SUPER-CONDUCTING WIGGLERS AND THE EFFECT ON INJECTION EFFICIENCY

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Abstract

The Canadian Light Source has two superconducting wigglers (SCW) operating at 2.1T and 4.3T peak fields. Injection efficiency into the storage ring is reduced by either device operating at high fields. Currently the CLS operates with a fill and decay mode, injecting with both wigglers at reduced field to avoid low injection efficiencies. Future implementation of a top-up mode will require both wigglers to be operating at full field and better injection efficiencies will be required. Simulations and experiments have shown that the poor injection efficiency is related to operating a high vertical chromaticity. Much improved efficiencies are observed at when the chromaticity is lowered. As well, small improvements to the injection efficiency have been achieved through local correction of the beta-beats and tune shifts caused by the wigglers and optimisation of the injection co-ordinates of the injected beam. Measurements of the injection efficiencies at various chromaticities will be presented along with the betatron functions before and after correction.

INTRODUCTION

The Canadian Light Source operates with two superconducting wigglers and future beam lines include adding two more high field (>2 T) wigglers. The 2.1 T wiggler was originally installed in 2005 on the HXMA beam line and since then has been in routine operation at 1.9 T; a PS upgrade in 2010 has enabled operation up to 2.1 T. There is some reduction of injection efficiency at full field and typically the field is reduced between 1.0 to 1.5 T for storage ring injections. The 4.3 T wiggler was installed on the BMIT beam line in 2007 but routine operation at full field has been limited; commissioning and injection studies have been performed at 4.3 T and there have been routine operations at 1.4 T. Operation of this device causes a significant reduction in the injection efficiency at operation above 2 T, which is mitigated by reducing the SCW field during injection to 1.4 T while operating in a fill and decay mode. Additionally, the relative injection loss caused by either device is not independent of the magnetic field set point of the other wiggler, indicating some dynamic interaction between the two devices that is not yet understood.

Until recently injection into the storage ring was done with wigglers at low fields in order to achieve reasonable injection efficiencies. This mode of injection would not be suitable for top-up injection and so exhaustive injection studies have been underway over the last year. With the machine this included careful steering of the beam through the injection line, careful steering of the beam through the wigglers and correction of beta-beating caused by the wigglers. At the same time simulations were done to try to discover the cause of injection losses. Early measurements indicated that it was the small sextupole component present in the wigglers that caused the problem. This suggested an improvement to the injection efficiency could be accomplished by lowering the vertical chromaticity of the ring. The storage ring had been operating with a vertical chromaticity of +6 in order to aid the transverse feedback system in allowing a 100% fill pattern of the ring.

Simulations and measurements also show a relationship between chromaticity and injection efficiency with and without the wiggler in operation. Further studies include a local correction of the vertical beta function and a global correction of the tunes. Small improvements to the injection were achieved but we were not able to greatly affect the injection efficiency with these corrections, unlike other labs, which have reported restoring injection efficiency with these types of corrections [1].

EFFECT OF CHROMATICITY

The storage ring has been run with vertical chromaticity at +6 until recently. In December 2010 the chromaticity was lowered and a marked improvement in the injection efficiency with the wigglers at full field was seen; this lead to a detailed study of the effect of chromaticity on injection. Measurements in the storage ring were performed at the same chromaticity values studied in the simulations.

Simulations

Simulations were done using DIMAD [2] with the horizontal chromaticity at +2 as used in the real ring and with no misalignments or multipole fields in the magnetic elements. Two sets of simulations were done. The first simulation had ideal injection and the second had an increased injection amplitude and vertical coupling.

For simulation 1 the beam is injected at -11 mm as described in reference 3. The BMIT wiggler is modelled as described in reference 4 with the inclusion of sextupole component at each end to account for the measured chromaticity change. Injection efficiency is shown in Figure 1.

For simulation 2 the beam is injected at -13.5 mm to account for the betatron oscillations caused by the unclosed kicker bump. As well coupling is introduced and the beam is collimated at 3.5 mm vertically.

Measurements

Measurements of the injection efficiency versus the wiggler field were taken for several different vertical chromaticities. For all measurements the horizontal chromaticity was unchanged at 2 while vertical chromaticity was varied from the normal operating point of +6 down to a value of 0. Injection efficiency was measured as the charge successfully transferred from the booster ring and captured in the storage ring, averaged over multiple shots of a complete injection cycle filling 280 of 285 RF buckets in the storage ring. The results of the measured injection efficiencies for various chromaticities and wiggler fields are shown in Figure 2.

Comparison

It appears there is some loss mechanism with the wiggler off that is not accounted for by an ideal model of the wiggler. This is possibly due to misalignments, not included in simulations, and/or high order multipoles in the ring magnets or wigglers.

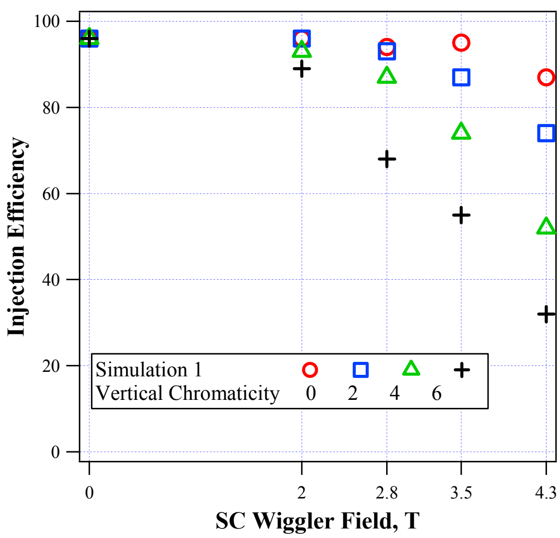

Figure 1: Simulation 1 and Injection efficiency for different BMIT wiggler fields and chromaticity.

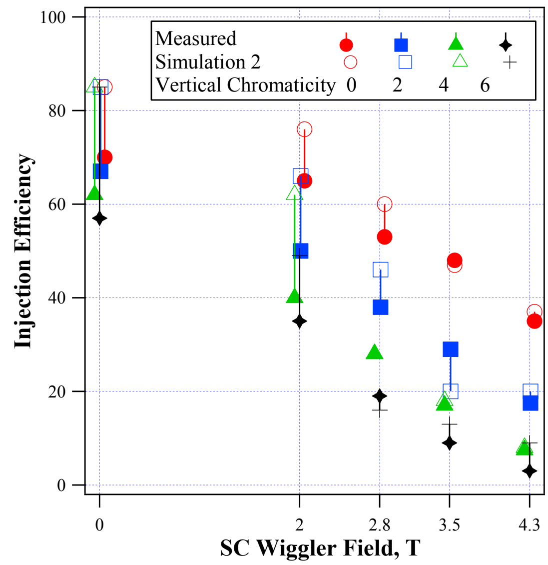

Figure 2: Simulation 2, Measurements, and Injection efficiency for different fields and chromaticity. (points are offset horizontally for clarity).

BETATRON CORRECTION

The focussing due to a planar ID causes a beating of the beta functions around the ring. The expected tune shifts and beta beat caused by an ideal wiggler were modelled using elegant [5] and compared to measured values. Local correction of the vertical beta beat was done with the use of four quadrupoles on either side of the wiggler straight. Quadrupole settings were calculated using elegant and applied to the lattice. Measurements with the local beta correction were taken and show the vertical beta beat was removed, see Figure 3; the horizontal beta function had no significant change. The local beta correction had no improvement in the injection efficiency.

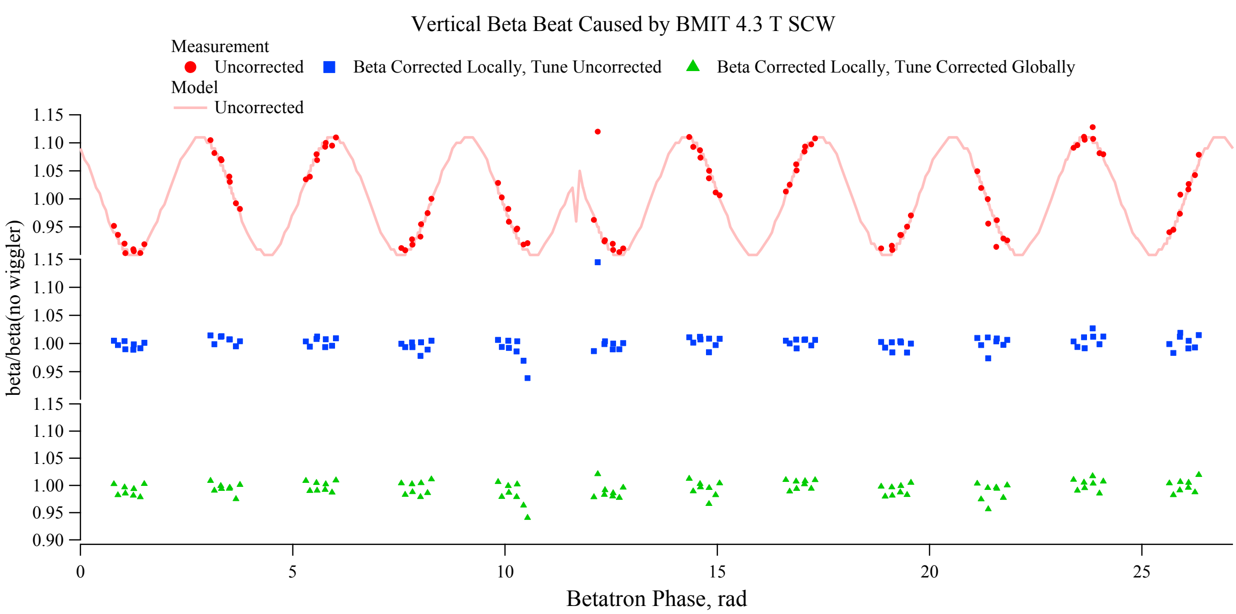

Figure 3: Measurements of the Vertical Beta Beat caused by a SCW at 4.3 T. Shown are the cases for uncorrected, local beta correction only, and local beta correction plus global tune correction.

A global tune correction was then applied by adjusting the quadrupole families to remove the tune shifts caused by the wiggler. This correction resulted in an increase in the injection efficiency from ~3% to ~10% when the vertical chromaticity was +6. At a vertical chromaticity of zero the betatron corrections increased the efficiency by 10%.

CONCLUSIONS

The CLS storage ring is now operated with a vertical chromaticity of +2. To do so we no longer attempt to fill the entire ring but leave a single gap of 5 buckets in the fill pattern. In the future new operating points will be investigated to possibly avoid coupling resonances that are driving the injected beam into the narrow gap insertion device vacuum chamber.

The reduction of injection efficiency due to the wigglers is strongly driven by the sextupole component present in the wigglers (and possibly higher order multipoles.) Future wigglers could have sextupole correction built into the devices in order to reduce their impact on injection.

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