INSERTION DEVICE COMMISSIONING AT SRC*

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Abstract

The Synchrotron Radiation Center (SRC) has been installing undulators on its 1-GeV electron storage ring, Aladdin, over the last 15 years. Commissioning these devices is subject to fairly demanding requirements related to the needs of the user community. A number of topics are discussed, including injection, trim-control, steering correction, beam size stabilization, and lifetime preservation. Experiences, problems, and solutions are presented from both machine and beamline aspects.

1 INTRODUCTION

SRC has just commissioned its 5th undulator, a 9th-harmonic device (Danfysik) which replaces the original Halbach ppm undulator [1]. In between, two electromagnetic undulators (Brobeck, SRC) and a 5th-harmonic ppm undulator (Brobeck) have also been placed online. Table 1 summarizes these devices, showing the long-straight section and year in which installed, period length λ_u, deflection parameter K ($=0.934 \cdot B(T) \cdot \lambda_u(cm)$), and number of full-strength periods N.

Table 1: Undulators Commissioned at SRC

Name	LSS	Year	Mfr	Type	λ_u (cm)	K_{max}	N
U2A	2	1986	SSRL/LBL	PPM	6.1	1.9	30
U4	4	1993	Brobeck	EM	16	1.8	14
U3	3	1995	Brobeck	PPM	7.1	4.6	48
U1	1	1998	SRC/PSL	EM	10.9	4.5	30
U2B	2	2000	Danfysik	PPM	6.8	4.6	51

2 OPERATIONAL REQUIREMENTS

Operational requirements for the insertion devices (IDs) can loosely be broken into two categories that ensure: acceptable ring performance for all users, including their proper integration and correction in the lattice; and the provision of a stable, tunable source of given spectral quality for the ID users.

Basic operational requirements for all users have been previously established [2]. These include: no degradation of injection; vertical beam stability of $\delta y \leq 10\ \mu m$ for position and $|\delta\sigma_y/\sigma_y| \leq 1.5\%$ for size; and no adverse variation in lifetime of the at-energy stored beam. For the most part these goals are being met.

Magnetically, the intrinsic undulator requirements are fairly standard. First-integrals and skew-quadrupole are sufficiently small that appropriate, existing corrections can compensate for them. Higher-order, static multipoles are small enough such that dynamic aperture, and lifetime, should not be affected. Separately, calculations indicate that dynamic-multipoles [3,4] should not be a problem owing to the combination of ample pole-widths and sufficiently low fields in the SRC undulators.

3 EXPERIENCES, RING-BASED

On the storage ring side, there are many facets to successful ID operation. These concern injection, control of internal undulator-fields, steering correction, beam size compensation, and minimizing any lifetime variations.

3.1 Injection

Satisfying the injection requirement has proved a non-issue, even with low, 108-MeV injection. Although the two electromagnetic undulators can be radially retracted from the ring, injection proceeds well if they are left inserted at reduced excitation. The two ppm-IDs have their gaps opened to 125 mm (normal, max operational gaps are between 71 & 76 mm) for injection. (As an aside, minor beam loss has been observed on one of them when closing gap, at-energy, at 185 mm.)

3.2 Intrinsic Trims

SRC's installed undulators include trim coils serving a number of functions. These include coils of the following configurations and purposes: long-B_x and long-B_y - to correct ambient-field 1st-integrals; short, end, differential-B_y - to correct 2nd-integral; localized - for reduction of rms phase error from long-wave B_x and/or B_y field errors; and opposed-B_y - for skew-quad correction. All such trims are pre-programmed vs. undulator excitation, based on magnetic-bench or insitu field measurements.

3.3 Global Steering

Despite the pre-programmed intrinsic-trim corrections in §3.2, slight residual steering errors are found empirically, and addressed in two ways. First, global feedback (GFB) control is used routinely to correct closed-orbit errors around the ring, including those that may dynamically arise from the undulators. Second, because of the finite response time of GFB, maximal reduction of orbit distortion during rapid ID scanning necessitates using a feed-forward (i.e. lookup) table derived from values obtained during quasi-static scanning. Practically speaking, meeting the beam positional stability requirement of 10 μm is routine.

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3.4 Beam Size Control

At the present time, no effort is made to counteract the reduction in natural emittance that accompanies undulator scanning. This means that there are no dedicated corrections to horizontal beam size (σ_x) variations which are already ≤ 3% (for U1+U2+U3). However, vertical beam size (σ_y) variations, if left uncorrected, can be significantly larger (> 10%), and exceed the requirement.

Generally, the tune-space operating point (ν_x=7.139, ν_y=7.239) is locked by a feedback loop ("Tune Tracker", TT) controlling QF and QD quads based on spectrum analyzer tune measurements. This tune point has been chosen to minimize derivatives of beam size/lifetime versus tunes [5]. In particular, TT is used as an integral part of global σ_y beam stabilization. Because of the finite response time of TT, maximal σ_y stability during rapid ID scanning necessitates usage of a feed-forward table derived from values for QF and QD measured during quasi-static scanning.

Local corrections to the lattice functions are made with quadrupole shunts. The long straight section geometries are F-D-F triplet, undulator, and F-D-F triplet. Of these six quadrupoles, two to three are shunted with pre-calculated values [6]. Referring to Eqn. 1 for tune-shift

$$\Delta \nu_y = \frac{\pi \langle \beta_y \rangle K^2 L}{2 \gamma^2 \lambda_u{}^2} \qquad (1)$$

by an undulator (L = ID overall length), the impact and correction scales with K^2. Calculations indicate that net stabilization of σ_y should be at about the 2% level: a figure that is nearly realized in practice.

Corrections based on pre-calculated values rely on stability of the lattice functions. Over a period of 10 weeks β-measurements were periodically made of the lattice. It was found that β_y values were stable to 0.2-0.4% rms, and β_x to 0.2-0.5% rms, and apparently are not a factor in the quality of correction.

SRC will shortly be switching to a new, low-emittance lattice [7] in which $\langle\beta_y\rangle$ is reduced by about a factor of two. From Eqn (1) one expects that the impact and correction for individual undulators will correspondingly diminish. Preliminary observations of undulator scanning and correction (with U3) in the new lattice show a further reduction in residual beam size variations, which is encouraging. A minor variation in the optics corrections for the low-emittance lattice is that "anti-shunting" of some quadrupoles will be required.

3.5 Coupling

In the present Aladdin lattice emittance-coupling is roughly 1% (@ 800 MeV) making vertical beam size rather sensitive to this parameter. An empirically useful measure, in our case with flat beams, is the beam rotation angle (θ, in x-y space) as seen on a CCD-image of the synchrotron radiation source. Beam rotation angle convolves betatron and dispersive coupling and varies with azimuth. Consistent with the requirements of §2, attempts are made to stabilize δθ to << 1°.

Effort still remains to measure, model, and correct the various sources of coupling. Empirically, skew quad excitation and dispersive coupling (from η_y, as caused by vertical orbit offsets or misalignments) produce linear variations in θ. By observing existing optical monitors (one CCD camera and two linear-array Reticons), and empirically adjusting ring skew-quads, maximum residual σ_y variations down to about 1% have been demonstrated during undulator scanning. Effort is presently being directed to increasing the number of x-y optical (CCD) monitors from one to one per quadrant to better measure θ variations and ultimately correct coupling effects.

3.6 Lifetime

Vertical aperture restrictions in the insertion device vacuum chambers can lead to attendant limitations in lifetime. These restrictions are 19-mm internal, vertical apertures in three of the four 4-m straight sections. With the stronger undulators, lifetime degradation vs. K-value has been observed up to about 25% for U3, 15% for U2B, motivating a better understanding of involved mechanisms. From §3.4, relative beam size stability varies up to only a few percent during individual undulator scanning. Such small changes in beam size cannot explain the much larger change in lifetime.

The lattice corrections referred to in §3.4 correct beam size *external*, not *internal*, to the undulator. Since the undulator is a K-dependent vertically focusing structure, β_y, and, hence, σ_y locally increase there. Reviewing historical scraper measurements of lifetime versus vertical aperture in the long straight sections (used originally to define the 19-mm aperture limitations at/inside "the knee"), *for a fixed* σ_y, shows that an effective aperture reduction of about 15% will result in a 10% lifetime reduction. Conversely, a local 13% σ_y increase would have about the same effect. Since the calculated increases can be as large as 25% for U2 (24% for U1) in β_y or 12-13% in σ_y, it is believed that local focusing and σ_y increase internal to the undulator, with the existing aperture limitation, is sufficient to explain the observed lifetime decrease, at least for U2. Testing this hypothesis, however, is not readily possible as undulators in all straight sections have led to the removal of all scrapers.

The aperture-lifetime problem will soon be largely solved in the new, low-emittance lattice. Machine trials with U3 in this lattice show that lifetime reduction and/or variation is significantly improved with lifetime change becoming +4%. There are two reasons for this improvement, both related to smaller β_y variation. First, there is less global σ_y variation external to the undulator (see comments, end §3.4). Second, more importantly, but speculatively, (see above discussion) smaller $\langle\beta_y\rangle$ internal to the undulator effectively results in a larger aperture with lesser lifetime reduction from internal σ_y increase.

As previously noted in §2, dynamic multipoles should not be a problem. In particular, they might otherwise affect beam lifetime.

4 EXPERIENCES, RADIATION-BASED

There are also points to be covered on the beamline side including initial determination of mean positioning and alignment, aiming stability, profiling, and verifying spectral harmonic widths, all of the undulator radiation (UR). These details are largely summarized as they are documented elsewhere [8,9].

4.1 Alignment

Before undulator installation ambient fields are measured along the vacuum chamber. These fields include both Earth's field and local ion pump effects that can otherwise lead to unwanted orbit distortion and problems with delivered UR. As necessary, ion pumps have been moved away from the central orbit, shielded, and permuted in terms of residual field orientations to reduce orbit deformation. Additionally, long B_x and B_y coils are retrimmed.

UR is directed into a beamline approximately 9 meters downstream. For initial, lab-frame positioning, a pinhole detector assembly [8,9] is useful to determine the mean, central UR ray, the stability of that ray, and profiling. Depending on numerous parameters (UR energy, flux, filtering, etc.) the accuracy of detection can be limited only by optical surveying methods; resolution and reproducibility can be on the order of only a few microns after background subtraction (from bending magnet radiation) and fitting. Once located, the central ray can be slightly resteered as necessary and fixed for subsequent beamline construction, alignment, and operation.

4.2 Energy

In a couple of cases, pushing field-strength to its highest value has been important, necessitating operation at either smallest gap (ppm device) or highest current (em device). Recently, this lead to a reevaluation of the ring energy as a discrepancy consistently turned up between observed and expected photon energies corresponding to an apparent ring energy error of about +1%. At present, ring energy calibration by more accurate resonant depolarization [10,11] is planned.

Better control of one of the electromagnetic undulators (U1) has led to use of an integral Hall probe. Because of hysteresis, there is a slight uncertainty in magnetic field versus excitation, corresponding to a relative photon energy uncertainty of as much as $\pm\frac{3}{8}\%$, which is not inconsequential compared to the spectral harmonic width. The probe is mounted off axis because of the vacuum chamber. The correct proportionality between the field measured in this position and the on axis field can be determined by using a monochromator, and the probe suitably used in feedback to operate the undulator in an eV-controlled mode.

Lastly, it has always been of interest to verify correct spectral functionality of the undulators. In principle, this would involve an accurate determination of spectral flux under well-known conditions for aperture and beam emittance. Making absolute flux measurements, and comparing to expectation, with a monochromator, however, has been less than satisfying. This approach (measurement of absolute flux) generally seems to reveal more about beamline operation than it does about insufficiency of undulator performance. An alternate technique has been to compare measured and computed spectral harmonic widths, which readily produces much better agreement.

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