

BETATRON COUPLING NUMERICAL STUDY AT ELETTRA

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Abstract

Elettra lacks skew quadrupoles and the coupling is controlled via the vertical orbit. Elettra has typical operational coupling of 1%, values as low as 0.3% were reached but however not easily established and reproducible. In order to control the coupling in a reproducible manner skew quadrupoles must be installed. Simulations of the coupling and correction of it for the Elettra synchrotron light source were performed and are here presented. The numerical study is based on measured machine misalignments and carried out with the ELEGANT particle tracking code. The inclusion of families of skew quadrupoles in the existing lattice is investigated and shown to be conclusive for the coupling correction at the level of 0.1%.

INTRODUCTION

Near and long term plans of upgrading Elettra are being considered [1]. Among them, correction of the electron beam betatron and chromatic coupling with skew quadrupoles. A natural way to face this problem is with numerical simulations of the electron beam dynamics including machine errors, orbit and tune correction, nonlinear maps, physical aperture restrictions, dynamic aperture and frequency map, momentum acceptance, off energy dynamics, finally coupling control with skew quadrupoles to produce either flat or (close to) round beam. In this article, we aim to reduce the total coupling, intended as the vertical to the horizontal emittance ratio, to the level of 0.1% in the bare lattice.

In the past, numerical and experimental studies concerning coupling were performed with the support of several different programs [2–4]. In order to use as few as possible software, we recently decided to model Elettra with ELEGANT [5].

ELEGANT MODELING

Elettra was modelled in ELEGANT with symplectic (canonical) elements and the particle dynamics treated up to the third order in the particle coordinates. Figure 1 shows the ring nominal optics. Classical synchrotron radiation and RF cavities were included to simulate synchrotron oscillations and the beam at equilibrium. So far, no injection process has been studied. Machine errors for the stored beam were included. These rely on a ring alignment survey [6]. Translations (10–500 μm range), roll angle (10–300 μrad range) and magnetic field tolerances in the range 0.01–0.1% rms of the dipole, quadrupole and sextupole magnets were included. Beam position monitors (BPMs) were also affected by roll angle

(50 μrad rms) and noisy signal (1 μm rms resolution). So far, only a representative set of errors has been used that produces an amount of coupling of 1%, so to reflect the state of the real machine. A statistics on machine errors is in the plan.

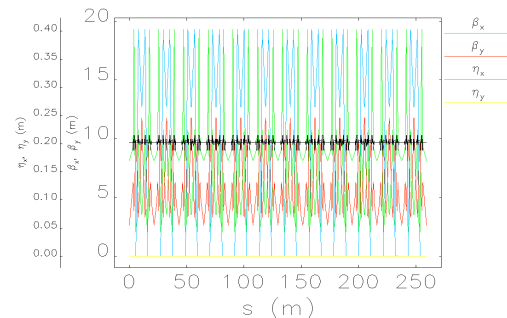


Figure 1: Elettra nominal optics along the 12 double-bend achromats.

BENCHMARK WITH PREVIOUS WORKS

In order to understand the correctness of our modelling in ELEGANT, we computed the dynamic aperture (DA), the momentum acceptance and the Touschek lifetime for the bare lattice. We then compared our simulation outputs with consolidated results [2,4,7]. These relied, as an example, on the use of the Racetrack code [8], which is also able to simulate the focusing effect of IDs.

The transverse dynamics was studied in ELEGANT with particle tracking runs up to 2000 turns. The DA was computed and the tune diffusion, $\log_{10}(\Delta v_x^2 + \Delta v_y^2)$ recorded as function of the particle's amplitude of motion. In the simulation, machine errors were included, then linear chromaticities corrected to +1 in both transverse planes and the betatron tunes corrected to the nominal working point (14.3, 8.2). However, no correction of the linear optics (e.g., beta-beating) was carried out. Then, frequency map analysis (FMA) was used to highlight the most dangerous, for the motion stability, resonances.

The DA was computed in proximity of the injection point. Physical restrictions of the vacuum chamber in correspondence of low-gap out-of-vacuum Insertion Devices (IDs) were included. The minimum vertical aperture restriction is 7 mm full gap over a few meters in length. Eleven low-gap chambers were included in the model. When the bare lattice was considered (no IDs), the vertical DA was limited by the physical restrictions. The DA for the bare lattice computed by ELEGANT (see Fig.2) was in rough agreement with previous Racetrack results and measurements [4,7]. A preliminary off-energy dynamics study was also given by the computation of the tunes vs. the reference energy deviation (not shown). In

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this way, crossing of resonances could be estimated and, in the continuing of this work, compared with off energy DA and FMA.

A momentum acceptance of approximately 3% predicted by ELEGANT fits well the Elettra RF acceptance. Finally, the Touschek lifetime was computed for a 100–300 mA average current at 2.0 GeV and found in agreement with previous studies [2]. The simulation of effects from IDs is in progress and not reported here.

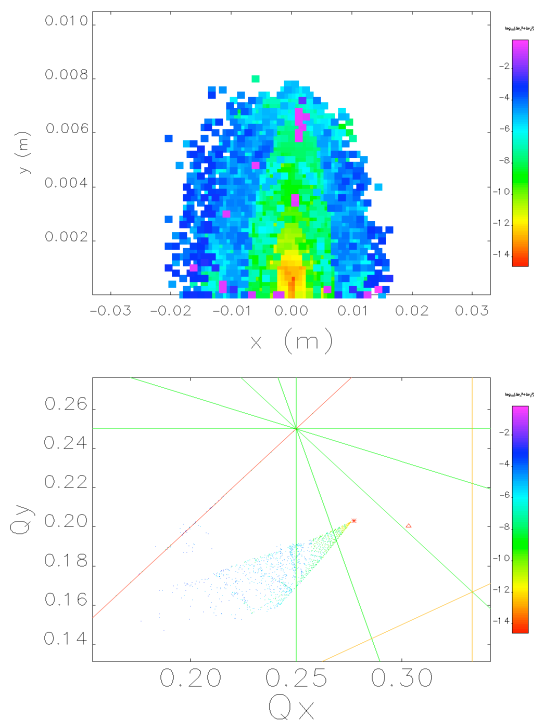


Figure 2: Dynamic aperture (top) and working diagram (bottom) for the Elettra bare lattice. The colour scale is for the tune diffusion coefficient.

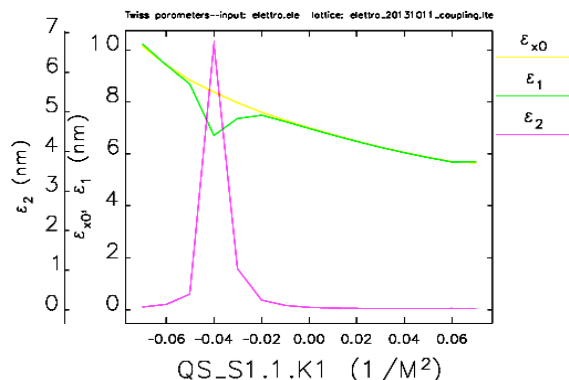
COUPLING

Elettra lacks skew quadrupoles. For this reason, so far the 1% coupling has been controlled via the vertical orbit in the real machine. Such coupling was evaluated in the past from measurements of the beam lifetime vs. the vertical dispersion, then fitting the experimental curve with the Touschek lifetime calculations by varying the coupling contribution [2]. Values as low as 0.3% were reached; nevertheless, they are hardly reproducible. In order to control the coupling in a systematic manner, skew quadrupoles must be installed. Such a study would also be mandatory for the upgrade of the entire lattice [1]. Betatron coupling is computed in ELEGANT as depicted in [9]. Chromatic coupling due to spurious vertical dispersion is also accounted for. The user can supervise the ratio of the vertical and the horizontal emittance at equilibrium, either for the betatron motion only or with the inclusion of energy dispersion. All machine errors and orbit distortion are included in the computation of the coupling integral and the vertical dispersion.

Simulations of the betatron coupling for one representative set of machine errors of the bare lattice were performed. Coupling correction to the level of 0.1% was investigated through the inclusion of at most 12 skew quadrupoles (SQs) in the existing lattice. Each SQ would be installed inside the unit double-bend achromat. The SQs would correct simultaneously the betatron and the chromatic coupling owing to the modulation of the vertical dispersion. The impact of the coupling correction on the betatron tunes can in principle be compensated by normal quadrupoles outside the achromat. However, in the following the tune correction is not applied, so to see the effect of the SQs on the working point as their strengths is varied. We started grouping the SQs in two families. We did a 2-D scan of the families' strengths looking to the reduction of the rms and the maximum vertical dispersion, the emittance ratio, the distance of the normal mode-1 emittance from the horizontal emittance and the distance of the perturbed tunes from the difference resonance. So far, no well-defined algorithm for the optimization of the coupling correction has been used. It is nevertheless in the plan. Also, the optimum number of families (*i.e.*, independent power supplies) of SQs has to be identified and the IDs included in the simulation.

We show first in Fig.3 how the emittance ratio and the normal mode emittances behave when the tunes move close to the difference resonance during the scan of one family of SQ's strength. As the resonance is crossed, the mode-1 emittance (ϵ_1) diverges from the horizontal one at equilibrium (ϵ_0), while the mode-2 emittance (ϵ_2) blows up due to the transfer of action from the horizontal to the vertical plane. Correspondingly, the emittance ratio blows up (mid plot). We also notice that the minimum of the betatron emittance ratio requires a different strength than the minimum of the total emittance ratio (the latter is computed including the spurious vertical dispersion). This is consistent with the behaviour of the rms and the maximum vertical dispersion modulated by the SQs (bottom plot).

A lower coupling is predicted in Fig.4, where the betatron emittance ratio is lowered down to 0.1% while the total ratio stays almost constant at 0.3%.



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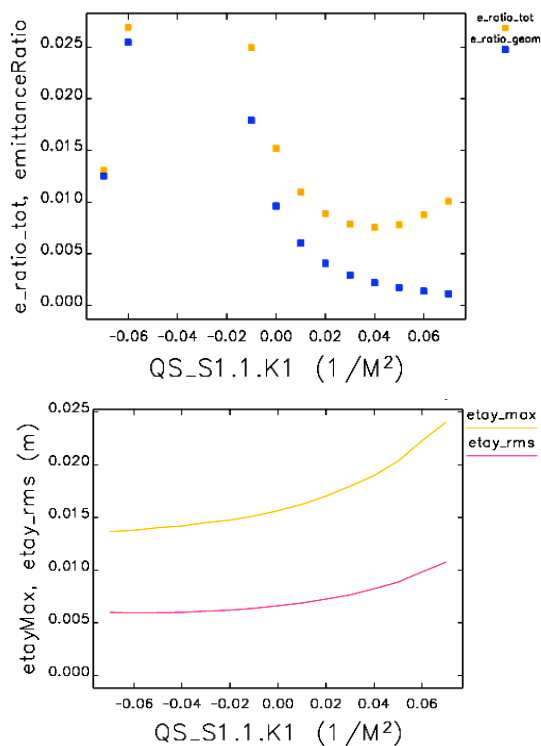


Figure 3: Scan of one SQs family's strength while looking to the horizontal and normal mode emittances (top), to the emittance ratio (middle), and to the spurious vertical dispersion.

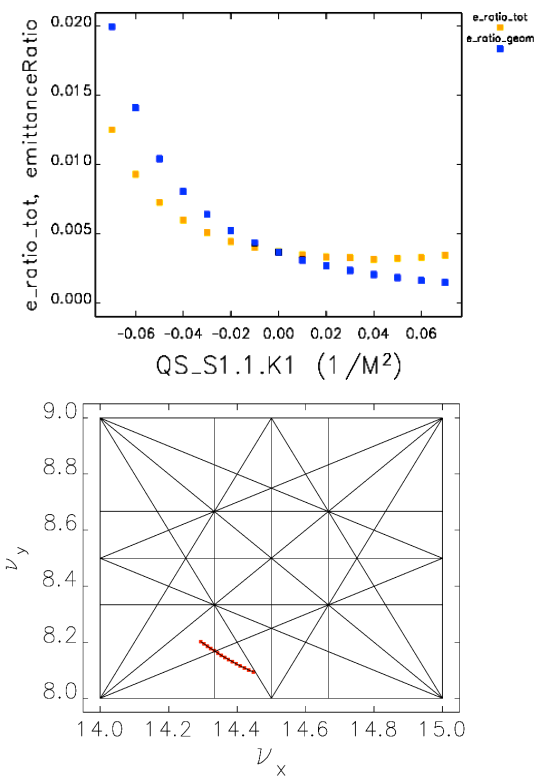


Figure 4: Scan of one SQs family's strength while looking to the emittance ratio, total and betatron only (top), and to the tune diagram (bottom).

CONCLUSIONS AND OUTLOOK

The ELEGANT package was used to study a possible installation scenario of SQs for coupling control in Elettra. To have the most realistic simulation of the transverse nonlinear dynamics, higher order transport matrices, synchrotron motion and classical synchrotron radiation were included. The momentum acceptance in the presence of realistic aperture physical restrictions and the betatron and chromatic coupling, whose control was simulated with the inclusion of 12 SQs (one per double-bend achromat cell) was computed. Two families of SQs may ensure coupling correction to the 0.1% level. It is planned to establish a well-defined algorithm for the search of the minimum coupling as function of the number of SQ families and the SQs' strength in order to consolidate these preliminary results. Seen the reliable results as compared with previous simulations and measurements, it was decided to continue the ELEGANT modelling of Elettra in order to carry on a statistical study of machine errors and the analysis of the nonlinear dynamics in the presence of IDs.

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