PREPARATION OF SLS FOR IBS MEASUREMENTS

N. Milas, M. Aiba, M. Böge, A. Lüdeke, A. Saa Hernandez, A. Streun, PSI, Villigen, Switzerland
F. Antoniou and Y. Papaphilippou, CERN, Geneva, Switzerland

Abstract

It is planned to use the Swiss Light Source (SLS) for testing damping ring issues related to linear colliders. One aspect is the study of Intra-Beam Scattering (IBS) effects, which are a limiting factor for ultra-low emittance rings. In this paper we present the setup and characterization of a new mode of operation in which the SLS runs at lower energy (1.57 GeV) with a natural emittance of 2.4 nm rad. This emittance is more than two times smaller that at the nominal energy of 2.4 GeV and should make IBS effects more easily visible. In order to be able to observe IBS a careful setup is required: Optics measurements and correction as well as measurements of the bunch natural energy spread and the onset of turbulent bunch lengthening. Also, a detailed discussion on the available diagnostics and their limitations are shown and finally some preliminary results of beam emittance measurements, in all three planes, as a function of single bunch current are presented.

INTRODUCTION

Since 2011 the Paul Scherrer Institut is part of the EU-project TIARA (Test Infrastructure and Accelerator Research Area)[1] collaboration [1]. The aim of this work package in this collaboration is to use the SLS as test bed for damping rings and future light sources, in this context Intra-Beam Scattering (IBS) studies is one subject of great interest. Although at nominal energy of 2.4 GeV IBS effects are minimal, of the order of a few percent [2], it can be strongly enhanced if the machine is operated at lower energy. Some effort has been spent in the last 2 years in setting up the storage ring to run at 1.57 GeV. In this paper we describe the effort in setting up a standard mode at 1.57 GeV and the work done in order to make vital diagnostic available to measure the effects of IBS.

1.57 GEV MODE SETUP

The way to set up the low energy mode is to scale down the whole 2.4 GeV optics to 1.57 GeV and do the extraction from the booster to the storage ring by changing the extraction timing. The first challenge encountered to make a working lower energy mode is the very nonlinear calibration of the superbends [3]. Since 2006, three dipoles in the machine were exchanged by a special type of high field dipoles, which are normal conducting magnets with fully saturated center iron pole at 3 T, and the down-scaling of those elements was one of the main difficulties during the set up of the low-energy mode during 2010, mainly due to unknown or limited knowledge of the saturation effects in those magnets. Another challenge are the accelerating cavities, which are optimized to run at higher energies and currents, thus exciting various unstable modes at different currents. Finally, since IBS is a single bunch effect and our diagnostics is able to resolve very low currents, as low as 0.1 mA in the longitudinal plane and 0.5 mA in the transverse planes, we decided to measure using only single-bunch mode.

The main ring parameters for the low-energy mode are described in the Table 1. We also performed a quick verification of the optics using turn-by-turn (TBT) measurements which indicated that it was close to the one at 2.4 GeV, as expected, and a that the residual beta-beat was below 10% in both planes. No further correction of the optics was attempted.

Table 1: 1.57 GeV Machine Parameters

Parameter	Description	
E	Beam energy	1.57 GeV
$\sigma_{\epsilon 0}$	rms energy spread ($\delta E/E$)	5.6×10^{-4}
α	Momentum compaction	6×10^{-4}
U_0	Radiation loss/turn	97.4 keV
ϵ_{h0}	Horizontal emittance	2.4 nm rad
V_{rf}	Main RF voltage	0.6-2.1 MV
σ_{z0}	Natural bunch length	11.2-6.8 ps
ν_{z0}	Synchrotron frequency	4.3-8.0 kHz

Fig. 1 shows a machine shift while the 1.57 GeV mode was optimized . At the time, due to coupled-bunch modes in the cavities we could not accumulate more than 150-155 mA. The horizontal beam size corresponds well to the predicted value, which at the emittance monitor position (see next section) should be 35 μm for an emittance of 2.4 nm rad.

DIAGNOSTICS

In the following section, a list of the main measurements that are performed during experiments in order to observe the effects of IBS is enumerated:

Transverse Beam Size

In the SLS we have a dedicated beamline to measure the transverse size of the electron beam (see Fig. 2). Utilizing radiation of the same dipole it is possible to simultaneously use two methods, X-rays for pinhole imaging

[1]The research leading to these results has received funding from the European Commission under the FP7-INFRASTRUCTURES-2010-1/INFRA-2010-2.2.11 project TIARA (CNI-PP). Grant agreement no 261905.

ISBN 978-3-95450-115-1

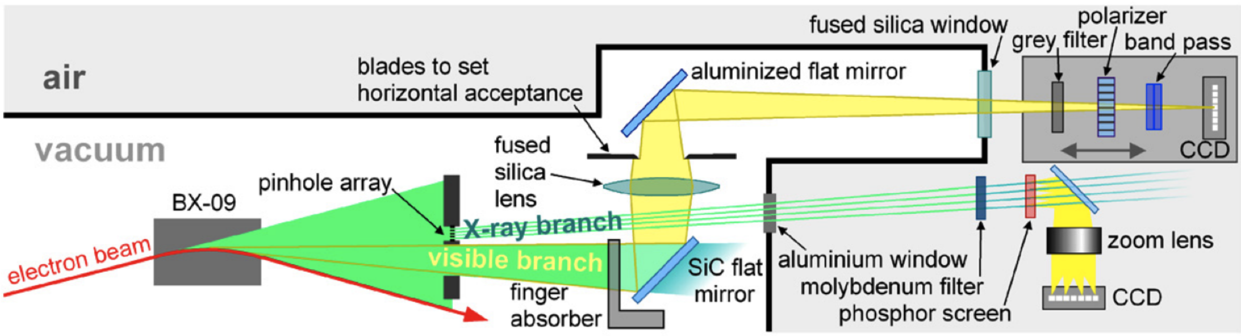

Figure 2: Schematics of the diagnostic beam line showing the vis-UV and the X-Ray branches.

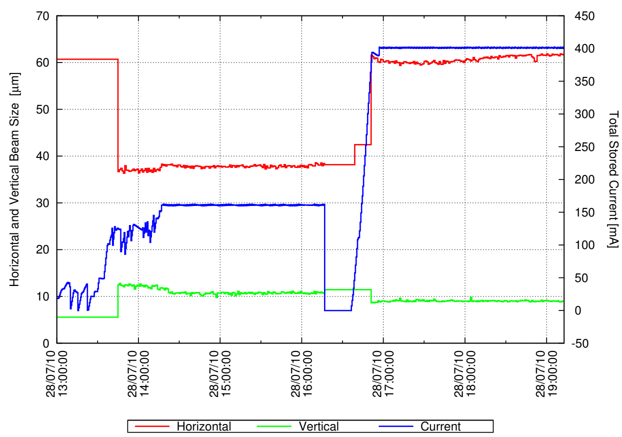

Figure 1: Machine shift showing the switch between 2.4 GeV mode to 1.57 GeV and back. Observe that the horizontal beam size drops from 60 μm to 38 μm, which corresponds to a change in emittance expected.

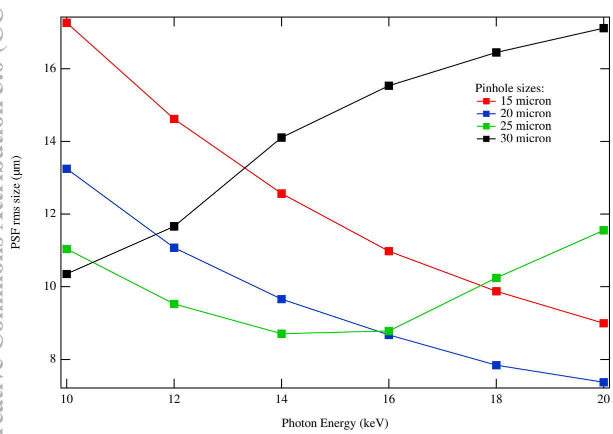

Figure 3: Calculated PSF for each pinhole size available in the SLS.

and vis-UV π-polarized light method [4]. With the π-polarized method it is possible to measure very accurately small beam heights, however it is not the optimum way to measure the horizontal beam size. To have a precise measurement of the horizontal beam size a series of pinholes can be used. In this beamline a pinhole array with sizes of 15, 20, 25 and 30 μm is available. In order to account for the non monochromatic X-ray spectrum and diffraction effects we calculated, using the Synchrotron Radiation Workshop (SRW) program [5], the point spread function (PSF) for each pinhole for different photon energies, as shown in Fig. 3. With the knowledge of the absorption characteristics over the X-ray path and also the phosphorous screen conversion of X-ray to visible light it is possible calculate the real convoluted PSF taking into account contributions due to the different X-rays photon energies that reach the CCD at the same time. For IBS studies no Molybdenum filter is used, since in single bunch mode the intensity on the CCD camera is very low, and for beam sizes around 40 μm the optimum setup is to use 25 μm pinholes, which yield the minimum PSF of 9 μm.

Bunch Length

To measure the bunch length we used an Optronics Streak Camera installed in the diagnostic beamline X05DB [6]. This Streak Camera enables to measure the bunch length of individual bunches with a precision better than 2 ps for currents of the order of 0.1 mA. In order to characterize the machine a measurement of bunch length versus current was performed at the nominal mode of operation (2.4 GeV and a total accelerating voltage of 2.1 MV) and then the same measurement was repeated at lower energy (1.57 GeV) and for two different cavity voltages (V_{rf} = 600 kV and 2 MV). Fig. 4 shows the measurements and also the fitted curves, corresponding to the I^a scaling for turbulent bunch lengthening, for each case [7]. From all three fits it is possible to confirm the scaling $a = 0.34 \pm 0.02$ on the bunch length with current already measured before [8], so verifying that turbulent effects are present. It is also possible to extract the turbulent current threshold (I_{th}) and the longitudinal broad brand impedance ($|Z/n|$) from each measurement and the results are summarized in Table 2. In all three measurements the impedance values for the longitudinal broad band impedance are in agreement with each other and the values for the current threshold are very close to those predict by the theory describing turbulent effects. It is interesting to notice that the impedance measured now of 440 ± 30 mΩ is double the value obtained in 2001 [8], 220 ± 10 mΩ, reflecting its increase as more and more insertion devices were installed in the past 10 years of operation of SLS.

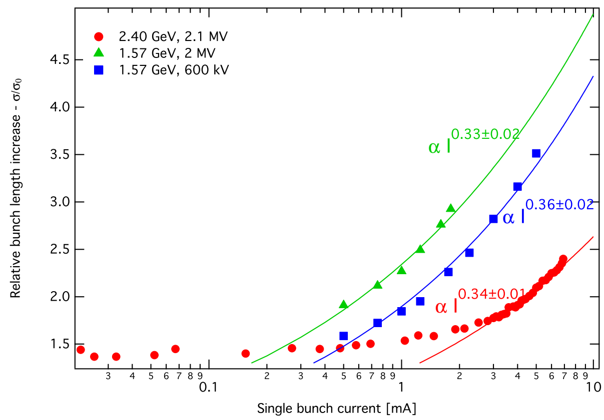

Figure 4: Measured bunch length as a function of single bunch current for 2.4 GeV (V_{rf}=2.1 MV) and 1.57 GeV (V_{rf}= 600 kV and 2 MV). The lines are the fits to the turbulent regime and the exponents obtained in the fitting are shown beside each line.

Table 2: Turbulent Bunch Lengthening Results

Energy	Cavity Voltage	I_{th} [mA]	$\lvert Z/n\rvert$ [mΩ]
2.41 GeV	2.1 MV	0.57±0.02	432±2
1.57 GeV	2.0 MV	0.08±0.01	482±1
1.57 GeV	600 kV	0.16±0.02	417±1

Energy Spread

We attempted to measure energy spread by estimating the size of the chromatic side bands of the transverse tunes [9]. This method, however, was not very successful, as impedances and off-momentum optics beta-beating influences the Fourier amplitude of the side-bands. In some cases the difference is so large that the results extracted from two complementary side-bands (i.e. $m = \pm 1$) are completely incompatible. We are now in the process of setting up the kickers of the longitudinal feedback system in order to create a resonant excitation around the longitudinal tune to be able to measure it more precisely.

FIRST RESULTS

On May 1^{st} 2012, the first successful machine IBS experiment using the 1.57 GeV mode was performed. Two sets of measurements of vertical, horizontal and longitudinal beam sizes, with total accelerating voltages of V_{rf} = 600 kV and 2 MV, were recorded. In order to disentangle IBS and turbulent bunch lengthening we measured the longitudinal beam size for each current with small vertical emittance (≈ 3 pm rad) and then used the skew quadrupoles to blow it up to about 50 pm rad and remeasured the longitudinal beam size. Although the results are still not completely analyzed [2] they indicate that IBS is visible in the SLS. Further studies are necessary and ongoing.

CONCLUSION

We established a mode in which the SLS runs at a lower energy of 1.57 GeV. Optics measurements using TBT data indicate that the residual beta-beat is smaller than 10% and that the optics scaling from 2.4 GeV to 1.57 GeV is satisfactory. With the available diagnostics it is possible to resolve the bunch intensities and sizes in this mode and it should be possible to verify the effects predicted for IBS in SLS. The measurement of the energy spread is still not possible. During our first dedicated shift at 1.57 GeV we measured the increase in bunch length, vertical and horizontal emittance as a function of single bunch current. Although the results are not fully understood yet, partially because of the lack of an energy spread measurement, they indicate that IBS effects are observable in this mode.

REFERENCES

[1] TIARA WP6: SVET R&D infrastructure, `http://www.eu-tiara.eu/rtd/index.php?id=42`, 2011.

[2] F. Antoniou et. al,"Intrabeam Scattering at the Swiss Light Source", TUPPR057, these proceedings.

[3] A. Gabard et al., "A 2.9 tesla room temperature superbend magnet for the Swiss Light Source at PSI", IPAC2011, San Sebastián, September 2011, THPC063, p. 3038.

[4] Å. Andresson et al., Nucl. Instrum. Methods Phys. Res., Sect. A 591 (2008) 437-446.

[5] O. Chubar, P. Elleaume, "Accurate and efficient computation of synchrotron radiation in the near field region", EPAC'98, Stockholm 1998, THP01G, p. 1177.

[6] V. Schott et al., "Using visible synchrotron radiation at the SLS diagnostic beamline", EPAC'04, Lucerne, July 2004, THPLT025, p. 2526.

[7] P.B. Wilson, et al., IEEE Trans. on Nucl. Sci. Vol. NS-24, No. 3, June 1977, p. 1211.

[8] A. Streun, "Beam Lifetime in the SLS Storage Ring", Internal Report SLS-TME- TA-2001-0191, `http://ados.web.psi.ch/slsnotes/tmeta010191.pdf`.

[9] T. Nakamura, "Chromaticity for energy spread measurements and for cure of transverse multi-bunch instability in the Spring-8 storage ring", PAC2001, Chicago, TPPH131, p. 1972.

ISBN 978-3-95450-115-1