EFFECTS OF NONLINEAR TERMS IN THE WIGGLER MAGNETS AT DAΦNE

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Abstract

Analysis of the experimental observations and comparison with magnetic measurements have pointed out relevant nonlinear terms in the DAΦNE wigglers and in the "C" corrector magnets. Different optics configurations aimed at reducing the impact of nonlinear terms have been studied and their effects on the collider performances are presented.

1 INTRODUCTION

Nonlinerities at DAFNE [1, 2] appeared since the very beginning of commissioning, already from the measured chromaticity which exhibits a nonlinear shape even switching off all sextupole magnets. Wigglers and dipoles have been indi-cated as a possible source of those nonlinearities and studied in detail.

Experimental observations showed also a dependence of coupling on the beam position at both interaction regions, hinting the presence of some coupling source nearby.Nonlinearities have been investigated measuring: chromaticity, tunes versus closed orbit bumps, beam dynamic tracking and compared with numerical simulation.

2 WIGGLERS

Wigglers in DAΦNE are used to increase the synchrotron radiation emission and are integral part of each ring lattice.

The horizontal and vertical tunes as a function of horizontal closed orbit bumps have been measured at each wiggler, by means of four correctors whose induced energy change has been cancelled by varying the RF frequency. The sextupole magnets, obvious source of nonlinearities, were switched off.

Results are presented in Fig. 1 and Fig. 2 for electron and positron ring respectively. The horizontal tunes exhibit a clear quadratic behavior whose average value, over all wigglers, is comparable in the two rings. The different curve maxima are displaced with respect to each other and from the bump origin, due to residual orbits in each wiggler.

Repeating the orbit bump scans switching off the wigglers, gave a further confirmation about the source of the observed nonlinearities, since the quadratic shape disappeared. Figure 3 shows the comparison between the two different situations.

The vertical tunes versus horizontal bump amplitude are reported in Fig. 4 for the positron ring. They show a quadratic term due to the small vertical b values in the wigglers and a linear term coming from a residual orbit displacement in the dipoles adjacent to each wiggler. This last assumption has been confirmed by subtracting corresponding measure-ments performed with wigglers off and on, that resulted in an almost flat vertical tune. Same behaviour has been de-tected in the electron ring. The tune measurements can be fitted introducing a cubic term in each wiggler pole.

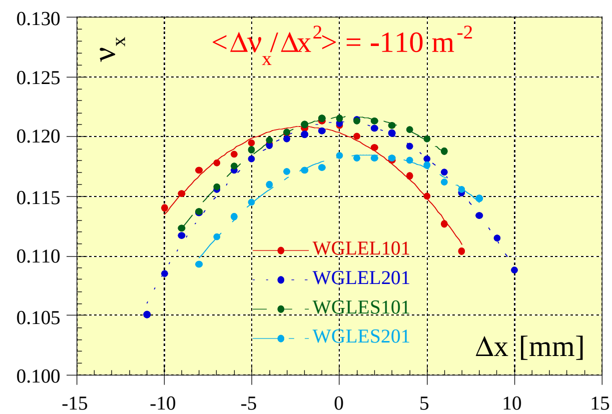

Figure 1: Horizontal tunes versus horizontal closed orbit bump at each wiggler in the electron ring.

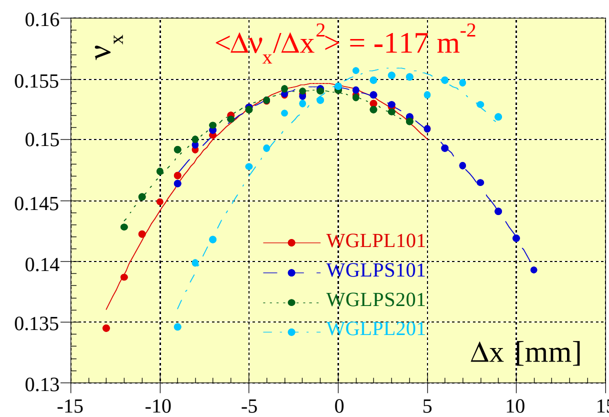

Figure 2: Horizontal tunes versus horizontal closed orbit bump at each wiggler in the positron ring.

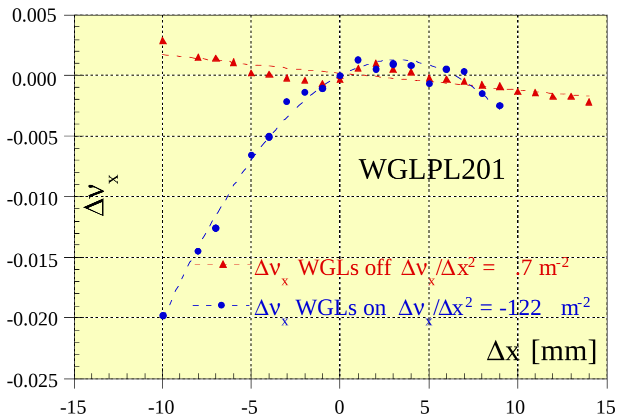

Figure 3: Horizontal tune shift versus horizontal closed orbit bump measured with the wigglers off and on.

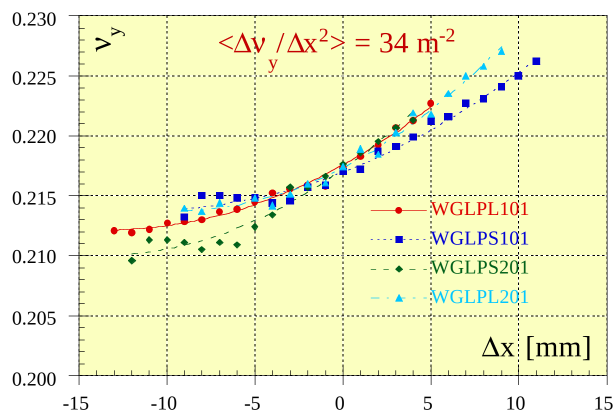

Figure 4: Vertical tunes versus horizontal closed orbit bump at each wiggler in the positron ring.

Figure 5 presents a comparison between simulated and measured horizontal tune versus horizontal closed orbit bump for a wiggler in the positron ring.

The integrated strength of the octupole-like term used in the simulation is K^3= -1000 m^{-3}. It fits also the chromaticity measurements [3].

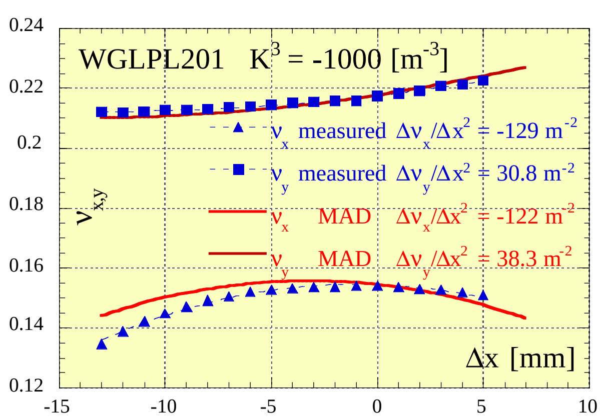

Figure 5: Comparison between measured and simulated tunes versus horizontal closed orbit bump.

Corresponding tune measurements while moving the vertical orbit can not be done due to the limited aperture of the vacuum chamber. An accurate analysis of the wiggler magnetic meas-ure-ments has shown how the cubic contribution rises from the superposition of a fourth order term in the wiggler field and the "wiggles" (~ 25 mm peak-to-peak) in the beam trajec-tory.

The same analysis by closed orbit bumps has been done at dipole location. Comparing simulated and measured tune shifts no unexpected nonlinear term has been observed.

Beam dynamic tracking [4] consists in exciting a free transverse betatron oscillation by kicking the beam and recording the transverse displacement turn by turn. This method allows to restore trajectory in the transverse phase space and can be used to measure the nonlinear coefficient C_{11} [5] relating the tune shift $\Delta\nu_x$ to the betatron oscillation amplitude J_x

$$\Delta\nu_x = 2c_{11}J_x$$

C_{11} depends on nonlinear element strengths, on betatron function at their position and on relative betatron phase advance between each other.

In DAΦNE, changing the lattice configuration, it varies in a wide range: $-6 < C_{11}\cdot 10^{-2} < 4$, see Table 1.

Table 1: Measured nonlinear coefficient for different main ring lattice configuration.

Optics	$C_{11}\cdot 10^{-2}$
KLOE optics	-6
Wigglers & Sextupoles off	+4
Wigglers off	+2
Wiggler’s field 15% reduction	-3
KLOE detuned optics	-3

The DAΦNE optics used for the KLOE experiment data taking during year 2000 had a large negative C_{11} term. Reducing the wiggler field by a 15% lowers C_{11} by a factor two, while switching off the wigglers C_{11} changes sign; this circumstance suggests the presence of other contributions than wigglers to the overall DAΦNE nonlinearities. The sextupole magnets also affect C_{11} introducing a small negative contribution. Its worth remarking that negative C_{11} values provide Landau damping beneficial to coherent beam instabilities.

3 "C" CORRECTOR MAGNETS

The "C" corrector magnets are placed at both side of each interaction region. They are used to vary the horizontal crossing angle and the relative vertical position of the colliding beams.

The observed dependence of the beam coupling on beam position at the interaction point is explained if skew magnetic terms are added in the "C" correctors.

A polynomial fit [6] of the “C” corrector magnetic measurements [7] pointed out the presence of a sextupole and a skew sextupole term when the horizontal and the vertical winding are respectively excited. By including this contribution in the “C” corrector model it was possible to fit the chromaticity and the tune shift measurements versus closed orbit bumps, see Fig. 6, as well as the coupling dependence with the beam position at the interaction point.

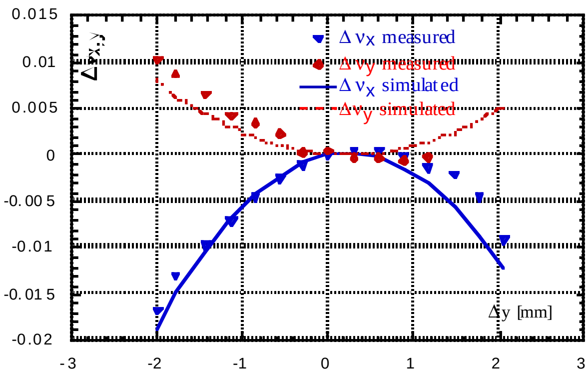

Figure 6: Tune shift dependence on displacement, using the "C" correctors, at the second interaction region.

4 OPTICS

During machine studies many different lattice configurations have been explored in order to quantify the impact of nonlinearities on beam dynamics. In this context an optics without wigglers has been computed and used for collision.

The maximum single bunch luminosity obtained was of the order of $7 \cdot 10^{28}$ cm^{-2} s^{-1}, with a maximum current of 5÷6 mA a bunch. As expected this lattice was much more sensitive to the transverse beam instabilities because the Landau damping, due to the cubic term, was removed and the damping time was 2-3 times larger than in the case of the optics with wigglers. It was clear that C_{11} positive value affects the beam-beam behaviour causing beam blow-up and lifetime degradation [8]. In this framework a new DAΦNE optics, called “detuned” [9], has been introduced with the idea of increasing the beams separation at the second interaction point and to lower the horizontal betatron function at the wigglers. This in order to have a smaller C_{11} given by the cubic terms in the wiggler, while still providing a reasonable amount of Landau damping. To implement those conditions, keeping the usual general constraints on lattice parameters, the vertical betatron function has been changed in the second interaction region removing the low-β condition. The detuned optics allowed a better coupling correction, since once eliminated the coupling contribution due to the "C" correctors, the only coupling source is the KLOE sole-noid, that is locally compensated in the interaction region.

Different lattice configurations were explored looking for the best condition of: single bunch luminosity, beam lifetime, injection efficiency and background [10] seen by the KLOE detector.

During these machine studies the detuned lattice performed definitely better from the point of view of beam–beam effects. Horizontal transverse instabilities, which in principle could expect to be stronger with this optics, were kept under control by a careful tuning of the feedback systems [11].

A single bunch luminosity of $1 \cdot 10^{30}$ cm^{-2} s^{-1} has been obtained, with a colliding current of the order of 18 mA per bunch. It was the first time that such results were achieved, in a reproducible way and with a reasonable lifetime (~2000 s), since the installation of the KLOE detector. Moreover high single bunch current up to 44 mA, that is the design value [1], has been let colliding, both for electron and positron, even if against lower current.

Detuned optics is currently used for KLOE data taking and is providing a peak luminosity of $2.8 \cdot 10^{31}$ cm^{-2} s^{-1} with a peak integrated luminosity of 1.4 pb^{-1} a day.

5 CONCLUSIONS

Nonlinearities at DAΦNE have been singled out and understood in detail. A wide set of measurements able to quantify their effects has been defined. Their impact on the collider luminosity performances has been reduced by modifing the DAΦNE optics.

Studies on a spare wiggler have been planned, in the next future, in order to suppress cubic nonlinearities by pole shimming. At the same time octupole magnets are under construction [12] to be installed in both rings in order to have predictable knobs to tune nonlinearities.

6 REFERENCES

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