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COMMISSIONING OF NEW KICKER POWER SUPPLIES TO IMPROVE INJECTION PERTURBATIONS AT THE ESRF

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Abstract

The ESRF-EBS storage ring resumed operation in 2020. Due to the reduced lifetime, top-up injection is required for all operation modes. Perturbations on the stored beam introduced by the pulsed injection elements represent a significant disturbance to the beam lines that need to run experiments across injection. In order to reduce these perturbations, new kicker power supplies with slower ramping times and better shot-to-shot reproducibility were developed at ESRF to improve the efficiency of the feed-forward compensation scheme. This paper reports on the design, commissioning and first experimental validation of these new power supplies.

INTRODUCTION

Off-axis injection with a closed injection bump generated by 4 pulsed kicker magnets was used in the previous ESRF storage ring [1, 2]. It was then adopted during the design of the ESRF-EBS storage ring as it was considered a low risk solution for the commissioning of the new machine and would allow to recuperate some of the existing hardware components such as the injection kickers power supplies based on thyratron technology. With these systems, the injection efficiency in User Service Mode (USM) with gaps closed is of the order of 80 % for a fully optimized machine [3], 10 % below design expectation of 90 %. Off-axis injection is unfortunately known to introduce large perturbations on the stored beam during injections that can affect beam lines experiments. Based on past experience, the injection perturbations compensation methods and systems presented in [4] were successfully applied to the ESRF-EBS storage ring. Nevertheless, the normalized residual injection perturbations are approximately an order of magnitude larger than for the previous machine due to the beam size reduction. This paper reports on the implementation and commissioning of new kickers power supplies featuring slower ramping times to facilitate feed-forward corrections and improve the injection perturbations.

POWER SUPPLIES DESIGN

The main limitation of the feed-forward system is to achieve large deflections at high frequency in order to affect the bunches individually. Increasing the bandwidth of the present feed-forward system was not possible, new kicker power supplies with slower ramping times were therefore designed to improve the injection perturbations and other aspects of the pulsers. Their characteristics are shown in Table 1. The proposed solution, based on IGBT (Insulated Gate Bipolar Transistor) technology significantly increases the ramping time of the kicker pulses and improves by a factor 4 the pulse-to-pulse jitter, thereby reducing the random fluctuations that cannot be corrected with a feed-forward system. The fall time is presently set to approximately 2.2 µs slightly lower than one storage ring turn but could be increased further depending on the horizontal tune working point. It should be noted that the detrimental effect from eddy currents flowing in the Titanium coating of the ceramic chambers is also mitigated by slower ramping times. The implementation of these new power supplies therefore allowed to increase the Titanium thickness and reduce the beam induced heating on the ceramic chamber without degrading the injection performance.

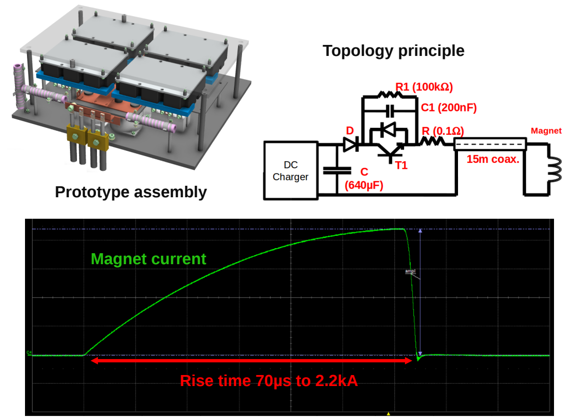

Figure 1: New kicker power supply assembly, topology and pulse shape.

Table 1: Comparison Between the Present Thyratron and the New Design

	Thyratron	New design
Voltage rating	30 kV to 40 kV	600 V
Max. current	2200 A	2200 A
Flat-top	1 µs	No flat-top
Rise/fall time	450 ns / 800 ns	70 µs / 2.2 µs
Pulse-to-pulse jitter	±0.2 %	±0.05 %

Figure 1 shows the new kicker power supplies assembly, topology and pulse shape. The design and assembly are done in-house. 2 prototypes were built and characterized in the laboratory before installation, demonstrating the parameters shown in Table 1 and showing excellent identity between the 2 systems, which is essential to minimize bump non-closure. However, the field experienced by the beam depends also on other parameters such as the magnet geometry and alignment

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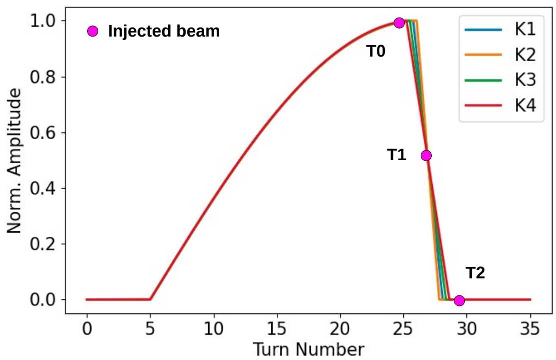

Figure 2: Schematic view of the optimal delay adjustment of the kicker pulses, T0 is the injection turn and T1 and T2 are the 2 subsequent turns.

or the Titanium coating of the ceramic chamber. Beam based adjustments are therefore necessary to optimize the bump closure and minimize injection perturbations.

POWER SUPPLIES COMMISSIONING

The full system including perturbation compensation was commissioned in 4 Machine Development Time (MDT) shifts of 8h organized as follows:

- **16h MDT on June 2021**: tuning of the power supplies and first test with beam
- **8h MDT on September 2021**: fine tuning of the power supplies delays, injection efficiency optimization and horizontal perturbation compensation
- **8h MDT on September 2021**: power supplies calibration, perturbation compensation in both planes, injection in single bunch

The ramp down of the new power supplies is approximately 2.2 µs, the length of a bunch train coming out of the booster is 1 µs and one storage ring turn is approximately 2.8 µs. In this configuration, the kickers field has not entirely vanished when the injected bunch train comes back on the second turn. To ensure that the injected beam sees a closed bump on the second turn and therefore provide optimal injection efficiency, the 4 kickers delays are adjusted such that it arrives at a crossing point. In order to minimize the injection perturbations, this crossing point is set at the half maximum of the pulse. This is illustrated on Fig. 2 where the injected beam crosses the injection point at T0 (injection time), T1 and T2. At these times the four kicker pulses are matched and the injected beam always sees a closed bump, therefore minimizing the injection oscillations and improving injection efficiency. This tuning is done first without beam with fine tuning coming later with beam measurements to find the optimal working point.

With this initial tuning, 60 % injection efficiency was achieved on the first try and quickly improved to 75 % by adjusting the global delay of the 4 kickers and finally 80 % could be obtained by closing the bump on the flat-top which was compatible with user service mode (USM).

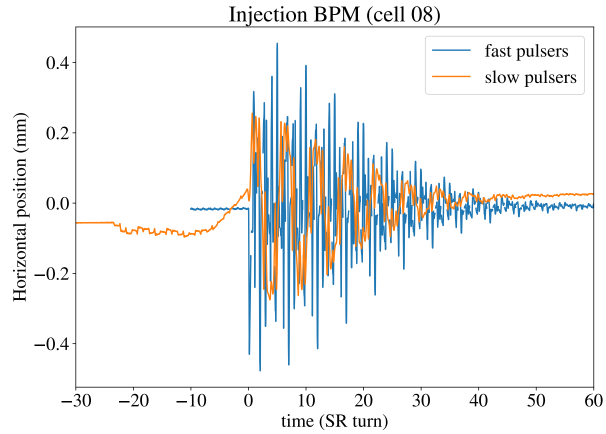

Figure 3: Horizontal injection perturbations with the fast and the slow pulsers. No feed-forward compensation.

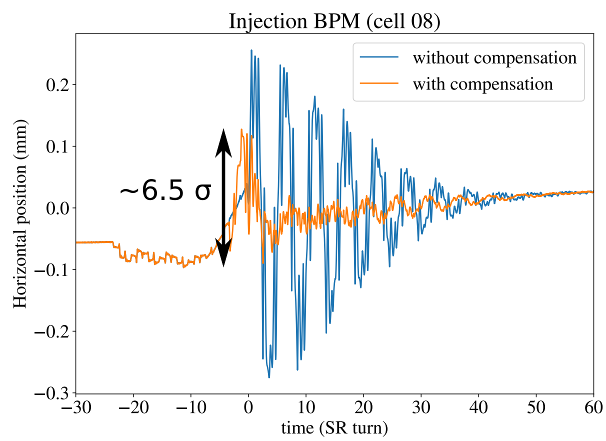

Figure 4: Reduction of the horizontal injection perturbation with the feed-forward system.

Figure 3 shows the measured horizontal injection perturbation for a fully filled storage ring with the slow and the fast pulsers. While the amplitude of the perturbation is not significantly improved it is clearly seen that the frequency of the perturbation is reduced with the slow power supplies.

INJECTION PERTURBATION COMPENSATION

The compensation system consists in a dual-plane wideband dipole magnet, the shakers described in [5], and a pickup capable of measuring the bunches transverse oscillations along the bunch train. The compensation is active only when the bump is pulsing. The amplifiers that drive these correctors are not powerful enough to cancel the perturbation in one pass. It is therefore cancelled in a few turns and has to be fast enough to prevent excessive increase of the beam size and therefore reduction of flux and coherence in the beam lines.

Figure 4 shows the reduction of the perturbation with the feed-forward system. As expected, the first few turns are not

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perfectly corrected and a residual amplitude of 6.5 σ remains. However it is reduced to a fraction of a σ in approximately 5 turns. The main drawback of the slow power supplies is that synchrotron phase errors accumulate along the ramp-up and drive synchrotron oscillations when the bump is removed in a few turns. This introduces additional perturbations for beam lines located in dispersive regions of the ring, typically the bending magnet beam lines. These oscillations could be well compensated by shifting the phase on the RF system when the bump is pulsing. The final implementation and performance for operation are under evaluation. The correction function is calculated during dedicated MDTs and then applied as a fixed feed-forward compensation. Its performance is therefore very sensitive to drifts and random fluctuations such as timing jitters. While there was no sign of significant drifts other than the ones introduced by the injection bump tuning, random fluctuations were observed. Although they are presently not dominating the remaining perturbation, they could represent the lower limit of the system once all other parameters have been fully adjusted.

OPERATION AND FEEDBACK FROM USERS

The storage ring is now operating with the new kicker power supplies and compensations active in USM. The reliability is on par with the old system with some minor control issues in the first months of operation. The injection efficiency remains nevertheless slightly lower that the one provided by the fast pulsers most likely due to imperfections seen by the injected beam on the second turn. This is illustrated in Fig. 5 where the measured injection efficiency in USM is shown for the runs before and after the installation of new kicker power supplies. While with the fast pulsers an injection efficiency of 85 % could be achieved on a regular basis with the new pulsers 80 % efficiency at maximum was delivered but with smaller fluctuations. It should be noted that towards the end of 2021 a degradation of performance is observed. This degradation is also observed on the lifetime and is for now not understood. It does not seem to relate to the installation of the new power supplies.

2 joint MDTs with beam lines were held to evaluate the improvement from the new power supplies and determine whether the residuals are small enough to allow data acquisition across injections. 3 beam lines participated in these measurements, 2 straight section beam lines and one bending magnet beam line. A significant improvement was observed by all beam lines but not sufficient to provide pseudo-transparent injection and it was determined that an additional factor 2 reduction would be required. To achieve this it is planned to adjust the electrical circuits and match the 4 power supplies with better precision and lengthen the ramp-down to further reduce the frequency of the perturbation.

SUMMARY AND OUTLOOK

Injection perturbations have been a major issue since the introduction of top-up operation at ESRF. While transparent

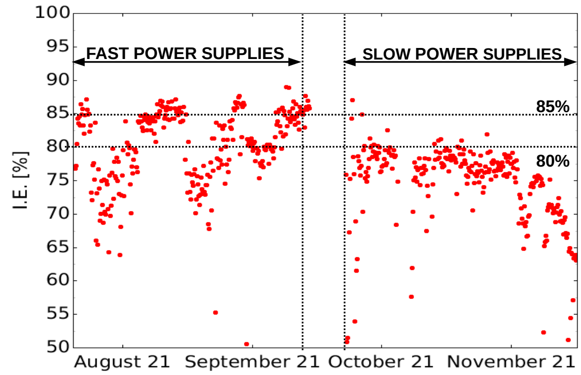

Figure 5: Delivered injection efficiency for the run before and after the installation of the slow power supplies.

injection could be achieved in the old machine, the reduction of the beam size from ESRF-EBS required an order of magnitude improvement. New kicker power supplies with slower ramping rates were used to mitigate the bandwidth limitation of the previous system. These were successfully commissioned and are now in operation at ESRF-EBS. Although the perturbation amplitude was significantly improved, experiments with beam lines indicated than an additional factor 2 improvement would be needed. Most of the room for improvement is on the power supply side either through a better matching of the 4 kickers pulses or an increase of the ramp down time. They will represent small incremental changes and are therefore not guaranteed to provide the necessary factor 2 reduction. Alternatively, new injection schemes involving non-linear kickers as introduced in [6] and later used in operation in [7] are presently evaluated at ESRF [8].

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