COMMISSIONING LOW EMITTANCE BEAM AT ALADDIN*

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Abstract

The Aladdin storage ring is now routinely run in a low emittance configuration at 800 MeV. Vertical beam sizes and lifetime are comparable to the original lattice, while the horizontal beam size is reduced by a factor of three. Tools used to commission the new lattice include model based correction to obtain the design machine functions, and model independent correction to set the desired transverse coupling. Newly installed optical profile and position monitors, shunts to trim individual magnets, as well as implementation of a new control system scripting language, were important in achieving the desired results. Special attention was given to operation of the fourth harmonic bunch lengthening cavity used to improve the beam lifetime, and noise reduction in the RF system to improve photon beam quality on the infrared beamlines. In addition, compensation of undulators allows their strengths to be varied with minimum perturbation to the beam outside the regions of the undulators. Details of bringing the low emittance lattice to operational readiness are presented.

INTRODUCTION

The Aladdin storage ring at the Synchrotron Radiation Center (SRC) is operated at 800 MeV and 1 GeV as a VUV and soft x-ray source. A new lattice referred to as LF15 [1] has recently been commissioned for operation at 800 MeV, which reduces the horizontal emittance from 120 to 41 π nm·rad. The beam current is unchanged, remaining at 280 mA at the start of a fill. Combined with changes to the β functions, the horizontal beam sizes at the source points are reduced on average by a factor of three. Vertical beam sizes are unchanged. This increases the focused flux density available on most beamlines, and is especially useful for Users in fields such as spectromicroscopy. LF15 is now the usual operating mode for 800 MeV beam at SRC.

INSTRUMENTATION AND CONTROL UPGRADES

To bring LF15 to routine operational readiness, it was necessary to make several upgrades. These include improvements to the beam profile measuring system, implementing the ability to trim individual quadrupole magnet strengths in the ring, and a new scripting language for the accelerator control system.

In order to make more precise measurements of the beam size, position, and rotation, the Optical Profile and Position Monitors (OPPMs) were replaced and expanded in number with improved versions. The new stations provide horizontal and vertical beam size, position, and beam rotation information at high data rates (10 Hz). Resolution of profile measurements is ~0.1 μm, with a minimum resolvable beam size of ~25 μm. These monitors have been important for determining beam reproducibility and stability, in particular with maintaining beam stability while scanning undulators, as detailed below.

The 48 quadrupoles in Aladdin are powered in families by 9 power supplies. In order to correct for small deviations in magnet strengths, shunts were installed on all quadrupoles to allow their strengths to be individually trimmed. The shunts are capable of reducing the current through each quad by 12%, up to a maximum of 25 A. Total currents in the quad families range from 60 to 296 A.

Finally, a new scripting language (Python [2]) was installed and interfaced with the existing accelerator control system. Its power and flexibility have facilitated both commissioning and routine operation of the low emittance lattice.

LATTICE OPTIMIZATION

The technique used for determination of the proper settings for the ring magnets depended on whether the deviation from the model lattice was due to a known effect (e.g., quadrupole strength errors), or of unknown origin (e.g., undetermined sources of *x-y* coupling.)

Model Based Correction

For the situation where the deviation from the ideal case was of known origin but unknown magnitude, corrections based on the lattice model where made. The code LOCO [3] was used to determine the appropriate settings for the 48 quadrupole shunts. Shunt currents ranged from 0.2 to 9.1% of the overall quadrupole current. When the LOCO calculated corrections were installed, the expected four-fold symmetry of the lattice was restored, and compensations for perturbations to the ring (specifically during undulator scanning) could be based on the ideal lattice.

Initial results with LOCO produced significantly better results correcting the ring β functions, than correcting the horizontal dispersion η_x around the ring. Inclusion of the "RFCAVITY" element in the MAD model used by LOCO, to guarantee the proper orbit circumference, improved the η correction.

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We have also made a differential version of LOCO. This takes the measured change in the response matrix due to a change in the machine, and compares it to that expected based on the model. It is useful for dealing with incremental changes to a lattice, particularly when the measured lattice is far from the model.

Model Independent Correction

In the case where the source of lattice imperfections was not identified, a more general, model independent approach was taken [4]. The general concept is to measure the sensitivity of a set of parameters to the values of a set of input variables. This was used to set the desired vertical beam sizes, and minimize beam *x-y* rotations, while maintaining good lifetime. Sizes and rotations were measured at the OPPMs as a function of the settings of four skew quadrupoles. The optimum settings for the skew quads were then determined using Tikhonov regularization [5]. This was used to arrive at a balance between achieving the desired beam sizes and rotations, against the available strengths of the skew quads.

UNDULATOR COMPENSATION

SRC presently has three undulators in routine operation, each with maximum *K* values of 4.5 to 4.6. As a User scans the strength of an undulator, the vertical focusing strength of the undulator changes. To compensate for this change, eight quadrupoles in the vicinity of the undulator are simultaneously adjusted. Skew quadrupoles are also adjusted to address any *x-y* coupling issues. The goal is to maintain constant vertical beam size, and beamline throughput, to within 2% peak-to-peak outside the region of the undulator, over the full undulator scan range.

The strengths of the quadrupoles used in compensation are calculated using MAD [6]. The ideal LF15 lattice is used as a starting point. An undulator is then included, modeled as a series of dipoles, including the reduced strength periods at each end of the undulator. The matching capabilities of MAD are used to calculate quadrupole strengths for which the lattice functions outside the undulator straight section, and phase advance through the straight section, equal those without an undulator [7]. The quad strengths resulting from this calculation are automatically K^2 scaled by the control system as the undulator is scanned. Skew quadrupole strengths as a function of undulator strength are determined empirically by minimizing vertical beam size variations over an undulator scan. In addition to quad compensation for beam sizes, steering feed forward and feedback are used to maintain a constant beam position.

The effectiveness of this compensation is shown in Fig. 1. With the undulator scanned over its full range, up to *K*=4.6, the vertical beam sizes measured at the OPPMs had a total variation of <2%. Similar results were obtained when measuring the throughput on various beamlines over an undulator scan. Variations in β outside the region of the undulator were ~1%.

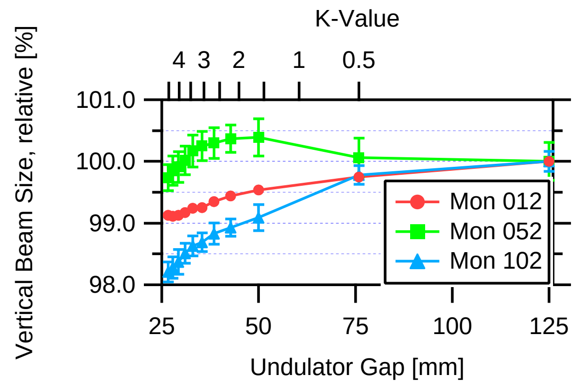


Figure 1: Variation in vertical beam size as an undulator is scanned over its full range. The beam size was measured by five OPPMs (three are shown), and is normalized to the size measured at full undulator gap (125 mm). The undulator period is 70.7 mm.

Further improvement in compensation can be made using LOCO. In particular, using the differential version of LOCO to compare the undulator in *vs.* undulator out cases has led to better tune correction by the eight compensating quadrupoles.

ADDITIONAL CONSIDERATIONS

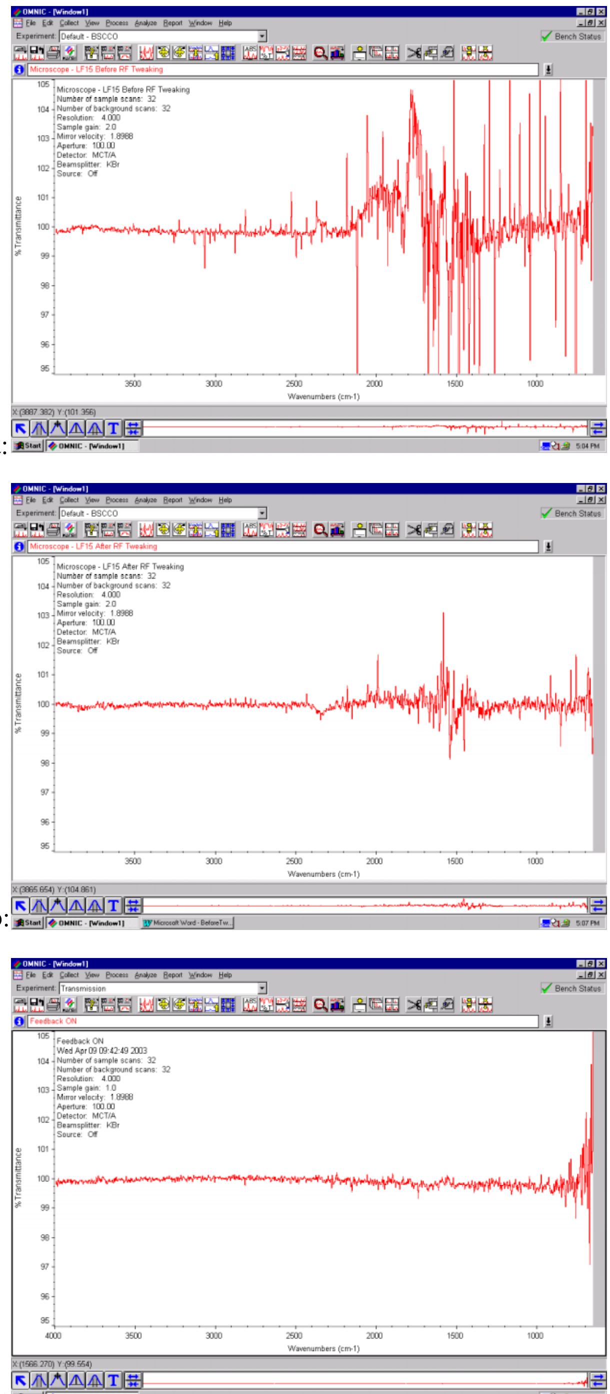
Lifetime and Stability

With the decreased horizontal beam size, plus a shorter natural bunch length due to the decreased momentum compaction of the low emittance lattice, the lifetime in LF15 is primarily Touschek scattering dominated. The current·lifetime product can be restored to its nominal value of 900-1000 mA·hr by lengthening the bunch using the fourth harmonic (200 MHz) cavity. This also stabilizes the beam by suppressing coupled bunch modes. The cavity is run passively. Both the fourth harmonic cavity and the voltage on the main RF cavity are controlled as a function of beam current by a Python script, set up to optimize beam stability.

The Infrared Beamlines

The majority of beamlines at SRC average data over time scales of seconds to minutes. However, the IR beamlines make use of Fourier Transform spectroscopy, and is therefore sensitive to beam motions into the kilohertz range. Operation in LF15 initially proved problematical for the IR line, due to the fact that the synchrotron frequency of the lengthened bunch was reduced from ~10 kHz to ~3 kHz. Also, harmonics of the 60 Hz line frequency, present in the RF systems, produced noise on the beam at frequencies up to several kilohertz. This longitudinal noise appeared as source position noise at the IR line due to the finite dispersion at the source location, and as a current modulation [8].

A program of noise reduction was undertaken to stabilize the beam for IR operation. To reduce the 60 Hz harmonic noise several improvements were made, including additional filtering and improved common mode noise rejection in both RF systems, a new low noise master oscillator, and conversion of the main RF amplifier tube filament from AC to DC. The results are shown in Figs. 2a and 2b. After this noise reduction, the dominant contribution was due to coherent synchrotron oscillations. This was reduced by implementing phase feedback in the main RF system. Results are shown in Fig. 2c.



a:

b:

c:

Figure 2: Spectra taken on the IR beamlines. For each plot 32 spectra are averaged, followed by another set of 32. The ratio of the two sets are shown as a function of wave number; a flat line at 100% would represent no noise. a) Before RF system improvements; b) After reducing 60 Hz harmonics; c) after implementing feedback to reduce coherent synchrotron oscillations.

Higher Energy Operation

Running of LF15 is presently limited to 800 MeV. When scaled to 1 GeV, and taking magnet saturation into account, the limits of various magnets, power supplies, and cabling are exceeded. However, an intermediate solution, referred to as "MF15", has been found, having a horizontal emittance of 142 π nm·rad. This is larger than the 800 MeV LF15 emittance E^2 scaled to 1 GeV (64 π nm·rad) but smaller than that of the 1 GeV lattice presently run (187 π nm·rad). MF15 has been tested, and showed the expected horizontal emittance reduction. Full implementation will require hardware upgrades (cabling), and is planned for the near future.

SUMMARY

We have successfully commissioned Aladdin in a low emittance configuration at 800 MeV. This is now the routine operating mode. In the process, we made use of new hardware and software, and lattice optimization techniques. Special attention was given to undulator compensation, and operation of the infrared beamlines. The result is a beam with increased flux density, good lifetime and unchanged vertical beam sizes. Future plans call for implementing a low emittance lattice at 1 GeV, and investigating at 800 MeV emittances lower than that of LF15. We also will study operation with smaller vertical beam sizes (subject to maintaining adequate lifetime), to take full advantage of low emittance.

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