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LIFETIME CORRECTION USING FAST-OFF-ENERGY RESPONSE MATRIX MEASUREMENTS

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Abstract

Following the measurements done at MAX-IV [1], we try to exploit for the ESRF-EBS Storage Ring (SR) off-energy response matrix measurement for the optimization of Touschek lifetime. The measurements performed with fast AC steerers on- and off-energy are analyzed and fitted producing an effective model including quadrupole and sextupole errors. Several alternatives to extrapolate sextupoles strengths for correction are compared in terms of lifetime. For the time being none of the corrections could produce better lifetime than the existing empirically optimized set of sextupoles.

INTRODUCTION

The ESRF-EBS SR Touschek lifetime is optimized routinely using an empirical approach [2]. In the recent paper by Olsson et al. [1] it was shown that it is possible based on on- and off-energy orbit response matrix measurements to determine a set of sextupoles able to improve the lifetime, by correcting the off-energy optics of the SR.

Having seen the promising results presented, the Nonlinear optics from off-Energy Closed Orbit (NOECO) technique shown in [1] is applied to the EBS SR. This paper reports about the initial simulations and the preliminary results obtained during the first two dedicated experimental shifts.

NOECO CORRECTION

The NOECO correction exploits the dependence on sextupole strengths of the off-energy orbit response matrix. A set of normal sextupole correctors $K_{\mathrm{sext}}^{\mathrm{cor}}$ is computed based on two off-energy orbit response matrices (ORM) and dispersion (η_h) measurements by solving the following system of equations using a SVD pseudo-inverse:

$$V = \frac{(ORM, \alpha_\eta\, \eta_h)_{+\delta} - (ORM, \alpha_\eta\, \eta_h)_{-\delta}}{\partial\delta} \quad (1)$$

$$V_{\mathrm{measured}} - V_{\mathrm{model}} = \frac{\partial V}{\partial K_{\mathrm{sext}}} K_{\mathrm{sext}}^{\mathrm{cor}} \quad (2)$$

where V is a vector including the variation of all the ORM elements and horizontal dispersion with respect to an energy deviation δ and α_η is a weight to determine the relative balance among ORM and η_h correction (initially set to give similar amplitude to the dispersion response compared to the ORM and then empirically tuned). Only the diagonal blocks (horizontal response to an horizontal steerer and vertical response to a vertical steerer) of the ORM are used. The Jacobian $\partial V / \partial K_{\mathrm{sext}}$ is computed numerically using the Matlab [3] version of Accelerator Toolbox (AT) [4]. In the analysis all the BPMs are considered equal and no weight factor is used. For the details of the correction we refer to the original paper.

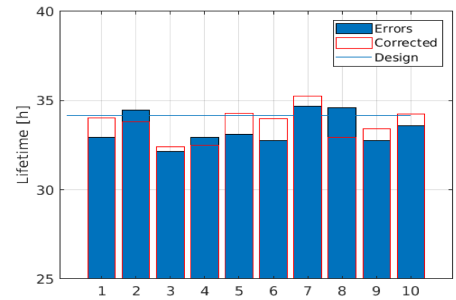

Figure 1: Lifetime before and after NOECO correction for 10 simulated lattices including errors and corrections with identical α_η and number of singular values. Three seeds out of ten require ad-hoc tuning of α_η and number of singular values in order to improve the lifetime.

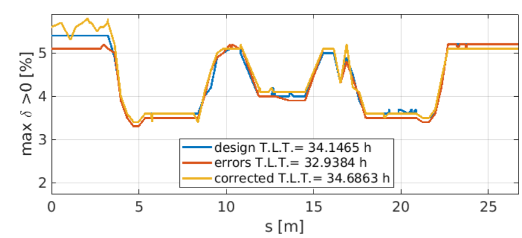

Figure 2: Local momentum acceptance for the first cell of the EBS SR for the design lattice without errors, a lattice with errors and the same lattice with sextupole corrections computed using NOECO.

SIMULATIONS

Simulations of the NOECO correction were done in AT using lattices with realistic errors and corrections based on a commissioning-like simulation loop [5]. For most of the seeds considered the computed lifetime improved after NOECO correction, as shown in Fig. 1. With a change of the singular values or of the weights α_η, seeds 2, 4 and 8 had their simulated lifetime improved compared to the one without NOECO sextupole correction. The local momentum acceptance for the first cell of the SR is compared in Fig. 2 before and after correction to the one without any errors. The NOECO correction effectively restores the ideal momentum acceptance. The injection efficiencies contextually computed for each seed do not show significant variations (<1%). The sextupole errors present in these lattices are taken from a random Gaussian with standard deviation of 0.35% of the main sextupole field as defined by the magnet

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design simulations [6]. The sextupole corrections strengths obtained with NOECO are of the same amplitude but uncorrelated. The corrections are small compared to the main magnet gradients, and well within the available power supply limits. An energy shift of 0.33 % is used in these simulations.

MEASUREMENTS

Given the promising results in simulations, two dedicated machine time shifts were devoted to the test with beam of the NOECO correction.

The capability to measure off-energy ORM and dispersion was included in the operation optics correction application [7]. Due to the large number of ORM necessary, the ORM measurement was done using the Fast Orbit Feedback AC steerers.

Fast Orbit Response Matrix

Fast ORM are measured exciting sequentially the 96 AC steerers of the ring with a sine wave signal and detect the resulting orbit variation amplitude at the same frequency with the 320 BPMs in the ring. The excitation frequency is 21 Hz such that it is well below the cut-off frequency of the steerers limited by the screening effect by the vacuum chamber. The average orbit is kept constant by running the fast orbit feedback (FOFB) with reduced PID parameters to have a slow time response (of the order of 1 second) as described also in [7]. Measuring two ORM (horizontal and vertical) takes approximately 5 minutes, which has to be compared to approximately 1 hour required to measure the response matrix with the legacy method using DC kicks.

Measurement Procedure

All measurements were preceded by an optics correction (fitting of the measured ORM to the theoretical one [7]) to determine the quadrupole (19 per cell) and skew quadrupole (9 per cell) strengths for the model and by a chromaticity measurement. The optics correction guarantees that the off-energy measurements are minimally polluted by initial optics modulation. The measured chromaticity is used to match the reference lattice chromaticity in order to provide the correct tunes off-energy. Variations of frequency of 100 Hz were applied in order to obtain the necessary $\delta = 0.33\%$ energy deviation, as used in simulations. Larger frequency shifts of 200 Hz were also tested without an evident gain in correction performance.

All BPMs not providing appropriate signals (bad electronics, cabling issues, large rotations or scale factors, ...) were excluded from the retrieved data. Finally 310 out of 320 BPMs are used to fit all the 192 sextupoles for the NOECO correction. The ORM repeatability was tested in the past and showed variations of the computed correction below 1 % when comparing two consecutive measurements. Considering the BPMs resolution of 80 nm at 10 kHz and the magnets power supplies stability, the resolution of a fast ORM measurement is estimated to be better than ~0.04 μrad^{-1}. The

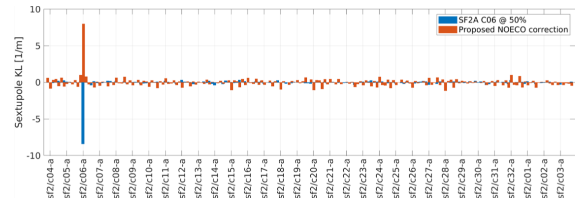

Figure 3: Sextupole pattern set in the SR for test of the NOECO correction scripts. The single magnet mistuned is correctly identified by the correction algorithm.

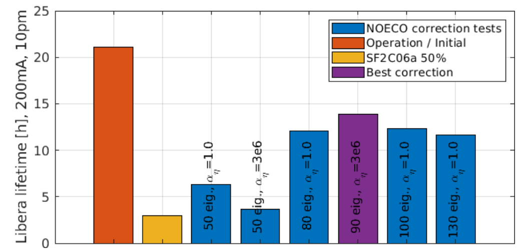

Figure 4: Beam lifetime for the operation setting (red), with a sextupole mistuned (yellow) and for several NOECO correction parameters (blue). The best set of correction parameters is shown in purple.

expected maximum amplitude of $V \cdot \delta$ is for comparison 83 μrad^{-1}.

Once the two ORM and dispersion datasets at $+\delta$ and $-\delta$ to compute V_{measured} (see Eq. 1) were collected a Matlab script would compute the Jacobian based on the present SR optics. The same script would analyze the data collected to apply the NOECO correction to finally provide a set of sextupoles corrections to be set to the SR.

Tests of NOECO Correction

The first test was reduced to a single source of error, localized in a SF focussing sextupole. A random magnet was selected and set to ~ 50% of its nominal strength. The pattern of sextupoles correction proposed by NOECO was clearly indicating the specific sextupole as the source of discrepancy in the measurement, as shown in Fig. 3.

The α_η weight and the number of singular vectors used for pseudo-inversion were varied to find the optimal ones. Settings with fixed chromaticity were also produced. Figure 4 shows the lifetime measured at high current and with fixed vertical emittance at ϵ_v =10 pm, normalized to 200 mA.

The mistuned sextupole has a significant impact on the beam lifetime, reducing it from 21 h to 3 h. The NOECO correction restored in this test the lifetime to 14 h. This is positive, as it proves that the algorithm can be used to spot sextupole issues. However, the lifetime after correction is not completely recovered. In fact all other sextupoles apart the mistuned one are modified and by a larger amount compared to the existing corrections, thus erasing their positive effect on lifetime [2]. This may be also due to lack of reiteration of the correction, to a poor measurement (for example not excluding some bad signal BPM) or to a lack

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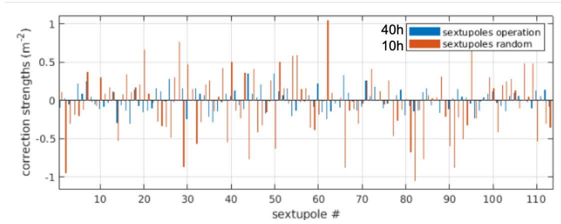

Figure 5: Correction strengths of the first 115 normal sextupoles empirically optimized for operation and randomly set to reduce the lifetime.

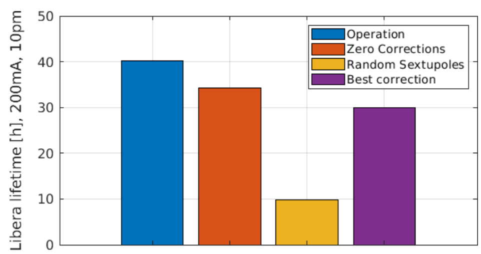

Figure 6: Beam lifetime for the operation setting (red), with a sextupole correction to zero (red), with random sextupole corrections (yellow) and for the best NOECO correction (purple).

in the nonlinear part of the optics model. The same exercise was done with a SD defocussing sextupole magnet. In this case, the magnet was not identified individually, however the lifetime was partially restored as for the SF sextupole case. A further test was performed introducing in the SR random sextupoles correction values (192 sextupoles) such as to obtain a lifetime reduction. The values were chosen empirically. For the peculiar configuration during measurements the Touschek Lifetime was reduced from 40 h to 10 h by sextupole correction strengths extracted from a Gaussian distribution with standard deviation of 0.4 m^{-2} (∼ 3% of the main sextupole field). These are about ten times larger than the values corrected in the initial simulations. The NOECO correction was then applied and a sextupole correction setting was defined. The random setting and the computed correction are presented in Fig. 5.

There is no correlation among the two settings, however the lifetime after correction is almost as good as in the case with all sextupole corrections set to zero, as can be seen in Fig. 6.

Referring to Fig. 6 the lifetime for the empirically optimized operation sextupole setting is also shown. The NOECO correction is again able to recover a good fraction of the lost lifetime due to the random sextupole settings, but it is unable to reach the performances obtained by simply setting all sextupoles to their design gradients, thus not applying any correction at all. The sextupole corrections (obtained by empiric optimization) presently set in the SR are about 1% of the main sextupole fields, three times larger then the values used for simulations.

A final test was performed, starting from zero correction strengths, to seek for an equivalent or improved operation

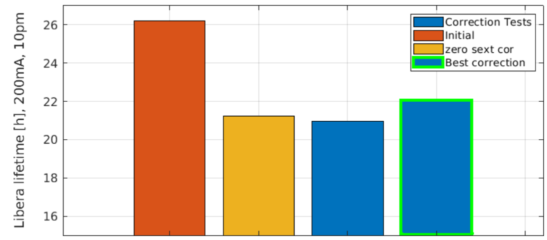

Figure 7: Beam lifetime for the operation setting (red), with a sextupole correction to zero (yellow), with NOECO correction (blue). The best set of correction parameters is shown by a green edge.

setting defined by NOECO. The zero correction strengths settings has a purely periodic pattern, except for the 12 sextupoles adjacent to the injection. The individual calibration factors of the sextupoles are included in such setting. Also, all sextupoles are combined function with steerers and skew quadrupoles, with a calibration curve taking in account also the main sextupole main coil in order to provide the correct strengths for all multipoles. The sextupole currents are thus not periodic, with variations up to more than 3% in each family. In case the NOECO correction could find a better solution than the one obtained by empiric optimization with specialized knobs, then a large amount of machine dedicated time could be spared, avoiding empirical optimizations during storage ring restarts activities. The test was in fact a failure. As shown in Fig. 7 the NOECO correction could not produce any solution with lifetimes similar to the ones used for operation. It could however, in some of the cases tested, mildly improve the zero sextupoles correction strengths setting.

CONCLUSIONS

The NOECO correction tested for the EBS SR has shown a great potential in simulations and in spotting localized sextupolar errors. Nevertheless it was not possible for the moment to obtain a better sextupole setting compared to the operational one. Future machine dedicated time will be devoted to further study the NOECO correction. In particular those will take place after a better non linear model of the lattice optics will be available. Slow ORM measurements (without FOFB) with larger energy deviation at low currents (to avoid safety interlocks) will be investigated. To obtain the best possible measurement, refined and updated ORM fit procedures will be investigated, in particular looking at the BPM and correctors scale and rotation factors and applying a more restrictive selection on the BPMs used for correction, if needed. Individual BPM weights will be measured and included as shown in the original work in [1]. A NOECO correction including also skew sextupole components will be considered. Finally, more iterations of the NOECO correction will be applied in a sequence until convergence of the computed corrections.

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