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PREPARATION OF THE EBS BEAM COMMISSIONING

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Abstract

In 2020 the ESRF storage ring will be upgraded to a Hybrid Multi Bend Achromat (HMBA) lattice. The commissioning of the new ring will require dedicated tools, either updated from the existing ones or newly developed. Most of the software and procedures were tested on the existing storage ring before its decommissioning. In particular we present experiments on first-turn steering and beam accumulation, check of magnet polarity and calibration, and injection tuning. The use of a control-system simulator proved to be crucial for the debugging of the software and the development of the new control system, as far as beam measurements and manipulations are concerned.

INTRODUCTION

The ESRF storage ring (SR) is currently being upgraded to a Hybrid Multi Bend Achromat (HMBA) lattice [1]. The commissioning of the injectors (linac, transfer lines and booster) will take place in November 2019, following hardware tests [2]. First beam into the SR will be allowed only as December 2, 2019. Strict dose limits are set for the storage ring operation and the full commissioning will have to take place injecting only when strictly necessary. Procedures to inject a single shot from the electron gun to the storage ring have been used in the previous SR and will be applied for the EBS upgrade.

The minimum parameters targeted during commissioning are listed in the Table 1.

Table 1: Minimum parameters to be exceeded during SR commissioning, starting December 2, 2019. MTBF stands for Mean Time Between Failures.

date in 2020:		**01 March**	**24 August**	**Dec.**
Current	mA	50	200	200
MTBF	h	>12	>30	>50
Up-time	%	90	95	97
Inj.Eff.	%	>50	>70	>80
Lifetime	h	>5	>10	>20
Hor. Emit.	pm	<250	<150	~ 135
Ver. Emit.	pm	<50	<20	<10
Stability	σ	<0.2	<0.1	<0.05

Goal of the first days of commissioning will be to obtain first turns in the new storage ring. This is not expected to be possible without orbit steering [3], and could be complicated by wrong cabling and magnetic field calibrations. Also the diagnostics at this stage will need to be synchronized and adjusted for optimum measurements in turn-by-turn (TbT) mode and with single shots from the injectors. To prepare and test the first-turns correction schemes it has then been decided to complete a "simulated commissioning" on the existing SR before its dismantling. This took place in October and November 2018 and has allowed some major software debugging.

Diagnostics

The ESRF storage ring (in 2018) holds 7 Beam Position Monitors (BPMs) per cell, therefore 224 in total (32 cells). Each of these BPMs have identical geometry with the S_x and S_y constants of 15 mm for the classical Delta-over-Sum (DoS) formula [4]. All BPM stations are equipped with Libera-Brilliance electronics and have Turn-by-Turn (TbT) capability. The Tango [5] servers of these devices operate with an anti-smear filter on the raw TbT data buffers coming from the Libera. This is needed since that raw data suffers from time-smearing effects due to a limited bandwidth of that TbT output.

The initial synchronization of all 224 units, needed when switching to TbT-mode, is performed by simply injecting the 1 µs long bunch train (typically 352 bunches) from the Booster Injector into the storage ring (start of cell-4) and then stopping all the electrons by a scraper jaw that is positioned at the end of cell-3. In this manner both the relative synchronization between all BPMs, and the absolute synchronization with the 1 µs beam signal (in the 2.816 µs ring's orbit turn) is conveniently achieved. Once done this synchronization is maintained for any subsequent injection shots and measurements.

The storage ring also holds a total 128 Beam Loss Detectors (BLDs) that are synchronized in a similar way [6]. They also provide their local loss data on TbT rate through their read-out electronics.

The device servers of the BPMs allow the user to select between two algorithms for the positonal calculations, the classical DoS or a set of polynomials. The latter offering the advantage of improved absolute precision for large beam displacements from the center of the BPM block. The BPMs also provide the sum signal (i.e. sum of the 4 button signals) on TbT rate which constitutes a beam intensity measurement, on each BPM. The pre-calibration of the sum signals for all the BPMs can also provide a relative intensity measurement along the machine. This information is in parallel to that of the 128 BLDs.

MEASUREMENTS

The measurement setup consisted in switching the existing ESRF storage ring from operational conditions back to commissioning-like conditions. The following list of settings has been set in the storage ring in order to return the machine to a commissioning-like state:

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1. orbit steerers to zero
2. normal and skew quadrupoles and normal sextupole correctors to zero
3. theoretical main magnets strengths
4. beam position monitor (BPM) measured offsets +0.5 mm random noise
5. 20 BPM disabled randomly in the BPM list
6. injection elements mistuning: septa and transfer line correctors
7. off energy injected beam

These conditions were enforced cumulatively in the above order, reaching an increasingly realistic commissioning-like case. After this, the first-turns correction was successfully used to restore circulating beam and accumulation (RF on) via trajectory steering only.

Trajectory Correction

A standard Singular Value Decompositon (SVD) based trajectory correction algorithm [7] was applied on the measured trajectory to make the beam circulating over one or few turns. The BPMs sum signal was used to locate where the beam loss occurred and the signal was restricted in terms of maximum amplitude in the two planes. Faulty or incoherent BPMs were excluded. Figure 1 shows the filtering of the signal to be corrected.

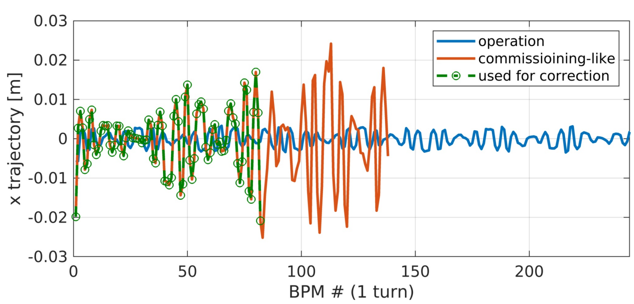

Figure 1: BPM single shot reading for first turn in standard operation (blue), raw trajectory signal for commissioning-like SR (red) and signal used for the trajectory correction (green).

The horizontal trajectory in the first turn has large oscillations due to off-axis injection. The off-axis reference trajectory is the target for the correction in the horizontal plane. An SVD pseudo inversion of the simulated trajectory response matrix is used for the correction of the trajectory. A low number of eigenvectors (10%) is used to correct with all correctors before the last BPM with signal.

Figure 2 shows the BPM noise (standard deviation over 10 consecutive measurements) vs the injected beam current. For trajectory correction the BPM noise shall not be larger than 1.0 mm or the injected current from the booster less than 1 mA. A booster current of 3 mA is the best case for the correction. The minimum observed BPM noise in single-shot TbT is 0.5 mm driven by the injection element (septa and kickers) repeatabilty errors. Figure 2 refers to injected

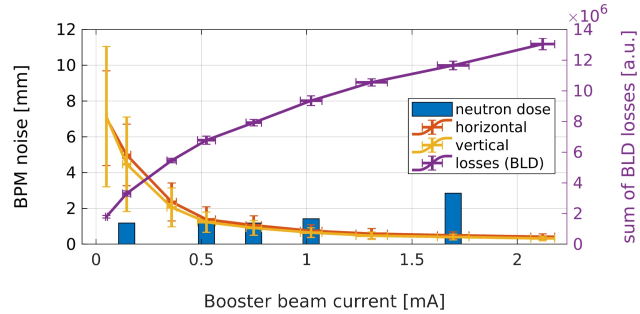

Figure 2: BPM reading error vs injected current.

beam during the first turn. The typical positional resolution of the BPMs in this TbT mode with 1 mA stored beam current circulating in the ring is about 50 µm rms.

Correction Results

An example of correction is shown in Figure 3. Each image shows the sum signal for an acquisition of BPM single-shot TbT data (35 turns). Progressing in the correction, more and more BPMs see signal within one single turn first, and over several turns later. The correction is initially performed over a single turn and then protracted to correct data over 2, 3, 4 and consecutive turns, according to the user choice. The correction tool allows the user to select how to proceed in the correction. No automation is introduced, in view of the large number of unknowns. On the other hand a large number of parameters is proposed to the user to allow further correction: which BPMs and correctors to use, the fraction of correction to apply, the plane, the possibility to keep the correction average to zero, the number of eigenvectors and the algorithm for the correction (SVD, best corrector or Tikhonov regularization).

In all cases starting from case 1 and adding complications up to case 7 first turn was found in few correction iterations (some correction providing signal on more BPMs and some reducing the over all signal amplitude) and beam accumulation was established after correcting several turns (~ 10) and switching on the RF. For case 7 the energy could be moved by less than 1% to avoid wrong triggering of the TbT data acquisition. For case 6 it was confirmed that tuning of injection elements must be done before the steerers in the SR to avoid large steerers strength to compensate for injection tuning errors. This was expected from previous experiments [8].

Calibration and Polarity Errors

An experiment on the detection of wrongly cabled magnets (steerers and quadrupoles) was also performed. A software modification of the control system was added to invert the polarity of a steerer. A script to find steerer polarity errors was executed to detect where the wrong polarity was. The function scans the steerers one by one and compares the measured trajectory response with the theoretical ones. Figure 4 shows the comparison between theoretical trajectory response and the ones obtained with errors and bpm noise.

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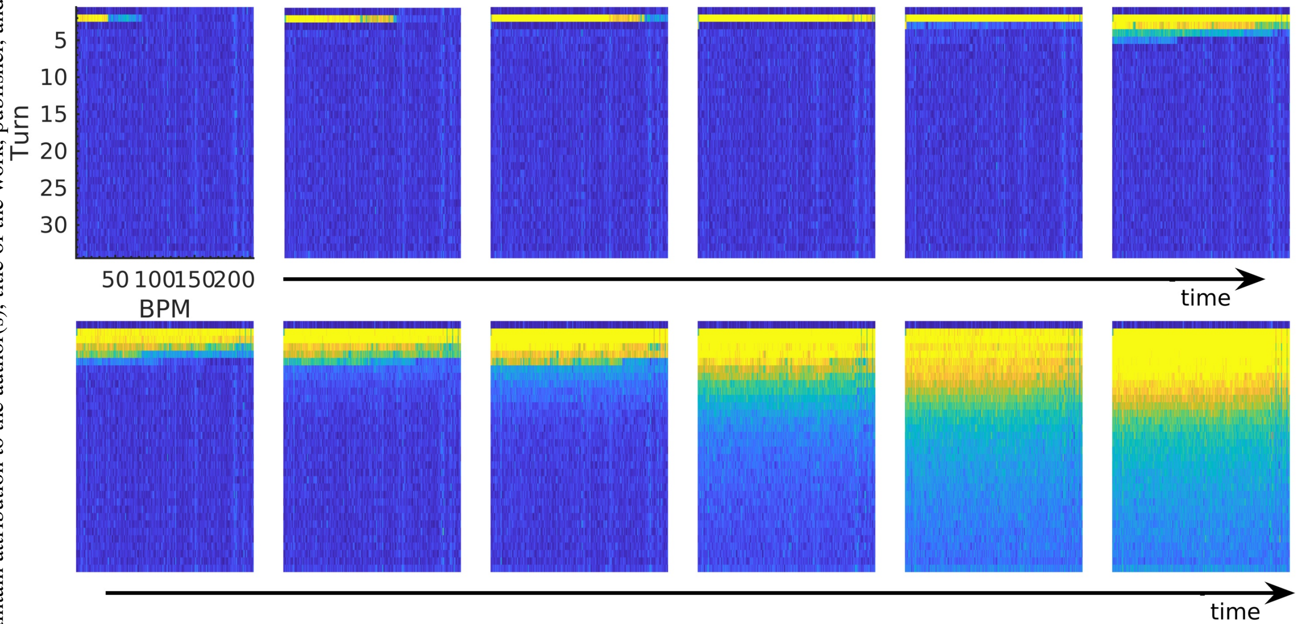

Figure 3: Measured TbT BPMs sum-signal during correction: initial conditions (top left), up to beam accumulation (bottom right, low injection efficiency).

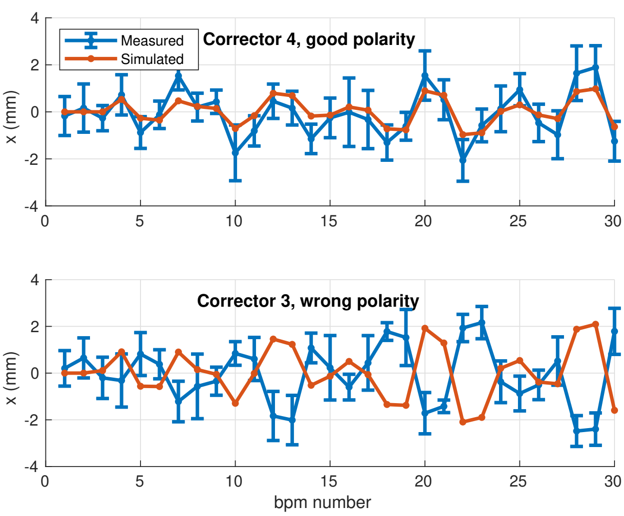

Figure 4: Steerer polarity error detection.

In a second experiment, a quadrupole with independent power supply was turned off and a script was executed to detect its location. The function compares the focusing effect of the quadrupoles with the model by generating a large trajectory displacement inside the magnet and reading the following bpm signal.

Control System Simulator

The software for the first-turns correction has been developed and tested off-line using the EBS control system simulator. This is a full-scale prototype of the Tango control system making use of the Accelerator Toolbox [9] lattice model to obtain data to be used by simulated devices for BPM readings, tune, orbit, emittances, etc.. The simulated devices are identical to the real ones in terms of attributes names and format. When the magnets strengths are modified in the simulator devices, the master simulator device modifies accordingly the strengths in the lattice model (with errors), triggering new data for all the relevant quantities (tunes, orbit, emittances,...). This allows to use the real device names and formats acting on the magnets strengths as if in the control room. To switch to operation, it is sufficient to switch the Tango host name to the operational one, while to change accelerator it is sufficient to provide the correct attribute names. The same methods where used for the ESRF SR (measurement only), ESRF booster (measurement only) and EBS SR (development in simulator). The software used for the first-turns correction and calibration/polarity errors detection is developed in matlab [10]. A single file defines all the parameters specific to the accelerator. The strengths are modified from matlab using tango-matlab binding methods [11].

CONCLUSIONS

For the ESRF storage ring upgrade to HMBA optics (and for most planned light source upgrade projects), first turns are not expected to be easily achieved. In order to test the tools developed for the determination of first turns, the last machine-dedicated beam times of the 3rd generation ESRF SR have been devoted to the simulation of conditions progressively closer to those of a new SR commissioning. In all tested cases it was possible to establish first turns thanks to the acquisition of single shot TbT data form the BPM and BLD systems and to the anticipated preparation of the software via the EBS control system simulator. It was also possible to detect a turned-off quadrupole and a mis-wired corrector.

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