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ALBA BEAM LIFETIME OPTIMIZATION USING RCDS

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Abstract

The ALBA synchotron operates in a Touschek dominated lifetime regime, which depends mainly on the momentum acceptance and the transverse beam size along the machine. Although in the current ALBA machine the RF dominates the momentum acceptance, this will not be the case for the foreseen upgrade of the machine ALBA-II. For this reason, we have implemented an algorithm to optimize the beam lifetime by varying the sextupole magnets. This algorithm is based on the Powell optimization of the Robust Conjugate Direction Search (RCDS) method, and several tests have been performed at the present ALBA machine. In this case the sextupole settings are first modified so that the RF is no longer the only limiting factor in the momentum acceptance. The algorithm optimizes the ALBA beam lifetime by varying the sextupoles to follow a constant chromaticity, while the skew magnets are tweaked to keep the beam sizes constant during the optimization. This paper shows the experimental results using this algorithm, and discusses its application to the ALBA-II case.

INTRODUCTION

Adoption of automatic online techiques for machine performance optimization has been steadily growing over the last decades and it is now a widely used strategy in the accelerators community. Many different techniques have been implemented, with complexities ranging from the Nelder–Mead Simplex [1], the Powell method based RCDS (robust conjugate direction search) [2] to the modern more sophisticated Gaussian process based techniques as in Ref. [3].

Presently, ALBA operates making use of such techniques in the linear accelerator stage [4]. The ALBA storage ring operation has been rather reliable and did not require going beyond simple manual optimizations from time to time. As we are now designing the future ALBA-II upgrade, it is becoming clear that its operation will probably be more challenging. In particular, the energy acceptance, which in ALBA is limited by the RF voltage, will be limited by the beam dynamics. That means that the Touschek beam lifetime, which is generally the main lifetime contribution, will strongly depend on the sextupole settings. That has not been the case so far in ALBA, where we can change the chromaticity without affecting too much about the beam lifetime nor the injection efficiency. Presently during operation the used chromaticity is $\xi = [3, 3]$ units in the horizontal and vertical plane respectively.

In this paper we present an online beam lifetime optimization tested in the present ALBA storage ring adjusting the sextupole settings with the RCDS algorithm. Similar studies have been carried out elsewhere [5]. Two cases are presented here, an optimization is performed with the operation settings ξ =[3, 3], and in another one we use ξ =[5, 5]. In the last case we estimate that the energy acceptance starts to be dominated by the non linear dynamics itself, and not by the RF voltage. As expected the second case lifetime optimization results are more relevant.

LIFETIME RCDS OPTIMIZATION

During normal operation, the beam lifetime is measured by fitting a 1 minute DCCT current I_DCCT trend. That measurement although precise in the short term is prone to drifts effects in the same time scales of the RCDS scans (seec1). For this optimization we use the sum of the 126 beam loss monitors (BLM) counts S_{BLM} installed next to the storage ring vacuum chamber [6]. The actual cost function in the optimization is $-I_{DCCT}^2/S_{BLM}$ (by default the algorithm minimizes) which is proportional to the lifetime times current product and is constant when the beam losses are dominated by the Touschek effect. Still, gas lifetime is also relevant, to keep the lifetime and lifetime product as constant as possible due to the current decay, the optimization is run in top-up mode.

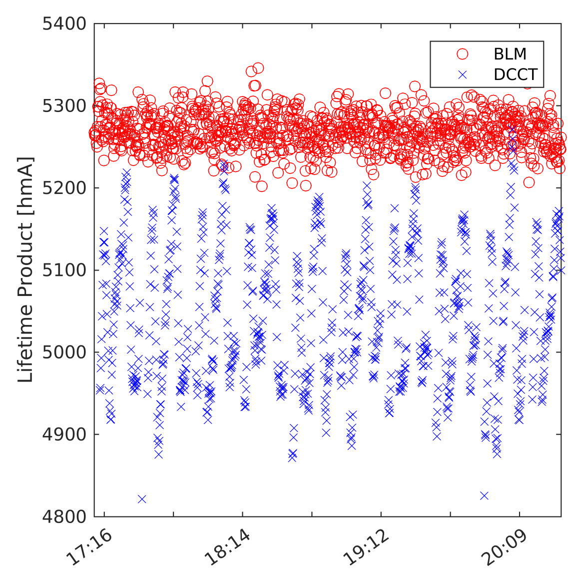

Figure 1: Measured lifetime product during a queit period in normal operation at $\xi_{x,y}$=3. Notice that the DCCT measurements seem more precise in short time scales but tend to drift much more than the BLM measurements.

The first attempts were quite unsuccessful. The first problem that we encountered is that at the end of the optimization

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the sextupole settings move to configurations were the coupling increases considerably. That is probably due to the fact that the beam passes vertically off-center at the sextupoles. To tackle this issue we calibrated a scaling factor for the skew quadrupole settings with respect to the beam size change measured in the pinholes (we have two pinholes available). A series of weights for each skew quadrupole were calculated based on the lattice model such that the coupling driving terms f_{1010} and f_{1001} change was suppressed and the vertical dispersion change magnified. The idea behind this choice is to avoid changing the on energy dynamics (and hence the injection efficiency) when correcting the beam size changes. The off energy dynamics is already optimized when optimizing the lifetime product. This beam size correction scheme was tested for a series of sextupole changes, we found that three iterations bring the beam sizes close to the initial value by a difference always smaller than the beam size noise.

A second problem we faced is related with the sextupole settings Δs. ALBA has nine power supplies powering nine families of sextupoles whose 120 elements in total are cabled in series. Each family cable goes around the ring and generates an unintended but substantial magnetic field in the inner side. As a consequence, the Linac performance, with a much lower beam energy, is affected by the sextupole settings. Each families cabling produces a rinng size loop in a direction such that with the initial design sextupole settings the overall magnetic field is compensated. With different sextupole settings, the magnetic field not compensated is cancelled with an additional power supply powering a coil that lays in the same cable try with a current ΔI_{comp}. To optimize the lifetime at ALBA in a similar regime as ALBA-II, the chromaticity is increased ($\Delta\xi_x$ and $\Delta\xi_y$) so that the off energy dynamics is deteriorated and it becomes the dominant component of the energy acceptance. That high chromaticity setting together with the optimization changing the sextupoles easily brings the not compensated magnetic field beyond the set-point limits of the additional power supply. Then the Linac performance gets deteriorated up to a point that the ongoing top-up process is stopped. To avoid this issue and also to keep chromaticity constant during the optimization, the sextupoles are varied in the null space of the chromaticity and compensation response matrix M:

$$\begin{pmatrix} \Delta\xi_x \\ \Delta\xi_y \\ \Delta I_{comp} \end{pmatrix} = M\Delta s, \tag{1}$$

where M is a 3 by 9 matrix. Its null space is a 9 by 6 matrix Z that can be used to contruct settings Δs_{null} that belong to the null space:

$$\Delta s_{null} = Z\Delta x, \text{ with } M\Delta s_{null} = 0, \tag{2}$$

where Δx is a 6 dimensional vector left free in the optimization.

To avoid hitting the settings bounds, the variables that RCDS uses are not actually Δx, it uses normalized parameters Δy respect to the maximum and minimum values of each parameter:

$$\Delta y = \frac{\Delta x - \Delta x_{min}}{\Delta x_{max} - \Delta x_{min}} \tag{3}$$

The sextupole settings have a maximum s_{max} of 215 A and a minimum s_{min} of 15 A. That limits convert into the Δx space using the matrix M into non orthogonal planes so that the limits of each component Δx_i depend on the others. To avoid that we calculate a set of limits Δx_{min} and Δx_{max} that maximize the search space volume $\prod_{i=1}^{6}[\Delta x_{i,max} - \Delta x_{i,min}]$ while still preserving the limits defined by s_{min} and s_{max}.

The cost function, including all the above mentioned steps, is evaluated in 35 seconds. Most of that time is devoted to the beam size control, the time it takes to measure the BLM counts is 10 seconds.

RESULTS

RCDS is used to optimize the ALBA lifetime with ξ= [3, 3] and also in ξ = [5, 5]. In both cases the nominal target current is 250 mA. Using ξ = [3, 3], which is the setting during normal operation, the DCCT lifetime product improvement is modest, from 4500 to 5500 mAh. At chromaticity [5, 5] the lifetime product is reduced to 3000 mAh and the RCDS optimization brings it to a similar optimized level of 5000 mAh. In both cases the estimated RMS is 10 mhA. This parameter is used during the optimization in order to limit the exploration in the solution space.

The lifetime product derived with the BLM was calibrated to the DCCT lifetime at the start of the ξ = [5, 5] optimization. Other than that, the agreement is quite bad. Indeed the optimization may make the agreement worse since part of the optimization may consist in producing the same losses such that those escape the BLM counts the most. Still as seen in Fig. 2 the trend is similar, whenever the BLM lifetime product increases also the DCCT lifetime product also increases but not in the same amount.

In the ξ=[3, 3] case, the optimization stopped because it could not find a better solution according to our cost function tolerance levels (see red line in Fig. 2). The injection efficiency was monitored during the optimization, it declined from 86% to 72% during the optimization. For a fair comparison the optics and the injection chain should be also corrected with the new sextupole and skew quadrupole settings.

In the ξ=[5, 5] case, the optimization stopped because it reached a limit in the SD5 sextupole family power supply. As can be appreciated in Fig. 3, the starting setting for that family is at 200 A, quite close to the power supply limit. In this case the injection efficiency varied from 54% to 60%. This case does not correspond to normal operation conditions and we did not optimize the injection efficiency specifically for this case before starting the optimization.

In any case the injection efficiency behaved quite stable during both optimizations and allowed the top-up during the whole process.

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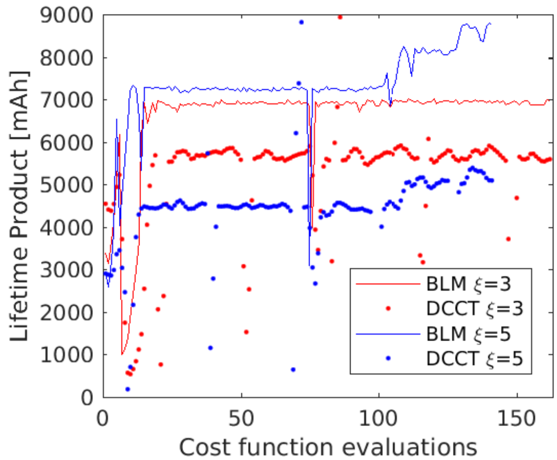

Figure 2: Lifetime product evolution during the two presented optimizations. Both the BLM (more precise) and the DCCT (more accurate) lifetime products are presented. The DCCT outlayer readings correspond to top-up injections.

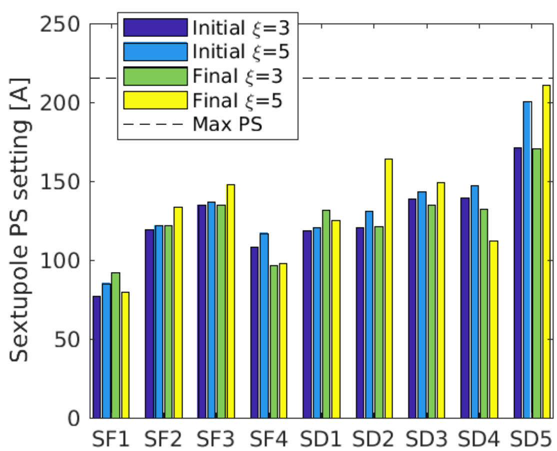

Figure 3: Power supplies settings of the sextupole families before and after the two RCDS optimizations. Notice that in the ξ=5 case the SD5 initial setting is already quite close to the limit.

CONCLUSIONS

The RCDS online optimization method has been used to improve the beam lifetime in ALBA both in operation conditions and with extra chromaticity that mimic the ALBA-II conditions. In both cases the lifetime can be optimized considerably keeping the injection efficiency in a reasonable range.

So far, these results have not been yet used for normal operation. The main reason is that ALBA usually runs with skew quadrupoles switched off.

In the next steps we plan to apply the RCDS to other observables like the injection efficiency and the stored beam injection bump closure. Also we intend to compare this technique with other algorithms used in the literature.

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