DEVELOPMENTS IN LINEAR AND NON-LINEAR DAΦNE LATTICE

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Abstract

The agreement between the DAΦNE model and the measured machine parameters (betas, dispersion etc) has further improved in the 2002 runs. A better dispersion function control has been obtained by modifying the closed orbit correction algorithm, which now includes corrector strength minimization.

The model has been integrated in the accelerator control system, providing a faster and reliable tool for fine and on-line machine optics tuning.

New measurements, such as the machine second order dispersion, have proved to be very effective in studying the second order terms in the rings.

Measurements of second order chromaticity and tune shift on amplitude have extended our knowledge about the lattice up to the third order.

INTRODUCTION

DAΦNE [1], the Frascati electron-positron collider working at the energy of the Φ resonance, has run in year 2002 mainly for providing luminosity to the physics experiments. Nevertheless, 10% of its uptime has been used for machine optics studies aimed at improving the machine model understanding as well as the machine performances.

DAΦNE has two Interaction Regions (IRs), each housing an experiment: KLOE studies CP violation in kaon decays and DEAR investigates exotic atoms. The two experiments cannot run at the same time and have different collision optics, due to the strong differences in their IRs magnetic structures and in their experimental setups.

LINEAR MODEL

As a matter of fact, the model of an operating accelerator evolves continuously. At DAΦNE during the past year the lattice model experienced a remarkable evolution due to a deeper understanding of the machine behaviour.

The model is based on the MAD design program [2]. The machine element description has been completely reorganized in order to make file sharing and evolution easier. The agreement between measured and simulated Twiss parameters (betas, dispersion, tunes) has been improved. The same model describes now, using the same set of model parameters, the two collider rings. These parameters have been moved back to their nominal values, with the exception of those few, describing situations really different from the nominal one. It's worth recalling that DAΦNE is a very compact machine (97.98 m long), with no periodicity at all, running with the KLOE strong detector solenoid always on ($\int Bds$ = 2.4 Tm, to be compared with a magnetic rigidity $B\rho$ = 1.7 Tm). As a consequence the model parameters are far from being independent.

The description of the machine quadrupoles has been improved and their focusing strength related directly to the magnet power supply readout. The same has been done for the splitter magnets.

Procedures have been written, using the MAD formalism, to easily change scalar quantities such as tunes, momentum compaction and energy at constant optical functions. The same has been done for optical variables such as betatron functions, horizontal and vertical dispersion and phase advances. Special care has been dedicated to the beta functions at the IPs to investigate their impact on luminosity and beam-beam behaviour and at the position of sextupoles to optimize their efficiency and therefore the dynamic aperture. All these procedures can start from any operating point of the ring, calculate the required variations, returning the results in terms of current changes to be set on the magnetic elements specified.

The upgraded model has been ported on the Control System [3] and almost completely integrated in the Control System Software. A first version of model interface has been developed allowing comparison among different simulated optics and between simulated and measured optical functions, see Fig. 1.

The on-line model has demonstrated to be a flexible tool not only in computing, but also in exploring efficiently different machine configurations, even during experiment data taking.

DEAR Optics

ONE of the most relevant modifications to the DAΦNE optics concerns the DEAR IR [4].

The original design of the DEAR IR is based on quadrupole triplets (FDF) placed at both sides of the Interaction Point (IP) and providing a low vertical beta. In this configuration at the end of 2001, the optical functions at the IP were β^*_x = 4.4 m and β^*_y = .04 m.

By switching off the inner focusing quadrupole and by retuning the other two (FD), it has been possible to reach β^*_x = 1.7 m and β^*_y = .038 m (see Fig. 1) thus reducing the DEAR IR contribution to the chromaticity. The optics of the two rings has been kept almost unchanged outside the DEAR IR, avoiding a time consuming optimization due to different phase advances between sextupoles, between injection kickers and different beta values at the feedback pick-ups.

Last but not least, the new configuration has provided 50% reduction of β_x at the first parasitic crossing (occurring .405 m from the IP), making collisions with

100 bunches out of 120 buckets possible [5] (20 empty buckets are necessary to neutralize ion trapping effects).

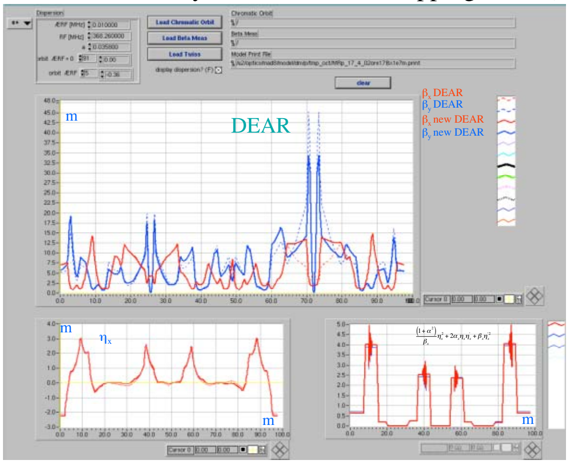

Figure 1: DEAR optics evolution presented by the Control System model interface.

Before such modifications DAΦNE was operated with interleaved bunches (one full and one empty bucket), with a maximum number of 50 bunches in collision. Further modifications in the DEAR IR optics have included an increase of the crossing angle, (from 25 to 29 mrad), and 10% reduction in the beam horizontal emittance.

In a four months run the collider has provided an integrated luminosity $L_{\int 2002}$ = 68 pb^{-1}(to be compared with $L_{\int 2001}$ = 3 pb^{-1}), enough for the DEAR experiment to go through its preliminary phase with the observation of kaonic Nitrogen, and to to make the first experimental test of the hydrogen target.

KLOE Optics

The extension of the β^*_x reduction adopted for the DEAR optics to the KLOE one has not been straightforward since low-β at the KLOE IP is realized with a couple of permanent quadrupole triplets embedded in the field of the experimental solenoid, whose field is compensated by two superconducting solenoids, one at each side of the IP. In this context it is not possible to locally modify the IR optics.

The KLOE horizontal beta has been modified by changing the currents of the quadrupoles closest to the IR, going, in successive steps, from β^*_x = 5.7 m to β^*_x = 2.7 m, the minimum compatible with the β_x limitation imposed, at the splitter magnets by stay-clear requirements. β^*_y has been only slightly changed, from .03 to .026 m, the minimum value compatible with the hour-glass effect. The horizontal emittance has been reduced by 10% in both rings also for the KLOE optics.

The reduction in β^*_x has been remarkable (~ 50%), but not enough to avoide parasitic crossing, in fact during 100 bunches operations problems such as bunch pattern degradation, beam blow-up and peak luminosity limitation have been still observed. Nevertheless the modified KLOE optics has given a relevant contribution to the luminosity improvement summarized in Table 1. The peak luminosity has reached L_{peak} = $.8 \cdot 10^{32}$ $cm^{-2}s^{-1}$, the best integrated luminosity over a day $L_{\int day}$ = 4.8 pb^{-1} and the luminosity lifetime τ_L = .6 hours.

Table 1: DAΦNE luminosity

	2001	2002
KLOE L_{peak} cm^{-2} s^{-1}	$.5 \cdot 10^{32}$	$.8 \cdot 10^{32}$ n_b=49
KLOE $L_{\int day}$ pb^{-1}	3.2	4.8 n_b=49
DEAR L_{peak} cm^{-2} s^{-1}	$.1 \cdot 10^{32}$	$.7 \cdot 10^{32}$ n_b=100
DEAR $L_{\int day}$ pb^{-1}	.24	2.2 n_b=100

CLOSED ORBIT CORRECTION

The closed orbit correction application has been upgraded and now includes explicitly a steering strength minimization procedure [6]. The steering strength minimization is beneficial in avoiding stray dispersion bumps as well as local orbit deviations due to the presence of couples of strong nearby perturbations; at DAΦNE it has proved to be powerful in minimizing parasitic dispersion and as well as in limiting the background rate seen from the experimental detectors.

NON LINEAR MODEL

Non-linearities at DAΦNE have been observed and studied from the beginning of machine operation; they essentially come from higher order components in the field of the wigglers [7]. Their negative influence affects machine dynamic aperture and beam lifetime and therefore the integrated luminosity. Moreover, non-linearities influence beam-beam behaviour inducing beam blow-up, thus reducing the achievable peak luminosity.

In 2002 three ocupole magnets have been installed in each ring in order to provide non-linearities tuning [8].

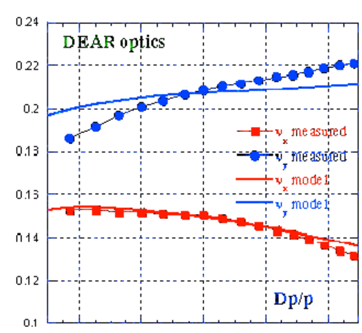

Figure 2: Tune shift versus energy for the DEAR optics.

The non-linear model has been upgraded to include the new elements and sextupole terms detected during the wiggler magnetic measurements have been included in the wiggler model.

The agreement between measured and computed chromaticity has been improved both at the first and second order, as shown in Fig. 2 for the DEAR optics and in Fig. 3 for the KLOE one. Still there is some discrepancy in the vertical plane, but it is small when compared to the machine chromaticity without sextupoles. The tune shift on amplitude predicted from the model is very close to the measured one [9], see Table 2.

Table 2: Strength of the cubic non-linearity

	$C_{11}^{\ measured}$ m^{-1}	$C_{11}^{\ model}$ m^{-1}
Sextupole on	-175.	-187.5
Sextupole off	-73.11	-98.5

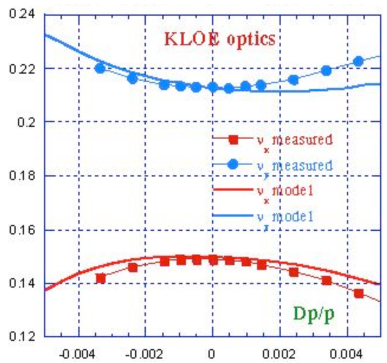

Figure 3: Tune shift versus energy for the KLOE optics

The second order dispersion η_{1x} has been measured as orbit shift versus energy and it is quite similar, for the KLOE optics (see Fig. 4), to the one predicted by the model.

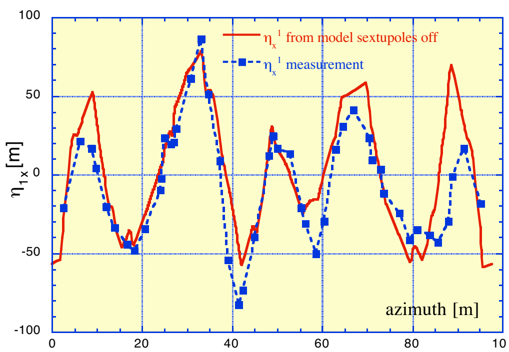

Figure 4: η_{1x} (sextupole off).

Even the computed sextupole contribution to $\eta_x^{\ 1}$ agrees with the measured one (Fig. 5) confirming once more that the betatron functions predicted by the model at the sextupoles are the same as the real ones in the machine.

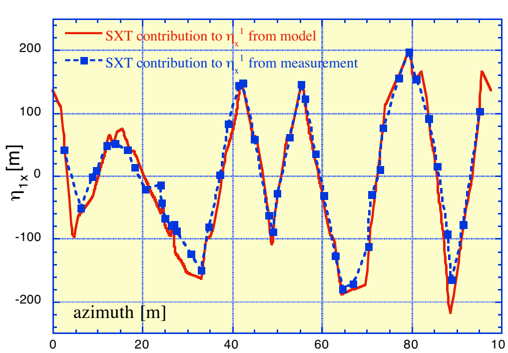

Figure 5:Sextupole contribution to η_{1x}.

Collider operation has shown that the reduction of η_{1x} is beneficial for dynamical aperture and beam-beam behaviour, since the best luminosity results have been obtained after cancelling, almost completely η_{1x} in the KLOE IR (IP at 25.72 m), see Fig. 6.

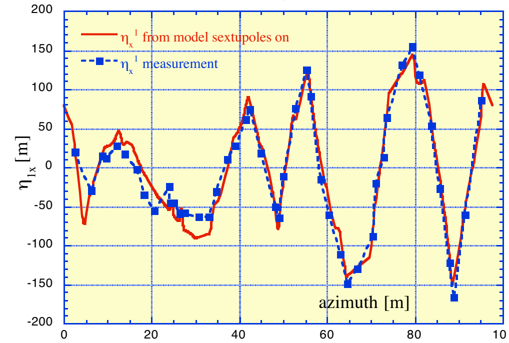

Figure 6: η_{1x} (sextupole on).

CONCLUSIONS

The linear and non-linear model has been extensively used to optimize DAΦNE optics, contributing to a gain of 60% in the peak luminosity and 50% in the daily integrated luminosity, with respect to the year 2001.

The improvements obtained in decreasing β^*_x at DEAR have suggested a new design in which the two IRs are rebuilt substituting quadrupole triplets with doublet ones. With this new configuration it will be possible to reach β^*_x as low as 1.5 m and collide with 100 bunches at both IPs, which could allow, assuming a current per bunch I_b = 20 mA, a total current per beam I_t = 2 A.

In this context it seems quite reasonable to expect further luminosity increases.

REFERENCES

[1] G. Vignola and DAΦNE Project Team, "DAΦNE the Frascati Φ Factory", PAC 93, Washington, May 1993.

[2] H. Grote and F. C. Iselin "The MAD program".

[3] G. Di Pirro et al., "DANTE Control System for DAΦNE based on Macintosh and LabView", PCaPAC 2002, Frascati, Italy.

[4] C. Biscari et al., "Half β^*_x at DEAR", DAΦNE Technical Note, BM-9, April 2002.

[5] A. Drago et al. "100 Bunches Operations at DAΦNE", this conference.

[6] P. Raimondi et al., "Emittance Optimization with Dispersion Free Steering at LEP", CERN-SL-2000-YY OP, DAΦNE May 2000.

[7] C. Milardi, " Effects of non-linear terms in the wiggler magnets at DAΦNE", PAC 01, Chicago, June 2001.

[8] C. Vaccarezza et al., "Preliminary results on DAΦNE operation with octupoles", EPAC 02, Paris, June '01.

[9] A. Drago et al., "The dynamic tracking acquisition system for e^+ e^- collider", DIPAC 01, Grenoble, France.