PRELIMINARY RESULTS ON DAΦNE OPERATION WITH OCTUPOLES

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Abstract

Octupole magnets have been installed in the DAΦNE e^+ e^- collider to compensate an octupole-like component measured in the wiggler magnets, so providing a knob to control unwanted non linear terms. DAΦNE operation is presently shared between two experiments : KLOE, measuring CP violation in Kaon decays, and DEAR studying exotic atoms. In the following, preliminary results on DAΦNE operation with octupoles and comparison with simulations are presented.

1 INTRODUCTION

The high order multipole terms in the magnetic field of the wiggler magnets of the DAΦNE e^+ e^- collider [1], mostly account for the measured betatron tune shift dependence on the particle oscillation amplitude and residual second order chromaticity. These non-linear magnetic fields affect the dynamic aperture, the beam lifetime (strictly connected with background and noise rates of the experiments), and the beam-beam performance. To simulate the consequences of such a multipolar effect in the machine model, an octupole term has been added to each wiggler, with an integrated strength of $K_3 l = 1000 \mathrm{m}^{-3}$ [2], in order to fit the non-linear coefficient of the chromaticity. To provide a knob for compensating the cubic non-linearities it has been decided to install octupole magnets in both rings with the same integrated maximum strength [3]. Three of them were installed in both rings in January 2002, as indicated in Fig. 1. This configuration has been chosen as the most feasible and less perturbative for the original machine layout. The main parameters of the magnets are reported in Table 1. In parallel with the routine operation for the experiments some work has been done to optimize the machine behaviour with the octupoles. In the following section the correction of the amplitude dependent tune shift effect and the second order chromaticity of the machine with the octupoles is described. A comparison between the simulation and the single beam experimental results coming from the octupole compensated lattice is discussed. In the last section results on octupole and sextupole tuning for the DEAR experiment configuration are presented.

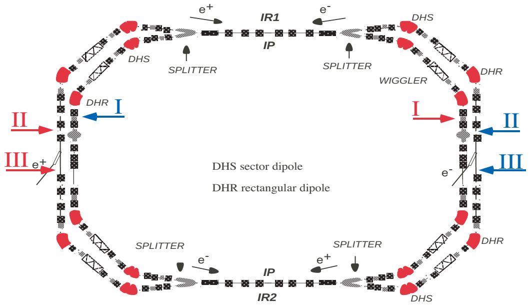

Figure 1: DAΦNE positron and electron ring layout with the octupole magnets location, (three magnets per ring, blue and red color marker respectively).

Table 1: DAΦNE octupole magnet parameters

Octupole constant	$K_3 l = 1000 \mathrm{~m}^{-3}$
Magnetic Length	$l = 0.1 \mathrm{~m}$
Bore radius	$a = 0.05 \mathrm{~m}$
Max excitation current	120 A
Current density	7 A/mm^2

2 FIRST RESULTS WITH SINGLE BEAM

The non-linear behaviour of the machine has been investigated in single beam mode. In particular, betatron tune measurements as a function of horizontal closed orbit bumps inside the wiggler magnets have shown that the tune dependence on the bump amplitude has a parabolic behaviour, on average comparable in the two rings, disappearing when the wigglers are switched off [2]. In order to study this effect, chromaticity and beam decoherence measurements have been performed on different lattices, with the wiggler magnets powered on and off [4]. The beam decoherence is measured by kicking a single bunch horizontally, using one of the injection kickers. A dynamic tracking system [5] allows to store turn-by-turn the position of the kicked bunch. The cubic non-linearity is then estimated by fitting the decoherence signal envelope. The results have proven that the wigglers are a strong source of both the second order chromaticity and the tune dependence on the oscillation amplitude. From the analysis of the wiggler magnetic measurements this cubic contribution is found to arise from the superposition of an actual fourth order term in the magnetic field and the horizontal wiggle (about 25 mm peak-to-peak) of the beam trajectory [6].

2.1 Amplitude Dependent Tune Shift

The tune shift of betatron oscillations due to octupoles can be calculated analytically:

$$\Delta Q_x = \frac{J_x}{16\pi} \int \frac{\partial^3 B}{\partial x^3} \frac{1}{(B\rho)} \beta_x^2(s) ds \approx \frac{J_x}{16\pi} \frac{K_3 l \bar{\beta}_x^2}{32\pi} \quad (1)$$

where J_x is the horizontal action variable.

From the decoherence measurements [5] we can obtain the c_{11} coefficient, characterizing the strength of the cubic non-linearity:

$$c_{11} = \frac{\Delta Q_x}{2J_x} = \frac{K_3 l \bar{\beta}_x^2}{32\pi} \qquad (2)$$

In order to check the octupole contributions to the lattice cubic non-linearity we have compared the measured c_{11} (estimated from the difference of the c_{11} coefficient measured with the octupoles on and off), and the c_{11} value obtained from the above analytical formula, using the beta functions provided by the linear optics model. The results are in good agreement as shown in Table 2.

2.2 *Second Order Chromaticity*

The second order chromaticity contribution of an octupolar term can be obtained from the general equation of the betatron motion when terms up to the second order in $\delta = \frac{\Delta p}{p}$ are considered. Keeping only the terms linear in the horizontal coordinate, x_β, the gradient error can be expressed as :

$$\Delta\kappa = -[(\kappa - m\eta_x)\delta - (\kappa - m\eta_x + \frac{1}{2} r {\eta_x}^2)\delta^2] \qquad (3)$$

where $m = \frac{l}{B\rho}\frac{\partial^2 B}{\partial x^2}$, $r = \frac{l}{B\rho}\frac{\partial^3 B}{\partial x^3}$, and η_x is the horizontal dispersion function.

Considering only the contribution coming from wigglers and octupoles, the resulting tune shift is given by:

$$\Delta Q_x = \frac{1}{8\pi}\oint [\beta_x r {\eta_x}^2 \delta^2]_{wigglers} + \frac{1}{8\pi}\oint [\beta_x r {\eta_x}^2 \delta^2]_{octupoles} \qquad (4)$$

A similar formula holds for the vertical plane.
The second order coefficients of a polynomial fit for the chromaticity measurements, performed with the DEAR lattice for the positron ring under different conditions, are reported in Table 3. Each octupole was powered at half of the maximum current, the sextupole magnets were always switched off. In the first column the second order coefficient is obtained by fitting the measurements, in the second one the same obtained by fitting the MAD [7] results for the computed ΔQ vs δ with the measured octupole term in the wigglers. The result of eq. 4 is given in the third column. The agreement is quite good for the horizontal plane, somewhat worse for the vertical one. By solving the system given by eq. 4 and its analogous for the vertical plane, it is possible to compensate the second order chromaticity coming from the wiggler magnets. Chromaticity measurements performed on the e^+ ring for the KLOE optics, for the two cases with and without the calculated correction, are shown in Fig. 2. The applied correction is about the 60% of the total calculated one; the second order coefficient of the fit is reduced from ≈ -760 down to ≈ -160 in the horizontal plane and from $\approx +640$ down to $\approx +130$ in the vertical one. The energy acceptance is also increased.

Table 2: Lattice cubic non-linearity, c_{11} coefficient values, calculated and measured.

Element	K_3l [m^{-3}]	c_{11}^{meas}	c_{11}^{calc}
OCTPL101	500	-30	-40
OCTPS101	500	+140	+130
OCTPL201	500	+110	+100

Table 3: The second order coefficient of the polinomial fit of the ΔQ vs δ curve, (horizontal and vertical plane), obtained from measurements, simulation and analytical estimates.

Horizontal plane

Element status	exp	Mad	anal.est.
Octupoles off	-1200	-1200	-1250
OCTPL101 on	-1100	-1480	-1390
OCTPS101 on	-1200	-1230	-1200
OCTPL201 on	-600	-460	-710

Vertical plane

Element status	exp	Mad	anal.est.
Octupoles off	680	250	590
OCTPL101 on	1340	1200	1000
OCTPS101 on	840	440	590
OCTPL201 on	520	-100	150

Tracking results, performed for the same lattice with octupoles on and off, showed a 20% horizontal enlargement of the dynamic aperture, obtained with 40% of this former correction, and a 30% vertical shrink, see Fig. 3. The horizontal dynamic aperture improvement is beneficial for the beam lifetime increase, that in our case is dominated by the Touschek effect. The shown vertical aperture limit corresponds to more than 100 σ_y, with the measured coupling of the machine, and this reduction is not expected to affect the lifetime. Beam lifetime and cubic coefficient c_{11}

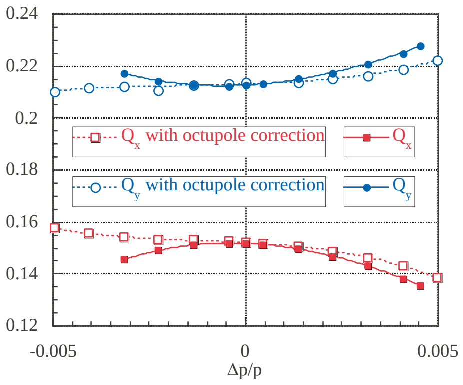

Figure 2: Measured chromaticity, with and without the octupole correction, (KLOE optics, cp progresse$^+$ ring, sextupoles on).

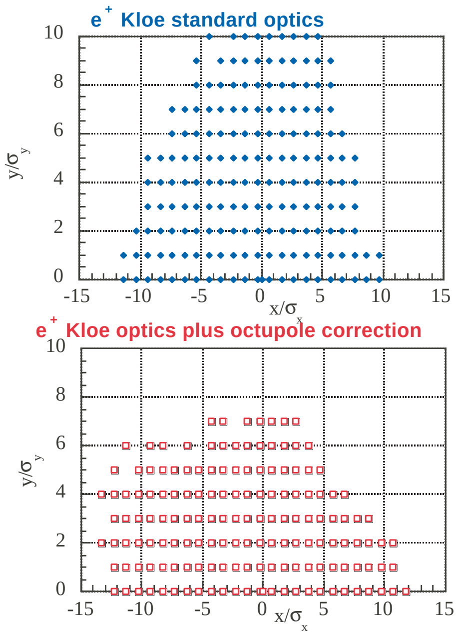

Figure 3: Above: dynamic aperture in number of sigmas of the Kloe standard optics, for positrons. Below: dynamic aperture of the same optics plus the octupole correction (σ_y full coupling, σ_x off coupling).

Table 4: Normalized beam-lifetime and c$_{11}$ vs second order chromaticity correction (Kloe optics), with a single bunch current $I_0 \approx 10\mathrm{mA}$, and $R_0 \approx 0.08$ at the sinchrotron light monitor.

τ_{norm} **[s]**	**c**$_{11}^{meas}$	applied correction [%]
1300	-77	0
1590	+15	20
1460	+80	40
1390	-	60

have been also measured: Table 4 reports the normalized beam-lifetime [8], $\tau_{norm} = \tau(\frac{I}{I_0})^{2/3}(\frac{R_0}{R})$, as a function of the applied correction, together with the measured c$_{11}$ values. Here I is the bunch current and R the ratio of the beam sizes, $R = \frac{\sigma_y}{\sigma_x}$. The best lifetime was observed for the 20% second order chromaticity correction when the c$_{11}$ value is reduced down to zero.

3 MEASUREMENTS IN COLLISION

In the DEAR experiment configuration, the tuning of the strength of two octupoles has been performed in collision to optimise peak luminosity, beam lifetime, and background rate. This optimisation work has been done also on the sextupole settings. A beam-lifetime increase of 15% has been obtained from the sextupole and a further 15% from the octupole optimisation. The octupoles have been found useful to improve the beam lifetime in collision because they compensate the strong beam-beam nonlinearities. Measurements of the chromaticity, for the standard DEAR optics and for the “octupole compensated” one are shown in Fig. 4. An energy acceptance increase of the 30% is evident. Besides, the second order coefficient is reduced of about the 15% in both horizontal and vertical plane, while the cubic non-linearity, c$_{11}$ value, is lowered from ≈ -450 down to ≈ -300.

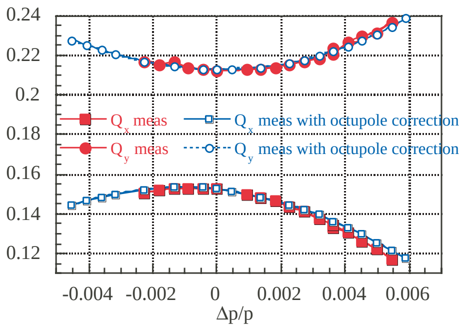

Figure 4: Measured chromaticity for the DEAR optics, e$^+$ ring, with and without octupole correction.

4 CONCLUSIONS

Measurements have been performed at DAΦNE in order to study the effect of the octupole magnets installed early this year. From the first results, the benefit of using octupoles to correct both second order chromaticity and tune shift on amplitude was clear. Simulations are still in progress to improve the non linear model. This effort will be useful to predict octupole and sextupole configurations capable to enlarge the dynamic aperture and increase the beam lifetime without loss of luminosity.

5 AKNOWLEDGMENTS

The authors wish to warmly thank J.M. Jowett for his precious suggestions and helpful discussions.

6 REFERENCES

[1] G. Vignola, DAΦNE Project Team, “DAΦNE The Frascati Φ-Factory”, PAC’93, Washington, May 1993.

[2] C. Milardi, et al., “Effects of nonlinear terms in the wiggler magnets at DAΦNE”, PAC 2001, Chicago, June 2001.

[3] C. Sanelli, S. Han, “Design of an Octupole Magnet for DAΦNE”, DAΦNE Tech. Note M-5,Frascati March 2001

[4] C. Vaccarezza, et al., “Non linear beam dynamics at DAΦNE”, PAC 2001, Chicago, June 2001.

[5] A. Drago, et al., “The dynamic tracking acquisition system for DAΦNE e$^+$ e$^-$ collider”, DIPAC 2001, Grenoble, France, 2001.

[6] M. Preger, private communication.

[7] H. Grote and F.C. Iselin, “The MAD program (Methodical Accelerator Design)”

[8] S. Guiducci, “Beam lifetime studies at DAΦNE”, these proceedings.