NON-LINEAR KICKERS USING EDDY CURRENT SCREENS AND APPLICATION TO THE ESRF

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Abstract

The ESRF storage ring injection and accumulation is performed using standard 4-kickers bump and septum magnet. Sextupoles are located within the injection bump leading to significant bump non-closure during the ramp-up and ramp-down and optics distortion for both stored and injected beam. Introducing non-linearities in the kickers allows for compensation of the perturbation from these sextupoles. We report on the feasibility of adding eddy current screens to a standard kicker magnet design to generate a non-linear field and its recent application to mitigate the injection perturbations at the ESRF.

INTRODUCTION

Injection into the ESRF storage ring takes place in cells number 3 and 4 with a traditional 4-kickers bump and in-vacuum septum magnet scheme [1]. Figure 1 shows a schematic view of the injection zone with the 4 kickers K1 to K4 and the in-vacuum eddy current septum S3. The peculiarity of the ESRF resides in the sextupoles (2 on each side of the septum, depicted by NS3 and NS4) located inside this injection bump. These sextupoles prevent bump closure on rising and falling edges of the kickers pulse which lasts for a total of 3 µs (1 µs rise-time, 1 µs flat-top and 1 µs fall-time), corresponding to one ESRF turn.

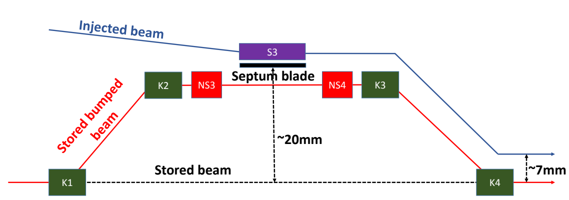

Figure 1: Schematic view of the ESRF injection.

IMPACT OF SEXTUPOLES INSIDE THE INJECTION BUMP

During injection, when the kickers are pulsing, the beam horizontal position in the sextupoles varies and consequently introduces a time-dependant vertical field. While the bump is closed on the flat-top by adjusting the target current of the four kickers there are no means to control the behaviour on the rising and falling edge of the kickers pulses. Several millimetres transverse oscillations are therefore introduced on the rising and falling edges of the kickers pulse. In addition, a sextupole field introduces an amplitude-dependent gradient. As opposed to beam oscillations, the β-beating introduced by the injection bump is not corrected on the flat-top and therefore it reaches a maximum when the kicker currents reach their target values.

Figure 2 shows the modeled beam displacement and β-beating perturbation due to the sextupoles inside the injection bump for the nominal bump amplitude of 18 mm. The rms beam displacement over one turn peaks at 2 mm during the rising and falling edges while the rms β-functions increase by almost a factor 4 on the flat-top. The rms beam at the injection point is approximately 400 µm, the perturbation therefore largely exceeds several σ. This feature was not an issue in the initial design for which top-up operation was not foreseen. However, since the introduction of top-up operation in 2016, it is necessary to contain any injection perturbation below the σ level in order to allow for continuous data acquisition from the beam-lines which is presently

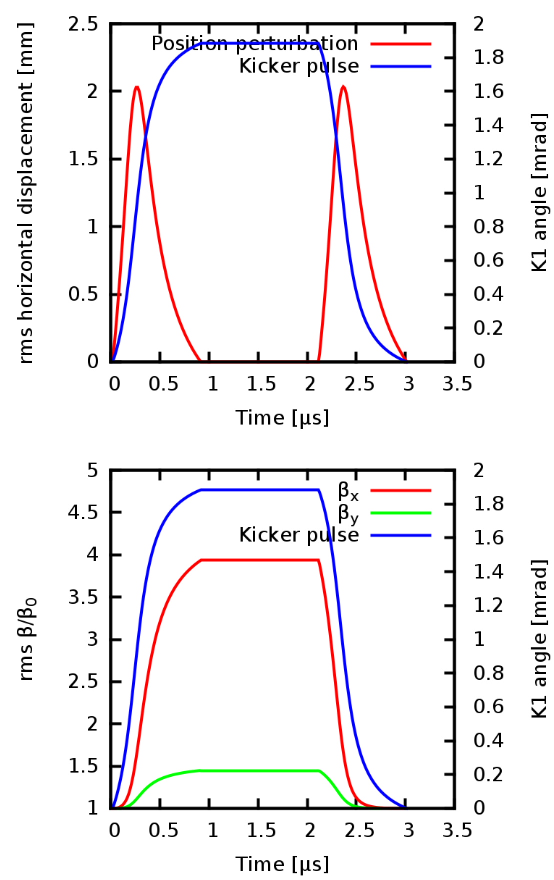

Figure 2: Injection perturbation due to the sextupole inside the injection bump.

not the case. Similar issue was encountered and solved in [2] by adjusting the sextupole settings. This method was tried at ESRF but lead to an unacceptable loss of lifetime. An alternative is to shape the kickers field in order to compensate the perturbation introduced by the sextupoles. It should be noted that the design of the ESRF storage ring upgrade [3,4] does not feature sextupole inside the injection bump where the beam experiences large horizontal excursions.

PASSIVE COMPENSATION USING NON-LINEAR KICKER FIELD

Sextupoles and more generally non-linear kickers have been or are planned to be used in several machines to achieve transparent injection [5,6]. The proposed scheme however featured challenging kicker design with multipole coils geometry to generate the non-linear field requiring significant development studies. A much simpler approach is to start from the standard dipole kickers and use eddy current shields, in our case copper plates, to attenuate the field as a function of the horizontal position of the beam.

Figure 3 shows the dependency of the vertical field on the horizontal position for several copper plates dimensions. The position of the stored and bumped beams are also indicated. The 40 mm plate which allows for 20% attenuation at the full bump amplitude, is the configuration installed in the ESRF storage ring and showed on the picture at the bottom.

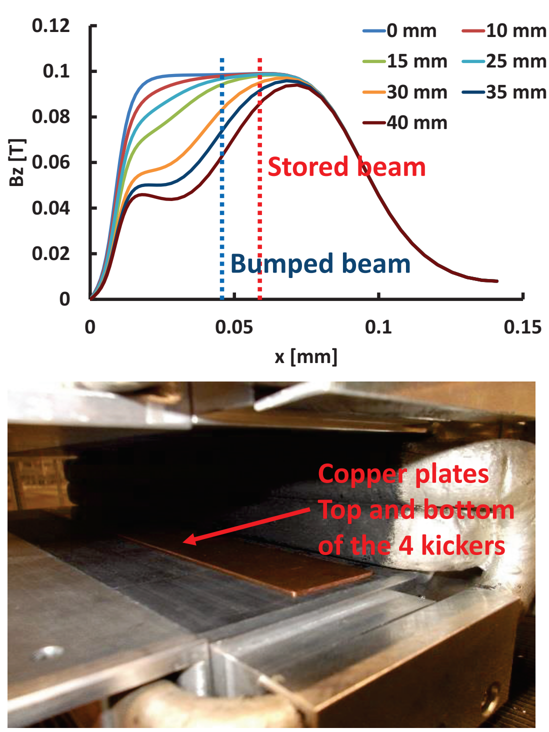

Figure 3: Field attenuation due to the copper plates and picture of the ESRF set-up.

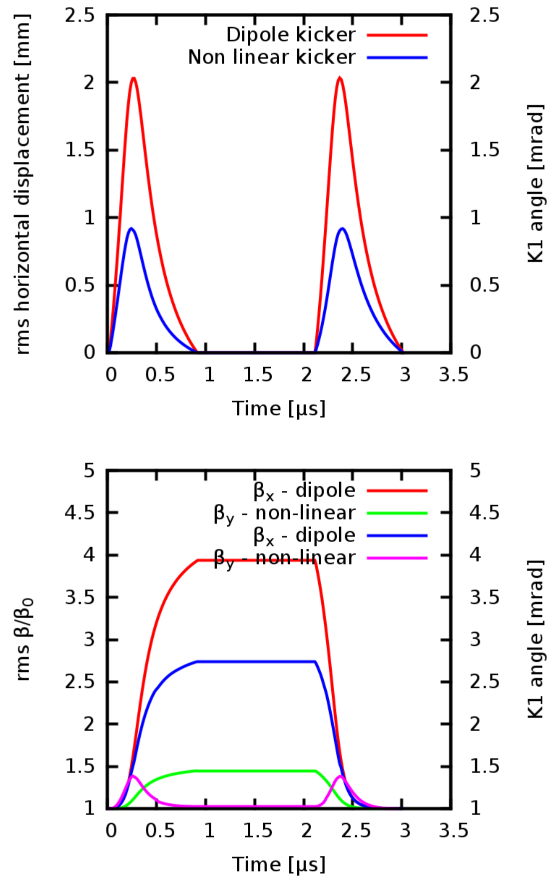

Figure 4: Injection perturbation due to the sextupole inside the injection bump with 40 mm copper plates.

Figure 4 shows the expected reduction of orbit perturbation and β-beating in the presence of 40 mm copper plates. Both are reduced by approximately a factor 2.

EXPERIMENTAL RESULTS

The results shown in Fig. 4 represents the ideal case for which all four kickers are identical and perfectly synchronized. In practice such situation is not achievable but it is possible to approach it with careful optimization. First the copper plate were installed inside the four kickers to preserve identity since the inductance of the magnet and hence the field rise-time were significantly affected by this modification. In addition, a dedicated diagnostic was developed to monitor the perturbation [7]. It consists of a pick-up that records the position of all individual bunches for a few turns directly after injection. When the 992 buckets of the storage ring are filled this allows to measure the perturbation along the kicker pulse for several turns and produce similar figures as the top plots in Fig. 2 and 4. By looking at the shape of the recorded perturbation it is possible to diagnose problems like unequal rise-times or mistimed kickers.

For instance, Fig. 5 shows a measurement of the perturbation before (blue) and after (red) timing adjustments after the plates were installed. The rising and falling edges are easily

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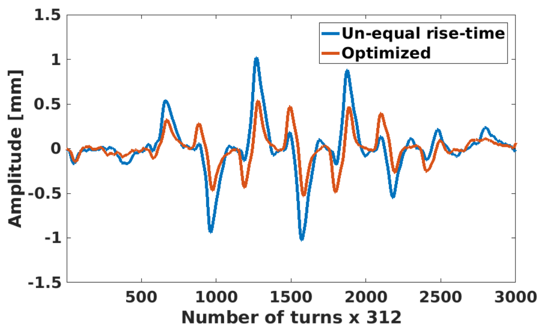

Figure 5: Perturbation measurements before (blue) and after (red) timing adjustments.

recognized from the characteristic double peak structure, the flat-top in this case does not fall to zero and is distorted by filtering applied in the data acquisition chain. The unequal rising and falling edges perturbation amplitudes is typical of mistimed kickers. Once the correction is applied we obtain the red curve where the two peaks are equal, thus indicating proper timing configuration.

Figure 6 shows perturbation measurements before (blue) and after (red) the 40 mm copper plates were installed. The peak perturbation is improved from 0.92 mm to 0.54 mm which is consistent with the factor 2 predicted improvement. The average perturbation over the acquisition window is reduced from 0.2 mm to 0.09 mm. This simple experiment shows that the principle is working, however, the perturbation remains comparable to the beam size which cannot be considered as transparent. With some design effort it seems possible to properly shape the kicker field in order to compensate entirely the sextupole perturbation which could allow for compact injection cell design with additional freedom concerning the sextupole layout.

VERTICAL PERTURBATIONS

As a consequence of the horizontal non-linear field in the injection kickers a vertical amplitude dependant field is introduced. A vertical offset of the beam or a vertical

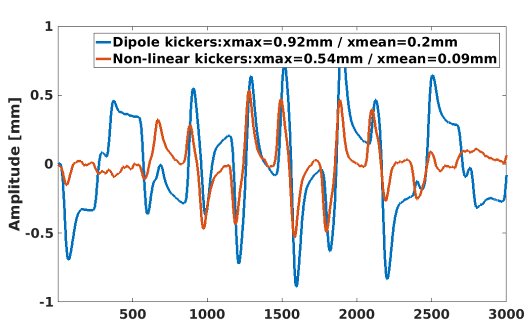

Figure 6: Perturbation measurements before (blue) and after (red) the 40 mm copper plates were installed.

misalignment of the kickers will therefore be a source of vertical perturbations. To correct these perturbations we use a pair of skew quadrupoles located inside the injection bump. As the bump is ramped up the vertical kick provided by these skew quadrupoles increases providing a local vertical correction present only during the injection process.

Figure 7 shows the rms vertical displacement on the first turn after injection as a function of the skew quadrupoles current, the final level of the perturbation is approximately 4 µm rms after correction. These measurements were done on the bunch seeing the flat-top only, bunches seeing the falling and rising edge are still experiencing perturbation of the order of several 10 µm originating from the horizontal plane.

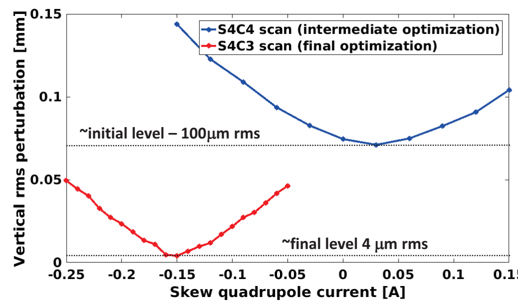

Figure 7: rms vertical orbit as a function of the skew quadrupoles current.

SUMMARY

The present ESRF machine suffers strong injection perturbation due to the sextupoles located inside the injection bump. This perturbation presently does not allow continuous operation of the beam lines. A novel correction scheme is proposed using non-linear injection kicker fields to compensate for the sextupolar field. First experimental results are consistent with expectation showing the validity of the principle. Vertical perturbations are corrected using a pair of skew quadrupole bringing down the vertical perturbation on the flat-top down to a few µm.

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