

COLLIMATION SCHEME FOR THE ESRF UPGRADE

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Abstract

The ultra low emittance foreseen for the ESRF Upgrade will translate into a limited Touschek lifetime, increasing substantially the loss rate around the ring compared to the present machine. Consequently it becomes crucial to know the distribution of electron beam losses to optimize the radiation shielding and to protect the insertion devices from radiation damage. Such loss maps of the storage ring can be produced thanks to the simulation of the Touschek scattering process along the lattice. It is shown that about 80 % of the beam losses can be collimated in a few chosen locations only, keeping the resulting lifetime reduction smaller than 10 %.

INTRODUCTION

The multi-bend achromat lattice of the ESRF upgrade will allow for a reduction of the horizontal emittance down to less than 150 pm.rad [1]. Assuming the same vacuum conditions as today, the beam losses will be dominated by the intra-beam Touschek scattering, implying a reduction of the lifetime by a factor ~ 3 compared to the present machine [2]. A detailed map of beam losses around the ring is necessary to protect the insertion devices and the various machine equipment from radiation damage, as well as to anticipate a proper shielding to guarantee a radiation free zone outside of the accelerator tunnel. For that purpose Touschek scattering has been simulated for the ESRF upgrade lattice using the simulation tool described in [3]. Concentrating most of the losses in a few locations only using scrapers would be highly desirable for radiation handling. The model and simulation results for the new lattice are introduced in the first part of this paper, before describing the collimation scheme. Detailed 6D coordinates of lost electrons on the machine physical aperture are available thanks to the tracking of scattered particles. As shown in the last part, these are valuable input for the collimators' shape optimization regarding the resulting radiation shower.

ESRF UPGRADE BEAM LOSSES

The ESRF upgrade lattice is made of thirty-two cells. The strict periodicity is broken first by the two non standard injection cells where the optics is optimised to allow off-axis injection, and second by the RF cavities, located in three distinct straight sections (cells 5, 7, 25). The physical aperture considered in the model is simplified to three regions plus the injection straight section (see Fig. 1). They correspond to the high betatron functions (β) regions on both sides of the regular cells, the central part with low β (a smaller bore radius is necessary for the high gradient quadrupoles), and

the straight sections where the aperture is defined by the Insertion Devices (IDs). To figure the presence of in-vacuum undulators, some parts of the straight sections have a vertical aperture as small as ± 3 mm. The main horizontal aperture restriction is at the septum location on the inside of the ring. The model contains either rectangular or elliptical aperture depending on the location.

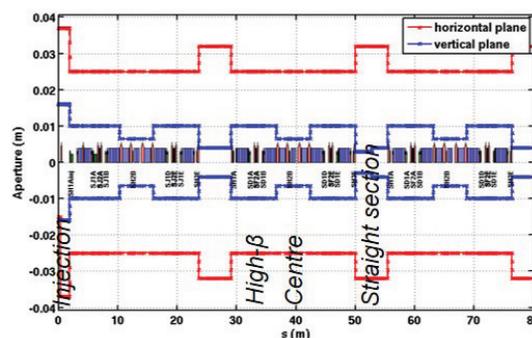


Figure 1: Physical aperture limits of the ESRF upgrade lattice cells. Dipoles, quadrupoles and sextupoles are figured by blue, magenta and green rectangles respectively.

The simulated Touschek loss map is shown in Fig. 2 for the lattice without errors, starting from the injection point. It assumes a vertical emittance of 5 pm.rad and 0.23 mA per bunch, leading to a Touschek lifetime of about 45 h. Each peak corresponds to a physical element of maximum 0.5 m length (including drift spaces).

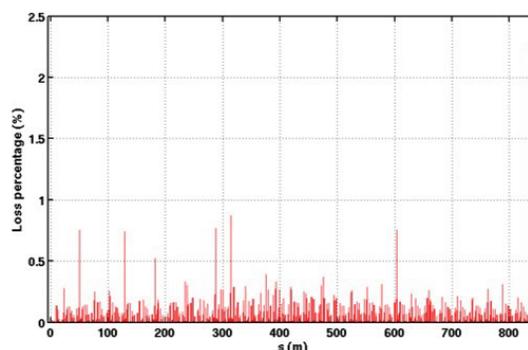


Figure 2: Touschek losses along the lattice without errors.

The highest peaks correspond to the in-vacuum IDs locations, except the last one at $s \approx 844$ m corresponding to the septum blade. Apart from these specific locations arising because of a smaller physical aperture, the effect of the periodicity breaking of the lattice functions is not so strong thanks to the careful nonlinear optics matching [2]. In Fig. 3 the losses of all cells are stacked over one machine period,

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evidencing that the losses occur in the same locations for all cells.

In this superimposed loss histogram we distinguish the losses depending on the impact transverse position on the physical aperture. Horizontal and vertical losses (x and y respectively) are defined with respect to the ratio of vertical over horizontal maximum aperture. Moreover, for each plane, losses occurring within the first turn of tracking are counted separately as most of them will not be intercepted by any potential collimator.

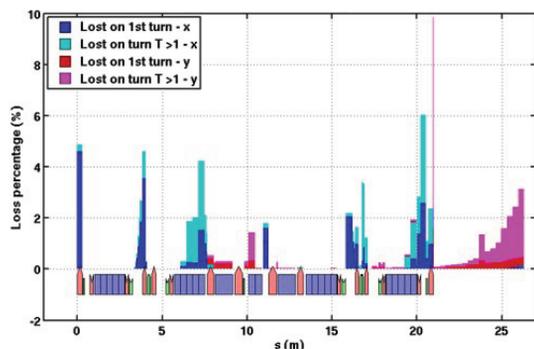


Figure 3: Superimposed losses of the 30 regular cells of the lattice without errors.

It is clear from that picture that losses in the straight sections are only on the vertical aperture. A high level of losses is to be expected at the entrance of the section (aperture reduction), then the rate increases all along the section until the aperture gets wider again. On the contrary, losses inside the cells are mainly in the horizontal plane, in the high dispersion regions (where the sextupoles are inserted) and at the entrance of the central part.

As these results are obtained with an ideal lattice (no coupling errors), the vertical motion is only due to the vertical extension of the Gaussian beam distribution. That is why most of the lost particles reach the aperture after several turns of tracking. This means that catching those particles using a scraper could be possible to protect the straight sections. This is to be considered only if the required scrapers' opening does not affect too much the beam lifetime.

COLLIMATION SCHEME

The acceptable limit on the lifetime reduction due to the scrapers insertion has been fixed to 10 %. The vertical beam dimensions and the absence of vertical dispersion are so that using vertical scrapers to catch the particles to be lost in the straight sections is too detrimental for the beam preservation. However as they result from the transfer of the horizontal motion to the vertical plane, placing horizontal scrapers in the dispersive regions turn out to be very promising for ID protection.

Potential positions for collimators should be long enough to arrange the necessary shielding and as far as possible from the experiments. Two locations are adopted to be reasonably distant from each other, one in cell 13 upstream from the

machine study dedicated straight section, and one in cell 24, upstream from one of the RF sections. An additional horizontal scraper may be installed in the injection section. It would help sharing the losses, but would not increase the collimation efficiency, so it is not considered in the following analysis.

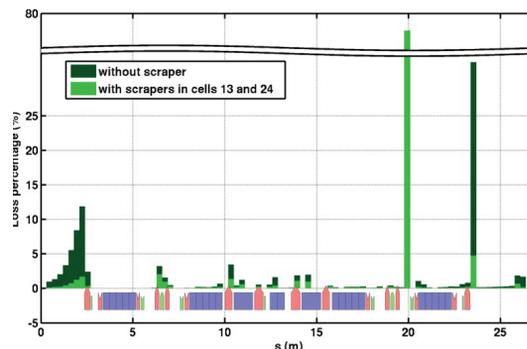


Figure 4: Impact of two horizontal scrapers on the superimposed losses of all 32 cells (lattice with errors, average over 10 seeds of set of random errors).

Losses averaged over 10 seeds of random errors [4] with and without the two closed collimators are shown in Fig. 4. Lattice errors reduce the lifetime from 45 h to 23 h on average. Setting the scrapers' jaws to (-8.4, +7.6) mm in both locations accounts for an additional lifetime reduction of ~4 %. The cumulative loss peak at the entrance of the straight section is taken down from 33 % to 5 %, and the losses growing over the section are also considerably reduced. The light green peak counting ~80 % of all the losses correspond to the sum of the two scrapers contribution. This collimation scheme consisting in using horizontal jaws to protect the vertical aperture has been tested successfully on the operated machine [3].

In the model the collimators are perfect scrapers, i.e. particles are marked as lost as soon as the transverse coordinates exceed the physical aperture. In reality they may either be lost or simply deviated and their impact on the scraper material will generate a shower of particles which have to be shielded.

RADIATION SHIELDING

Loss concentration in a few known locations would be best for shielding and access management to activated areas. Particle tracking using ideal beam particles stoppers proved that such a collimation scheme is possible in theory. The same tracking simulations made also available the particle coordinates (x, x', y, y') and energy deviation δ at the scrapers. These distributions are shown in Fig. 6, a) and b) respectively for the first scraper (distributions on the second scraper are very similar). Losses are concentrated along the horizontal direction apart from the region very close to the edge of the blade. Regarding the energy distribution we can see the gap around $\delta = 0$, corresponding to the momentum acceptance, and the asymmetry between the inside and

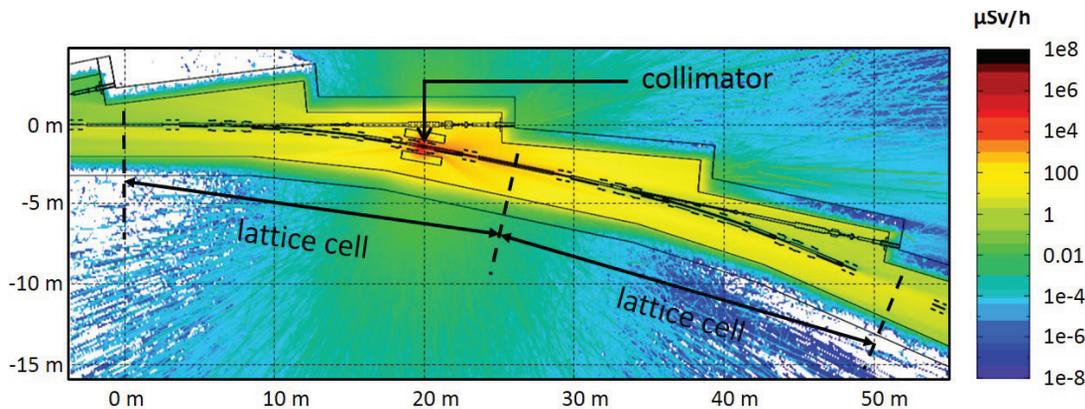


Figure 5: Resulting radiation dose around two lattice cells containing one collimator after shaping of the W-scraper and shielding with Pb-walls.

outside of the ring. Particles lost on the internal jaw have negative energy deviation and vice-versa for the external jaw due to the high dispersion at the scraper location.

These distributions are used as input to FLUKA simulations for prediction of radiation showers [5], allowing the optimisation of the collimators' jaws, as well as the evaluation of the required shielding to guarantee the low radiation dose outside of the accelerator tunnel.

terized by the β -functions in order to limit the loss leakage (schematic view in Fig. 7). The sides will be movable, but fixed blocks are added to intercept particles in the vertical direction. Including 2 m long lead walls on each side of the collimator (black empty rectangles in Fig. 5), the residual dose outside the tunnel wall is one order of magnitude smaller than the background noise of $0.5 \mu\text{Sv/h}$.

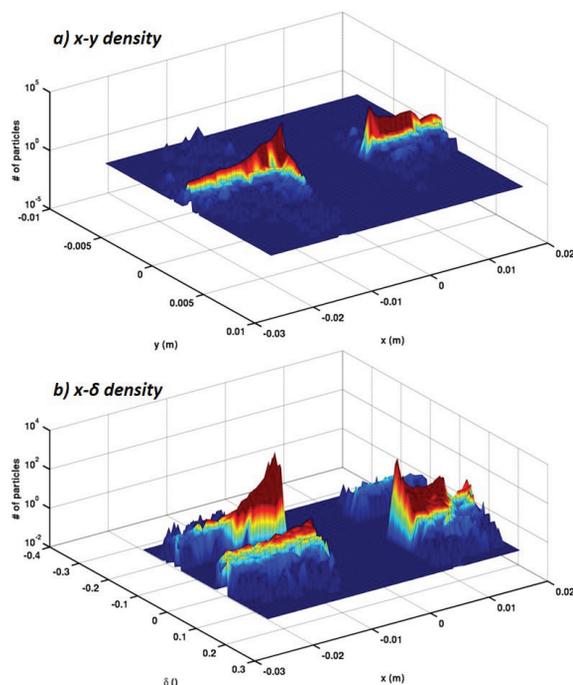


Figure 6: Transverse position and energy distributions of electrons impacts on an ideal collimator's blades.

The resulting dose map for two lattice cells is presented in Fig. 5. The FLUKA simulations assume a pessimistic case of 21 h lifetime without errors, and 45 % of the losses localised on each scraper. The scraper is visible at the position (20, -2) m. It is made of tungsten, is 30 cm long and its shape has to be profiled to follow the beam envelope charac-

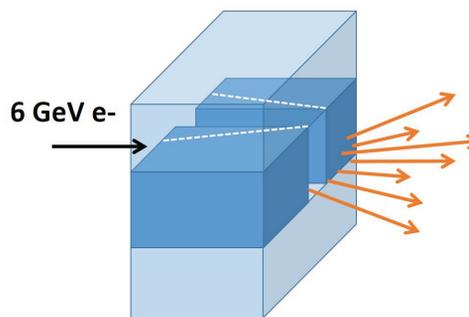


Figure 7: Schematic view of the collimator block after shape profiling to reduce the radiation shower.

CONCLUSION

The recent development of a model to simulate Touschek losses around the ESRF has been applied to the upgrade lattice in order to study a possible collimation scheme. Results showed that up to 80 % of the losses occurring mainly in the straight sections, and therefore potentially harmful for the insertion devices, can be relocated in two chosen locations. Even though the losses are provoked by the vertical aperture restrictions, the most efficient collimation system consists in catching the electrons in the horizontal plane before they get to the limit of vertical amplitude. According to first FLUKA simulation tests, the space dedicated to the two collimators should be large enough if they are properly tapered and if additional shielding walls are installed on their sides in the accelerator tunnel. This provides a sufficiently low level of radiation dose in the free access area.

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