ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-TUPOMS007

A LONG BOOSTER OPTION FOR THE ESRF-EBS 6 GeV STORAGE RING

S. Liuzzo, N. Carmignani, L.R. Carver, L. Hoummi, T. Perron, S. White
ESRF, Grenoble, France

Abstract

Despite the several fruitful upgrades undergone, the present injector complex of the ESRF-EBS has a rather large horizontal natural emittance at extraction of > 60 nm rad. Several light sources [1–3] have adopted booster injectors fitting in the same tunnel as the main SR. The study of such an injector is shown in this paper for the ESRF-EBS. The proposed solution is based on a DBA lattice structure with five quadrupole families and two sextupole families. The possibility to install this long booster on the internal wall of the ESRF storage ring tunnel is assessed and the adequate distances are analyzed. The possibility to keep the existing injector is also considered in order to use this additional ring as an accumulator ring. Injection and extraction schemes are described.

INTRODUCTION

After the successful upgrade of the ESRF-EBS storage ring (SR) lattice to HMBA [4] injection efficiency is below the design, reaching at most 85% in User Service Mode (USM) while the simulations predicted up to 95% injection efficiency [5]. The simulations assumed a smaller injected beam in the storage ring and larger errors than those observed in the SR. Also the measured dynamic aperture of the EBS SR is about 1 mm less than the expected one (see [4]). Moreover future upgrades will potentially have a detrimental impact on injection efficiency, such as the possibility to reduce insertion devices minimum gaps below 6 mm. For these reasons several options have been studied to upgrade the injectors of the ESRF storage ring and in particular the full energy booster, toward a lower injected beam horizontal emittance [6–8]. In this paper we study only one of the options considered: a long booster fitting the same tunnel of the storage ring. This option is not easily feasible due to the limited space in the tunnel, but it is studied in order to compare performances.

LATTICE

The double bend achromatic (DBA) lattice has been simplified and scaled to the appropriate length. Considering a common RF frequency with the main storage ring, the length is defined by the harmonic number of the storage ring minus a given value. For the lattice presented here, the main SR harmonic number is 992 and the booster harmonic number is set to 979. This value is chosen as it gives a distance between the storage ring beam and the booster beam of 1.76 m, fitting within the minimum total available distance of about 1.90 m and leaving 14 cm from the wall to be occupied by the magnet's yokes. Even if this space seems limited, ramped magnets have a smaller profile that standard magnet

Table 1: ESRF-EBS Long DBA Booster Magnet Gradients Required at 6 GeV

	L	KL	$KB\rho$
B	3.5 m	98.1748 mrad	0.5614 T
QF1	0.6 m	0.3822 1/m	12.7489 T/m
QD2	0.6 m	-0.3992 1/m	-13.3172 T/m
QD3	0.6 m	-0.3065 1/m	-10.2232 T/m
QF4	0.6 m	0.3121 1/m	10.4108 T/m
SF2	0.2 m	0.7034 1/m^2	70.3909 T/m^2
SD2	0.4 m	-2.5523 1/m^2	-127.7056 T/m^2

(imagine for example septa dipoles). Considering the SR magnets, about 1 m free space remain between booster and SR. Further investigation will define the optimal value of the harmonic number of the booster to allow maximum flexibility for the main SR filling patterns. The option to install the booster at a different vertical height is also envisaged, but not studied in the present document. The possibility to place the booster on top of the existing storage ring is discarded for geometry and maintenance issues.

The optics for one cell of the proposed ESRF-EBS long booster are shown in Fig. 1.

Compared to classic DBA cells [9] there are only two sextupole families and the defocusing sextupole and quadrupole in the center of the cell are swapped, to allow for larger separation and increased beta functions at the sextupoles. The straight sections are kept, but may be shortened if needed. The ring is composed of 32 cells, corresponding to the main SR cells. The maximum magnet gradients presented in Table 1 are easily achievable. The relevant parameters at 6 GeV are available in Table 2, in particular producing an equilibrium emittance of 6.2 nm rad.

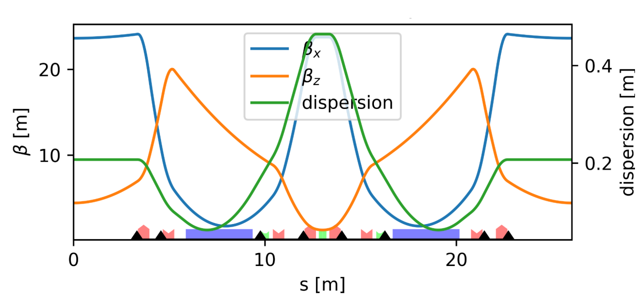

Figure 1: Magnets layout for a 32 cells DBA booster injector. Only two sextupole families will be required.

A total of seven synchronous ramped power supplies are needed for: one dipole family, four quadrupole families and two sextupole families. The magnets lengths are as much

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Table 2: ESRF-EBS Long DBA Booster Parameters at 6 GeV

Circumference	832.918 m
# cells	32
ramp	0.2-6GeV
repetition rate	4 Hz
$\epsilon_{h,6.0GeV}$	6.24 nm
vertical emittance	10 pm
energy spread	8.60 10^{-4}
momentum compaction factor	6.24 10^{-4}
bunch length (I=0 A)	6.10 mm
tune	25.230 22.300
natural chromaticity	-53.90 -33.4
operation chromaticity	1.4, 2.2
Energy loss / turn	3.2 MeV
RF voltage	9.0 MV
RF frequency	352.2 MHz
harmonic number	979
damping times	10.4 10.4 5.2 ms

as possible identical for each multipole, to minimize design requirements to 4 magnets. Movers may be envisaged on several or all quadrupoles to allow for orbit correction and on several or all sextupoles to correct optics. Presently the cell design does not require combined function magnets, as the horizontal equilibrium emittance is already 6.24 nm rad. Including a gradient in the dipoles is possible, and may be tested in future versions of this design.

Figure 2 depicts a zoom of the injection region for the booster and storage ring layout including an dummy transfer line.

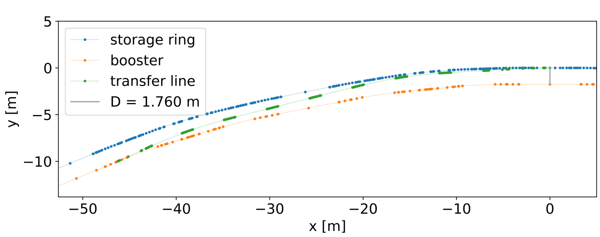

Figure 2: Survey of the extraction-injection region of the EBS facility considering a full energy booster in the same tunnel as the main storage ring.

The design is automatically rescaled as a function of the selected harmonic number for the booster.

A dummy transfer line is matched to the correct geometry and reasonable optics for display purposes. The line uses the same dipoles of the booster lattice with modified field to match the required geometry. Two septa of −25 mrad for the booster to transfer line extraction and three septa (two of 25 mrad and one of 5 mrad) for the injection in the main SR are included in the design. The passage off axis in the SR injection quadrupoles is not considered for this transfer line design (it is just a dummy transfer line, a dedicated optic has not been studied). The transfer line is imagined as ramped and synchronous to the main booster dipoles, to allow tuning of the extracted beam energy.

Perturbations induced on the SR beam by the ramped booster power supply have not been addressed at this stage.

Injection and Extraction

The relatively long space available in the straight sections allows to introduce the on-axis injection and extraction elements. Figure 3 shows the extraction region, where a 3 mrad kicker with a rise time of about 1 µs allows for extraction to a septum placed at 16 mm from the horizontal beam axis. A slow bump may be used (as it is presently the case at the ESRF) to approach the beam at the septum blade, before the extraction kick. The required strength for the extraction kicker is in this case strongly reduced. The solution envisaged for the injection is identical and symmetric.

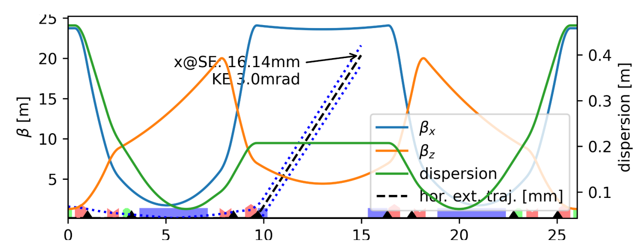

Figure 3: Trajectory of extracted beam in the horizontal plane.

Dynamic Aperture

Figures 4 and 5 present the dynamic aperture (DA) and longitudinal momentum acceptance (MA) for the booster lattice at full energy with random errors of 70 µm and corrections as computed in AT [10] with tracking simulations for 512 turns.

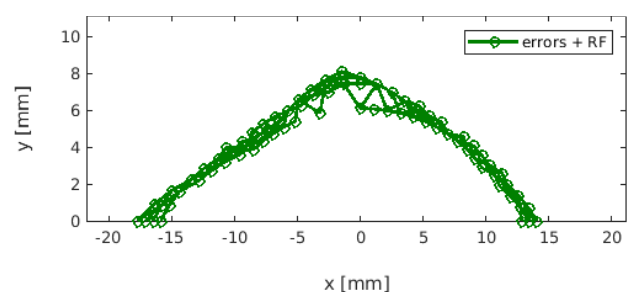

Figure 4: On-energy dynamic aperture starting at center of straight section and tracking a 6 GeV beam for 512 turns with errors.

Assuming 1 mm thick stainless steel elliptic vacuum chambers with apertures of 30x10mm everywhere the dynamic aperture feels a good fraction of the available space.

Working Point

To define the optimal working point and verify the tunability range of the lattice, tune and chromaticity scans are performed. Figure 6 shows an example of such studies.

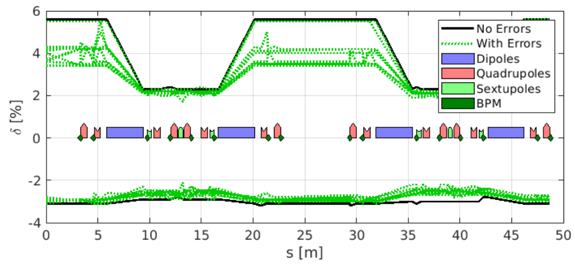

Figure 5: Momentum acceptance with and without errors for 2 cells of the DBA lattice for a long EBS booster injector or accumulator with $V_{RF} = 7MV$.

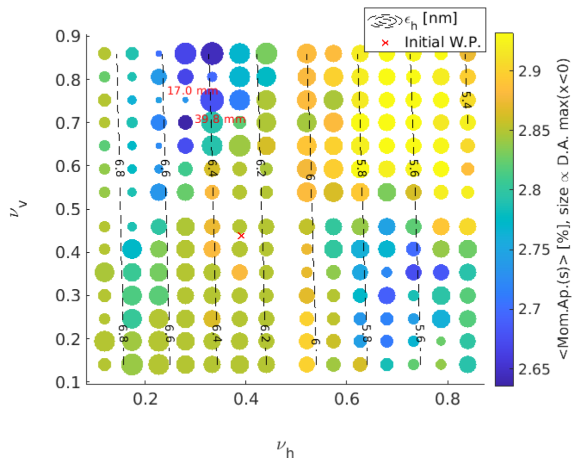

Figure 6: Average local momentum acceptance and D.A. at injection vs tune working point. The size of the circles is proportional to the horizontal negative DA; the maximum and minimum are marked by red text.

In the image, the circle sizes correspond to DA and the color to the average local momentum acceptance over 2 cells at 6 GeV. Iso-horizontal-emittance lines are also drawn and show a sharp dependence of the natural horizontal emittance on the horizontal tune. Small (1 µm) random errors are set in all quadrupoles and sextupoles to make more sensitive spots visible. The adjustment of the lattice is possible in the whole range studied, with an optimum for $\nu_{h,v} = [0.15, 0.35]$ range in both planes. Optimal tunes and chromaticities are presently set as in 2. Tunes could be moved to (0.23, 0.30) accepting a small degradation on the horizontal emittance.

Errors and Corrections

For the correction of orbit, three movers on the first, central and last quadrupoles in the cell may be envisaged. Movers on quadrupoles are presently in use at the ESRF booster and proved to be very effective [11]. Movers instead of correctors also allow to have corrections at all energies during the ramp and avoid the installation of dedicated correctors in the lattice. Presently the optics includes eight beam position monitors (one for each quadrupole) per cell. Those may be reduced to 4/6 bpms per cell with later studies, considering the correct phase advance between bpms. The present setup is imagined to allow individual quadrupole beam based alignment. The correction of optics could be performed assuming horizontal and vertical movers on sextupoles for quadrupole and skew quadrupole field generation (the dipole contribution from sextupole movements is ignored, as orbit correction will recover it). In the simulations presented the optics corrections are omitted. Errors of 70 µm rms (truncated at 2σ) are set in all magnets and a full commissioning-like set of simulations is performed following [5] and shown in Fig. 7. The injection efficiency is considered for on-axis injection and with an injected round beam of 500 nm rad, 1 mm bunch length and 1.0 % energy spread, originated from a 0.2 GeV Linac [12].

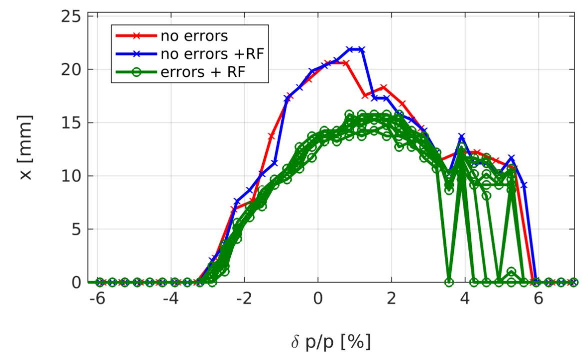

Figure 7: Off-energy max($x > 0$) dynamic aperture for 10 lattices with errors of 70 µm rms in all magnets and correction of first turns, orbit, tunes and chromaticity.

Injection efficiencies of 100% (linac to booster) and orbit and optics correction at the level of 3rd generation synchrotron light sources are achieved for each seed.

CONCLUSIONS

A booster injector for the EBS storage ring has been designed to fit the same tunnel of the main SR. The emittance provided at full energy by this booster design is below 6.3 nm rad and allows for injection efficiency of ~ 100% in the main SR storage ring [4]. The DBA lattice design is very flexible and tunable and has still large margin to reduce the required magnet gradients keeping the overall performances. Simulations of commissioning-like corrections and tuning exploiting magnets on movers instead of electromagnet correctors, show that the design is tolerant to errors. The same design could be used as an accumulator instead of a booster, with fixed magnetic fields, if swap-out injection is needed. The definition of transfer line optics and the assessment of the impact of eddy currents are still to be performed.

ACKNOWLEDGMENTS

The authors wish to acknowledge the use of MATLAB [13] and Python [14] Accelerator Toolbox [10] for the simulations presented. Also the use of the ESRF SLURM [15] computing cluster has been crucial.

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