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STATUS OF THE NATIONAL SYNCHROTRON LIGHT SOURCE*

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Abstract

The status and performance of the NSLS 700 MeV ring and 2.5 GeV ring is described. Emphasis is placed on properties of the stored beam pertinent to synchrotron radiation production, the factors determining these properties, and efforts to improve performance of the rings.

Introduction

In the past two years,[1] the injector and storage rings of the National Synchrotron Light Source have been put into operation. The booster synchrotron first accelerated electrons in June of 1981. Electrons were first stacked in the VUV storage ring during December 1981, and the first synchrotron radiation beam line received light in May of 1982. Electrons were first stacked in the X-ray ring in December 1981, and X-rays from a 2 GeV beam were first observed in an experimental beam line in January of 1982.

At present, eleven experimental light beam lines are in operation around the VUV ring. By the end of 1983, it is expected that nineteen beam lines will be operating in the VUV ring, and thirty beam lines will be operating around the X-ray ring.

The following is a description of the NSLS Facility. Emphasis will be placed on beam characteristics of the VUV ring and efforts to improve its performance. A more comprehensive description of the NSLS Facility and storage ring design can be found in Ref. (2).

Linac

The two Varian accelerating sections of the S-band linear accelerator supply 50 mA of beam at 85 MeV before momentum selection. Using a pair of electrostatic deflectors, the 2μsec pulse from the MKIV diode gun is normally chopped down to 500 nsec before entering the first section. In addition, it is now possible to chop the beam into 10 nsec pulses separated by 95 nsec, thus filling only one of the five RF buckets in the booster. This is done by making one of the deflectors part of a tank circuit resonating at the booster revolution frequency, 10.58 MHz.[3] In either mode of operation, the beam emerging from the chopper is bunched, accelerated and transported without loss to a ± 1% momentum selection slit. A single 10-20 mA x 500 nsec pulse, or twenty pulses, 20-30 mA x 10 nsec each, arrives at the booster injection septum, depending on the chopping mode. Injection to the booster is repeated once per second.

Booster and Transfer Lines

Two or three turn injection to the booster together with 50% RF capture efficiency results in maximum currents of 23 mA in the booster, and 6-10 mA is routine. The booster accelerates to 605 MeV. Ramp waveforms for the quadrupole and dipole power supply are stored in a microprocessor. The quadrupole ramp waveform is converted to an analog signal while the booster dipole supply regulator[4] is itself digital and reads the ramp waveform in digital format. Three or four of the five bunches avoid hitting the booster extraction septum and enter either the VUV or X-ray transport lines. While transport efficiency combined with VUV capture efficiency is about 20%, the VUV ring can be filled to 200 mA in less than ten minutes. Pairs of magnets from each transport line are in series; the process of resetting power supplies to change between VUV and X-ray ring injection takes about five minutes.

VUV Ring

The maximum current stored in the vacuum ultraviolet storage ring to date is 215 mA. The ring is routinely filled with 200 mA, distributed among all nine R.F. buckets. Acceleration from 605 MeV to 747 MeV requires one minute. The ring has also been ramped down to 300 MeV in preparation for the free electron laser experiment.[5] Injection is repeated approximately every four hours, when the stored current is reduced to 35 mA. The beam lifetime at various currents is listed in the Table. Closed orbit errors have been reduced from 7 mm rms to 1 mm rms by powering trim dipoles in the ring.[5]

The first beam instability identified in the VUV ring was longitudinal coupled-bunch oscillation. Based on parasitic mode measurements of the 52.89 MHz accelerating cavity,[7] the threshold of this instability was expected to be about 2 mA. Operation of the ring without damping antennae in the R.F. cavity verified this prediction. The stored current could be increased over one hundred fold beyond this threshold without catastrophic results. At currents from 40 mA to 150 mA, all modes of coupled rigid bunch oscillation were present, while longitudinal quadrupole oscillations were seldom observed. Persistent oscillation, with amplitudes up to ± 0.75 nsec were observed, corresponding to energy oscillations of ± 0.2%. These oscillations moved the beam by up to ± 1 mm at the points of maximum dispersion in the bending magnet. Damping antennae have been installed in the cavity, moving the coupled bunch instability threshold up to 7 mA. Also, the amplitude phase of longitudinal oscillation is reduced to ± 0.25 nsec with 150 mA of beam in nine buckets. Beam displacement in the bending magnet is reduced proportionally, to ± 0.3 mm. A longitudinal feedback system similar to that of the CERN PS booster[8] has been operated in the VUV ring. Its detection and amplification circuits were designed and tested in prototype form by F. Pederson. It operates in the frequency range 323-348 MHz. The system derives phase information from a stripline monitor located at a dispersion-free point in the ring, and applies longitudinal kicks to the beam using another pair of striplines, driven in common mode by a broadband amplifier. The stipline kickers have a maximum longitudinal shunt impedance of 136 ohms. Driven in balanced mode, they are transverse deflectors used for tune measurements.

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Bunch Dimensions in the VUV Ring

Bunch length measurements have been performed using a Hewlett-Packard 1815B sampling oscilloscope connected to a stripline monitor. Thus far, data has been taken at 750 MeV with nine bunches stored and oscillating due to longitudinal coupled bunch instability. The stripline signal varied from 320 ± 30 picoseconds FWHM for a 60 picocoulomb bunch to 440 picoseconds for a bunch containing 1.7 nanocoulombs. The expected damped bunch length is 323 psec. Since the damped length of a bunch at 605 MeV in the X-ray ring is 120 psec FWHM, the 150 psec signal from an identical stripline monitor in this ring implies that the delta-function response of the device is 90 psec FWHM.

Transverse beam dimensions have been measured at two points in the ring, using a scanning slit placed in front of a photomultiplier tube. Results are summarized in the Table. The data show that the horizontal emittance varies by less than 60% for stored currents between 40 mA and 200 mA. In contrast, the vertical emittance increases three fold between 40 mA and 200 mA. At currents below 10 mA, the horizontal emittance remains about 50% larger than the expected damped emittance, and the vertical emittance is consistant with 7% coupling. The increase in the vertical emittance with current is attributed to ion trapping by the beam. Ion trapping would also account for the large tune spreads observed at currents above 20 mA.

Betatron tunes are measured using a Hewlett-Packard 141T spectrum analyzer, 8553B RF section and 8443A tracking generator. Generally, the 10 dbm output of the tracking generator applied to a stripline kicker is sufficient to produce a measurable betatron signal at the stripline monitor. Presently the working point is $\nu_x = 3.25$, $\nu_y = 1.36$. At currents below 5 mA, the beam responds to excitation over a 20 KHz range, corresponding to a tune spread of $\Delta\nu_{x,y} \approx 0.001$. The beam response increases to $\Delta\nu_y = 0.03$, $\Delta\nu_x = 0.02$ with 200 mA stored.

First observations of the VUV ring with only one bucket filled show that up to stored currents of 50 mA, there is practically no tune spread beyond the low current value. In the near future beam size measurements will test the belief that the small tune spreads are associated with small transverse beam dimensions.

The only transverse beam instability observed to date is the head-tail effect. If the chromaticities are set to $\xi_{x,y} = -0.5$, beam current is limited to 1 mA with one bucket filled and 150 mA with nine buckets filled. Presumably the betatron tune spread provides Landau damping of the instability with all buckets filled. Indeed, one can observe an increase in emittance in this case as the chromaticities become more negative. With chromaticities set to zero, no transverse instabilities have been observed.

An undulator has been installed in the VUV ring for the free electron laser experiment. The magnet is constructed entirely of rare-earth cobalt permanent magnet blocks, arranged to give thirty-eight full periods of length 6.5 cm. The vertical magnet gap and peak mid plane field can be varied from 6 cm and 0.2 tesla to 1 cm and 0.75 tesla. The undulator can be operated as a high-flux sycnhrotron radiation source for wavelengths between 80 and 500 Å.

The undulator will also be used as a 3500 Å light amplifier and, ultimately, as a free electron laser. In preliminary studies to the undulator gap has been closed to 1.5 cm, for the purpose of adjusting the electron optics of the ring to compensate for the edge focusing effect of the undulator, and to allow viewing of the first harmonic of the undulator in the visible spectrum, about 5000 Å.

A tune splitting R.F. cavity has been designed for the VUV ring. It will operate at the fortieth rotation harmonic, 235 MHz, with a gap voltage of 2.8 kilovolts. It will produce a 5% spread in synchrotron tunes. The cavity is designed to have a shunt impedance of 500 Ω and a bandwidth of 20 MHz, and will serve as a longitudinal feedback kicker as well. The resonant frequency of the cavity is positioned midway between the fortieth and forty-first rotation harmonics, so that there should be no change of the coupled bunch instability threshold when the ring is operated with three or nine buckets filled.

TABLE 1. Beam lifetime and emittance (± 1 σ) versus stored current in VUV Ring with all nine buckets filled equally. Tunes are $\nu_x = 3.26$, $\nu_y = 1.36$; chromaticities are $\xi_x = \xi_y = 0$. Beam energy is 750 MeV.

I(mA)	$\left[\frac{1}{I}\frac{dI}{dt}\right]^{-1}$ (minutes)	ε_x (mm.mrad)	ε_y (mm.mrad)
207	50	0.35	0.063
168	82	0.32	0.063
150	87	0.28	0.058
126	93	0.29	0.047
117	100	0.29	0.050
94	114	0.28	0.035
81	126	0.27	0.025
77	128	0.20	0.023
51	147	0.22	0.023
40	140	0.22	0.015
12	200	0.14	0.011

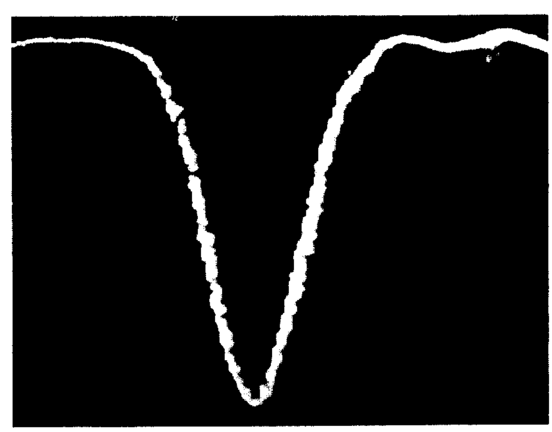

Fig. 1. First pulse of the stripline response to a bunch in the VUV ring. 0.5 volts/division; 0.2 nsec/division; the peak current is 0.9 amps and total charge is 115 picocoulombs.

X-Ray Ring

Machine studies on the X-ray ring have been aimed at closed orbit measurement and correction at 0.6 GeV and 2 GeV. Though the closed orbit is not in its final position, residual errors are small enough to allow installation of the X-ray beamline front ends. Lifetime measurements at 2 GeV and low current (0.25 mA) give $\left(-\frac{1}{I}\frac{dI}{dt}\right)^{-1}$ = 20 minutes. This is consistent with the gas scattering lifetime expected for the presently attained chamber pressure, 2×10^{-8} torr.

Three magnets are in various stages of preparation for the X-ray ring straight sections.[9] A superconducting high-field wiggler has been built and trained to six tesla; it will be installed by May of this year. The magnet has five high-field poles and two half-field poles. It will have a full vertical beam aperture of 2 cm. It will produce a continuous photon spectrum with critical wavelength $\lambda_c = 0.5$ Å when the X-ray ring is operated at 2.5 GeV.

A "hybrid" wiggler, constructed from rare-earth cobalt permanent magnets and vanadium-permandur poles, is being designed and tested. Its dimensions are based on calculations done by K. Halbach.[10] This magnet will have a 1.3 tesla peak midplane field when its vertical aperture is closed down to 2 cm. With twelve periods of wavelength 13.6 cm, it will produce a continuous spectrum of photons with critical wavelength $\lambda_c = 2.3$ Å. Enhanced intensity will be available in the 1 Å region.

A true undulator is also being designed to produce a very bright source of soft X-rays. It will be built from permanent magnets and iron poles. The magnet will have forty periods of wavelength $\lambda_o = 7.5$ cm. Its K value[11] can be varied from 0.5 to 1.5. It will be used for experiments employing spatially coherent soft X-rays in the 30 Å region.

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