NSLS II: A FUTURE SOURCE FOR THE NSLS

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Abstract

The National Synchrotron Light Source at BNL was the first dedicated light source facility and it has now operated for more than 20 years. During this time the user community has grown to more than 2400 users annually. To insure that this vibrant user community has access to the highest quality photon beams, the NSLS is pursuing the design of a new ultra-high brightness (~ 10^{21}) electron storage ring, tailored to the 0.3-20 KeV photon energy range. We present our preliminary design and review the critical accelerator physics design issues.

INTRODUCTION

The NSLS has operated in excess of 20 years during which time it has undergone numerous enhancements to improve the spectral brightness including pioneering state of the art technologies such as global orbit feedback systems and small gap insertion devices for the NSLS user community which now exceeds 2400 users annually. To advance beyond the present performance and open new scientific vistas a new source is required. The plans for an upgrade to the NSLS were initiated in 2003 as one of BNL's contributions to the U.S. Department of Energy's (DOE) Office of Science Strategy Plan for future facilities [1]. After close consultation with the NSLS user community and the DOE a preliminary design of a 3 GeV ultra-high brightness (~ 10^{21}) electron storage ring tailored to the 0.3-20 KeV photon energy range has been developed. A conceptual rendering of the proposed NSLS II complex is given in Figure 1 [2].

Figure 1: Conceptual Layout of the NSLS II Complex

NSLS II Status

The first machine advisory committee meeting was held in November 2003 to review the preliminary technical design. In March 2004, 400 attendees participated in the NSLS-II Science Case Workshop at BNL to support the proposed NSLS II facility and to discuss the scientific opportunities enabled by the new source. Also in March 2004, a report detailing the scientific case and mission need for the NSLS II facility was submitted to the DOE for review (see Figure 2) [2]. The technical design is continuing to evolve and the status is given in the remainder of this paper.

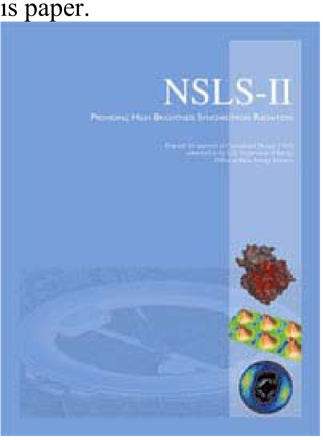

Figure 2: NSLS II Science Case and Mission Need Report

THE NSLS II MACHINE

Machine Overview

The goal of the machine design was to achieve a brightness ~ 10^{21} ph/sec-mrad^2-mm^2-0.1%BW in the 0.3-20 KeV photon energy range with ~ 20 insertion devices. To minimize the construction and operating cost of the machine, an energy of 3 GeV was adopted which together with a 24 cell triple bend achromat (TBA) lattice results in a nominal emittance of ~1.5 nm. The main parameters of the preliminary storage ring design are listed in table 1. A comparative estimate of the brightness of the existing NSLS I and the proposed NSLS II machines is given in Figure 3.

Table 1: NSLS II Storage Ring Parameters

Nominal Energy [GeV]	3
Circumference [m]	634.8
Superperiods / Type	24 / TBA
Straight Section Length [m]	7
Natural Emittance [nm]	1.6
Betatron Coupling [%]	0.5
Momentum Compaction	0.000167
Bend Radius [m]	8.4
Betatron Tunes H/V	34.18/16.28
Energy Spread [%]	0.09
RF Frequency [MHz]	500
RF Acceptance [%]	3-4
Natural Bunch Length [ps]	11-13
Current [Amp]	0.5

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* Work supported by U.S. DoE, Contract No.DE-AC02-98CH10886

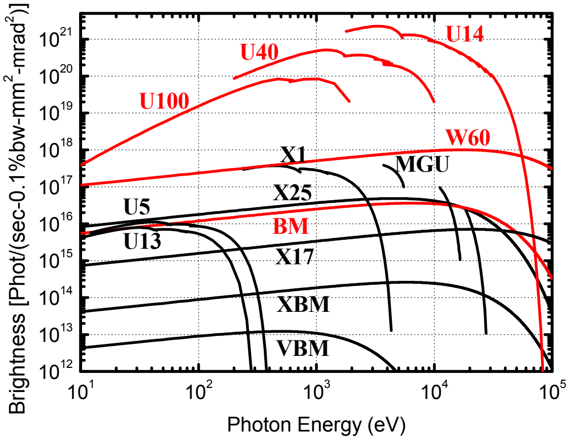

Figure 3: Brightness Comparison of the Existing NSLS I (black) and the Proposed NSLS II (red)

Storage Ring Lattice

While several lattice designs are being explored, the baseline design is a 24 cell TBA lattice. The Twiss parameters for one superperiod of this lattice are shown in Figure 4. Work is ongoing to optimize the sextupole arrangement to maximize the dynamic aperture for a large energy acceptance of δ = 3-4% to provide a good lifetime.

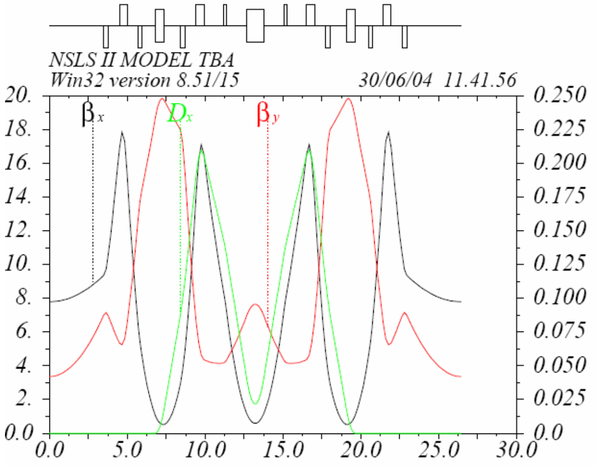

Figure 4: TBA Cell for NSLS II Ring

Radiofrequency (RF) Systems

Superconducting RF systems have matured sufficiently to be integrated into routine operation of synchrotron light sources as demonstrated recently by the CLS project and planned for in the DIAMOND & SOLEIL machines. Our present plan is to use SC 500 MHz single cell cavities of the type developed by Cornell. Present technology allows for an input coupler to handle 300 KW which would necessitate four cavities to handle the radiated power from the dipoles and insertion devices. We're exploring the possibility of two couplers per cavity to reduce the number of required cavities.

Incorporating a third harmonic bunch lengthening RF system (1500 MHz) is envisioned to improve the Touschek lifetime, reduce resistive heating to insertion devices and to help combat collective instabilities. With the ring operated in top off mode it is possible to run the harmonic cavity passively, but we are also considering powering the cavity to increase the flexibility of the system based on our experience with the VUV ring.

Injection System

The low emittance of the ring (1.5 nm) together with the large stored currents (0.5 A) results in lifetimes of a few hours so to maximize performance top-off operation is required. Two alternate injection systems are being explored to determine the best option in terms of cost, performance and future development; 1) a 3 GeV S-band linac or 2) a low energy linac combined with a 3 GeV low emittance booster synchrotron cycling at 3-10 Hz.

INSERTION DEVICES

With a ring energy of 3 GeV one desires as short of an undulator period as possible while maintaining K ~ 2.2 to provide good tuning in the 2-20 keV range. To achieve this with a reasonable gap (4-5 mm) we are exploring superconducting undulators (SCU) with λ_u ~ 14 mm.

Efforts toward the development of an SCU for NSLS-II advanced with the design and construction of a state-of-the-art cryogenic Vertical Test Facility (VTF), now nearing completion (Figure 5). This device will allow precise magnetic field mapping of SCU models up to 0.4 m long, using a motorized Hall probe array which has been calibrated at both room temperature and in liquid nitrogen against a NMR standard. An in-situ superconducting Helmholz coil will provide a calibration check in liquid helium. The apparatus also incorporates three channels of liquid He calorimetric instrumentation to measure thermal performance and quench behavior for a realistic operating scenario, including simulated beam heating.

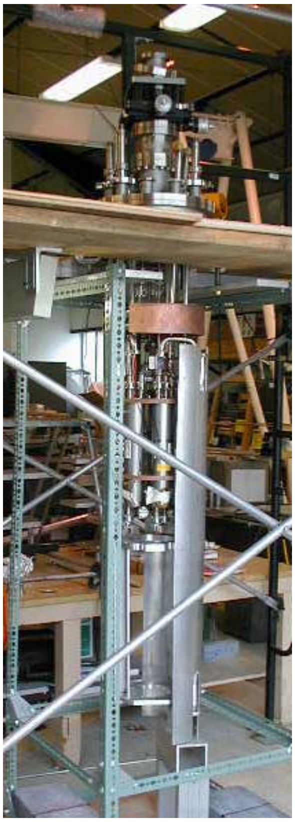

Figure 5: SCU Measurement Apparatus

A pulsed-wire insert, interchangeable with the Hall probe mapper, is also being developed, to provide a complementary magnetic measurement technique. The apparatus will be installed at the Superconducting Magnet Division's facilities and commissioned by the end of FY-2004. In early FY-2005 we plan to measure test models developed by both Lawrence Berkeley and Argonne National Laboratories, who are partnering with NSLS in a multi-lab SCU R&D collaboration. For our part, we have also developed a SCU design based on the new "APC-type" NbTi superconductor and incorporating a novel cryogenic thermal management system to intercept the high beam heat loads expected in NSLS-II and future ultra-high brightness synchrotron light sources.

COLLECTIVE EFFECTS

Work is continuing on the NSLS-II impedance budget. So far we have only considered several critical components such as mini-gap undulators (MGUs), RF cavities, as well as the coherent synchrotron radiation (CSR) impedance.

Due to large number of MGUs they will dominate the vertical impedance in the single bunch spectral range. This impedance is of great importance since it may drive transverse coherent single bunch instabilities. In general both the geometric part, due to the tapers, as well as the resistive wall, contributes to this impedance. We are presently planning for fairly shallow MGU tapers ($L = 0.5$ m on each side, $\theta = 20$ mrad) so that $\sigma_z / \theta >>$ beam pipe radius. The transverse impedance in this regime is purely imaginary and could be found analytically [3].

Transverse mode coupling instability (TMCI) thresholds due to this impedance have been estimated with some simplifying assumptions and confirmed by calculations with MOSES code [4]. These thresholds have been found to be at least an order of magnitude higher than the single bunch design current. Lower, but still acceptable threshold values, have been obtained taking the NSLS-II taper impedance equal to that calculated for the relatively steep APS taper geometry [5].

For the resistive part, the TMCI threshold was estimated by comparing the resistive wall tune shift to the synchrotron tune. This results in comfortably large thresholds in the case of cold bore SC MGUs where the extreme anomalous skin effect regime applies to the inner bore pipe. On the other hand, room temperature MGU design scenarios warrant further investigation, since the estimated tune shifts at the design current make up a fairly large fraction of the synchrotron tune.

We are presently performing GdfidL [6] calculations to quantify the geometric impedance in a more realistic elliptical geometry. Later the combined geometric and resistive wall impedance will be used in tracking as well as dispersion-relation based codes to confirm our estimates.

The CSR instability has been analyzed and was found to be harmless for the NSLS-II parameters due to the vacuum chamber shielding of the CSR impedance.

Multi-bunch instabilities due to the RF cavities, as well as due to the long range resistive wall wake, have been studied analytically and with ZAP code [7]. Assuming SC RF cavities, the longitudinal coupled bunch instability thresholds exceed the NSLS-II design currents. In the vertical plane a feedback system may be needed mostly due to the resistive wall contribution of the MGUs. While conceptually straightforward this feedback system has some unresolved technical issues, for example stabilizing the motion to a small fraction of the already small vertical beam size.

Another area of concern in case of SC MGUs is beam driven heat loads. Assuming that the synchrotron radiation from the upstream dipole is well collimated our estimates show that the resistive wall generated heat (~ 5 W/m) dominates the heat load budget for MGUs shorter than ~ 4 m. For longer IDS the heat due to the undulator's own synchrotron radiation takes over. These estimates have prompted the exploration of cryogenic heat removal designs that go beyond the single cryo-cooler which are currently being pursued at the NSLS.

Finally we note that most coherent instabilities, as well as the issues associated with MGU heating, become less of a concern if we employ a harmonic RF system for bunch lengthening.

VUV & IR

The existing NSLS facility is comprised of two storage rings, the VUV/IR and the X-Ray ring. While the new NSLS II ring will provide greatly enhanced performance for the x-ray users it is very difficult to accommodate the IR and VUV on the 3 GeV ring. To continue to serve the vital IR & VUV user communities we propose to move the existing VUV ring to the new NSLS II complex and fill it with the NSLS II injection system.

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