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CONSIDERATION OF BEAM INSTRUMENTATION FOR SOLARIS LINAC UPGRADE

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Abstract

SOLARIS linac currently operates at 540 MeV and is used as an injector to the storage ring, where after the accumulation the energy is ramped up to 1.5 GeV via two active RF cavities. Top-up injection would be of extreme benefits for user operation, therefore a new 1.5 GeV linac is being designed. The idea is to replace the current machine without infrastructural interventions in terms of tunnel expansion. Performed studies demonstrate that the best solution is provided by a Hybrid S-band/C-band LINAC. One of the main goals is to achieve bunch compression below the picosecond level and low-emittance beams for a future short-pulse facility or a Free Electron Laser. Within this presentation the results of performed simulations will be presented together with the concept of different diagnostics as BPMs, current transformers, YAG screens, coherent diffraction radiation monitor distribution.

INTRODUCTION

SOLARIS National Synchrotron Radiation Centre (NSRC) is first light source infrastructure built in Krakow, Poland. Currently it consists of 600 MeV linac with thermionic gun, 1.5 GeV storage ring and 5 operating beamlines serving for the users community. The storage ring operates in the decay mode with 2 injections during the day. An optimal perspective for the future operations at SOLARIS [1] would be the beam injection from the LINAC [2] into the storage ring at full energy, i.e. 1.5 GeV. There are several advantages related to this approach. The most intuitive is the possibility to keep the stored current at a constant level. This would favor the user operation requiring a constant level of brilliance of the synchrotron source and/or of the sources associated to insertion devices. The radiation source, therefore, can operate continuously, avoiding injection downtime and energy ramp. Additionally, from an operational point of view, all the machine settings, which are normally current-depending, could be kept at the same value. Avoiding invasive feedbacks meant to follow the electron current's decay, would allow the establishment of fine feedbacks working around equilibrium conditions for the beam parameters (like emittance, optics and orbit stability). Fine feedbacks could efficiently maintain optimal performances for days.

Furthermore, having a 1.5 GeV LINAC machine would open up a wide range of new possibilities for the facility, solely related to the LINAC as independent module. It's worth specifying that in a top-up injection system the LINAC is permanently serving the storage ring, nevertheless a beam-splitter system might be thought in order to save a fraction of charge for diverse applications, bypassing the transfer line to the ring. It has been already demonstrated the interest of doing electron irradiations with the LINAC [3]. Currently, a diagnostic station placed before the LINAC dump is already under development for tests/experiments on novel concepts of beam diagnostics [4]. A futuristic view of the same area would foresee a Free Electron Laser (FEL). Indeed, such a FEL source would be pulsed on a much shorter scale length than the pulses provided by the storage ring, and it would be designed to cover a different frequency range.

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OPTICS DESIGN AND BEAM DYNAMICS

There were several considerations for the new linac design. However due to space constrains in the linac tunnel the decision was made to change the technology from S-band to C-band allowing for higher accelerating gradient. The layout of the new LINAC placed in the existing tunnel is reported in Fig. 1. The schematics of the lattice elements is, instead, reported in Fig. 5. Such schematics will be discussed later on in this paper, specifically regarding the beam instrumentation used for beam diagnostics. The start-to-end simulations studies, from the cathode to the injection point for a Hybrid S-band/C-band LINAC were done by using the ASTRA and elegant [5] codes. The start-to-end simulation has been conducted for several different beam charges [6].

For the case of 100 pC the resulting beam optics in terms of rms beam sizes (Sigma x and y) is reported in Fig. 2. It is possible to notice that the beam size is maintained within the range of a few hundreds microns all along the LINAC, corresponding to a normalized emittance $\varepsilon_{Nx} \simeq \varepsilon_{Ny} \lesssim 5\,\mathrm{mm \cdot mrad}$. The emittance at the gun is around $1\,\mathrm{mm \cdot mrad}$ but it reaches such a value in the magnetic compressor due to space charge [6]. The final rms bunch length St is in fact ≃500 fs rms, as depicted in Fig. 3. Such a short bunch length may be used in the future to drive radiation sources or to perform ultra-fast irradiations for different applications.

ERROR STUDIES

Once the start-to-end simulation studies have been finalized, spanning over beam parameters, and beam optics solutions have been found to efficiently transport low-emittance, compressed beams, to the end of the full-energy LINAC, investigation of the errors in the lattice elements has been performed. The goal has been to evaluate if the selected focusing elements and their positioning is suitable for preserving the beam optics even for non-ideal elements, and

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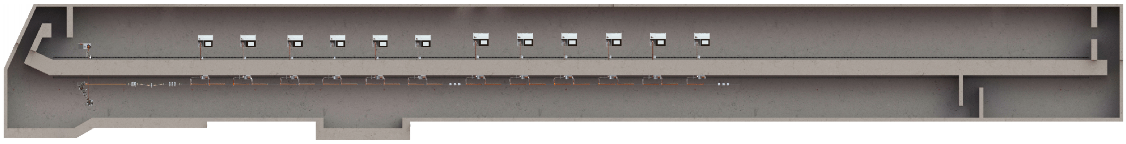

Figure 1: SOLARIS LINAC tunnel: gun on the left, transfer-line on the right.

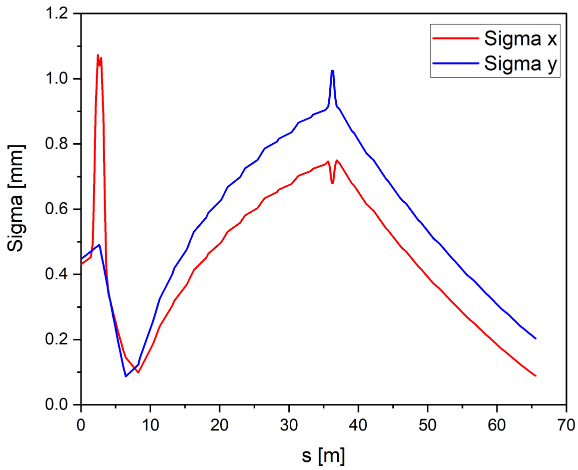

Figure 2: Evolution of the rms beam sizes (horizontal x and vertical y) along the LINAC.

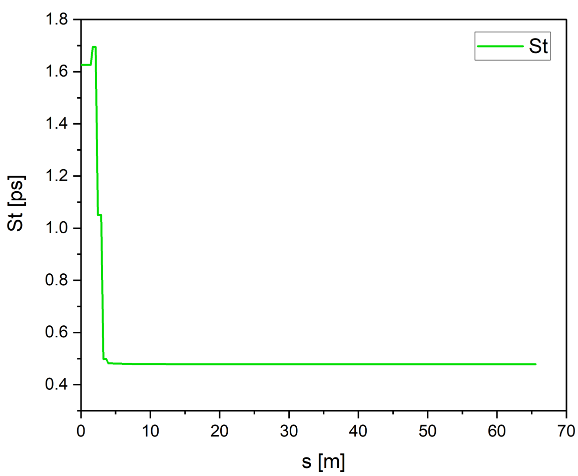

Figure 3: Evolution of the bunch length along the LINAC.

as well to study the beam orbit and how (and where) to correct it in case of spurious offsets along the lattice. The number of correctors has been set to 5 pairs: the first before the magnetic chicane, the second after, two pairs along the C-band LINAC between sections, and finally a pair before the transfer line. Concerning this latter, it includes an extra horizontal corrector for the definition of the horizontal angle of injection, as in the present layout of the SOLARIS injector LINAC. The "global" correction model for elements' alignment has been assumed, in order to minimize the average of error all along the machine, in both planes. For all the selected errors normal distributions have been considered, where the rms error seeds are listed in Table 1. Errors have been considered both for magnetic and RF elements.

Table 1: Rms value for the error distributions (all normal) considered on different elements along the lattice.

Errors and units		Rms error value
Field Amplitude Error	[MV/m]	0.1
Field Phase Error	[deg]	0.1
Cavity/Quad/Solenoid Offset	[mm]	0.1
Cavity/Quad/Solenoid Rotation	[mrad]	0.01
Solenoid Field Error	[mT]	1
Quad Strength Error	[1/m^2]	0.01
Bending Radius Error	[m]	0.001

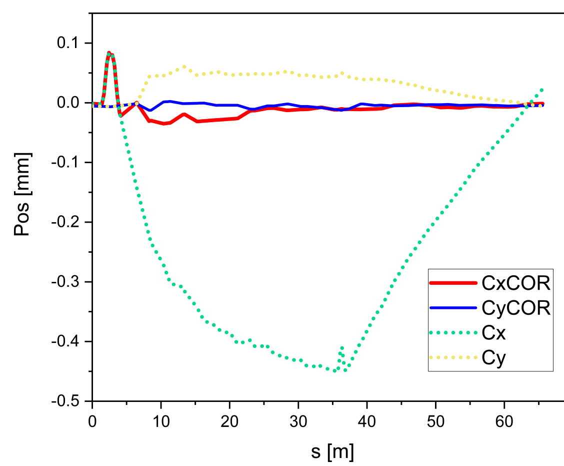

Figure 4: Error studies along linac.

In Fig. 4 the beam centroids are shown with (solid lines) and without (dashed lines) correction, when the errors presented in Table 1 are applied to the lattice configuration. A global correction better than a few tens of microns is reached in the x-plane and a correction on the level of a few microns is reached for the vertical plane y. The difference is due to the fact that the magnetic chicane disperse the beam in the horizontal plane giving an extra kick to the beam to be compensated.

BEAM INSTRUMENTATION

The electron beam diagnostics system should provide information required for the proper accelerator operation, as well as ensure a safe operation. Several types of diagnostic tools to be used to measure the relevant quantities with sufficient precision.

The beam properties are planned to be measured at various places along the SOLARIS LINAC. The diagnostic instruments that are foreseen for this purpose partially will be reused from the existing machine. Currently, for beam

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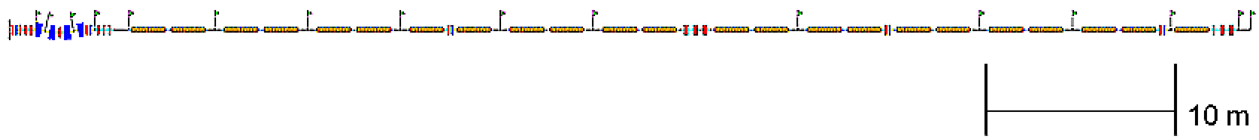

Figure 5: New Elegant lattice including BPMs, correctors and screens.

position and feedback system the stripline BPMs with Libera single pass electronics and correction system is used. For the linac upgarde the additional BPMs and correctors need to be added. The transverse beam size and the beam emittance are within the set of most important parameters for the beam characterisation. Therefore, emittance measurement stations will be available at several positions along the linac. The stations will be equipped with transverse beam size monitors as YAG screens in the distance from the quadrupole magnets. The emittance will be measure with the quadrupole scan. Moreover the YAG screens installed in the disperssive section of bunch compressor and transfer line will allow to determine the energy spread of the bunch. In Fig. 5 we show the latest version of the machine lattice, which includes BPMs, correctors and screens.

Table 2: Description table for the diagnostic flags depicted in Fig. 5.

Flag	Diagnostics
1	BPM 1
2	Screen 1
3	Screen 2
4	BPM 2
5	Screen 3
6	BPM 3
7	BPM 4
8	BPM 5
9	Screen 4
10	BPM 6
11	Screen 5
12	Screen 6
13	BPM 7
14	BPM 8
15	BPM 9
16	Screen 7

In Table 2 we have listed the meaning of the 16 flags found in the Elegant lattice at Fig. 5. The first two BPMs are useful for the knowledge of the beam position at the entrance and exit of the magnetic compressor. The two screens in the compressor are used to measure the beam energy spectrum, to check the alignment and the optics in the magnetic chicane. The third screen is used for quad scan purposes, to measure the beam emittance. The BPMs and screens along the C-band LINAC are used to check and control the beam optics and orbit along the machine. The fifth screen may be also used for quad scan purposes, with the caveat of well-aligning the beam in the C-band that is placed just before it (or switching it off during the measurement). The last two BPMs can give information on the beam angle at the injection.

The last screen yields the final beam profile, matched to enter transfer line. For the bunch length diagnostics some tests are undergoing based on the measurement of Coherent Diffraction Radiation (CDR). Such a method provides information on a limited amount of spectral bands composing the beam spectrum. Therefore, it strictly relies on a model or a direct measurement of the beam spectrum (bunch profile), in order to minimize the error of the measurement. Despite several CDR diagnostic stations may be placed all along the new machine to locally control the bunch length, a direct diagnostic station for the bunch profile (and then spectrum after Fourier transform) may be needed. The current idea is to introduce a S-band RF cavity at the end of the machine, on the straight line after the septum magnet which sends the beam into the transfer line to the ring.

For the current measurement, current transformers will be used distributed all along the machine. One of them may be placed before the magnetic chicane, one after (to measure the possible losses), then one in the middle of the lattice and one at the end after the last focusing doublet.

CONCLUSIONS

We have presented the most updated results for the beam dynamics and the error studies on the newly designed SOLARIS injector LINAC. The Hybrid S-band/C-band technology presented allow for the 1.5 GeV energy LINAC design within SOLARIS tunnel space constrains. This machine will be necessary to implement the top-up injection at the synchrotron facility. Specifically, we have presented the distribution of different beam instrumentation and diagnostics all along the lattice configuration allowing for correction of the beam trajectory with sub-micormeter level and for transversal and longitudinal beam parameters measurements.

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REFERENCES

[1] A.I. Wawrzyniak, R. Panaś, A. Curcio, M. Knafel, G. Kowalski, and A. Marendziak, “Solaris synchrotron performance and operational status”, *Nucl. Instrum. Methods Phys., Res. Sect. B*, vol. 493, pp. 19-27, 2021. doi:10.1016/j.nimb.2021.01.020

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[2] A. Curcio, R. Panaś, M. Knafel, and A.I. Wawrzyniak, "Liouville theory for fully analytic studies of longitudinal beam dynamics and bunch profile reconstruction in dispersive lines", *Nucl. Instrum. Methods Phys., Res. Sect. A*, vol. 986, p. 164755, 2021. doi:10.1016/j.nima.2020.164755

[3] A.A. Ahmed, A. Wrońska, A. Magiera, A. Curcio, M. Jaglarz, and A.I. Wawrzyniak, "Study of M99o and long-lived impurities produced in the Mnato (γ, x) reactions using an electron beam", *Radiat. Phys. Chem.*, vol. 177, p. 109095, 2020. doi:0.1016/j.radphyschem.2020.109095

[4] A. Curcio, R. Panaś, M. Knafel, G. Kowalski, M. Waniczek, and A.I. Wawrzyniak, "Bunch Length Characterizations for the Solaris Injector LINAC" in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 2117–2119. doi:10.18429/JACoW-IPAC2021-TUPAB277

[5] M. Borland, "Elegant: A flexible SDDS-compliant code for accelerator simulation", No. LS-287, Argonne National Lab., IL, US, 2000. doi:10.2172/761286

[6] A. Curcio, R. Panaś, A.I. Wawrzyniak, and J. Wiechecki, "Simulation study towards a new injector linac for the SOLARIS synchrotron facility", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 1967-1969. doi:10.18429/JACoW-IPAC2023-TUPL109