TRANSVERSE COUPLING COMPENSATION AT THE UVX LNLS STORAGE RING

X. R. Resende* and L. Liu
LNLS – Laboratório Nacional de Luz Síncrotron, CP 6192, 13084-971, Campinas, SP, Brazil.

Abstract

In this paper we report on recent developments in transverse coupling characterization and compensation in the UVX storage ring at the Brazilian Synchrotron Light Laboratory (LNLS). We have designed and manufactured a compact skew quadrupole with which it was possible to completely compensate coupling introduced by insertion devices (IDs) in the ring.

INTRODUCTION

The beamline of the second insertion device installed in the LNLS UVX storage ring [1] is to have its commissioning started by the end of 2010. This beamline uses synchrotron radiation of an EPU built in-house with a 0.5 T minimum gap magnetic field amplitude and 50 mm period. This beamline is very demanding with respect to orbit stability and beam sizes. Considerable reduction of the vertical emittance is necessary in order for the beamline to achieve its design performance.

The first insertion device installed in the LNLS ring was a 2.0 T wiggler manufactured by STI Optronics. During its commissioning a significant increase in transverse coupling was observed [2]. The coupling value of ~ 0.3% without the wiggler went up to 1.5% when the wiggler was introduced and its gap closed. As a consequence the one skew quadrupole family A2QS05 that had been used for increasing beam lifetime by enhancing vertical beam size could now be turned off. The EPU itself introduces negligible coupling.

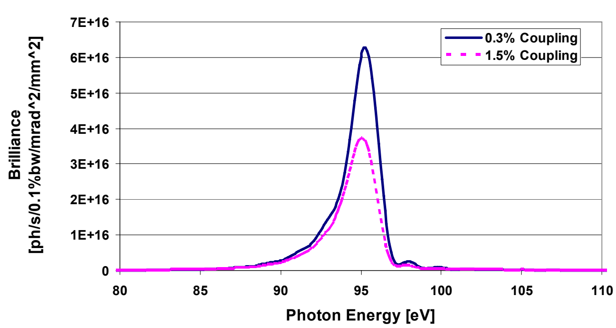

Figure 1: Calculated EPU 1st harmonic brilliance reduction due to coupling enhancement from the 2.0 T wiggler.

Coupling correction schemes using skew quadrupole correctors have been implemented in many storage rings over the years. Complete global correction maybe accomplished, within the weak coupling and difference resonance approximations, using two independent families of skew quadrupoles. Local coupling correction schemes require more families. As for the LNLS UVX ring, in past years there have been many attempts in trying to understand and characterize its residual coupling. Traditional closest tune approach, beam size from imaging systems [3] and cross-orbit response measurement methods [4] have been used without fully satisfactory results. In view of the pressing need for a solution for coupling compensation before the end of this year a more pragmatic approach was in need.

Our first attempt had been to use the A2QS05 family with its two skew quadrupoles. Due to beta phase advances between its quadrupoles and the wiggler, this family proved inefficient to reduce global coupling. We could try finding new positions in the ring for these quadrupoles but this would be very inconvenient since each magnet weights around 170 kg. We opted for designing and manufacturing a new compact skew quadrupole corrector that we could easily transport and test in many different locations around the ring.

COMPACT SKEW QUADRUPOLE CORRECTOR

The residual coupling introduced by the wiggler field, degrading as it is for the EPU beamline performance, is very small and can be corrected with modest fields. According to FEMM simulations a rather compact skew quadrupole is sufficient. Such a skew corrector was designed, built and bench-characterized. Its main magnetic and mechanical parameters are listed in Table 1.

Table 1: Parameters of the Skew Quadrupole Corrector

Width	490 mm
Height	490 mm
Length (with coils)	58 mm
Pole width	40 mm
Pole height	70 mm
Bore radius	70 mm
Total weight	30.4 kg
Maximum current	± 10 A
Max. Integrated Skew Gradient	0.22 T

The maximum integrated skew gradient of the corrector corresponds to an integrated normalized strength of ~ 0.048 m^{-1} at the machine top energy of 1.37 GeV, which in turn, depending on beta function values where the

*ximenes@lnls.br

corrector is installed, results in coupling corrections up to 9.5%. There is plenty of room for correcting the effect of the 2T wiggler.

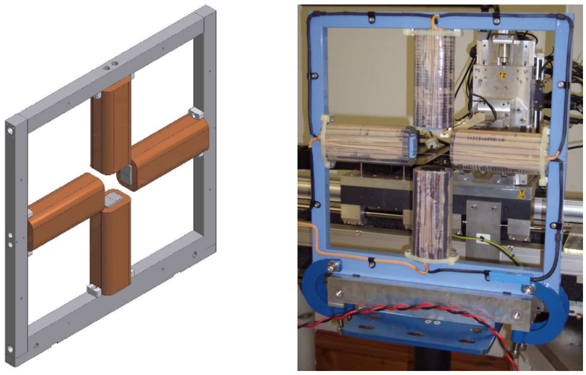

Figure 2: CAD drawing and photo of the skew quadrupole corrector.

It remained the task of finding a suitable position for it in the ring with the correct betatronic phase advances. Compactness of the skew corrector (see Fig. 2) allowed for its quick installation in various locations.

COUPLING COMPENSATION

Places adjacent to the wiggler are the most obvious positions for the installation of the skew corrector. But these locations seemed inaccessible at first because of the various magnetic, diagnostics and vacuum elements which are already in that straight section. The corrector was then tried in many other locations in the ring. In none of them it contributed to a reduction of the vertical beam size (see Fig. 3). After the sixth unsuccessful trial, the vicinity of the wiggler was inspected again and a vacuum chamber support was found just upstream the wiggler - in the section labelled TR01A - that could be removed for the insertion of the skew corrector in its place.

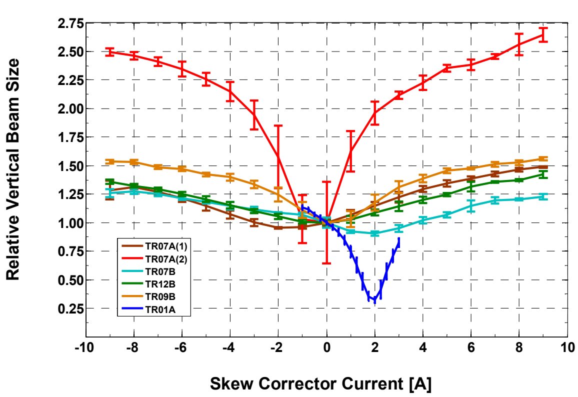

Figure 3: Measured vertical beam size as a function of the excitation current of the skew quadrupole corrector.

At this location, and with an excitation current of 2A, the skew corrector was able to substantially reduce the vertical beam size (see blue curve in Fig. 3). Figure 4 shows beam pictures taken at the x-ray diagnostics beamline DFX taken with the same set of imaging system parameters. Reduction of vertical size and of tilt angle is very pronounced after the coupling compensation.

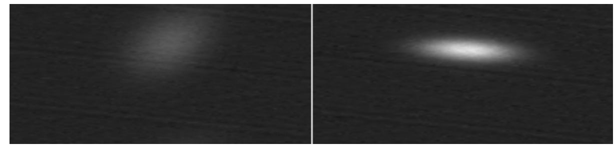

Figure 4: Raw images from the pinhole x-ray imaging system at the DFX diagnostics beam-line. On the left is the beam image with closed IDs and 1.5% coupling. On the right the coupling has been reduced to < 0.2% with the skew corrector excited at ~2A.

A nearly zero tilt angle at the DFX beamline is a strong indication that the compensation achieved with the skew corrector was not only global but local as well. In the coming months a new independent imaging system will be commissioned at the DFE beamline – a visible light diagnostic beamline sourced by a DFX downstream dipole. This system should help checking if the tilt angle was indeed corrected all around the ring. Distance between wiggler and skew corrector at the TR01A sector is short and small beta phase advances between perturbation and correction points is a possible explanation as to why local coupling compensation was possible, although low vertical beta at the section and the lack of a model for the wiggler skew field distribution weaken this analysis.

CHARACTERIZATION AND ANALYSIS

Having found a configuration for the skew quadrupole corrector that successfully compensates the wiggler coupling, a standard closest tune approach characterization of the residual coupling was performed for relevant configurations. Results are compared in Figure 5

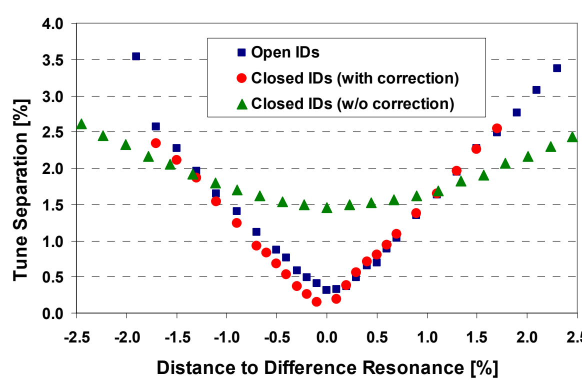

Figure 5: Closest tune approach measurement of residual coupling.

The two QF and QD families of quadrupoles were linearly varied in order to nominally switch the fractional parts of the horizontal and vertical tunes.

Curve fittings to the data sets in Fig. 5 give residual couplings of 0.3%, 1.5% and 0.2% for the transverse dynamics with opened IDs, closed IDs without and with correction, respectively.

The analytical expression for the emittance ratio based on solutions to the equations of motion within the weak coupling difference resonance approximation [5],

$$\frac{<\varepsilon_y>}{<\varepsilon_x>} = \frac{|\kappa|^2}{|\kappa|^2 + 2\Delta_r^2},$$

was fitted in order to explain measurement data of beam sizes versus skew corrector current *I*. Size blurring due to beam energy dispersion and to pinhole diffraction effects was corrected. Fitting worked well only for small tilt angles, when the ratio between coupling coefficient and tune distance to difference resonance is small, $|\kappa(I)|/\Delta_r < 0.26$. For higher coupling values accuracy of measured tilt angle seems to become compromised.

The impact of different coupling configurations on the beam lifetime was registered together with improvements on photon flux measurements at the SGM beamline (see Fig. 6). As expected, coupling compensation reduces beam lifetime τ: from roughly 24h to 17h at 210 mA. When the IDs gaps are all opened τ = 18h, corroborating previously shown closest tune approach coupling measurements which indicate that the skew quadrupole indeed went beyond in correcting the IDs effects. SGM data shows a 3.5-fold increase in photon flux due to coupling compensation. Interestingly, SGM data shows that, although small residual coupling of the configuration with opened IDs has been restored with the skew corrector, photon flux at the beamline remains reduced. This has not been understood yet.

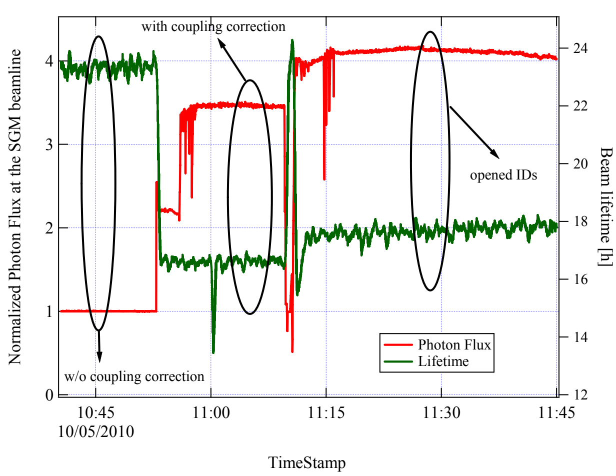

Figure 6: Different coupling configurations and their impact on beam lifetime at and on the SGM photon flux (top energy, 210 mA).

For all configurations a fixed spectral resolution corresponding to a vertical slit aperture of 100 μm was used. Optimal realignment of optical elements in the beamline was taken before each data acquisition.

CONCLUSIONS

The compact skew quadrupole corrector was very successful at compensating coupling in the ring from the two IDs spurious skew fields. Its compact design proved very useful for easy and fast transportation and fixation on tentative positions in the ring. Moreover, its fields are so modest that detailed optimized pole profiles and non-linear beam dynamics were not needed, as there were no surprises in injecting, energy-ramping and storing nominal beam currents.

Coupling was reduced from a value of 1.5% down to 0.2%. Measurements of closest tune approach, beam lifetime, beam sizes and photon flux at the SGM beamline are all consistent and prove the complete compensation of the coupling from the IDs.

Strategies to ameliorate the unavoidable beam lifetime reduction that comes with coupling compensation are yet to be discussed. If injection time continues to improve over time, as has been the case over last semesters, one option is to have three 250mA beam injections per day, instead of the current two. For the time being, the skew corrector is kept off during users' shifts since the EPU beamline is still under construction.

There are plans to build an additional skew corrector of the same design for preventive coupling compensation of the 4.0 T superconducting wiggler. This ID should be reinstalled in the ring during machine shutdown by the end of the year.

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