FIRST RESULTS OF SOLARIS SYNCHROTRON COMMISSIONING*

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Abstract

Solaris is a third generation light source recently constructed at the Jagiellonian University in Krakow. The installation of the 600 MeV S-band linear accelerator with thermionic RF gun and transfer line as well as the 1.5 GeV storage ring is now complete. In November 2014 subsystem tests and conditioning of the Solaris linac were started. A 300 MeV electron beam at the end of the linac was observed for the first time in February 2015 after which the machine was shut down for 2.5 months to complete transfer line and storage ring installation. In May the commissioning of the linac together with the transfer line and storage ring began. The beam was soon observed on the YAG screen monitor, installed at the injection straight in the storage ring. The beam current measured with the fast current transformer in the transfer line was 8 mA over 180 ns, at 360 MeV. The commissioning of the machine is still in progress and preliminary results of Solaris are presented.

INTRODUCTION

Solaris is a third generation light source constructed at the Jagiellonian University (JU) in Krakow, Poland. The project was started in 2010 with a unique cooperation between JU and Lund University/MAX-Lab in Lund, Sweden. Within this framework two twin 1.5 GeV storage rings were designed and built.

The installation of the Solaris accelerators started on May 2014 and was completed one year later. In November 2014 subsystem tests and conditioning of the linac started and by the end of February 2015 a 300 MeV electron beam at the end of the linac was observed for the first time. After this achievement the machine was shut down for 2.5 months to complete the transfer line and storage ring installation. In May 2015 the commissioning of the linac together with the transfer line and storage ring began. In June first turns were observed and then beam was accumulated and stored with the single kicker and RF system. On the 19th of June a 7 µA current was stored at 360 MeV and the first synchrotron light from the dipole was detected at the fluorescent screen in the front end of the PEEM beamline. In August the machine was shut down for a month to allow installation of an aluminium vacuum chamber and an elliptically polarized undulator (EPU) in the 5th straight section of the storage ring.

MACHINE DESCRIPTION

The Solaris injector is designed to efficiently fill the storage ring. Since the RF linac structures and waveguides are not completely conditioned yet, injection into the storage ring takes place at the energy of 490 MeV. After accumulation of the electron beam, the energy will be ramped in the storage ring to 1.5 GeV and RF power is provided by two 100 MHz RF cavities fed by two 60 kW solid state amplifiers.

Injector

The Solaris injector consists of a 0.6 GeV S-band linac with a thermionic RF gun and a vertical dog-leg beam transfer line (TL) [1,2]. The electron source is a thermionic RF gun with a BaO cathode that has been chosen for simplicity of operation. This gun was designed and manufactured at MAX IV Laboratory. The energy of the electron beam exiting the gun is 2.8 MeV and the average current of the bunch train right after the gun is 200 mA. To focus the bunches two solenoid magnets are installed after the gun. The beam is transported through the chopper section and an energy filter in order to compress and clean the beam.

Storage Ring

The Solaris 1.5 GeV storage ring is composed of twelve double bend achromat (DBA) cells [3-5]. Most of the magnets in the DBA are multifunction:

- Bending magnets with defocusing gradient and pole face strips;
- Focusing quadrupoles with focusing sextupole content;
- Defocusing sextupoles with trim coils for skew quads;
- Correction sextupoles magnets with additional coils of steering magnets.

All the magnets within one DBA cell are shaped in one Armco block. This innovative approach allows the mutual alignment of magnets within the DBA cell to be within a 25 µm tolerance range and makes the cell short - 4.2 m. This implementation however comes at a cost of challenging manufacturing of magnets and vacuum chambers and their assembly.

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Table 1: The storage ring design parameters

Energy [GeV]	1.5
Current [mA]	500
Circumference [m]	96
RF frequency [MHz]	99.931
Harmonic number	32
Radiation losses [keV]	114.1
Betatron tunes (H/V)	11.22/3.15
Nat. chromaticities (H /V)	-22.98/-17.14
Corrected chromaticities (H/V)	+2/+2 or +1/+1
Momentum compaction factor	$3.055 \cdot 10^{-3}$
Damping partition numer Jx	1.46348

There are twelve 3.5 m long straight sections in the storage ring. Two of them are completely occupied with diagnostic instruments, a vertical pinger, the injection septum magnet (1st straight), two 100MHz RF cavities and two Landau cavities (12th straight). Additionally, in the 3rd straight section the dipole injection kicker magnet is installed. All the other straight sections are fully dedicated for insertion devices (IDs).

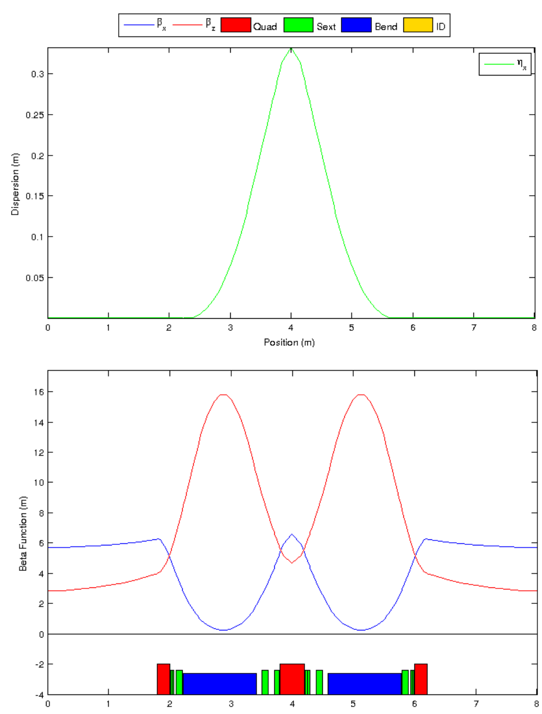

Figure 1: The optical functions for single DBA cell.

The optical functions for the achromat are shown in Fig. 1. As one can see, the beta functions and dispersion have low values, reducing the need for large vacuum chamber apertures. The cross section of the vacuum chambers has inner dimensions of 40/20 mm (horizontal/vertical), however at the center of the double-bend achromat the aperture is increased to 56/28mm.

Beam injection into the storage ring is done by a single pulsed dipole magnet installed in the 3rd straight section. The detailed studies of the injection to the 1.5 GeV storage ring at 0.55 GeV and ramping are presented in [6,7].

INSTRUMENTATION

In the linac injector seven current transformers (CTs) from the company FCC are installed in different places for beam current measurements. The bandwidth of the CT is 100 MHz. The data is acquired by Rohde & Schwarz RTO1004 oscilloscopes. For the beam position measurements eight quarter wave directional stripline beam position monitors (BPMs) with Libera Single Pass electronics from Instrumentation Technologies are used. Additionally, YAG screens are installed in a few places along the linac and the transfer line and injection section. The YAG crystal is inserted in the beam path by either a pneumatic actuator or by a stepper motor. The YAG screens are equipped with CCD Basler cameras using Tokina and Computar 100mm and 50 mm focal lenses.

In the storage ring the in flange “New Parametric Current Transformer” (NPCT) probe from Bergoz is connected to a Keithley 3706A DMM (7.5 digits) readout device. One method for the tune measurement uses a stripline kicker followed by spectrum analysis of button pick-ups. The second method uses the vertical (pinger) and horizontal (kicker) pulsed magnets to excite the beam and a fast Fourier transform (FFT) of BPM signals. In the injection section straight vertical and horizontal scrapers are installed. The vertical scraper will give information on the average pressure in the machine and as a result - on elastic and inelastic and Touschek lifetime. Furthermore, with knowledge of the vertical beta function, the vertical acceptance of the ring can be determined. The horizontal scraper will reveal the dynamic energy acceptance and/or the RF energy acceptance.

The Solaris storage ring uses 36 button pickups in a diagonal architecture for the beam position monitors. These BPMs are connected to commercial electronics from Instrumentation Technologies – Libera Brilliance+. The electronics, in addition to ‘turn-by-turn’ mode, can operate also in ‘first turn’ mode to help with commissioning. A slow orbit correction is possible at 10 Hz. Additionally, the Libera electronics is equipped with GDX modules for fast orbit feedback at 1kHz (input). However this option will be used in the future.

SOLARIS COMMISSIONING

The beam current in the pre-injector was measured with current transformers connected to oscilloscopes. The average current of the beam right after the gun body is about 200mA over 1.1 µs. When the beam is transported through the 500 MHz chopper and the limiting aperture about three-quarters of the current is lost. After passing

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the energy filter where the beam is compressed and cleaned of low energy electrons, the current of the beam entering the linac is 12mA over 200 ns. Figure 2 shows the current data from the oscilloscope.

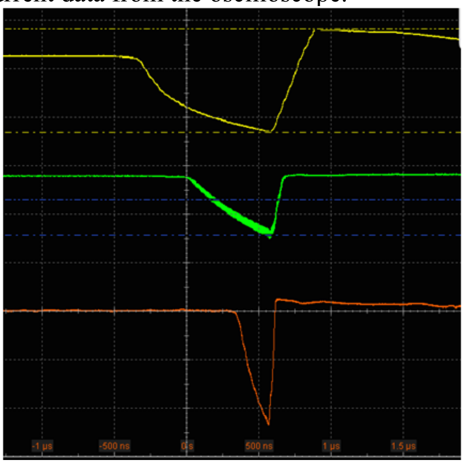

Figure 2: The beam current measured at 3 different locations in the pre-injector. Yellow: current of the electron beam after the gun body (200 mA), green: before energy filter (EF) (50mA) whereas the orange: after energy filter before entering the first linac section (12mA).

In the linac the beam is accelerated up to 490 MeV. The energy was measured in the transfer line using the 17° dipole magnet as a spectrometer. The beam current was measured at the exit of the transfer line and this value was used to estimate the injection efficiency. The average charge of the beam is 1.4 nC, which is injected into the storage ring at a 1 Hz repetition rate. The current is measured with the NPCT in the storage ring. An example plot of 13.4 mA current accumulation is presented in the Fig. 3.

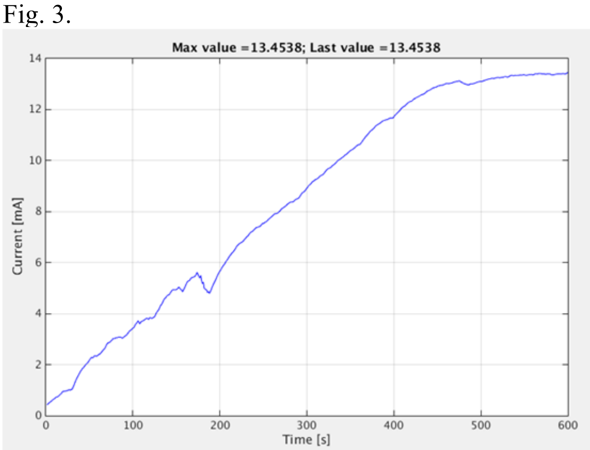

Figure 3: Accumulated current in the storage ring.

The transport of the charge from gun to the storage ring is less than 1% and its improvement is underway. The main location of losses is at the septum magnet.

It has to be noted that so far injection to the storage ring as well as accumulation takes place without any correction of the closed orbit. The alignment of the magnet, which act as their own girders, is very good and the rms values of the closed orbit without orbit correction are 2.28mm horizontally and 0.7 mm vertically. The closed orbit is shown in the Fig. 4.

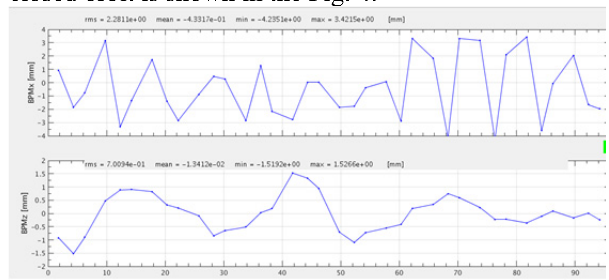

Figure 4: the closed orbit of stored beam without any correction.

The tune measurements were done by exciting the beam with the vertical pinger and the horizontal kicker magnet and a button BPM signal was processed using Libera Brilliance + turn-by-turn data. The fractional tune was plotted using MATLAB software and is presented in the Fig. 5. The tune of the machine is 10.78 and 3.601, which is different from the design values presented in Table 1. However the optics was found to be more stable and the injection more efficient. Due the some temporary problems with the pole face strips, that are used to change the gradient, it was not possible to operate at the design optics.

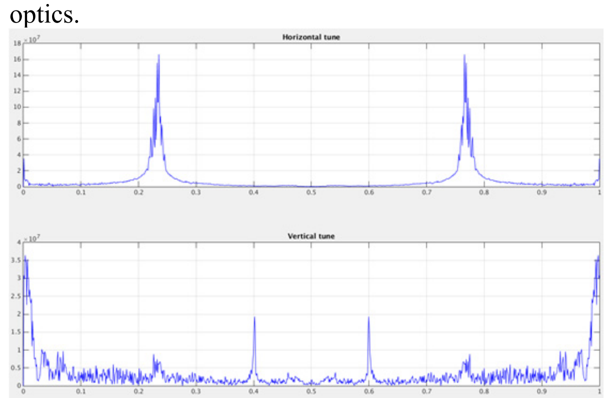

Figure 5: The fractional tune measurement.

Ramping of the stored beam in the storage ring was tested during the last few days before shut-down. The beam was ramped up to 743MeV before the total stored current was lost due to a fault on power supply controllers. Further tests of the ramping software to 1.5 GeV will be conducted after the summer shutdown and no issues are expected.

The vacuum system in the storage ring uses 61 ion getter pumps and 12 titanium sublimation pumps from Gamma Vacuum and also 24 non-evaporable getter strips from SAES. The mean pressure without beam depends on maintenance work and is usually around $3.5 \cdot 10^{-10}$ mbar. The pressure level in the storage ring without a beam is presented in the Fig.6. During accumulation of the current in the storage ring up to the level of 13.4 mA (Fig. 3) the mean pressure in the storage ring was $5.1 \cdot 10^{-9}$ mbar (Fig. 7).

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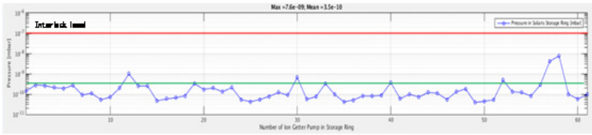

Figure 6: Pressure level inside the storage ring without the beam. Green line represents mean level of the pressure and red line interlock level.

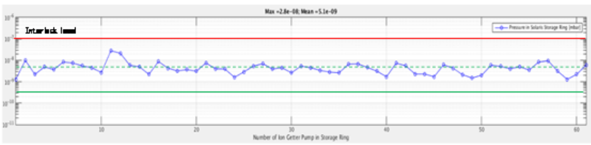

Figure 7: Pressure level inside the storage ring with the beam. Solid green line represents mean level of the pressure without the beam, dashed green line with the beam and red line represents interlock level.

So far the vacuum interlock level in the storage ring has never been triggered.

The total beam lifetime at 13.4 mA is around 5 min and increases with decreasing the current reaching 32 min at 1.5 mA. At this stage the lifetime is dominated by the gas scattering.

SUMMARY

Commissioning of the Solaris light source is on-going. The linac and storage ring RF systems have not yet reached their full performance and are still being conditioned. Therefore, injection to the storage ring is done at 490 MeV with a repetition rate of 2 Hz maximum. The injection efficiency is low and is being optimised. The ramping to full energy is under going tests and the linear optics at intermediate energies between 490 MeV and 1.5 GeV has to be corrected and proper snapshots need to be prepared in order to ramp the beam without losses. For the present the storage ring does not operate at its nominal optics but is expected to do so as commissioning progresses with full characterisation of the optics and closed orbit correction.

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