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PROGRESS ON THE NEW BOOSTER FOR SOLEIL II

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Abstract

The SOLEIL II storage ring project will require an injected beam with small transverse and longitudinal sizes. To meet this requirement, a new multi-bend 14BA Higher-Order Achromat lattice has been designed to reduce the booster emittance from the present 140 nm.rad to 5 nm.rad @ 2.75 GeV. In this paper we report the progress in the booster beam dynamics studies, considering the linac energy increase from 110 to 150 MeV, and all errors coming from injection magnets, injected beam parameters, booster magnets and RF system, whereas the resistive wall study is reported elsewhere. The progress in designing the magnets, the vacuum system, the ramped power supplies, and the diagnostics is presented.

INTRODUCTION

SOLEIL is the French third generation light source routinely operated for external users since 2008 with an electron beam emittance of 4 nm.rad at an energy of 2.75 GeV in high intensity (500 mA, multibunch) and temporal structure (e.g., 1 and 8 bunches) modes [1, 2]. It is currently preparing the Technical Design Report for a major facility upgrade. The objective is to reduce the storage ring emittance to the 80 pm.rad range for the multibunch mode, while preserving a time structure mode with 32 bunches [3]. Injection studies showed that Top-Up injection in this new storage ring requires a reduced emittance of the injected beam in the range of 5 nm.rad as well as lower bunch length [4], that can only be provided by a newly designed booster [5]. The injector shall also maintain the Long and Short Pulse modes (LPM and SPM) to meet the need for the modes of operation mentioned above, but also to provide efficient tools for a homogeneous filling in the storage ring. Indeed, the latter has become an issue since a harmonic cavity is planned to be installed in the SOLEIL II storage ring [6].

LINAC UPGRADE

It is well known that the increase in energy of the beam injected into the booster can only be beneficial: in terms of remanent field in the booster magnets, of geometric emittance of the injected beam and its relative energy spread due to beam loading in accelerating structures, of the eddy current sextupolar component in booster dipole and finally for the gas lifetime.

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The SOLEIL linac, commissioned in 2005, is a conventional S-band one, initially foreseen for 100 MeV [7]. But the need of a high reliability led us to use 2 klystrons and 2 high gradient, 4.5 m long accelerating structures. This gives us the opportunity to ramp them in power in the future, in such a way to produce a 150 MeV beam with reasonable safety margin.

Other new equipment is envisaged in order to promote a more homogeneous filling of the storage ring: a new linac event synchronisation system (Greenfield Technology generator) to fine-tune the duration of the LPM and reduce the phase error between the RF and the beam ; a new linac triode gun PCB card to better control the LPM rise time and overshoot, and also provide an automatic adjustment of the SPM charge during the Top-up injection process ; a new solid-state modulator as spare in first intention, that will control its output voltage better than +/-0.1% over 1 µs.

These significant changes (including the change of the magnet power supplies and of the beam stoppers on the LTB (Linac to Booster) transfer line), are scheduled before 2026, that is well before the foreseen SOLEIL shutdown (2028). They should preserve the present range of beam charge in LPM and SPM modes (nominal 4 nC in 300 ns and 0.5 nC/bunch at linac output), at a repetition rate of 3 Hz. An in-depth study of the charges and repetition rate actually required is underway.

BOOSTER VACUUM STUDIES

The SOLEIL vacuum group started studying with MOLFLOW+ and SYNRAD software [8] the current booster vacuum evolution throughout the years, to validate the outgassing data usually found in literature. Then, a first hypothesis of a round vacuum chamber 20 mm internal diameter was put forward for the SOLEIL II booster, with a lumped vacuum pumps system, 4.1 m apart and 10 l/s, made of baked stainless steel. The 2 existing RF cavity modules are reused as well as the booster injection pulsed magnets. A thermal desorption value of 10^{-11} mbar.l/s/cm2 was chosen to consider possible tricky equipment, as well as a realistic initial Photon Stimulated Desorption (PSD) of 3 10^{-2} mol/ph. As a result, a static average pressure below 10^{-8} mbar may be obtained for day 1, but a drastic increase of pressure is expected with beam: typically, 10^{-7} mbar with 0.03 nC/s and 3.10^{-6} mbar with 1 nC/s.

At that stage, an evaluation of the ion production and accumulation was made, considering the energy ramping of the booster. Thanks to the LPM mode filling pattern of 295

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ns over the 522 ns booster period, the neutralization factor $\eta = \frac{[CO^+]+[H_2^+]}{[N_e]}$ is relaxed and covers all the values described in Fig. 1 for an initial charge of 1 nC, which is finally considered as the reasonable maximum one for the first injected beam. In these conditions, the time to reach the critical photon dose of 10^{20} ph/m to initiate an efficient conditioning is evaluated to 6 hours. Then, we expect less than one month to finalise the conditioning and allow a nominal beam injection.

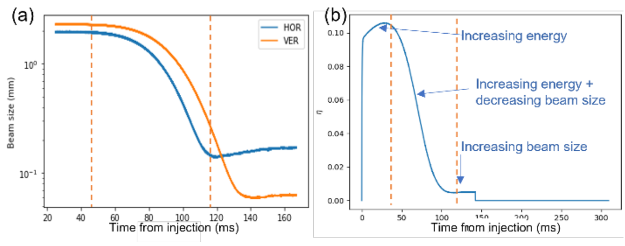

Figure 1: (a) Foreseen beam sizes along the booster ramp and (b) ion neutralization factor of day 1 w/ a total pressure of 3.10-6 mbar and in presence of 1 nC/s.

BOOSTER BEAM DYNAMICS

The booster optics presented in [5] and Fig. 2, with main parameters listed in Table 1, remains our baseline lattice, waiting on the final storage ring circumference to adjust its own length. A systematic study of the orbit correction has been made using 38 BPMs and 38 horizontal /38 vertical dipolar correctors the majority of which are located in the sextupoles. Errors are described in Table 2, including alignment, calibration errors of magnets, as well as power supply tracking errors. Tunes are systematically corrected as well as chromaticities at the nominal values of [1,1]. In the ongoing simulated commissioning study, girders are added as well as the coupling correction to give an emittance exchange the best chance. The resulting D.A. (Dynamic Apertures) shown in Fig. 3 also include the systematic multipoles in magnets whose impact is significant despite their low value.

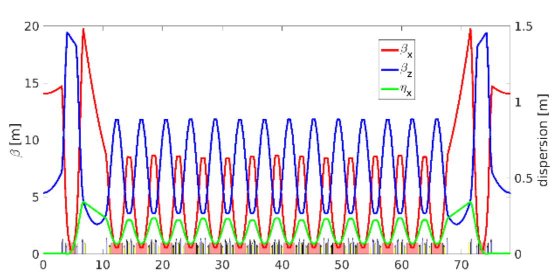

Figure 2: New booster optical functions (half ring).

BOOSTER BEAM STAY CLEAR

Some parameters greatly impact the Beam Stay Clear (BSC). Firstly, the linac beam time structure as shown in Fig. 4: in LPM mode, the linac gun triode is modulated by the main 352.2 MHz SOLEIL clock, leading to a succession of ~5 micro-bunches spaced @ 3 GHz, injected in the booster RF acceptance. In SPM mode, a local generator modulates the gun emission in a 2 ns full width pulse, leading to ~6 micro-bunches. The micro-bunches far from the booster synchronous phase will lead to the most critical off-momentum losses.

Secondly, the decreased value of the booster momentum compaction factor compared to today's forces to consider the RF frequency issue: the static error from circumference mismatch between SOLEIL II storage ring and booster (+/- 1 mm respective circumference errors will lead to a f_{RF} mismatch of +/- 3.2 kHz), and the f_{RF} fluctuating variation (with seasons, thermal load and electron path length variation w/ IDs gap). Figure 5 shows the typical SOLEIL f_{RF} behaviour since 2006. A global error of +/- 6 kHz is then considered in the study.

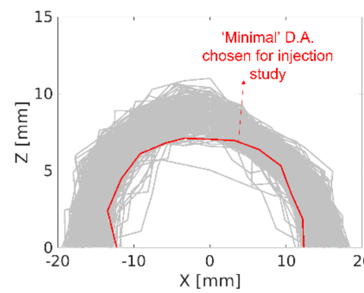

Figure 3: On momentum dynamic aperture of the SOLEIL II booster in presence of all errors (300 seeds), calculated at the middle of the long straight section.

Table 1: Main Parameters of the New Booster, 2.75 GeV

Parameter	Unit	Designed booster
Circumference	m	156.46
Natural emittance	nm.rad	5.2
Betatron tunes	-	13.19, 4.19
Natural chromaticities	-	-27, -12
Mom. comp. factor	-	$3.3 \cdot 10^{-3}$
Damping partitions	-	1.58, 1.0, 1.42
Natural damping times	ms	3.3, 5.2, 3.7
Energy loss per turn	keV	554
Natural energy spread	-	$0.93 \cdot 10^{-3}$
RMS bunch length	ps	25 @ 3 MV

Last parameter with high impact, the linac beam emittance $\varepsilon_{n90\%}=4\sigma\sigma'\beta\gamma$ is chosen as 200.10^{-6} πm.rad (conservative value), keeping in mind the 50.10^{-6} πm.rad measured value in 2006 [9].

Considering only single particle tracking at that stage, a 6D tracking is performed with Accelerator Toolbox code, at the injection energy for a large number of turns, to determine the maximum beam envelope (Fig. 6). As the incoming beam is round, the working point at injection may be set on the coupling resonance, with no expected growth of the vertical envelope. Finally, the injection rate into the booster is shown in Fig. 7 in case D.A. is minimal, in presence of an elliptical vacuum chamber of internal dimension H36 x V22 mm.

In a second step, a resistive wall study has been carried out using mbtrack2 code [10,11], that shows that the Amplitude Dependant Tune Shifts of the particles help to

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stabilize the beam during the energy ramp, regardless the chosen chromaticities. This result gives confidence in the chosen vacuum chamber aperture.

Table 2: Main Injector Errors

Part of injector	Parameters	Value
Linac beam @ 150 MeV	Energy offset	0.25 10^{-2} RMS
	Max. phase shift of the linac micro-bunch	+/- 0.6 π @ 352 MHz
LTB line	Emit. amplification due to mismatch	1.2
Pulsed magnets	Repeatability	2 10^{-4} RMS
	Roll error	0.4 mrad RMS
Booster	Max. f_{RF} shift	+/- 6 kHz
	Magnet alignment RMS	100 µm, 400 µrad
	BPM error RMS	500 µm
	Magnet calibration	10^{-3} RMS
	Pow. sup. track. error	5 10^{-4} RMS
	Magnet systematic multipoles	< a few units of 10^{-4} @ r=11 mm
	Decapole induced by corr. in sextupoles	$\Delta B/B_{corr}$=18% @ r=11mm

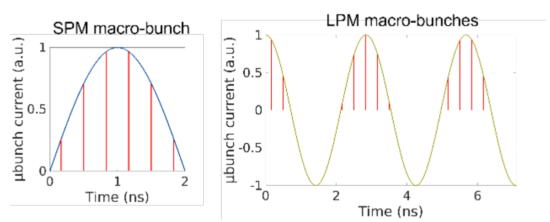

Figure 4: Linac beam time structure at booster entrance with its 3 GHz µ-bunches in SPM mode (1 to 4 macro-bunches) and LPM mode (104 macro-bunches).

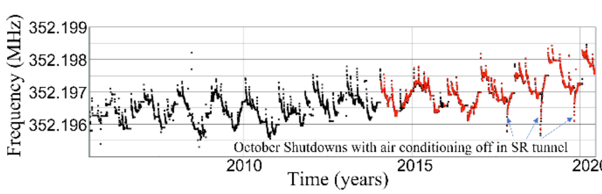

Figure 5: SOLEIL RF frequency variation since 2006.

MAGNET, POWER SUPPLIES, DIAG.

The magnets shown in Fig. 8 have been studied in terms of optimized inductances and harmonic content of the magnetic field. The ramping aspect of the fields has been considered in presence of the stainless-steel vacuum chamber, currently 1 mm thick. It provides slightly different magnetic lengths depending on the energy, especially between the dipole and quadrupole components inside the combined function long dipole.

The power supply group devised a strategy to reuse existing booster equipment, adapt existing storage ring one, and/or purchase SIRIUS-CERN power supplies, all equipped with an FGC-CERN command-control.

The design of a synchrotron light monitor mounted at the exit of the short dipole is in progress, being of great importance to commission the low emittance booster. Tests are underway to legitimise the reuse of the BPM electronics Libera of our present storage ring.

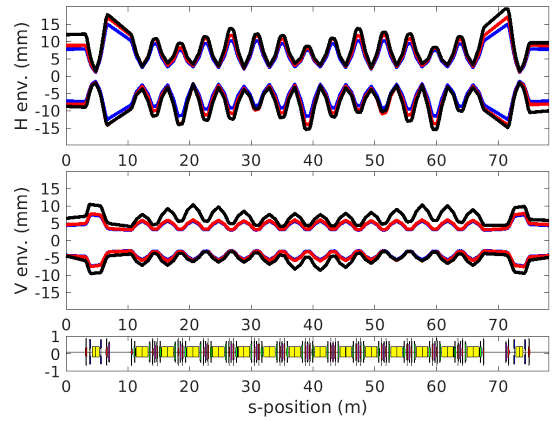

Figure 6: Beam envelopes at injection for an emittance $\varepsilon_{n90\%}$= 100.10^{-6} πm.rad and (red) the ideal lattice w/o coupling (blue) the ideal lattice w/ 99% coupling and maximum f_{RF} shift (black) the lattice w/ all errors giving the minimal D. A. Only half booster is represented.

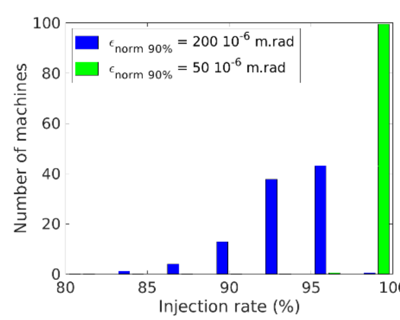

Figure 7: Injection rate of the SPM macro-bunch from LTB transfer line into the booster, w/ an elliptical aperture H36xV22 mm^2, considering the worst booster D.A. and all injection errors in 100 seeds.

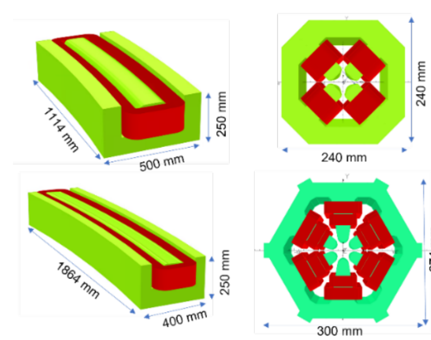

Figure 8: Booster new magnet design for short and long dipoles, quadrupole and sextupole.

CONCLUSION

The feasibility phase of the new booster for SOLEIL II is now well advanced, without any showstopper at this time. The very next step will be to confirm the repetition rate of the whole injector, which can ensure adequate filling quality of the SOLEIL II storage ring.

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