TESTS OF WAKEFIELD-FREE STEERING AT ATF2

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Abstract

Charge-dependent effects on the orbit and on the beam size affect the performance of the Accelerator Test Facility (ATF2) in a non-negligible way. Until now small beam sizes have only been achieved running with a beam charge significantly smaller than the nominal value. These detrimental effects on the beam have been attributed to wakefields, in the cavity BPMs, in the multi-Optical Transition Radiation (OTR) systems as well as in other components of the beamline. The successful tests of a Wakefield-free Steering (WFS) algorithm at FACET have encouraged performing tests of the same correction scheme at ATF2. The performance of the algorithm has been simulated in detail, including several realistic imperfection scenarios, including charge-dependent BPMs resolution, and incoming injection error and position jitters, which are described in this paper. Tests of Dispersion-free Steering (DFS) and of WFS have been performed at ATF2 during December 2014. The results are discussed here.

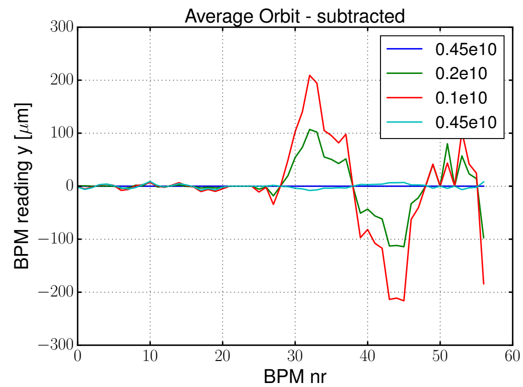

Figure 1: Example of a current-dependent beam orbit. The orbits are displayed relative to charge 4.5×10^9 particles per bunch.

INTRODUCTION

ATF2 [1] is a scaled demonstrator for the final focus system of future linear lepton colliders, the so-called local chromaticity correction scheme [2]. ATF2 is built as an extension of the ATF complex at KEK (Japan). The beam from a low emittance damping ring is extracted into the ATF2 beamline.

Effects depending on the beam current affecting the orbit and especially the beam-size, have repeatedly been reported for the ATF2, preventing it from achieving the target nominal beam-size at the focal point and from running at its fullest nominal beam current of 10^{10} electrons per bunch [3, 4]. Figure 1 shows the average beam orbit for different intensities with respect to the orbit with a bunch charge of 4.5×10^9 particles, as it was measured in April 2013. A beam orbit that changes with the bunch charge can be symptom of the presence of strong wakefields induced by some beamline components.

Techniques such as Dispersion-free steering and Wakefield-free steering have proven to be effective in reducing dispersive and wakefield effects on the orbit, and in most of the cases also managed to significantly reduce the emittance growth associated with such effects [5, 6]. These successes motivated the tests we are reporting about in this paper.

SIMULATION

The extraction line of the ATF2 was simulated using the code PLACET [7]. Wakefield effects were added at the cavity BPMs according to the calculations performed in [4]. Several static and dynamic imperfections were considered in the simulation: element misalignment, BPM resolution, and time-dependent effects such as pulse-to-pulse random variations in beam energy, position, and angle at injection. These jittering quantities were meant to assess stability and robustness of the algorithm in a realistic dynamic environment. 100 misalignment seeds were simulated with a RMS misalignment for magnets and BPMs of 100 μm. 55 BPMs were used for the steering, together with 11 correctors in both the vertical and horizontal plane. WFS was applied in 3 iterations with weights of $\beta = 5$ and $\omega = 26$. An explanation of the function of β and ω, as well as details on the implementation of WFS, can be found in [6]. The fact that the resolution of the BPMs drops with a lower charge was taken into account. Two beam charges of 8×10^9 and 5×10^9 particles per bunch were chosen as test beams for WFS, since these two values of the charge don't compromise excessively the BPM resolution, see Fig. 2, which shows the measured BPM resolution of a cavity BPM typical of the ATF2 [8].

The results of the simulations are shown in Fig. 3, where the final emittance after correction is plotted as a function of the weight parameter ω, for DFS and for WFS in combination with DFS respectively. Figure 4 shows the profile of the relative emittance growth along the beamline. Each of these results is the average of the 100 random seeds previously mentioned.

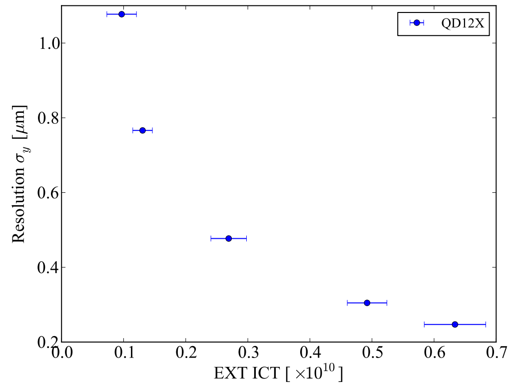

Figure 2: Resolution of MQD12X, a 20 dB attenuated cavity BPM, as a function of beam charge.

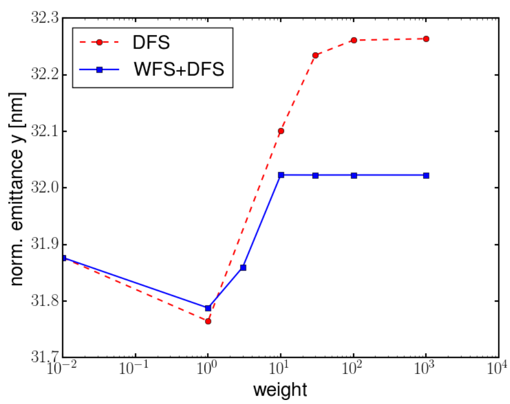

Figure 3: Simulated weight scan: vertical emittance after BBA correction as a function of the weight parameter, ω. The uncorrected emittance is several orders of magnitude larger, and it's not shown in the plot.

EXPERIMENTAL SETUP

Given the exploratory nature of this study (it was our first test at ATF2), we focused on the extraction line, excluding the final focus optics. This choice aimed at avoiding sections featuring non-linear elements such as sextupoles, which inherently complicate the convergence of any optimization procedure, including DFS and WFS. Applying beam based alignment (BBA) to the final focus might be the objective of future tests. Our test was performed in several steps: (1) measure the orbit transfer response matrix and verify its correctness via bump excitation; (2) measure the dispersion transfer response matrix and verify its correctness; (3) apply dispersion-free correction and measure a reduced residual dispersion; (4) measure the charge-dependent transfer response matrix; (5) apply WFS and verify the reduced impact of the wakefields on the orbit. Due to some technical difficulties we couldn't measure the emittance. Therefore, the only observable to quantify the effectiveness of our BBA algorithms was the orbit itself.

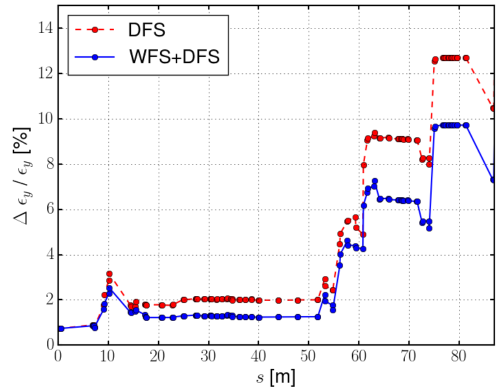

Figure 4: Simulated emittance growth along the ATF2 extraction line lattice after BBA.

The BPM resolution for the cavity BPMs was below the micrometers level, whereas for the strip-line BPMS was of the order of few micrometers.

RESULTS OF THE TESTS

The response matrix is measured by exciting each corrector several times, and by recording the effect of each excitation on the BPMs. A sophisticated set of algorithms is then used to fit the response matrix in optimal manner, which included data filtering, using Singular-Value Decomposition (SVD) to remove the noise, as well as specific solutions to reduce the impact of slow drifts, which we experienced as severely affecting the machine. Once the trajectory response matrix was measured, a bump was excited in order to verify its goodness. The result of this test is visible in Fig. 5, where the measured orbit is plotted against the expected one (as anticipated by the measured response). In the plot the vertical scale is micrometers, showing that the agreement between expected and measured orbits is well within the BPM resolution of few micrometers. The disagreement noticeable in BPMs #2 and #3 is likely due to energy fluctuations of the incoming beam, in fact those BPMs are located in a region of large dispersion, which is needed to close the dispersion of the extraction region.

Matched-dispersion Steering

The application of Dispersion-free steering needed to take into account the fact that there exists a design dispersion at the beginning of the extraction line. Having a design dispersion implies that the steering algorithm must aim at finding a "matched-dispersion", rather than a dispersion-free, trajectory. For this reason we call this implementation of DFS: Matched-dispersion steering (MDS). MDS was applied measuring the dispersion via a change of the damping ring revolution frequency, by +2 kHz. This method is routinely used ATF2 to perform a dispersion measurement and

ISBN 978-3-95450-168-7

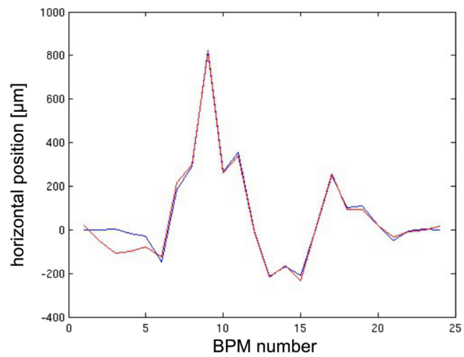

Figure 5: An orbit bump was excited to test the goodness of the optics measurement: in blue the target horizontal orbit and, in red the measured one.

has the effect of reducing the beam energy by 4 MeV from the nominal energy of 1.3 GeV, which results in a relative energy difference $dE/E = -0.15\%$. Figure 6 shows the result of MDS.

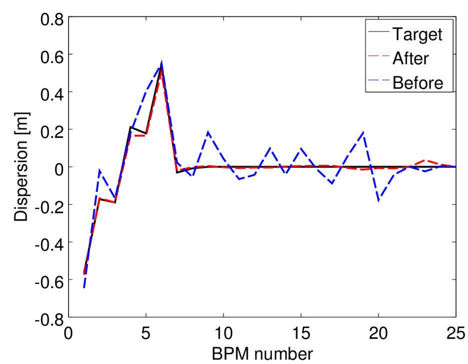

Figure 6: Horizontal dispersion before and after Matched-dispersion steering (MDS), compared to the design dispersion.

Wakefield-free Steering

The application of WFS is meant to reduce the impact of charge-dependent effects on the orbit. The orbit deformation due to a different bunch charge was measured comparing the orbits of two charge states: 8×10^9 and 6×10^9. These numbers are well within the BPM resolution acceptance displayed in Fig. 2. Differently from what was measured in April 2013, shown in Fig. 1, only a modest impact on the orbit was observed. For this reason we moved vertically both the reference cavity and a collimator closer to the beam, in order to excite more wakefield. In this configuration we could measure a strong wakefield effect, that WFS successfully removed from the orbit. Figure 7 shows the (square root of the) figure of merit of WFS, χ^2, as a function of the number of correction iterations applied. For the vertical axis χ^2 reads

$$\chi^2 = \sum_{i \in \text{selected BPMs}} \left(y_{i,q_1} - y_{i,q_2}\right)^2 \quad (1)$$

(it is analogous in the horizontal direction). In Eq. (1) y_{i,q_1} and y_{i,q_2} indicate the BPM readings for the two charge states, 6×10^9 and 8×10^9 electrons per bunch. A decreasing χ means that the two orbits are steered toward each-other, effectively converging to a new orbit that zeroes any charge-dependent effects. Note that χ should not be expected to converge to zero as the beam jitter and BPM resolution become dominant when the two orbits coincide.

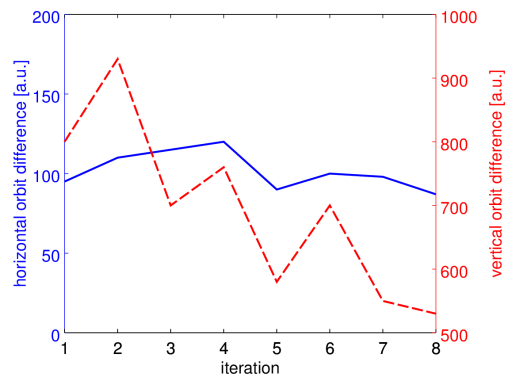

Figure 7: Data convergence plot: the figure of merit χ in Eq. (1) for the horizontal (blue) and vertical (red) axes. The wakefield effect gets reduced only in the vertical direction, the only direction where in fact it was excited.

CONCLUSIONS

Beam-based alignment was successfully applied to the extraction line of the ATF2 test facility. Dispersion-free steering, in this case Matched-dispersion steering, and Wakefield-free steering were applied finding in both cases an orbit free of unwanted dispersion and wakefield effects. As the tests were performed only in the extraction line, excluding the final focus, the direct impact of DFS and WFS on the beam size at the IP was not assessed. More tests of BBA inclusive of final focus optics are foreseen in the near future.

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ISBN 978-3-95450-168-7