Performance of the Phase I Superconducting X-Ray Lithography Source (SXLS) at BNL*

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Abstract

The Phase I SXLS electron storage ring has a circumference of 8.5 meters, it uses conventional dipole magnets, $B \leq 1.1$ T and $\rho = 60$ cm, and it is capable of operating in the range of 50-250 MeV.[1] It is the forerunner of the Phase II SXLS ring which will operate at 700 MeV and will make use of superconducting dipoles, $B_0 = 3.87$ Tesla, as a source of $\lambda_c = 10$ angstrom x-rays for proximity printing lithography. The Phase I storage ring has been successfully commissioned; stored currents in excess of one ampere have been achieved. A report on the performance of the machine is presented.

1. Operational Status

Using the NSLS 80 MeV linac & booster ring as the injector, any pattern of 1-6 bunches can be filled in the SXLS ring with energies in the range of 80-200 MeV. Table 1 displays the present operational status of the machine; E is the injection energy, I_{ave} is the stored current that is routinely achieved, I_{max} is the maximum current achieved and N_B is the number of symmetric bunches. The maximum stored current of the machine is limited primarily by the the injector performance and secondarily by instabilities. Roughly 85% of the study time has been dedicated to 200 MeV operation as both the storage ring & the injector perform their best.

E [MeV]	I_{ave} [ma]	I_{max}[ma]	N_B
200	900	1200	6
200	900	1200	3
200	300	450	2
200	400	500	1
160	600	762	6
120	NA	360	6
80	180	270	6

Table 1: Present Operational Status (3/92)

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2. Electron Beam Lifetime

Figure 1 displays the decay of 1, 3 & 6 bunch fills of 200 MeV electrons. The lifetime does not improve proportional to the number of bunches that are filled, i.e., $\tau_6 < 6\tau_1$, as would be expected if Touschek scattering were the only effect determining the lifetime. Intrabeam scattering, bunch lengthening, vacuum and ions all contribute to the lifetime.

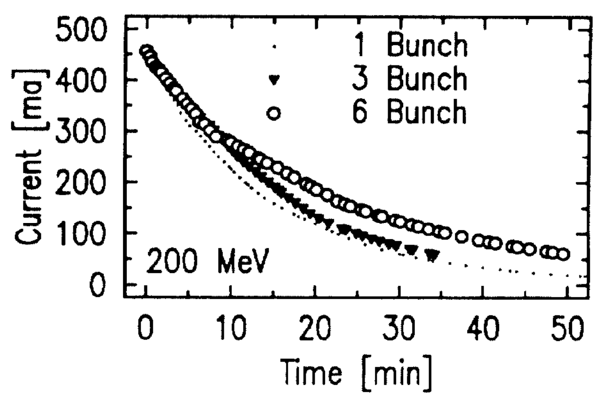

Figure 1: Stored Current (1, 3 & 6 Bunch) vs. Time

3. Vacuum

To date the machine has accumulated roughly 100 A-hrs of operation. The initial pressure rise at the beginning of conditioning was 1 ntor/ma and decreased to less than 2×10^{-3} ntor/ma after 50 A-hrs of operation. Subsequently the ring was brought to atmospheric pressure of LN_2 boil-off about 5 times and once to lab air. Less than 0.5 A-hr was required to bring the pressure to before vent levels for the nitrogen vents and for the air vent without bakeout, almost 10 A-hrs were needed. Table 2 lists the residual gas composition.

Gas Type	After 17 A-hrs	After 90 A-hrs
H_2 (2)	45 %	74 %
CH_4 (16)	25 %	12 %
CO (28)	18 %	11 %
CO_2 (44)	12 %	3 %

Table 2: Residual Gas Composition

The high CH_4 content is due to the absence of DIPs in the dipoles and to the low ion pump speed for CH_4 at low pressure (10^{-10} torr).

4. RF System

The RF system consists of a solid state low level driver with a tetrode power output stage. The system is capable of 10 KW output power at an operating frequency of 211.55 MHz. Amplitude and tuning servo loops compensate for beam loading.

The re-entrant cavity has a Q of 12,818 and a shunt impedance of 588 KΩ. A loop tuner provides for any frequency detuning. Higher order modes are damped by means of dipole antennas connected to water cooled loads.

During routine operation the cavity power is nearly 5 KW yielding a gap voltage of 50 KV. At the present time, efforts are being made to determine the amount of HOM power dissipated by the cavity and to examine the effect of the HOM impedances on instabilities.

5. Instabilities & Feedback

For two symmetric bunches there is no evidence of a longitudinal instability. The beam is quiet, as is the case in single bunch operation, but in two bunch mode the maximum stored current is limited to about 450 ma.

For three symmetric bunches the beam develops synchrotron sidebands on the "forbidden" rotation lines (see Figure 2). It is believed that the HOMs in the RF cavity provide the coupling impedance and the instability comes and goes as the tuner moves. The instability is not necessarily fatal as it is present during the fills up to and in excess of an ampere. The instability can be quelled with a single channel of a narrow band longitudinal feedback system.

Six bunch operation is fraught with coupled bunch motion but again the instability is not necessarily fatal. Two additional channels of feedback are being assembled for six bunch operation.

The longitudinal feedback system is of the type developed for the CERN PS booster[2]. The beam signal is picked up on a two plate stripline, processed through a notch filter and fed back to the beam through a four plate stripline on the opposite side of the ring.

During injection, a fast transverse beam oscillation is observed that blows up the horizontal beam profile (Figure 3) and initiates an abrupt dropout of some of the stored beam. The instability can appear during 1, 3 or 6 bunch operation and typically occurs for currents of about 50 ma when the clearing electrodes are powered. The cause of the instability is not understood although fortunately it is possible to turn off the clearing electrodes, inject through this instability and continue filling to high currents where the instability is absent. The longitudinal feedback system can also help to suppress the beam oscillation which points to synchro-betatron coupling as the source of the instability.

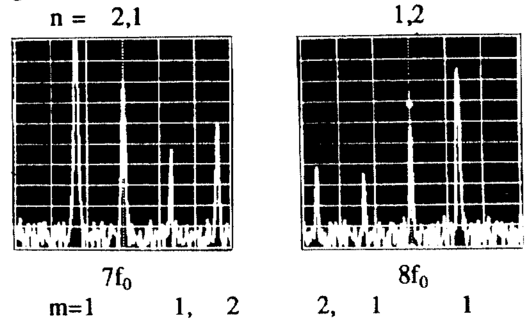

Figure 2: Synchrotron sidebands on rotation lines during longitudinal coupled bunch instability for 3 symmetric bunches, $f_p = |(n + 3p)f_0 + mf_s|$, $-\infty < p < \infty$

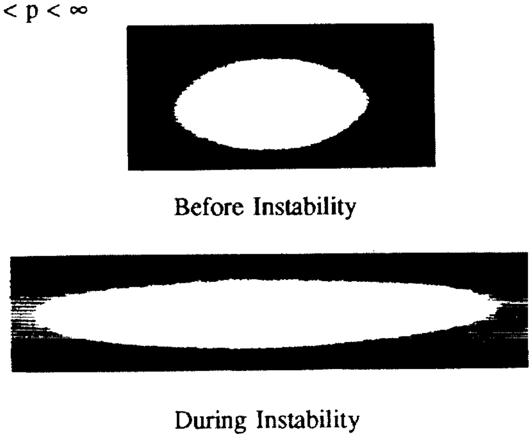

Figure 3: Beam profile before and during transverse instability

6. Bunch Length

Bunch length measurements have been performed using stripline kickers installed in the ring as a pickup[3]. This stripline provides the rms bunch length assuming the bunch is Gausssian, by using the risetime of the direct signal from the bunch as measured by a high frequency transient digitizer. Since the stripline was combined with vacuum pumpout slots, the impedance mismatches prevented a measurement of the current profile, without obtaining detailed measurement of the impulse response of the stripline. The low current bunch length at 200 MeV and an rf voltage of 35 kV was 58 ±8 psec, somewhat larger than the expected 40 psec. As the current was increased the bunch length shortened to about 48 psec at 20 mA/bunch and then started lengthening as the current increased, approaching 100 psec at a current of 150 mA/bunch.

7. Ion Clearing

The storage ring is fitted with 12 clearing electrodes, 5 in each dipole magnet and one in each straight section. The electrodes, are 50 Ω striplines of width 2.5 cm, capable of supporting a 5 KV potential difference. Voltages in the range of 0-1 KV have yielded the best results. The main qualitative conclusions are as follows: i.) Clearing electrodes are necessary to store currents in excess of 400 ma in 1, 3 or 6 bunch operation, ii.) The vertical beam size can be reduced by a clearing voltage, iii.) One electrode charged to 0.5-1.0 KV is "effective", two is better and any additional electrodes have little effect.

Figure 4 is a plot of the relative electron beam sizes for single bunch operation obtained by fitting the beam profile from a synchrotron light monitor with a 2-D Gaussian distribution. The vertical beam size is subject to large variations even in the presence of clearing electrodes. No matter how many electrodes or how much voltage is applied it is not possible to reduce the beam size back to the low current values. The number of clearing electrodes in the Phase II ring will be reduced to reflect the above results and because the electrodes needlessly draw many tens of watts of power from the electron beam.

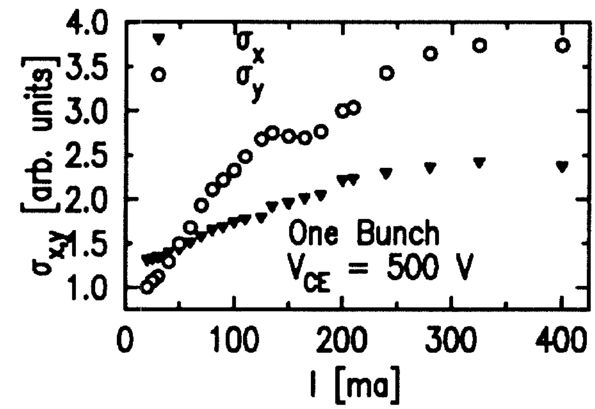

Figure 4: Electron Beam Sizes

A sharp reduction in the lifetime during injection is occasionally observed. It is thought to be related to the ions as changing the clearing voltage or modifying the betatron tunes eliminates the problem.

Resonant shaking of the ions at frequencies from 1-10 MHz has also been tried and the results are reported in reference 4.

8. Diagnostics

The SXLS ring is instrumented to permit on-line measurements of all the basic beam parameters such as intensity, transverse and longitudinal size, transverse position and the horizontal and vertical betatron tunes. There are four flag (fluorescent screen) stations in the ring for establishing an injection orbit. Pick-up electrodes (PUEs) have been built into the vacuum chamber to provide beam position information at six points around the ring. Beam positions for individual bunches turn by turn are determined by processing PUE signals with hybrid networks and a 1 GHz digitizing oscilloscope. The closed orbit is measured at a 10 Hz rate with dedicated rf receiver type position monitors. In addition to PUEs, two sets of stripline electrodes have been provided, one for "kicking" the beam and the other for monitoring.

Beam intensity is determined by peak-detecting a rotation harmonic in a PUE sum signal. Transverse dimensions of the electron beam are measured by imaging the beam with a telescope on a CCD TV camera using synchrotron light coming out of one of the dipole ports. The camera video signal is continuously processed by a beam analyzer made by Spiricon. Tune measurements are made using a 500 MHz network analyzer (HP 4195A), a set of wideband rf power amplifiers (ENI 5100L) and the kicker and monitoring striplines.

9. Closing Remarks

Studies on the ring will continue through July 1992 when the ring will be decommissioned to prepare for the Phase II machine.

10. Acknowledgements

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11. References

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