RECENT DEVELOPMENTS AT ALADDIN*

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Abstract

Following on the success of lower emittance operation at 800 MeV, SRC is pursuing a number of additional enhancements to the performance of the Aladdin storage ring. Work on Aladdin has included development of low emittance lattices at 1 GeV, which will maximize the capabilities of a recently installed spectromicroscopy beamline and a proposed high-resolution keV beamline. Installation of one-meter long insertion devices in the short straight sections within the quadrant arcs of the four sided storage ring is being pursued to increase the number of undulator beamlines from four to possibly eight. Studies have been made to determine what is the minimum insertion device gap that does not interfere with nominal ring operation (injection, ramping, and lifetime at full energy), and indicate that smaller-gapped devices for higher photon energy are reasonable. Lifetime increases or further emittance reductions appear possible with modest aperture increases at a small number of points on the ring. Finally, planning is under way for long term projects such as a new injector or a next generation VUV/soft-xray source for the Midwest. Details are presented.

INTRODUCTION

The Synchrotron Radiation Center (SRC) operates the Aladdin storage ring at 800 MeV and 1 GeV as a vacuum ultraviolet (VUV) and soft x-ray light source. Beam currents at the start of a fill are 280 mA at 800 MeV and 190 mA at 1 GeV. After completing the commissioning of a low emittance operating mode at 800 MeV, in which the horizontal emittance was reduced from 120 to 41 π nm·rad [1], we have embarked on a number of projects to upgrade and expand the performance of the ring.

INSERTION DEVICES IN SHORT STRAIGHT SECTIONS

Aladdin is basically a four-sided ring, with each side containing a 4 m long drift. Undulators located in these “long straight sections” source some of the most oversubscribed beamlines at SRC. However, each of the quadrants of Aladdin comprises three dipoles with intervening quadrupoles and sextupoles. Downstream from the first and second dipoles in each quadrant there is approximately 1 m devoid of any beam handling components or instrumentation. We are now beginning to put insertion devices (IDs) in these “short straight sections”. This will allow us to increase the number of beamlines sourced by insertion devices.

Without modification to the ring magnets and instrumentation, the short straight sections can accept IDs with a maximum length (including vacuum system transitions) of 1.09 m. Tests have shown that the SF sextupole at the downstream end of some of the short straights can be removed. The short straights can then accommodate slightly longer devices, up to a maximum of 1.24 m.

Of the eight short straight sections in Aladdin, some are unavailable for IDs. For example, one contains injection hardware, and on another the straight-through port on the downstream dipole is used for an infrared beamline using edge radiation. We have identified four short straight sections which are suitable for IDs.

Aperture Studies

When designing and specifying new beamlines being sourced by insertion devices, it is important to know what is the minimum permitted insertion device gap (vertical aperture). A number of different effects can determine the minimum usable gap. These include the need to maintain adequate at-energy beam lifetime (which can give different limits, depending on what lattice is being run), the ability to inject into the ring, ramp up in energy, and slew from one lattice to another. In order to experimentally determine the minimum acceptable gap, we have installed two sets of “scrapers” (adjustable apertures), one set (top and bottom) in a short straight and one in a long straight section. The behavior of the beam, be it lifetime, amount of current which could be injected, or losses during ramping or slewing, was observed as a function of scraper position to determine the minimum gap which does not interfere with any aspect of accelerator operation. Results to date indicate that the need to inject into the ring at 108 MeV places the most severe restriction on the permitted gap, though these studies are ongoing.

EUV Insertion Device

The first insertion device to be placed in a short straight section is presently in production. It will be used by the University of Wisconsin Nanoscale Science and Engineering Center (NSEC) in the extreme ultraviolet (95.5 eV) for next generation lithography. The undulator is a pure permanent magnet design with a period λ_u = 41.6 mm and an overall length of 0.9 m. The new EUV undulator is shown in Fig. 1.

At the present time, the NSEC EUV work is done using the SRC U2 undulator. Because this undulator sources three beamlines, NSEC is limited to 1/3 of its available time. NSEC will have full use of the new undulator,. In addition, the calculated power density at the exposure plane will increase from 155 mW/cm^2 to 700 mW/cm^2.

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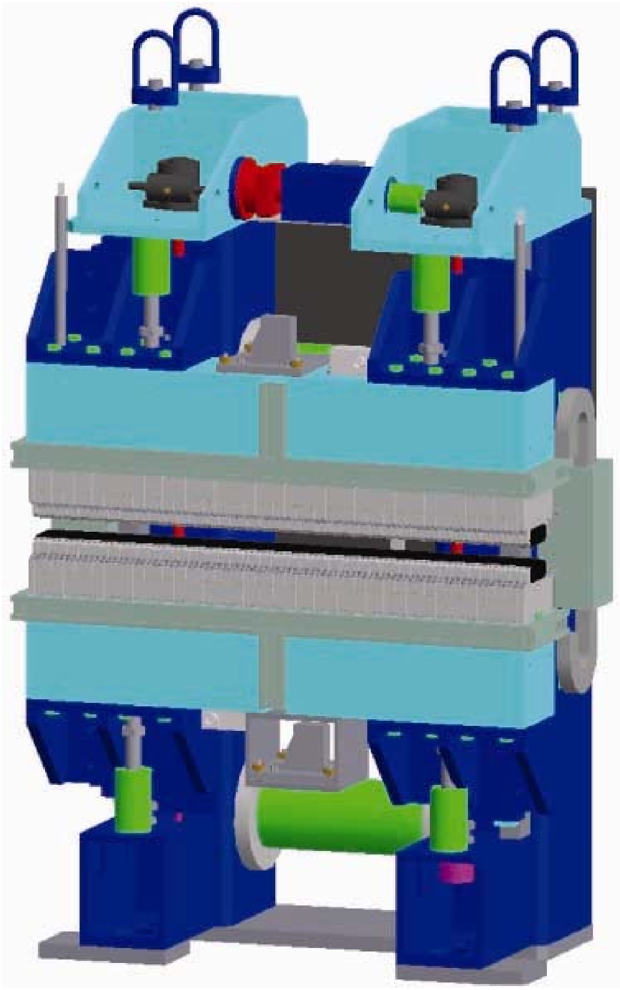

Figure 1: Draft version of the EUV undulator to be installed in a short straight section. Courtesy of ADC. [2]

This results from several factors: operating the undulator in the first harmonic at a 21 mm gap rather than in the third harmonic at a 42 mm gap, modifying the beamline to remove a window and improve the reflectivity of mirrors, accepting a broader bandpass, and shortening the beamline.

REDUCED EMITTANCE AT 1 GEV

Future high energy, high performance beamlines proposed for SRC require a reduction in the horizontal emittance of the higher energy electron beam in order to achieve full performance. However, the low emittance lattice used at 800 MeV cannot be simply scaled up for use at 1 GeV due to limitations on the quadrupole and sextupole magnets, power supplies, and cabling. To accommodate the proposed beamlines, we have developed an alternate low emittance tuning of the ring for use at higher energy. Although we cannot reach 1 GeV with this tuning, we can operate at 950 MeV with a horizontal emittance of ~41 π nm·rad, compared to the 187 π nm·rad presently run at 1 GeV. The only modification needed is upgrading the cabling on 12 of the 48 ring quadrupoles to handle higher currents. At the present time, 9 of the 12 quads have been upgraded.

LIFETIME IMPROVEMENTS

Stable low-emittance operation of Aladdin requires ring currents exceeding 80 mA. At lower currents, the passively driven fourth harmonic cavity cannot be used to suppress coupled-bunch instabilities and lengthen the bunch for improved lifetime. To prevent the ring current from dropping below 80 mA between injections, the horizontal-vertical coupling of the ring is adjusted to 3% to give adequate Touschek lifetime.

Theoretical studies indicate that the lifetime is limited by the horizontal apertures of 8 horizontal beam-position monitors (BPMs) that are located where the horizontal dispersion is maximum. This was confirmed by experiments where the horizontal beam position was varied at the BPM locations. If the horizontal apertures are increased by replacing the existing 2-electrode in-plane BPMs with a 4-electrode 45° design, a 50% lifetime increase is computed. Consequently, a smaller vertical emittance and beam size could be used without having the ring current drop below 80 mA. Alternatively, a lower-emittance lattice with smaller horizontal beam sizes could be utilized. Either approach would allow the ring's brilliance to be increased by about 50%.

Thus, by replacing the 8 horizontal BPMs that limit the lifetime, we expect to increase the ring's brilliance by about 50%. In addition, the 4-electrode BPMs allow determination of both the horizontal and vertical positions of the beam, significantly increasing the diagnostic value of the BPMs.

200 MEV LINAC/RECIRCULATOR INJECTOR

Operation of Aladdin at higher current, even lower emittance, and with smaller gap insertion devices would provide a dramatic increase in experimental capabilities for our User community. For example, with shorter magnetic periods, smaller vertical gap insertion devices and more poles would provide a higher energy reach or more photon flux. This would be particularly valuable for developing short-straight-section undulator beamlines or for optimizing upgrades to exotic devices such as variable polarization undulators, which are not consistent with in-vacuum designs. Intriguingly, accelerator studies indicate that with our standard 800 MeV low emittance tuning, vertical apertures in undulators could be reduced by a factor of two from roughly 20 to 10 mm. Unfortunately, these same studies show that the injection process at 108 MeV would not tolerate such an aperture reduction.

At an injection beam energy of 108 MeV, the damping time for transverse oscillations is 14 seconds. The transverse oscillations of injected electrons undergo little damping during the one-second period between injected pulses. Because an undamped pulse is scraped by the septum during the injection of subsequent pulses, only 9% of a 3 mA pulse is calculated to survive long enough to contribute to the stored beam. With our stored beam lifetime, a current of 300 mA may be accumulated. Studies indicate that insertion device chambers with a height much smaller than the 19 mm used in the existing long straight section ID chambers would substantially decrease the lifetime of the stored beam, preventing accumulation of sufficient current for ring operation. Injecting with a 200 MeV beam, the transverse damping time becomes 2 seconds, so that 55% of an injected beam pulse is calculated to survive long enough to contribute to the stored beam, with most losses at the septum. Consequently, calculations predict that a stored current of nearly 800 mA may be accumulated with the stored beam lifetime measured for a 10 mm vacuum chamber height.

The concept for the new injector is based on a scaled-down version of the 500 MeV recirculating linac recently commissioned at MAX-lab, including their innovative, cost-effective recirculation transport and electron gun [3]. In this approach, with single pass recirculation and SLEDing, the energy reach of a standard linac is enhanced by nearly a factor of four, with almost proportional cost savings. The specifications of the linac are: normal conducting 3 GHz structure, >50 MeV (un-SLEDed) with a single 35 MW klystron. SLEDing gives ~100 MeV beam energy with 200 MeV achieved on recirculation. The present SRC microtron injects into Long Straight Section One of Aladdin and the proposed linac would inject into Long Straight Section Two to allow minimal interference with User experimental programs during commissioning and change over.

LONG TERM POSSIBILITIES

We see at SRC a vibrant User community pursuing science of the highest impact. It is natural to ask what major initiative would best complement the current performance and likely upgrades of the Aladdin Complex, and would qualitatively expand the experimental reach for this community. It is clear that storage rings are rapidly reaching very fundamental limits of performance, and that it is likely that linear-accelerator-based photon sources (energy recovery linacs) will prove to be superior in achieving higher brilliance, higher coherence, and shorter pulse durations. This was the subject of the 2005 ERL Workshop [4]. ERLs also offer high quality, high flux coherent infrared synchrotron radiation from the short electron bunches, and can serve as drivers for free electron lasers.

To serve our core mission of providing the highest quality photons from the infrared to ~1 keV, we are pursuing designs of a superconducting energy recovery linac operating at 1 GeV with subpicosecond bunch lengths for investigating time resolved phenomena or for generating coherent infrared. Full coherence will enable diffraction-limited focusing using Fresnel zone plates, or coherent diffractive imaging using emerging iterative phase retrieval techniques. Synchronizing subpicosecond soft x-ray pulses with ultrafast lasers will naturally lead to many novel pump-probe experiments. The flux and brightness from a fourth generation synchrotron radiation facility based on an ERL would allow these spatial and temporal sensitivities to be combined so that the dynamics of intrinsically complex and nanoscale-structured materials could be probed.

Although there has been much progress in controlling the costs of superconducting RF (SRF), estimates indicate that two passes of acceleration followed by two passes of energy recovery would yield substantial savings, reducing costs by more than a third. In the regime of highly de-Qed, overlapping higher order modes, two passes effectively reduce the coupling impedance (for fixed final energy) by a factor of two, partially compensating for the fact that extra passes exacerbate the instability. Also, beam breakup threshold currents scale inverse-quadratically with operating frequency [5], so there is a strong advantage in moving to structures at lower frequencies, for example, 750 MHz. These considerations indicate that a multipass energy recovery linac should be able to achieve average currents well above 100 mA. Ideally, the source would be diffraction limited for photon energies ≤1 keV, for coherence, highest-resolution monochromators (vertical emittance), or high flux density. At 1 keV, the diffraction limit ($\lambda/4\pi$) yields normalized emittances at the 0.2 nm·rad level. Although this appears achievable at lower bunch charges (~10 pC) with several approaches, SRF gun technology will likely be required to achieve this goal for high average current operation. For monochromators, ribbon beam configurations with angular-momentum generated in a magnetic field [6] would offer an alternate solution.

SUMMARY

The Aladdin storage ring at SRC is being upgraded in a number of ways to enhance its performance as a vacuum UV and soft x-ray light source. These include new insertion devices, and operation at reduced horizontal natural emittance. Additional capabilities are planned for the future of SRC.

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