OPTICS MEASUREMENTS IN DAΦNE

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Abstract

In the two rings of the DAΦNE collider the presence of two Interaction Regions and of the experimental solenoid and the absence of periodicity make the assessment of the linear optics a challenging issue. Due to the low integer part of the tune, matching of the interaction parameters, emittance tuning or movements in the tune diagram always involve the whole ring optics: the collider model is therefore a critical tool to control luminosity. The Response Matrix is extensively used in the operation for closed orbit correction, localized bumps and especially in restoring the optimum luminosity conditions on the reference orbit. The Response Matrix information is also exploited for coupling analysis. Measurements on transverse space dynamic tracking are finally reported.

1 INTRODUCTION

DAΦNE [1] is a low energy, double ring, electron-positron collider. The two rings are symmetric and share two Interaction Regions (IRs). In one of them the KLOE [2] detector has been installed and is presently running.

The DAΦNE optics have been designed to optimize the single bunch luminosity. A reasonably large horizontal emittance, ε_x, limits the beam-beam tune shift for a given bunch charge. Four wigglers per ring placed in a dispersive region, inside the arcs, allow ε_x tunability. They introduce an extra radiation damping, welcome in a low energy ring in which the natural damping time corresponds to hundred thousand turns. Transverse coupling may excite resonances and seriously limit the single bunch luminosity by vertical emittance blowup, and colliding overlap reduction. The Kloe detector, with its 2.4 Tm solenoidal field, represents a strong perturbation to the collider lattice and may introduce a huge source of coupling if not properly compensated.

Luminosity is the last step of a collider tuning-up process. Accurate measurements of orbit, betatron functions, coupling, and dynamic aperture prelude to any luminosity achievement.

2 ORBIT

A fast orbit measurement system [3] is used extensively for position, dispersion and Response Matrix (RM) measurements. A *golden orbit* corresponds to the optimum luminosity set-up; restoring the *golden orbit* the best luminosity condition is immediately reproduced.

Closed orbit correction, beside the absolute orbit reduction, is aimed to the minimization of the transverse displacement in sextupoles, of the vertical dispersion and related coupling. It is performed using the orbit decomposition by eigenvalue of the measured RM, allowing to free the correction process from any model approximation and to minimize the corrector strengths. This method has been also used to compute localized displacement bumps. IP bumps, with the accuracy of the order of few μm, are routinely used for beam-beam scans and luminosity optimization [4].

3 MODEL

In the DAΦNE lattice the behaviour of the phase advance along the ring is tightly conditioned by the two IRs, the arcs, housing the wigglers, and the injection region. Flexibility is guaranteed by individually powered quadrupoles. Since any change in emittance, momentum compaction and tune involve the whole ring optics, a very reliable model is required. The first optical model of the rings was based on magnetic measurements of all the elements. Then measurements of betatron functions, dispersion and RM have been used to update the optical description of all the magnets. The betatron functions are measured by the gradient kick method in all quadrupoles. This method cannot be applied to the KLOE IR and its low beta quadrupoles, which are permanent magnet ones and have no steering coils. A variation in the compensator solenoid field is used to check the symmetry of the betatron functions around the IP and the position of the low-beta waists in the two rings.

The optical model takes into account:

- Splitter and dipole fringing fields.
- Wiggler fringing fields and focusing on the trajectory due to the quadratic term in the vertical field.
- Longitudinal behaviour of solenoid field of KLOE and C_2 and C_1 compensators.
- Longitudinal behaviour of the gradient of the permanent magnet quadrupoles in KLOE low beta, which due to the small ratio between gap and magnetic length are not well represented by the step model.
- Tilt of these quadrupoles, which compensate the transverse rotation introduced by the KLOE solenoid.

The two rings have the same magnetic structure. The difference between their tunes, with equal quadrupole settings, is of the order of $5*10^{-2}$, which correspond to 1% of the total tune. This difference is essentially due to the stray fields of the transfer line magnets, which introduce an asymmetry between the two ring lattices, and to the presence of ion clearing electrodes in the electron ring.

The model reproduces the betatron functions within 5% (see Fig. 1), the betatron tunes within 0.01 (0.2% of the absolute value), the dispersion function within few cm (see Fig. 2), the emittance within 10% and the momentum compaction within 1%. All these features allow exploring different working points, as well as emittance and momentum compaction tuning.

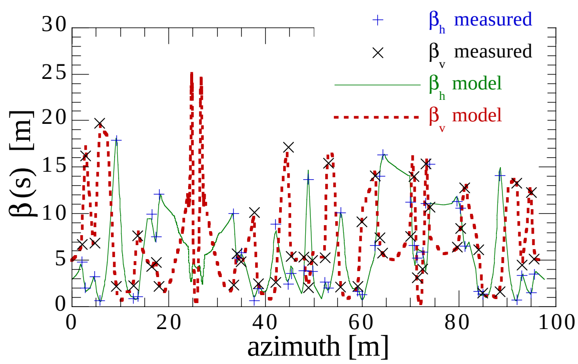

Figure1: Comparison between computed and measured betatron function for the electron ring.

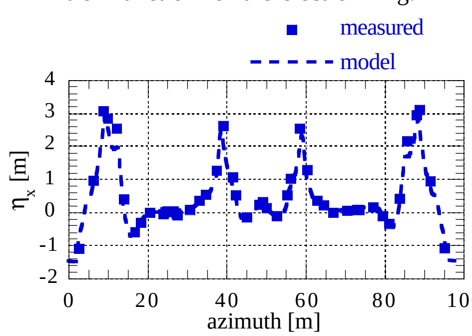

Figure 2: Comparison between computed and measured horizontal dispersion for the electron ring.

4 COUPLING

In DAΦNE the design beam-beam tune shifts in the horizontal and vertical plane are equal, obtained with 1% ratio between vertical and horizontal emittances and between vertical and horizontal β* (β at the IP). Just after the installation of the KLOE detector, tuning compensators and skew quadrupoles, the κ design value of 1% was obtained [5], but still the beam-beam behaviour was affected by coupling.

In the presence of coupling the betatron motion is no more purely horizontal and vertical [6]. Nevertheless it is still a combination of two independent modes, the pseudo-horizontal mode *a* and the pseudo-vertical mode *b*. The beam parameters at the IP are described in the normal mode formalism and the beam sizes depend on both modes. In a flat beam ring with no vertical dipoles, the emittance of the *b* mode, ε_b and therefore the coupling parameter κ, rise from transfer of amplitude oscillation of *a* mode around the ring. The contribution of any linear coupling source to ε_b is quadratic, while the contribution to the tilt of the pseudo-horizontal mode is linear. At the IP the decrease of luminosity due to coupling may come from large ε_b, relative tilt between the axis of the *a* modes in the two rings and from the projection of the *a* mode onto the vertical plane. The simulation analysis of the different coupling source in DAΦNE [7] [8] has shown that values of κ of the order of 1% are compatible with tilt values, at the IP, of the order of ±0.5%. Moreover the *a* mode projection in the vertical plane can even double the beam vertical size at the IP, depending on the source type and to its phase advance with respect to the IP. The κ design value of the order of 1% is therefore large for DAΦNE.

4.3 Coupling Correction

The design tolerances on all the magnet alignments in both rings are well satisfied, as demonstrated by the collider commissioning without Kloe, when values of κ of 0.4 % were obtained. The situation with the detector is well different, since the solenoidal compensation scheme cancel the coupling only if the low-beta quadrupole tilts and the beam rotation, introduced by detector and compensator fields, are exactly matched and the beam energy has its nominal value.

Survey measurements on the low-beta triplets, done in last winter shutdown, showed a tilt misalignment of the order of 1°, which therefore reduce the efficiency of the compensation method. Operative experience pointed out another source of coupling in the second IR, where beams are presently vertically separated and pass off–axis in the stray field of the adjacent splitter magnets. Simulation showed how this coupling source propagates around the ring with almost the same phase advance of a coupling source rising in the Kloe region. Tuning the solenoid fields and the beam separation in IP2 can therefore produce a global decoupling. Using this method the DAΦNE coupling has been corrected to values of 0.2% in the positron ring and 0.3% in the electron one, without using any skew quadrupole.

The more obvious measurement of the coupling is done at the Synchrotron Light Monitor. Beam-beam scans done at very low current [4], so not affected by beam-beam effect, provide a more accurate measurement of the dimension of the colliding beam overlap. Values of convoluted vertical sigma a factor 3 below the design ones confirm the SLM estimation.

Figure 3 presents the κ measurements as a function of the KLOE and compensator solenoidal field, square points correspond to the actual working configuration.

More information about the coupling has been obtained from the measured RM. The horizontal and vertical closed orbit distortion caused by all horizontal steerings, at each beam position monitor, are used to evaluate the average amount of horizontal oscillation transferred to the vertical plane. The transferred oscillation amplitude is presented as the slope, α, of the linear interpolation of the horizontal and vertical displacements at each azimuth along the machine. A comparison between ring configuration corresponding to different solenoid setups and κ values are presented in Fig. 4.

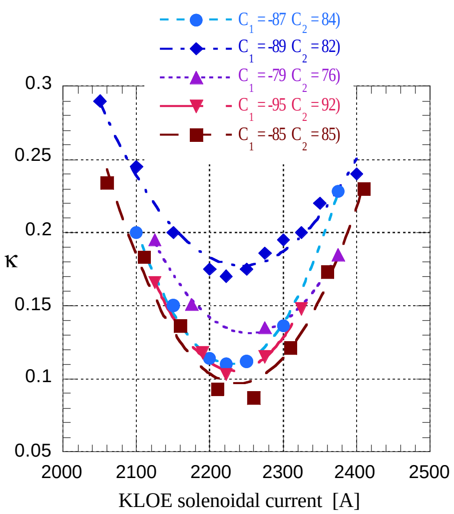

Figure 3: Measured κ value as a function of the KLOE and compensator solenoidal fields.

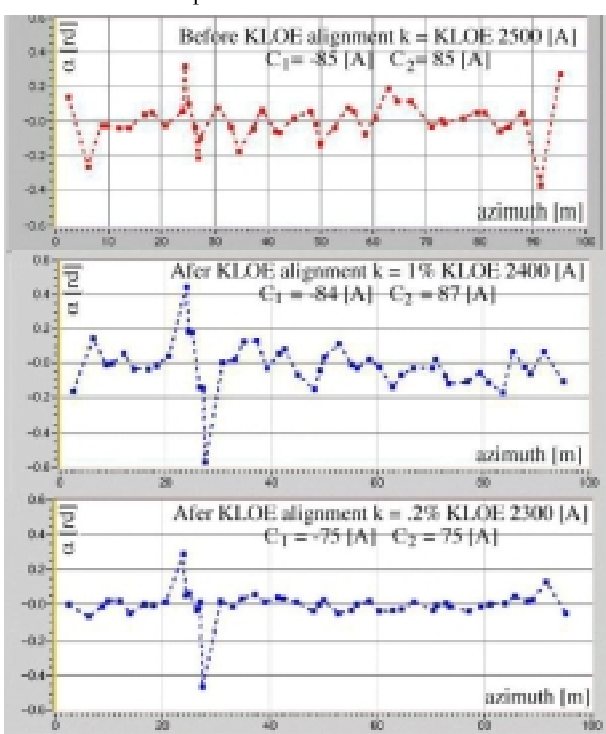

Figure 4: Average amount of horizontal oscillation transferred to the vertical plane as obtained from the measured RM.

5 TRANSVERSE SPACE ANALYSIS

The effect of machine non-linearity on the particle motion are investigated using a phase space monitor, a system allowing to store and analyze turn-by-turn the position of a kicked beam. A single bunch is excited horizontally pulsing one of the injection kickers. The coherent betatron oscillation amplitude is recorded over 2048 turns providing information on trajectories in the phase space and betatron tune shifts with amplitude. The coherent oscillation amplitude decay through nonlinear filamentation helps to estimate directly nonlinear tune spread due to the nonlinearities, and provides a quick tool to improve the dynamic aperture by varying sextupole settings.

Figure 5 shows an example of measured coherent oscillation decay and respective phase space trajectories, found by applying the Hilbert transform to the measured signal [9]. The seven branches in the phase space suggest that the betatron tune is close to the seventh order resonance.

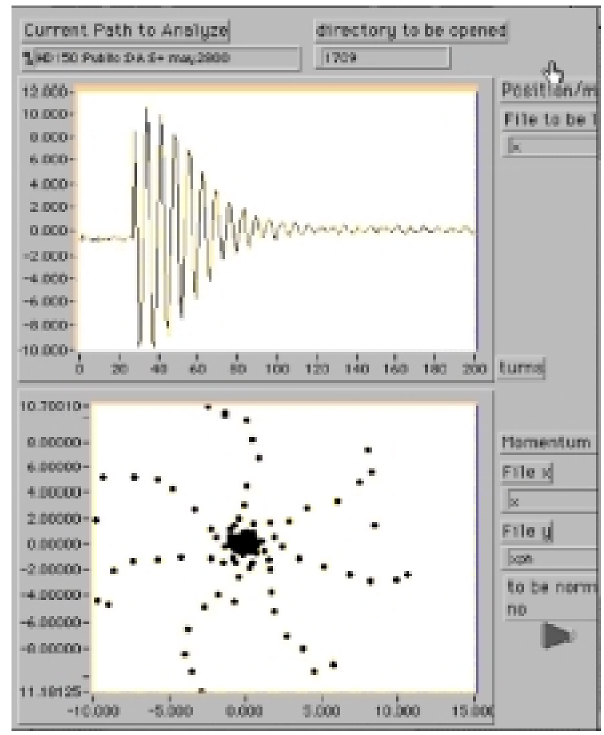

Figure 5: Coherent oscillation decay and corresponding phase space trajectories.

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