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A LONG BOOSTER OPTION FOR THE USSR 6 GeV STORAGE RING*†

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Abstract

The design of the optics of a full length 6 GeV booster for the USSR (Ultimate Source of Synchrotron Radiation) [1] are presented. This option already followed with success by other laboratories, would allow to obtain a small emittance injected beam thus enabling smooth top-up operation. Details of the design inspired by the ESRF DBA lattice and the possible operating modes are described. The transfer lines booster to storage ring are also addressed in this paper.

INTRODUCTION

The USSR (Ultimate Source of Synchrotron Radiation) storage ring (SR) lattice is an adaptation of the ESRF-EBS lattice with a reduced horizontal emittance of 70 pm rad. The storage ring optics are detailed in [2] and the beam dynamics properties with errors in [3]. One of the options to inject in this green field storage ring is to install a full energy booster in the same tunnel of the main storage ring. This choice is presently in place at several facilities such as [4–6]. This choice allows for ultra low (1-5 nm rad) injected beam emittance and potentially a reduced cost, making use of a common radiation safe tunnel for injector and main storage ring. The simulations and optics matching presented in the following are performed using the Matlab and Python versions of Accelerator Toolbox [7,8] and the ESRF computing cluster.

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 1294 and the booster harmonic number is set to 1274. Further investigation will define the optimal value of the harmonic numbers to allow maximum flexibility for the main SR filling patterns.

The optics for one cell of the USSR 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. A number of cells corresponding to the main SR cells is chosen (40 cells). The gradients and other relevant parameters are available in Tables 1 and 2.

Table 1: Long Booster Option Maximum Gradients Required at 6 GeV

	L	KL	$KB\rho$
B	3.5000 m	78.5398 mrad	0.449 T
QF1	0.9434 m	0.3485 1/m	7.3933 T/m
QD2	0.5337 m	-0.2891 1/m	-10.8429 T/m
QD3	0.4221 m	-0.2636 1/m	-12.4973 T/m
QF4	0.5196 m	0.3566 1/m	13.7339 T/m
SF2	0.4000 m	2.1045 1/m^2	103.7 T/m^2
SD2	0.4000 m	-1.7507 1/m^2	-85.8 T/m^2

Table 2: Long Booster Table of Parameters

Circumference	1 083.5 m
# cells	40
ramp	0.5-6GeV
repetition rate	1-2-4 Hz
$\epsilon_{h,6.0GeV}$	2.8 nm
vertical emittance	10 pm
energy spread	7.7 10^{-4}
momentum compaction factor	3.12 10^{-4}
bunch length (I=0)	4.9 mm
tune	34.44, 13.39
natural chromaticity	-67.7, -33.6
chromaticity	1.0, 1.0
Energy loss / turn	2.57 MeV
RF voltage	9.0 MV
RF frequency	352 MHz
harmonic number	1274
damping times	16.8 16.8 8.43 ms

Seven synchronous ramped power supplies are needed for: dipoles, 4 quadrupole families and 2 sextupole families. Movers may be envisaged for quadrupoles to allow for orbit correction and sextupoles to correct optics. Presently the cell design does not require combined function magnets, as the horizontal equilibrium emittance is already below 3 nm rad. Including a gradient in the dipoles is possible, and will be tested in future versions of this design.

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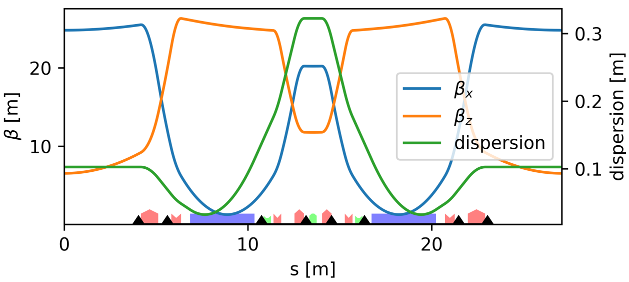

Figure 1: Magnets layout for a 40 cells DBA booster injector. Only 2 sextupole families will be required.

Figure 2 depicts a zoom of the injection region for the booster and storage ring layout.

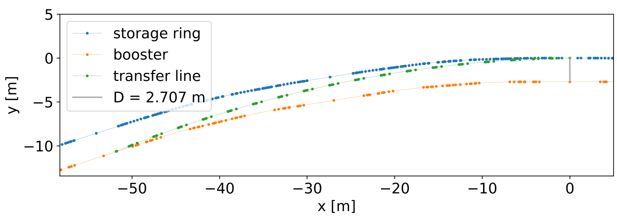

Figure 2: Survey of the extraction-injection region of the USSR facility considering a full energy booster in the same tunnel as the main storage ring.

The design is easily scalable and presently allows a distance of 2.7 m between the booster and the storage ring. A slightly different booster lattice is matched for both options presently under consideration for the USSR main storage ring.

Perturbations induced on the SR beam by the ramped booster power supply have not been addressed at this stage, and will be studied only in case this option for the USSR injector is pursued.

A dummy transfer line is matched to the correct geometry and optics for display purposes. The line uses the same dipoles of the booster lattice with modified field to match the required geometry. Two septa for the booster to transfer line extraction and three septa for the injection in the main SR are included in the design. The transfer line is imagined as ramped with the main booster dipoles, to allow tuning of the extracted beam energy. Further studies will assess optimal optics for this part of the facility if the booster injector option is retained.

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 17 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.

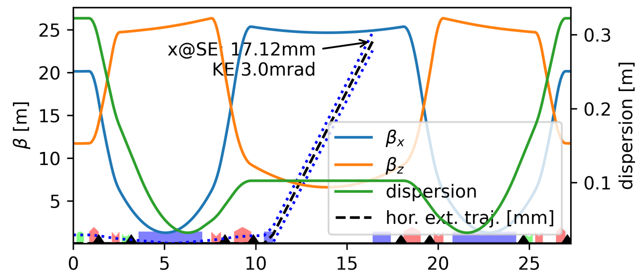

Figure 3: Trajectory of extracted beam in the horizontal plane. A 3 mrad kick displaces the beam at the septum by more than 17 mm. 3σ envelope is also displayed with blue dashed lines.

Dynamic Aperture

Figures 4 and 5 present the dynamic aperture (DA) and longitudinal momentum acceptance (MA) for the booster lattice at full energy without errors.

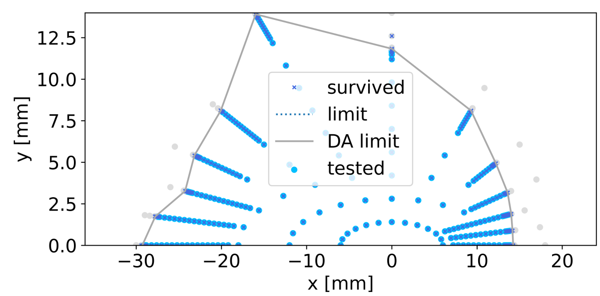

Figure 4: On-energy dynamic aperture starting at center of straight section and tracking a 6 GeV beam for 1024 turns.

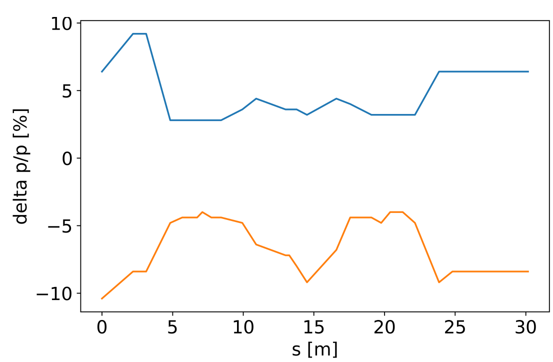

Figure 5: Momentum acceptance.

Assuming 1 mm-thick stainless- steel elliptic vacuum chambers with apertures of 30x10 mm everywhere the dynamic aperture exceeds the available space.

The vacuum chamber and the magnets are yet to be designed, their study being postponed until the final decision on the USSR facility injection scheme is taken.

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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.

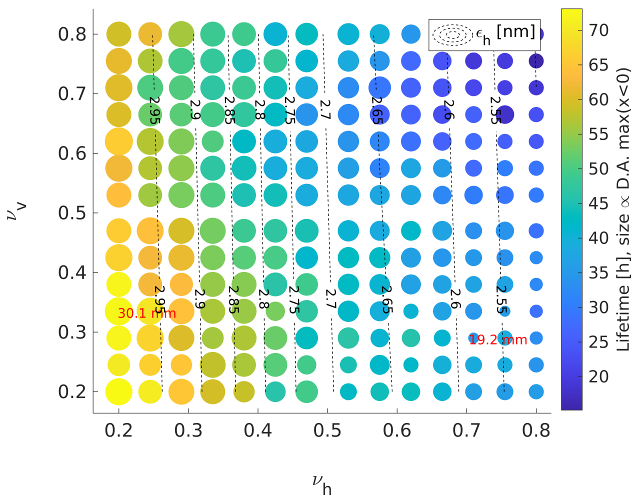

Figure 6: Average momentum acceptance and D.A. at injection vs tune working point. The size of the circles is proportional to the horizontal negative DA; the maximum and minimun are marked by red text.

In the image, the circle sizes correspond to DA and the color to the expected average momentum acceptance along the lattice at 6 GeV. Iso-horizontal-emittance lines are also drawn and show the 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.

Optimal tunes and chromaticities are presently set as in 2. Tunes could be moved to (0.21, 0.34) 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 [10]. 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 include 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 is 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).

Errors of 70 µm rms (truncated at 2σ) are set in all magnets and a full commissioning-like set of simulations is performed following [11] and shown in Fig. 7. The injection efficiency is considered for on-axis injection and with an injected round beam of 5 nm rad, 16 mm bunch length and 0.5% energy spread, originated from a 0.5 GeV Linac.

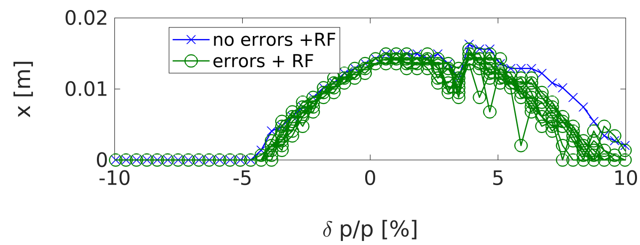

Figure 7: Off-energy max(x>0) dynamic aperture for 10 lattices with errors of 70 µm rms in all magnets and corrections.

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 USSR 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 3 nm rad and allows for injection efficiency of ~ 100% in the main USSR storage ring [3]. 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, 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. A final decision concerning the USSR injector is still pending and the injection with a full energy linac is presently the envisaged and favoured solution.

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