INJECTION USING A NON-LINEAR KICKER AT THE ESRF

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Abstract

The ESRF injection consists in a standard four kickers bump off-axis injection. Although this scheme is very robust and reliable it is known to disturb users during injections and may represent a severe limitation in case frequent injections are required. The non-linear kicker injection scheme provides a possible solution to this problem by acting only on the injected beam. This paper reports on the potential integration of a non-linear kicker injection scheme at the ESRF. A layout and specifications for the kicker are proposed and simulations are provided to evaluate the performance and limitations of such scheme.

INTRODUCTION

The standard four kicker bump injection scheme used on the previous machine [1, 2] was adopted for the ESRF-EBS as a low risk solution for the commissioning of the new machine. This option also allowed to recuperate existing hardware from the previous machine such as the septum magnets or the kickers power supplies. 80 % injection efficiency could be achieved in user service mode (USM) with this scheme [3]. Nevertheless, the normalized residual injection perturbations are approximately an order of magnitude larger than for the previous machine due to the beam size reduction. Even though new slow kicker power supplies combined with feed-forward corrections [4] allowed for a major reduction, experiments with beam lines indicated that an additional factor 2 reduction was necessary [5]. Some small incremental improvements are still possible but the present systems are now showing their limits to achieve the ultimate goal of transparent injection with 100 % efficiency and alternative schemes have to be considered. Advanced injection schemes were proposed in recent years to solve this problem such as: single non-linear kicker [6–8],swap-out injection [9–11],longitudinal on-axis injection [12–14] or shared oscillations using a fast kicker [15]. This report concentrates on the non-linear kicker (NLK) option that is the only one capable of providing fully transparent injection with multiple bunches as demonstrated in [16].

INTEGRATING THE NLK DOWNSTREAM THE INJECTION POINT

This solution was proposed in [17], it consists in placing the NLK downstream the injection point where there is free space such as a straight sections or available drift spaces in the arcs. This scheme allows to preserve the present injection systems and allows staggered integration and commissioning of the new ones without disrupting the operation of the storage ring. However, large transverse oscillations will occur between the injection point, located in straight section 4, and the NLK that may deteriorate the injected beam properties and consequently the injection efficiency. To evaluate this effect we consider four possible locations: 2 drifts spaces in cell 5 ($ARC5_{1,2}$) and the straight sections of cells 6 and 8 (ID6 and ID8). All are realistic candidates with space available for the installation of the NLK, however, the arc drift spaces are only approximately 0.4 m. Integrating a complex device in such short space may be challenging.

Table 1: Injection Efficiency Considering Different Types of Kickers at Different Location in the Ring (x_0=6 mm Corresponds to the Present Off-axis Injection)

	Kicker type		
	Dipole	**Octupole**	**Oct. + Sext.**
x_0=6 mm	99.9%	99.9 %	99.9%
$ARC5_1$	99.4%	36.9%	95.0%
$ARC5_2$	99.5%	38.5%	96.5%
ID6	94.0%	31.3%	72.5%
ID8	76.5%	15.4%	50.1%

The first and second columns of Table 1 summarizes the results of the tracking simulations done using a pure dipole kicker for which all particles receive the same kick and an octupole kicker to model the case of a realistic NLK for which particle will receive a kick that depends on their transverse amplitude. The simulations were performed using an ideal storage ring lattice (no errors) and the following injection beam parameters: $\epsilon_{x,y}$ = 45 nm, σ_s = 20 mm, σ_p = 0.0012. These correspond to the present conditions assuming the booster beam is extracted on the coupling resonance. For all cases, the initial angle and twiss parameters were optimized to give to largest efficiency. Cases are ordered by increasing distance with respect to the injection point and the present off-axis injection is represented by x_0 = 6 mm. The dipole kicker simulations allow to evaluate the impact of the large transverse oscillations between the injection point and the kicker. It is seen that as the distance to the injection point increases the performance degrades and the situation becomes unacceptable in ID8. For the more realistic case of the octupole kicker the field needs to vary from zero to the design kick of approximately 1.5 mrad in 3-4 mm. Unfortunately, the field variations are too strong across the transverse beam extension and a large part of the injected beam is kicked out of the acceptance. There are 2 possibilities to solve this issue: reduce the injected beam size or cancel the kicker field gradient at the amplitude of the injected beam. The latter was demonstrated and used in [4] where it was shown that multipoles of different order can be used to cancel the field gradient at any given amplitude. In this report, we will use an additional sextupole component, that can be generated by either the proper coil arrangement or with a compensation

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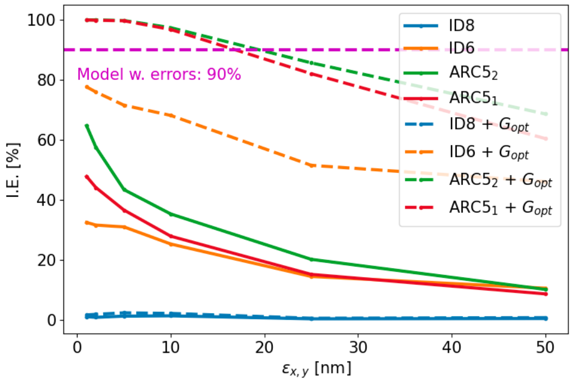

Figure 1: Injection efficiency as a function of emittance for different scenarii. Only one seed of errors was considered for these simulations.

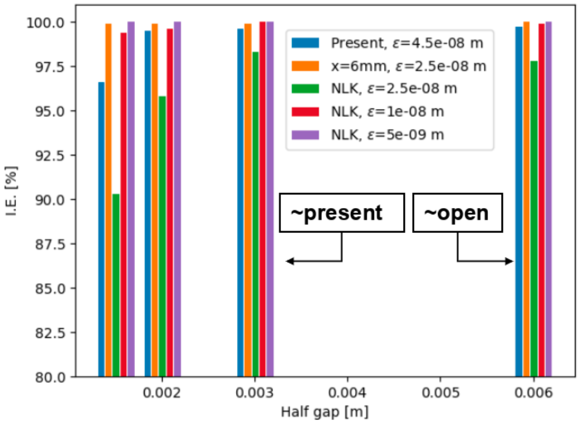

Figure 2: Injection efficiency as a function of the gap settings for the present off-axis injection and the NLK.

kicker, to adjust the kicker field gradient at the injected beam amplitude.

The third column of Table 1 summarizes the results of the simulations using a combination of an octupole and sextupole to optimize the field gradient seen by the injected beam. All other parameters are the same as for the results of the first and second columns. A significant improvement is observed in all cases. The kickers located in arc 5 provide good efficiency but still below the ideal dipole kicker case. On the other hand, for the ID cases the injection efficiency is still strongly degraded and cannot they be considered as viable options for operation.

Figure 1 shows the dependency of the injection efficiency on the injected beam emittance. In this case a lattice with errors was used and both octupole and combined sextupole and octupole (G_{opt}) kickers were considered. All other parameters are identical to the ones used above. The initial angle and twiss functions were re-optimized to account for variations due to the errors. Using the ESRF-EBS design injection efficiency of >90%, it is seems that a low emittance booster (10-20 nm) would be needed to restore the present performance.

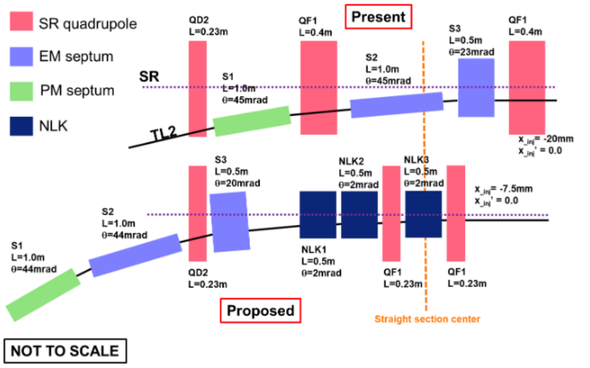

Figure 3: Proposed layout for the transfer line (TL2) and storage ring (SR) injection straight to integrate non-linear kickers.

A possible scenario to further improve the brilliance of the machine is to reduce the insertion devices (ID) gaps. The new injection systems should therefore be compatible with low gap operation. This is particularly important with the NLK as the tails of the injected beam will see a kick that is different from the optimal one. Generation of non gaussian tails is therefore expected and may be a source of losses on the ID gaps. Figure 2 shows the dependency of injection efficiency on the gap values for the present off-axis injection scheme and the most promising NLK configuration (ARC5$_2$). For the present injection, an emittance of 25 nm would be required to close the gaps down to 4 mm while for the NLK an emittance of 5 nm is required to achieve the same performance which confirms the presence of large amplitude particles introduced by the NLK.

The integration of a NLK downstream the injection point at ESRF-EBS would require a low emittance booster. This represents a major intervention and will disrupt the physics program of the facility. In addition, the drift space in the arcs are rather small and integrating a complex kicker in these region is challenging. Finally, although simulation seem to indicate that 5 nm is sufficient, non-linear dynamics at large amplitude is very difficult to correctly model. Safety margin would therefore be necessary and going below 5 nm would involve building a full length booster. For all these reasons, the initial assumption of maintaining the present injection to allow for smooth integration and commissioning is not realistic. One should therefore consider to integrate the NLK at the injection point that is the optimal location for such device.

INTEGRATING THE NLK IN THE INJECTION STRAIGHT

This option was already presented in [18] but was not considered for installation as there was still reasonable hope to achieve pseudo-transparent injection with the installation of the new kickers power supplies as presented in [5].

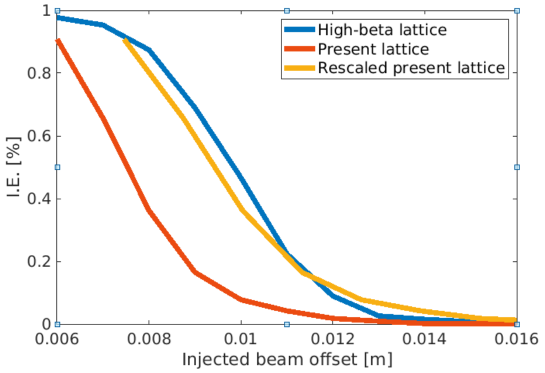

Figure 4: Injection efficiency as a function of injected beam offset for the nominal and high-β lattices.

Figure 3 shows a schematic view of the proposed TL2 and injection straight section layout integrating the NLK at the bottom, and for comparison, the present layout at the top.

The optimal location for the NLK is where the β-function reaches a maximum, which in the case of the ESRF-EBS is the injection straight. The horizontal β-function is 18.6 m by design at ESRF but can be increased to 31.5 m by reducing the distance between the last two focusing quadrupoles (QF1) on either side of the injection point as shown on Fig. 3. The acceptance will then theoretically increase from 6 mm (as considered in the above simulations) to 7.8 mm.

This is shown in Fig. 4 where tracking simulation were performed to compute the injection efficiency as a function of the initial injected beam offset. The results for the nominal lattice were then re-scaled with β for comparison with the high-β lattice. One can see on this figure that increasing the β function at the injection point as proposed does not reduce the acceptance of the machine as the tracking simulation matches the re-scaled results, therefore providing an acceptance of almost 8 mm at the injection point at constant injection efficiency. A full assessment of this lattice including adjustments to mitigate the local increase of chromaticity, errors and lifetime calculation is nevertheless necessary to determine its feasibility.

Assuming this result will be confirmed, the NLK flat-top therefore needs to be produced at 7 mm instead of 3 mm as described above which considerably relaxes the design and may allow to completely flatten the field on the injected beam trajectory to avoid the creation of non gaussian tails. In this case only a modest reduction of the injected beam emittance to 25 nm would be compatible with 4 mm gaps. This reduction requires only a re-cabling of few quadrupoles in the existing booster as presented in [19].

The proposed layout features 3 NLK at the end of the TL2 transfer line, all other elements are (septa and quadrupoles) compatible with existing ESRF-EBS hardware. The NLKs need to be designed to produce a deflection angle of 2 mrad over 0.5 m length at a distance of 7 mm from the stored beam axis and the field gradient needs to be flatten on the injected beam axis. Assuming such conditions can be fulfilled, this layout removes most limitations from the NLK potentially providing high efficiency transparent injection compatible with low-gap operation. It should be noted that this scheme can be combined with a fast stripline kicker to further reduce the injection oscillations by a factor 2 as proposed in [15]. To summarize, in terms of hardware upgrades and developments this scheme would require:

- Development and mechanical integration of 3 (identical) NLK
- Adapt the TL2 transfer line magnetic layout to the new injection
- New vacuum vessels in the transfer line and the storage ring straight section
- Adaptation and mechanical integration of septum magnets
- Modest upgrade of the booster to reduce the emittance to 25 nm on the coupling resonance [19]

These are fully compatible with the existing storage ring layout and the intervention would therefore concentrate on the end of TL2 and the injection straight. Installation could be envisage without increasing the total intervention time over a year but rather combining 2 or more shutdown periods into a long shutdown.

SUMMARY

Two solutions to integrate the NLK injection in the ESRF-EBS were studied. The first one preserves the present injection to allow for smooth transition without disrupting the physics program of the facility by installing the kicker in a drift downstream the injection point. However, this scheme involves large oscillations through several cells and a rather aggressive kicker design for which the field has to reach its design value in less than 4 mm. This strongly degrades the injected beam properties and injection efficiency. Although several mitigation measures were probed the only feasible solution fulfilling all constraints involves a low emittance booster requiring a long intervention and discards any possibility of a smooth transition.

Alternatively, it may be possible to modify the TL2 transfer line to integrate the NLK at a large β location in the ring: the injection straight section. This allows to significantly relax the kicker design and only a modest reduction of emittance in the booster to achieve design specifications. More detailed studies are required to validate this approach.

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