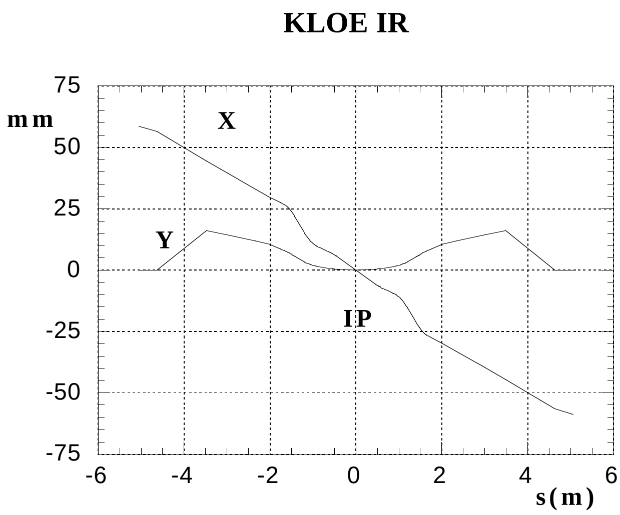

Figure 1 - Reference trajectory in the KLOE IR, θ = 12.5 mrad (e^+).

2.1 Displacement of the magnetic axis

The closed orbit produced in the x and y directions by a displacement $\Delta x = 1$ mm of the magnetic axis of the KLOE solenoid with respect to the machine axis is shown in Fig. 2. In Fig. 3 the orbit due to a displacement of the same quantity of the axis of the six KLOE low-β quadrupoles is shown. Here and below the longitudinal coordinate of the figures starts from the center of the long straight section.

From comparison of the two figures it can be seen that the orbits have the same phase and opposite sign. Therefore aligning the axis of the low-β quadrupoles on the magnetic axis of the solenoid, even if this is displaced by $\Delta x = 1$ mm from the machine axis, gives a closed orbit very small (less than 2 mm) all over the ring, as shown in Fig. 4. Anyway each of these orbits exhibits a smooth fifth harmonic behaviour (the main harmonic component of the orbit corresponds to the integer part of the tune) and can be easily corrected by the dipole correctors in the ring, out of the IRs.

The closed orbit given by a displacement of the solenoid and of the low-β quadrupoles in the vertical direction ($\Delta y = 1$ mm) has also been calculated and it is so small that can be neglected; the maximum and rms value of the closed orbit in x and y are listed in Table I. As a comparison the maximum and rms value of the orbit given by the displacement ($\Delta y = 1$ mm) of one of the strong vertical focusing low-β quadrupoles (QUAI1002) are also shown in Table I.

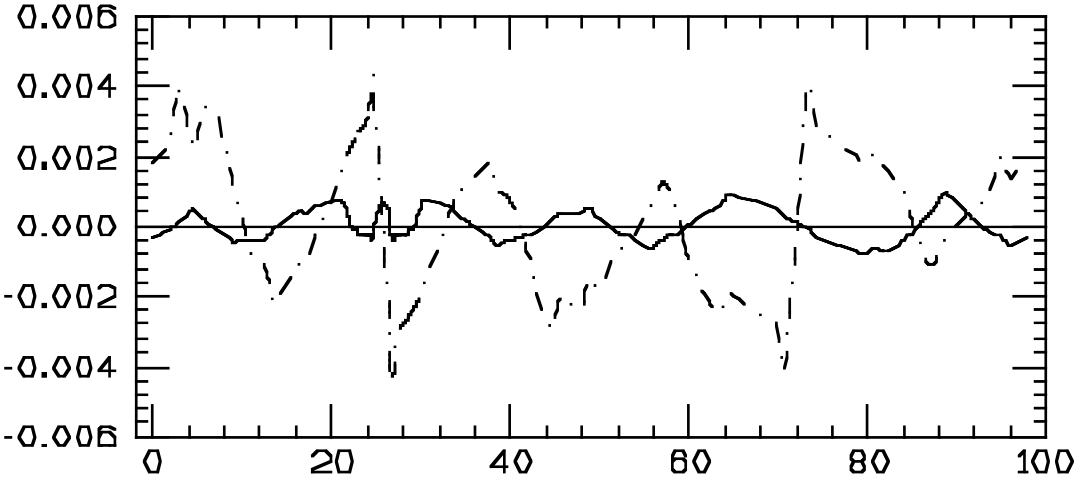

Figure 2 - KLOE solenoid displaced by Δx = 1 mm

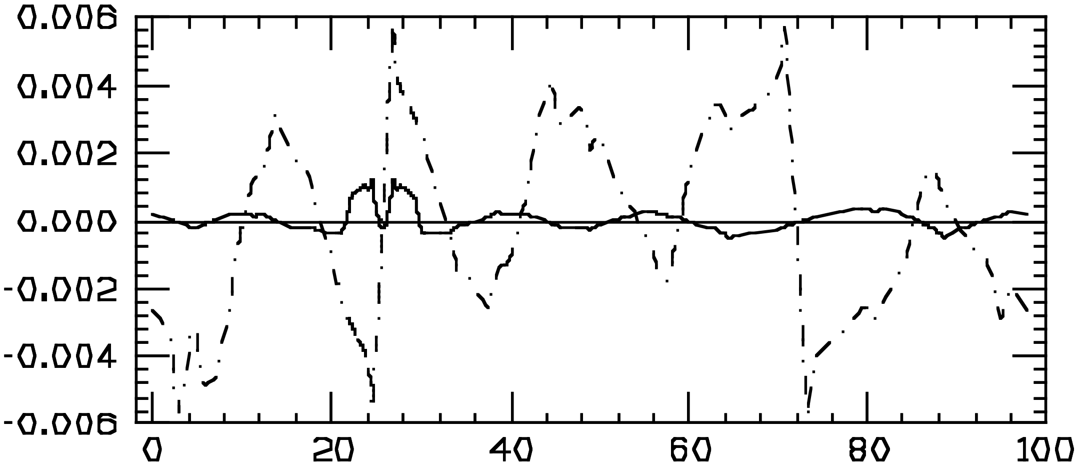

Figure 3 - KLOE low-β quadrupoles displaced by Δx = 1 mm.

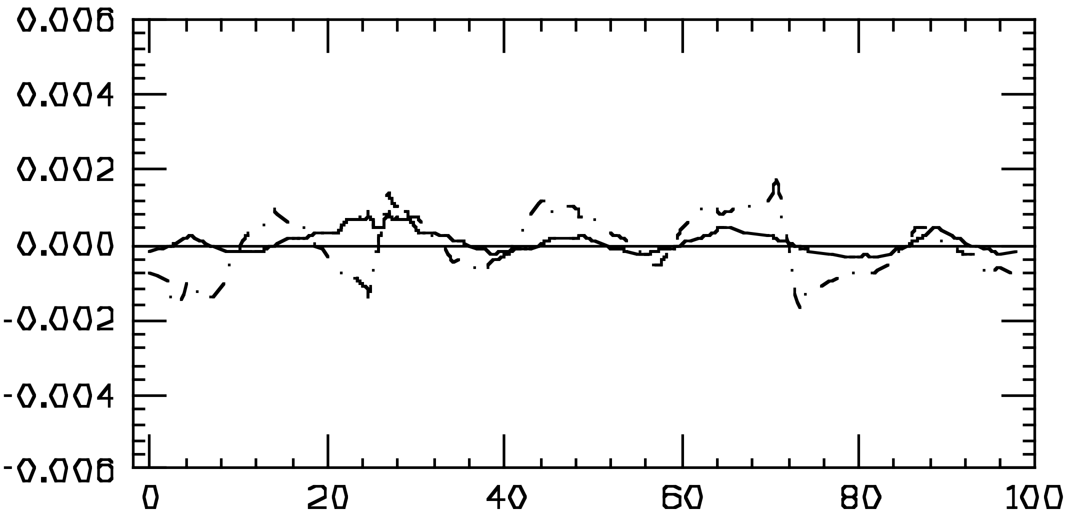

Figure 4 - KLOE solenoid and low-β quadrupoles displaced by Δx = 1 mm.

Table I - Displacement of the magnetic axis; peak and rms value of closed orbit.

Δy =1mm	x_{max} (mm)	x_{rms} (mm)	y_{max} (mm)	y_{rms} (mm)
KLOE solenoid	1.42	0.48	0.10	0.03
KLOE IR quadrupoles	0.37	0.17	1.47	0.81
QUAI1002	10.58	5.31	35.08	18.08

2.2 Tilt of the solenoid magnetic axis

The effect of a tilt of the solenoid magnetic axis with respect to the machine axis on the closed orbit has been also evaluated. The results are shown in Table II for a tilt of the solenoid in the xs plane (ϕ_x = 1 mrad) and in the ys plane (ϕ_y = 1 mrad).

Table II - Tilt of the magnetic axis; peak and rms value of closed orbit.

solenoid tilt	x_{max} (mm)	x_{rms} (mm)	y_{max} (mm)	y_{rms} (mm)
ϕ_x = 1 mrad	.32	.13	.72	.35
ϕ_y = 1 mrad	4.65	2.57	1.0	.41

3. Coupling effects

3.1 Solenoid longitudinal displacement

A longitudinal displacement (Δs = 1 cm) has been simulated for the KLOE solenoid to evaluate the effect on the coupling of an asymmetry of the magnetic field with respect to the IP. Due to this displacement the half IR transfer matrices have non zero coupling terms and are no more diagonal. By varying the rotation angles of the low-beta quadrupoles and the compensator field these coupling elements can be made exactly zero.

After the installation of the IR, only two parameters are available for the correction, the compensator field and one rotation angle for the quadrupole triplet inside the solenoidal field. The first order transfer matrix from the IP to the splitter entrance is shown in Table IIIa before and after correction; the IR description is given in the MAD file [fisacc.mad]kloe1298.mad. The quadrupole rotation angle and the compensator field required for the correction are reported in Table IIIb.

By using only two parameters the matrix cannot be made exactly diagonal but the coupling terms are reduced nearly to zero. The variation of the quadrupole rotation angle is negligible and the asymmetry of the longitudinal field integral with respect to the IP is corrected by varying the field in the two compensators.

TABLE IIIa - Half KLOE IR first order transfer matrix.

before correction (Δs =+9 cm)

0.812315	4.715782	-0.059138	0.001994
-0.148264	0.370023	-0.015202	-0.003621
-0.014359	-0.076400	-3.674408	0.219523
0.002023	-0.006259	-0.952938	-0.215154

after correction (Δs =+9 cm)

0.801913	4.669377	-0.000001	0.000005
-0.158805	0.322328	0.000019	-0.000054
-0.000152	-0.000905	-3.645854	0.214677
-0.000043	-0.000254	-0.923075	-0.219931

TABLE IIIb - Half KLOE IR correction parameters.

element	B_0 (T)	correction ΔB (T)	angle α (rad)	$\Delta\alpha$ (rad)
KLOE sol	.60			
QUAI1K01			-.271979	3.97×10^{-4}
QUAI1K02			-.185919	3.97×10^{-4}
QUAI1K03			-.106364	3.97×10^{-4}
QUAI1K04			.106364	5.61×10^{-4}
QUAI1K05			.185919	5.61×10^{-4}
QUAI1K06			.271979	5.61×10^{-4}
Comp C1	-1.227	-.056		
Comp C2	-1.227	.056		

3.1 Quadrupole rotation

Another source of coupling is an error in the rotation angle of one of the quadrupoles. As an example the angle of the strong vertical focusing quadrupole QUAI1002 of the KLOE IR has been changed by $\Delta\alpha$ = 1 mrad. In this case the cancellation of the coupling elements of the half IR matrix cannot be obtained with the two parameters available but, using the four skew quadrupoles in the long arc, it is possible to make block diagonal the matrix between IP1 and IP2.

The strengths of the skew quadrupoles required to cancel the coupling terms are given in Table IV. These strengths are quite low and correspond to a small machine coupling.

Table IV- Skew quadrupole integrated strengths and currents.

	kl (m-1)	I (A)
QSKPS101	$2.48 \cdot 10^{-3}$	4.43
QSKPS104	$-1.46 \cdot 10^{-3}$	2.61
QSKPS202	$-3.80 \cdot 10^{-3}$	6.80
QSKPS205	$7.87 \cdot 10^{-3}$	14.06

4. Measured configuration

The alignment errors of the KLOE IR quadrupoles have been carefully measured and are shown in Table V [3]. In the vertical plane the magnetic axis of the KLOE solenoid is aligned with the machine axis within the measurement errors, while in the horizontal plane it is displaced by Δx =.92±.1 mm. The quadrupole displacements listed in Table V are referred to the KLOE axis. The alignment in the horizontal plane is quite satisfactory, while the vertical displacement of one of the triplets and the rotation angle of both triplets require a further correction. The tools for the fine tuning of the alignment of the two triplets are ready. This operation can be performed during a machine shutdown with the KLOE end-caps opened; in the meantime the effects of the misalignment errors are compensated by the correcting elements in the machine. A simulation of these effects on the closed orbit and the machine coupling is presented in the following.

Table V - Misalignment errors for KLOE IR quadrupoles.

	Δx (mm)	**Δy (mm)**	**$\Delta\alpha$ (rad)**
QUAI1K01	.17	.46	.012
QUAI1K02	.1	.56	.012
QUAI1K03	.04	.64	.012
QUAI1K04	-.15	.13	-.017
QUAI1K05	-.18	-.07	-.017
QUAI1K06	-.22	-.27	-.017

The closed orbit due to the quadrupole displacements is shown in Fig. 5. The maximum of the vertical closed orbit is y_{max} = 10 mm; the correction requires high strengths for the dipole correctors of the rings.

The coupling due to the rotation error of the triplets can be reduced by adjusting the current of the KLOE and of the compensator solenoids. To obtain a cancellation of the coupling terms of the machine transfer matrix four parameters are needed. The strengths of the eight skew quadrupoles have been calculated in order to make zero the coupling terms of the transfer matrix at the two IPs of the machine.

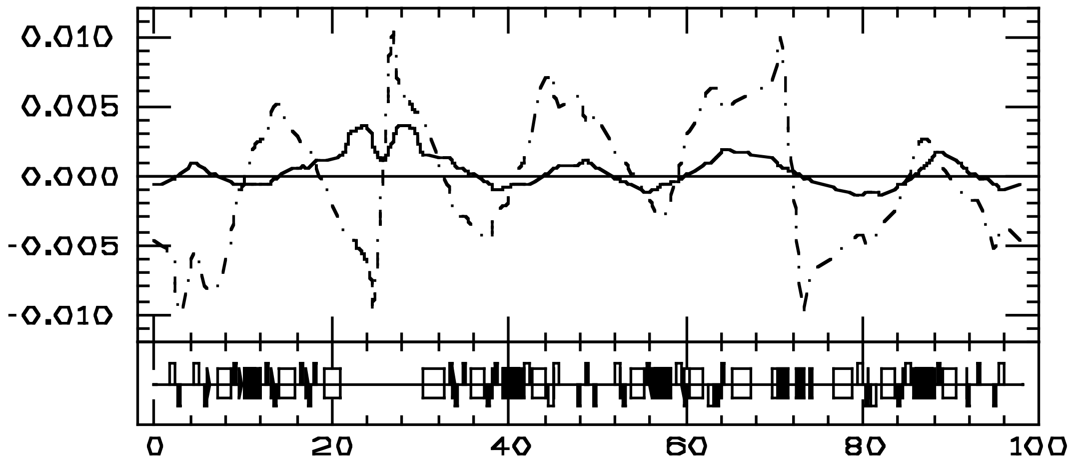

Figure 5 - Closed orbit due to the measured displacements of the IR quadrupoles.

The solutions for three different configurations are presented in Table VI, the first one corresponds to the nominal values of the KLOE and compensator solenoids, the remaining two to reduced values of the solenoid fields. For the configuration shown in the second column the two compensators have the same integrated field, while for that listed in column three they are different. In each column of Table VI are listed the betatron tunes before and after correction with the skew quadrupoles, the angle ϕ, defined in ref. [4], calculated at IP1 and the currents of the skew quadrupoles. The solution with lower solenoid fields is preferable because reduces the coupling at the ends of the IR and makes smaller the strengths of the skew quadrupoles. The configuration with asymmetric values of the compensators is not convenient because it gives an asymmetry in the beta-functions at the IP.

Table VI- Betatron tunes, coupling angle and skew quadrupole currents for different configurations.

	I_{KLOE} = 2661 A **I1 = 100 A** **I2 = 98 A**	**I_{KLOE} = 2500 A** **I1 = 83 A** **I2 = 81 A**	**I_{KLOE} = 2500 A** **I1 = 79 A** **I2 = 85 A**
Q_x no skews	5.140	5.091	5.090
Q_y no skews	5.218	5.165	5.166
ϕ no skews	20.8°	5.7°	8.8°
Q_x	5.152	5.092	5.092
Q_y	5.208	5.164	5.164
QSKPL201 I(A)	73.8	22.0	29.5
QSKPL204 I(A)	-31.1	-19.5	-19.8
QSKPL103 I(A)	-13.0	-14.3	-10.2
QSKPL106 I(A)	-44.1	-19.7	-20.4
QSKPS101 I(A)	18.6	19.7	25.0
QSKPS104 I(A)	-7.0	8.9	16.1
QSKPS202 I(A)	-25.7	-8.9	-7.0
QSKPS205 I(A)	56.1	-8.9	-20.9

5. Conclusions

The effects of different kind of misalignment errors in the DAΦNE IRs magnetic elements on the closed orbit and machine coupling have been studied. Each one of these effects can be corrected by means of the dipole correctors and skew quadrupoles of each ring and by small mechanical adjustments (cam system in the support cylinder of the low-β quadrupoles). When the machine is operated with the detectors all these effects are combined together and with the alignment errors in the rest of the ring. The alignment errors produce coupling directly and via the closed orbit passing off axis in the machine sextupoles. As the achievement of a small coupling factor ($\kappa \leq .01$) is necessary to obtain the design luminosity the reduction of the alignment errors is crucial. The results of this note can be used both to determine the alignment tolerances and to define a correction strategy.

References

[1] S. Guiducci: "The DAΦNE Interaction Regions", 14th ICFA Workshop on "Beam Dynamics Issues for e^+e^- Factories", Frascati, October 1997.

[2] M. Bassetti, M.E. Biagini, C. Biscari: "Solenoidal Field Compensation", 14th ICFA Workshop on "Beam Dynamics Issues for e^+e^- Factories", Frascati, October 1997.

[3] F. Sgamma, Private Communication.

[4] D.A. Edwards, L. C.Teng: "Parametrization of Linear Coupled Motion in Periodic Systems", PAC 73, S. Francisco, IEEE Trans. Nucl. Sci, NS-20, N. 3, p. 885. 1973.