DESIGN AND PERFORMANCE OF INTRA-TRAIN FEEDBACK SYSTEMS AT ATF2*

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Abstract

The major goals of the final focus test beam line facility ATF2 are to provide electron beams with a few tens of nanometer beam sizes and beam stability control at the nanometer level. In order to achieve such a level of stability beam-based feedback systems are necessary at different timescales to correct static and dynamic effects. In particular, we present the design of intra-train feedback systems to correct the impact of fast jitter sources. We study a bunch-to-bunch feedback system installed in the extraction line to combat the ring extraction transverse jitters. In addition, we design a bunch-to-bunch feedback system at the interaction point for correction of position jitter due to the fast vibration of the magnets in the final focus. Optimum feedback software algorithms are discussed and simulation results are presented.

INTRODUCTION

The final focus test beam line facility ATF2 [1], currently under commissioning at KEK (Japan), will provide an unique experimental bed to investigate the performance of a compact final focus optics such as designed for the future linear colliders, e.g. the International Linear Collider (ILC) and the Compact Linear Collider (CLIC). The two major goals for the ATF2 facility are (I) the achievement of 30-40 nm beam sizes, and (II) the control of beam position down to 2 nm level ($\lesssim 5$ % of the rms beam size σ_y^*), which will require a stability control better than 1 μm at the ATF2 final focus entrance. In multi-bunch mode operation bunch-to-bunch feedback (FB) systems will be essential to achieve the required beam stability. In this report we describe the following ongoing studies:

- Performance evaluation by means of computer simulations of a beam-based intra-train FB located in the ATF2 extraction (EXT) line.
- Design and simulation of a beam-based intra-train FB at the ATF2 Interaction Point (IP). The aim is to correct residual beam jitter due mainly to the vibration of the magnets in the Final Focus System (FFS), and to achieve thus a stability control better than ~ 5 nm.

Simulation results are presented in order to understand the beam dynamics in the ATF2 beam line and assure an optimal performance of the FB systems. Furthermore, we discuss the FB system integration in terms of joint simulation of the different beam orbit steering and tuning procedures.

INTRA-TRAIN FB IN THE EXT LINE

The beam-based intra-train FB systems for linear colliders are based on the measurement of the incoming trajectories of the early bunches in the electron or positron trains. This information is then used as the input to the feedback for steering the later bunches.

In the context of the Feedback On Nano–second Timescales (FONT) project [2], an intra-train feedback system has been designed and installed in the extraction line of ATF2. This system is described in Ref. [3]. The main goals are:

- The development and test of the necessary technology for the intra-train feedback systems of future linear colliders.
- Beam position stability control better than 1 μm rms at the ATF2 final focus entrance.

The key components of the FONT system at ATF2 are: a pair of stripline kickers, located with $\pi/2$ phase advance in between them, for applying beam position and angle correction in the vertical phase space; three stripline Beam Position Monitors (BPMs) for registering the beam orbit; and additional electronics components, such as FB circuits, fast amplifiers and data acquisition devices. Details of the hardware components are given elsewhere [2]. This system has been adapted to the ATF2 requirements with BPM resolution of ≈ 1 μm and 140 ns latency budget. Fig. 1 illustrates possible FB loops for beam position and angle correction.

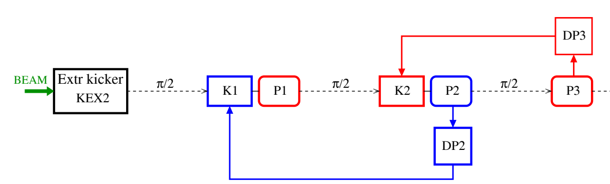

Figure 1: Scheme of an intra-train feedback system for the ATF2 EXT line, downstream of the second extraction kicker KEX2. K1 and K2 denote kickers; P1, P2 and P3 denote BPMs; and DP2 and DP3 digital processors.

Simulation Procedure and Results

In order to study the accuracy of the orbit correction using the FONT elements, we have used the so-called Singular Value Decomposition (SVD) algorithm [4] implemented in the tracking code Placet-octave [5]. The SVD

* This work is supported by the Commission of the European Communities under the 6^{th} Framework Programme "Structuring the European Research Area", contract number RIDS-011899.

algorithms are easy to implement and very robust. Commonly used in orbit steering correction, it can also be used for fast FB simulation, selecting appropriate BPMs and correctors (in our case the FONT elements). Here we consider the correction of y and y' beam offsets.

For the simulations we have considered 40% σ_y beam position jitter at the entrance of the EXT line, and the following errors for the FONT instruments: 1 μm BPM resolution and 0.5 $\%$ kicker field imperfection.

In our simulation model we have also added 30 μm position jitter for all the ATF2 quadrupoles. In a second step, beam-based alignment (BBA) has been applied with 11 steering magnets and 50 BPMs along the lattice (EXT line + FFS) to minimise $\sqrt{\sigma_x^* \sigma_y^*}$ at the IP applying the Simplex algorithm. After BBA, dynamic imperfections have been included, i.e. the so-called model K of ground motion [7] has been applied during 10 s before macroparticle tracking along the ATF2 lattice and before FB orbit correction. Finally, FB correction is carried out. Fig. 2 compares the residual vertical position jitter at the IP for 100 shots with (Fig. 2, left) and without (Fig. 2, right) FB correction. After FB correction the standard deviation of the offset distribution has been reduced by a factor 2.

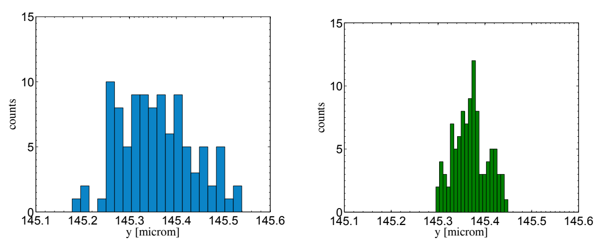

Figure 2: Beam position jitter distribution at the IP, without correction (left) and with FB correction (right).

In multi-bunch mode operation the FB correction is done as follows: measurements of the position and angle offset of the first bunch in a train; knowing the response matrix, the SVD method is applied to correct the rest of the bunches of the train. Alternatively, the FB system can be implemented using a classical Proportional-Integral (PI) control loop [8] (see Fig. 1 for possible combinations of kicker-BPM loops).

It is important to remark that the intra-train FB system efficiently works for bunch-to-bunch position correlation better than 60%. For uncorrelated bunch-to-bunch jitter, the FB system might even add more jitter, which would not be desired.

INTRA-TRAIN FB AT IP

An intra-train FB system in the EXT line would correct beam position and angle jitter of extracted beams to reach 1 μm rms level stability at the FFS entrance. However, we should also be concerned about beam trajectory errors in the FFS. Inter-train jitter due to correlated ground motion ($\lesssim$ 10 Hz) can be combated by means of inter-train FB systems [9]. Nevertheless, fast magnet vibration and other imperfections in the FFS could introduce additional beam jitter. To combat this an intra-train FB system located at the IP (upstream of the dump) could be used.

We have simulated an intra-train FB system at the IP of ATF2. A schematic of this system is shown in Fig. 3. In this case a cavity IP-BPM with nanometer level resolution [10] can be used to measure the input position signal at the IP. An upstream stripline kicker, located approximately at 1 m from the IP-BPM, gives the necessary correction angle.

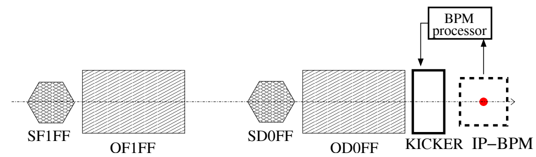

Figure 3: Schematic of a beam-based intra-train FB system at the IP of ATF2.

Simulation Procedure and Results

In this case, for the simulations we have used a PI algorithm to correct beam position, with 2 nm IP-BPM resolution and introducing 0.5% kicker field imperfection. Here we have studied the performance of the FB system in terms of correcting beam position offset caused by ground motion (model K) and by vertical position jitter of the FD quadrupoles.

For example, Fig. 4 compares the bunch position for a train of 20 bunches with and without IP-FB correction. Here 10 s of ground motion (K) have previously been applied. The position is well corrected for the second bunch and subsequent bunches. The BPM resolution imposes the main restriction on the accuracy of the correction.

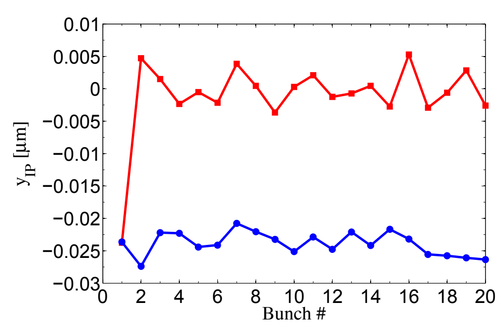

Figure 4: Example of vertical offset correction by an IP-FB system for operation with 20 bunches in ATF2. The blue line shows the vertical bunch position at the IP without IP-FB correction. The red line shows the bunch position at the IP with IP-FB correction.

Another exercise has been the test of the FB system to correct beam jitter at the IP due to vertical position jitter of the final doublet magnets. For example, FD quadrupole jitter in the interval $[0, 30]$ μm has been scanned (1 random seed per jitter). The result is shown in Fig. 5. The IP-FB system steers the beam position offset into nominal value for the third bunch. For instance, for an input of 30 μm vertical position error of the FD magnets, the response of the kicker is ≈ 25 μrad to steer the bunch position into nominal vertical position at IP. We have also studied the FB system performance for operation with three bunches. Fig 6 shows the vertical bunch position at the IP versus y jitter of the FD magnets. Each point represents an average over 100 simulated machines. The error bars correspond to the standard error $\sigma_{\mathrm{IP}}/\sqrt{100}$, with σ_{IP} the standard deviation of bunch position distributions at the IP for the 100 simulated machines. We can see that the position of the third bunch is totally corrected.

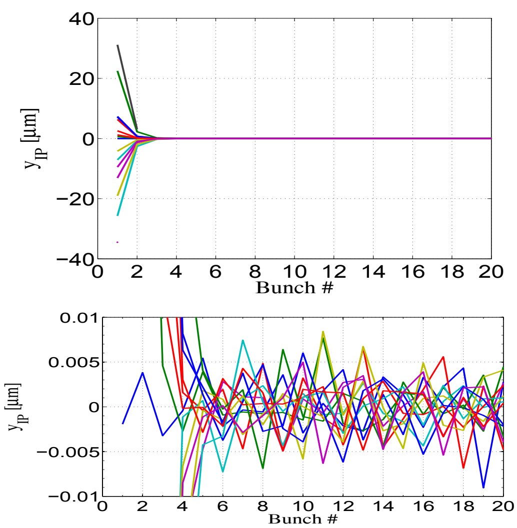

Figure 5: IP vertical bunch position correction by the IP-FB system for several vertical position jitters of the FD magnets in the range $[0, 30]$ μm. On the bottom plot the ordinate scale has been reduced.

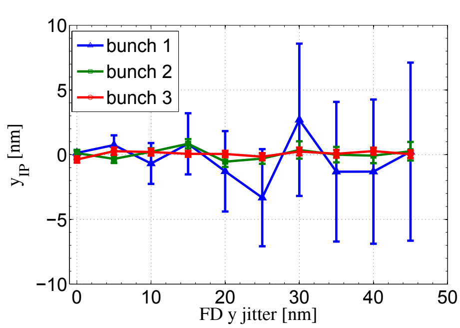

Figure 6: IP bunch position versus vertical position jitter of the FD magnets for operation with three bunches in ATF2, applying IP-FB correction.

FB INTEGRATION

In order to achieve the desired 5% σ_y^* level stability, a combination of BBA methods, orbit steering techniques (inter-train FB in EXT line and FFS) [9], fast intra-train FB systems (in EXT line and IP) will be necessary. Therefore, it is important to characterise the joint operation of the different feedback systems at different timescales. Here we propose the following tentative guidelines for integrated simulations:

- Element misalignment with "standard" errors (G. White's specifications [6]).
- Application of BBA. For example, using the steering corrector magnets and the BPMs along the EXT line and FFS in order to minimise the beam spot size at the IP.
- x-y coupling and dispersion corrections in the EXT line and FFS.
- Addition of beam jitter due to dynamic imperfections, e.g. ground motion. Application of pulse-to-pulse FB system in the EXT line and in the FFS [9].
- Joint operation of bunch-to-bunch FB systems (for multi-bunch operation mode): (I) measurement of position and angle offset of the first bunch (pilot bunch); (II) the EXT fast FB system (FONT) corrects position and angle of the 2nd bunch; (III) then the IP fast FB system uses the 2nd bunch signal as reference for correction of the residual jitter of the 3rd bunch at the IP.

SUMMARY AND OUTLOOK

We have presented the status of the simulations of beam-based intra-train feedback systems at ATF2. Two bunch-to-bunch FB systems are evaluated: a fast FB system located in the EXT line to combat the ring extraction transverse jitters during multi-bunch mode operation, and a fast FB system at the IP to reduce residual beam position jitter.

It is necessary to remark that a fast FB in the EXT line is currently under commissioning at ATF2 in the framework of the Feedback On Nano–second Timescales (FONT) collaboration [2].

Ongoing studies are the joint operation of feedback systems on different timescales, and benchmarking with the results from other software algorithms.

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