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ONLINE OPTIMIZATION OF THE ESRF-EBS STORAGE RING LIFETIME

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Abstract

In the first year of operation of the EBS storage ring, online nonlinear dynamics optimisations were performed to increase the Touschek lifetime. Several sextupole, octupole and skew quadrupole knobs have been studied in simulations and tested in the machine. A fast optimisation procedure has been defined and it is followed at each machine restart. The knobs and the optimisation procedure are described in the paper. As a result, up to 41 h Touschek lifetime in nominal multi-bunch mode have been achieved.

INTRODUCTION

The new ESRF storage ring has been successfully installed and commissioned in 2019 and 2020 [1] and it has been in operation with users since August 2020.

The lattice is a Hybrid Multi-Bend Achromat with 6 sextupoles per cell, divided in 3 families [2]. The two injection cells have 6 additional sextupole families used to correct the chromatic functions [3]. In addition to the 192 sextupoles, there are 64 octupole magnets, 2 per cell, grouped in a single family, used to reduce the horizontal tune-shift with amplitude.

All sextupoles and octupoles are powered with independent power supplies, so that any sextupole and octupole correction can be applied. Different ways to tune independently the sextupoles and the octupoles have been considered. The use of off-energy orbit response matrix to fit the sextupole setting and compute the sextupole corrections, like it has been successfully done at MAX-IV [4], is under study and some results are shown in [5]. In this paper we show how some sextupoles and octupoles knobs have been selected and are used to improve the lifetime.

The sum of the beam loss detectors (BLD) signal [6] is a very reliable quantity to use in nonlinear dynamics optimization. It is very fast to update, the signal is refreshed at 0.5 Hz, and the fluctuations are small enough to see the effect of a small change of lifetime due to a change of nonlinear magnet. The beam loss detectors signal has been used from early phase of the commissioning to precisely tune the 6 families of the injection cell. This method has then been used to find the optimum amplitude for a large number of sextupoles or octupoles knobs.

SIMULATION

Several hundreds sextupole, octupole and skew quadrupole knobs were tested in simulation to study their effect on the lifetime and on the dynamic aperture. The lattice used for the simulation is obtained fitting the measured orbit response matrix. The knobs are tested with the same maximum amplitude in the positive and negative direction. The knobs that have the strongest effect on the Touschek lifetime (reducing or increasing it) and with a small effect on the dynamic aperture were selected to be tested in the storage ring. The dynamic aperture and the Touschek lifetime for the lattices with the different knobs have been computed with matlab Accelerator Toolbox [7] on the ESRF computing cluster.

Pseudo Sextupolar Singular Vectors

Starting from the idea that the sextupoles can be used to correct the chromatic functions [4] [5], a list of *pseudo sextupolar singular vectors* has been obtained by SVD inversion of the derivative of the orbit response matrix (ORM) respect to quadrupole components inside the sextupoles.

$$J_{quad} = \frac{\delta ORM}{\delta K_{quad}} \quad (1)$$

$$K_{quad} \propto 2 K_{sext} \eta_h \quad (2)$$

$$J_{sext} = J_{quad} \cdot 2\eta_h \quad (3)$$

where η_h is the horizontal dispersion function.

Each singular vector of J_{sext} has been tested in simulation to see its effect on the Touschek lifetime and DA. The effect of the first 96 vectors is shown in Fig. 1. Singular vectors number 9-10, 19-20 and 81-82 are the ones with the strongest effect.

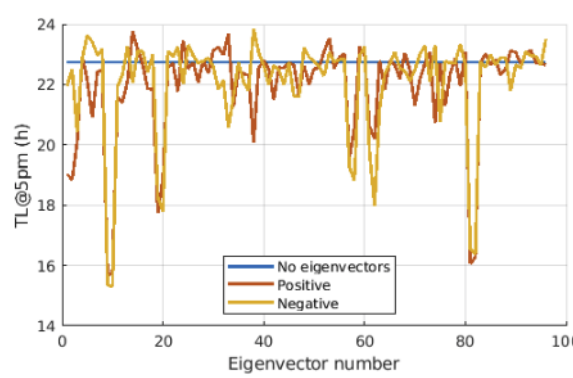

Figure 1: Effect of the off-energy optics correction singular vectors on the Touschek lifetime. The red and the yellow line are the lifetimes with a positive of negative knob applied to the sextupoles, the blue line is the lifetime without knobs.

The few singular vectors with an impact on chromaticity were excluded, for example number 1 and number 8 (Fig. 2).

Sine and Cosine Sextupolar and Octupolar Knobs

A second category of knobs tested in simulation is a sine or cosine wave with different frequencies added on the values

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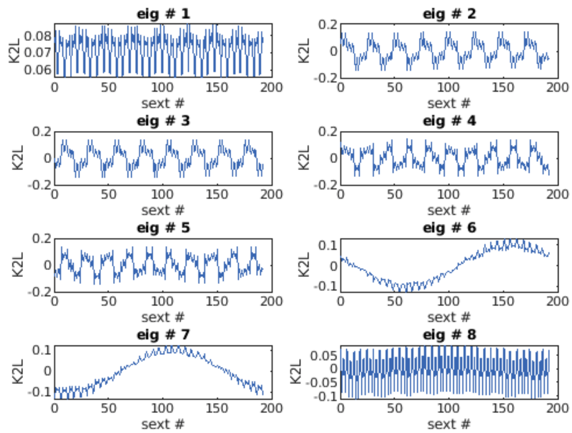

Figure 2: Sextupole pattern of the first 8 singular vectors.

of the sextupoles, only the focusing, only the defocusing or all of them, or on the octupoles. An example of the *sin(2x)* sextupolar knob is shown in Fig. 3.

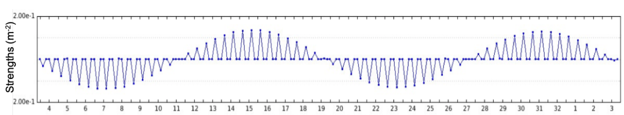

Figure 3: Sin(2x) knob applied to the focusing sextupoles.

The knobs with the strongest effect on the lifetime were selected to be tested in the machine. Figure 4 shows the effect of the octupolar sine wave knobs on the Touschek lifetime, computed in simulation.

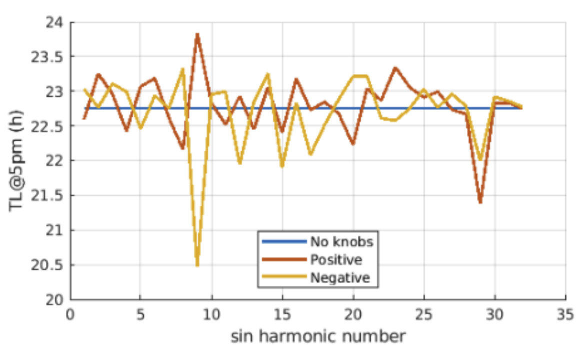

Figure 4: Effect of the sine wave octupolar knobs on the Touschek lifetime.

OPTIMIZER

The optimizer is a Matlab based code that allows to scan any sextupole, octupole, skew quadrupole or quadrupole knob in a range defined by the user. The knobs are tested at 7 different amplitudes and at each of them the sum of the BLD signals and the lifetime computed with the beam position monitors is measured 4 times. Both the total losses and the lifetime measurements are fitted with a parabola and the optimum value of the knob is chosen to be either the minimum of the parabola fitted on the losses data or the maximum of the parabola fitted on the lifetime data (Fig. 5).

During the scan, the closed orbit and the vertical emittance can slightly change, so the fast orbit feedback and the vertical emittance feedback are kept running. The slow orbit feedback is not used to avoid software errors due to the simultaneous action on sextupoles main coils by the optimization loop and by the orbit steerers installed in the sextupoles.

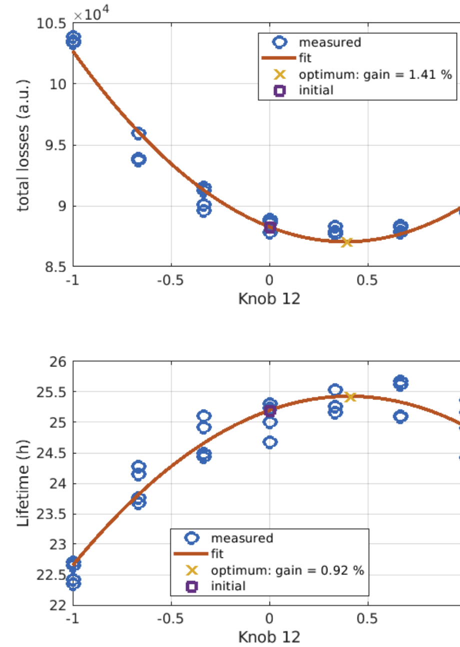

Figure 5: Scan of one sextupolar knob. The sum of the BLD signals (top plot) and the beam lifetime (bottom plot) as a function of the knob amplitude. The optimal value is the minimum of the parabola fitting the BLD data.

The evolution of the total losses during the scan of 24 knobs is shown in Fig. 6.

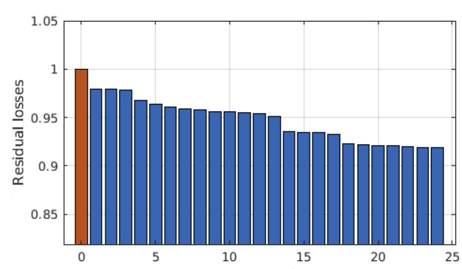

Figure 6: Fraction of total losses left after the optimization of 24 sextupole knobs. Total losses are reduced by about 8% at the end of the scan.

OPTIMIZATION PROCEDURE

At each run, a small reduction of lifetime, usually less than 5%, is observed in one or two months of operation. The

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reason is not yet explained, but it can be related to a small change of the set point of the sextupoles or to a small change of the machine alignment. In order to recover this small loss of lifetime, an optimization shift is scheduled at each restart of the machine. After the linear optics correction, the nonlinear correction strengths from the previous run are gradually reduced up to the periodic setting, in order to see if the correction still has a positive effect on the lifetime. An example of the scan of the amplitude of the corrector strengths is shown in Fig. 7.

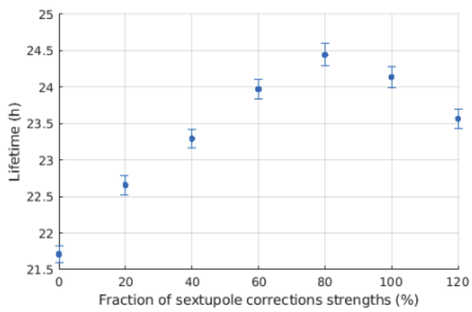

Figure 7: Scan of the amplitude of the previous run sextupole corrections before the new optimization. In this case, the best lifetime is with correctors at 80% of their initial value.

The scan of 24 sextupole knobs and 4 octupole knobs is performed starting from the fraction of sextupole and octupole correction giving the highest lifetime. The full scan is completed in about 2.5 h. In Fig. 8, the Touschek lifetime of the sextupoles and octupoles setting of the previous run are compared with the periodic setting and with the settings after sextupoles and octupoles optimizations.

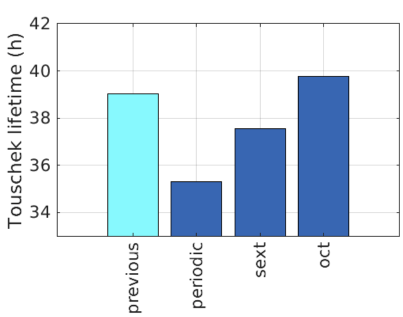

Figure 8: Touschek lifetimes at 200 mA in multi-bunch mode at 10 pm vertical emittance with sextupoles and octupoles setting from the previous run, periodic, after sextupoles optimization and after sextupoles and octupoles optimization.

This procedure allows to have a Touschek lifetime at 200 mA in multi-bunch mode at 10 pm vertical emittance 41 ± 5 h (see Fig. 9), which is more than the design value for the ESRF-EBS storage ring with errors [8]. This result is possible thanks to the excellent alignment errors, which are better than design specifications [1].

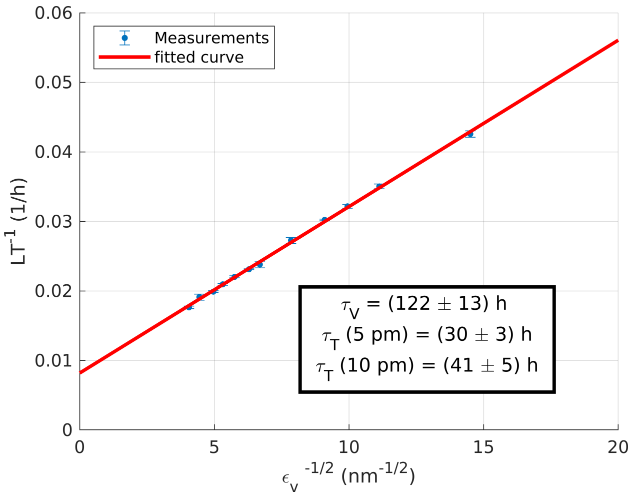

Figure 9: Touschek (τ_T) and vacuum (τ_V) lifetime measurement at 200 mA after the optimization.

HIGH CHROMATICITY OPTICS

In order to operate the machine at nominal currents in the 16-bunch mode and in the 4-bunch mode without the bunch-by-bunch feedback, an optic with higher vertical chromaticity has been studied and is now in operation for all modes of operation.

The chromaticities in the optics used in operation until the beginning of 2022 were 10 in horizontal and 8 in vertical. Those chromaticities were chosen to maximize the beam lifetime. The vertical chromaticity has been increased to 10 units, keeping constant the horizontal, by applying a variation to all the focusing and defocusing sextupoles.

A full optimization similar to the standard one defined in the previous section has been performed, with the addition of the tuning of the sextupole families keeping constant chromaticities and the tuning of the octupoles family.

The Touschek lifetime at higher vertical chromaticity is about 10% lower than the lifetime with old setting, but the single bunch stability threshold has increased, allowing to put more than 10 mA in a single bunch without bunch-by-bunch feedback.

CONCLUSION

The online optimization method allows to exceed the design performance of the ESRF-EBS storage ring in term of Touschek lifetime. The optimization shift repeated at each restart can recover the small lifetime loss that might happen during one or two months of machine operation.

The online optimization has been used also to improve the high chromaticity setting, which was studied to allow to have 10 mA in a single bunch without the bunch-by-bunch feedback.

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