SIMULATION STUDY OF INTRA-TRAIN FEEDBACK SYSTEMS FOR NANOMETRE BEAM STABILISATION AT ATF2*

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Abstract

The commissioning of the ATF2 final focus test beam line facility is currently progressing towards the achievement of its first goal: to demonstrate a transverse beam size of about 40 nm at the focal point. In parallel, studies and R&D activities have already started towards the second goal of ATF2, which is the demonstration of nanometre level beam orbit stabilisation. These two goals are important to achieve the luminosity required at future linear colliders. Beam-based intra-train feedback systems will play a crucial role in the stabilisation of multi-bunch trains at such facilities. In this paper we present the design and simulation results of beam-based intra-train feedback systems at the ATF2: one system located in the extraction line at the entrance to the final focus, and another at the interaction point. The requirements and limitations of these systems are also discussed.

INTRODUCTION

The commissioning of the ATF2 final focus test beam line facility [1] is currently progressing towards the achievement of transverse beam sizes of about 40 nm at the focal point. On the other hand, R&D activities have already started to achieve the second ATF2 goal, i.e., the control of the beam position at the level of 5% of the RMS beam size σ_y^*. Future milestones at ATF2 during the years 2011 and 2012 are the development and commissioning of the necessary beam-based intra-train feedback (FB) technology and the demonstration of the required beam stabilisation in multi-bunch train operation.

Two beam-based intra-train FB systems are foreseen to contribute to the ATF2 second goal: a FB system installed in the extraction line from the damping ring, and one FB system at the IP. Fig. 1 shows a schematic of the ATF-ATF2 accelerator complex, indicating the position of the two intra-train FB systems.

In this paper, by means of computer simulations we investigate the feasibility of the required beam stability by using these two intra-train FB systems.

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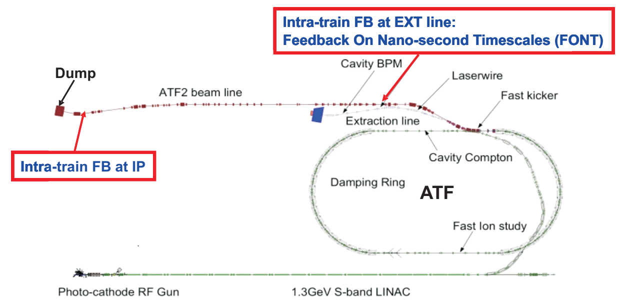

Figure 1: ATF-ATF2 test beam facility layout.

THE INTRA-TRAIN FB SYSTEM IN THE ATF EXTRACTION LINE

In the context of the Feedback On Nano–second Timescales (FONT) project [2, 3, 4], an intra-train feedback system has been designed and installed in the extraction line of ATF2 (see Fig. 2). Its function is to reduce the incoming pulse-to-pulse jitter (jitter that is correlated between bunches) in order to control the beam position stability better than 1 μm RMS at the ATF2 final focus entrance.

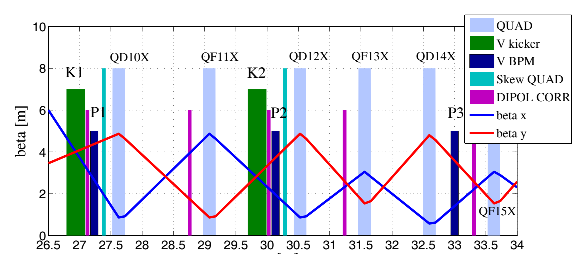

Figure 2: Schematic layout of the extraction line of the ATF2 optics where the FONT elements are located: FONT kickers denoted as K1 and K2, and FONT BPMs P1, P2 and P3. The transverse betatron functions are also represented.

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 electronic components, such as FB circuits, fast amplifiers and data acquisition devices. Details of the hardware components are given elsewhere [3]. This system has been adapted to the ATF2 requirements with BPM resolution $\lesssim 1$ μm and 140 ns total latency budget.

An important characteristic of the FONT system at ATF2 is its flexible operation, allowing a variety of FB algorithms. The control FB loops (see Fig. 3) are based on a single FB digital board (FONT5 generation [3]), which allows simultaneous and coupled y and y' corrections or, on the other hand, the configuration of two independent loops for y and y' corrections separately. In addition, this system can be carried over to feed-forward.

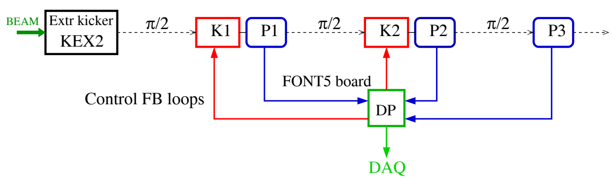

Figure 3: Scheme to illustrate the FONT control loops at ATF2 using one single FB digital processor (FONT5 board). As indicated, this system is located downstream of the second extraction kicker KEX2.

Montecarlo tracking simulations along the ATF2 beamline have been performed considering a BPM resolution of 0.35 μm in order to study the FB performance and compare with real data (from measurements during the ATF2 run period on April 2010). Fig. 4 compares the simulation result with a sample of real FONT data for 1000 pulses (3 bunches/pulse). A remarkable agreement has been obtained between simulation and real measurement data. After applying the FB correction, the vertical position jitter is approximately reduced by a factor 5 for the second and third bunches.

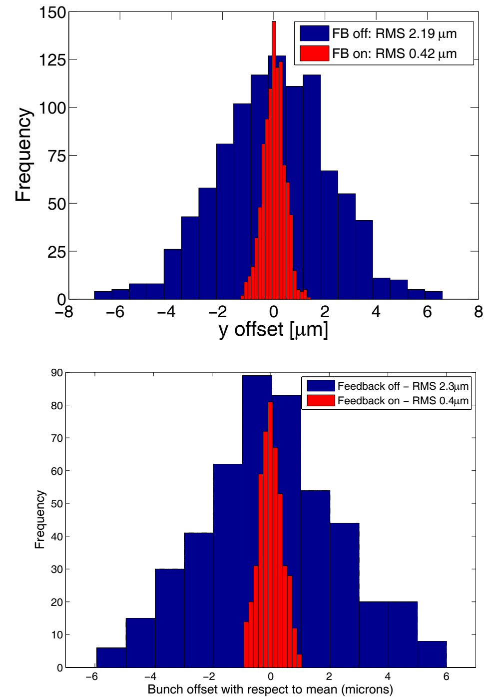

Figure 4: Second bunch position jitter at BPM P2 with and without FB correction. Top: simulation result. Bottom: experimental data from the ATF2 FONT shift on 16th April 2010.

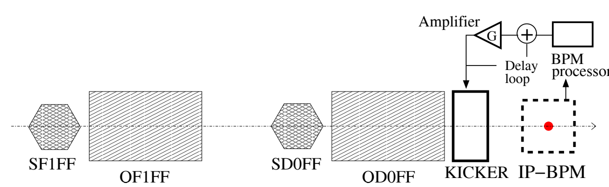

Figure 5: Schematic of the ATF2 IP-FB system.

THE ATF2 INTRA-TRAIN FB AT THE IP

In order to counteract the beam position jitter at the IP caused by dynamic imperfections in the final focus system, e.g., the vibration of the final doublet quadrupoles, a beam based intra-train FB system is foreseen to be located at the IP (see Fig. 5). This FB system will be essential to demonstrate the required nanometre beam stability level. The key components of this system are one stripline kicker, located just downstream of the final quadrupole QD0FF, and one high precision cavity type BPM at the IP (low-Q IP-BPM). A R&D project is taken place for the development and optimisation of cavity IP-BPMs with ~nm resolution; up-to-date resolutions of ≈ 9 nm has been achieved [5]. Further R&D activity is necessary to improve this resolution.

Bunch-to-Bunch Jitter Tolerance

To be effective, intra-train FB corrections require high bunch-to-bunch transverse position correlation, i.e., as small bunch-to-bunch jitter as possible. By simulation using a classical proportional control loop, we have evaluated the bunch-to-bunch jitter tolerance. We have assumed 2 nm IP-BPM resolution. As input errors we have considered a set of 20 different pulse offsets in the range [0,100] nm. Each pulse containing 3 bunches. Fig. 6 shows the RMS vertical position offset (Δy_{IP}) of the third bunch after FB correction. In this figure each point represents the average over all the simulated offset errors and over 100 pulses/offset. We can see that for good intra-train FB correction, with RMS $\Delta y_{IP} \approx 5\%\ \sigma_y^* = 2$ nm, the bunch-to-bunch jitter should be $\lesssim 0.4$ nm, which means practically perfect bunch-to-bunch correlation. This imposes tight tolerances to the extraction kicker errors in multi-bunch train operation. If we perform the backward propagation $\vec{y}_{EXT} = \mathbf{R}_{y,y'}^{-1}\vec{y}_{IP}$, with $\vec{y}_{EXT} = (y, y')_{EXT}$ the vertical beam position and angle at the exit of the extraction kicker and $\vec{y}_{IP} = (y, y')_{IP}$ at the IP, and $\mathbf{R}_{y,y'}$ the 2×2 linear transfer matrix (for the vertical phase space) from the exit of the extraction kicker to the IP, 0.4 nm IP bunch-to-bunch jitter results in 12 nm bunch-to-bunch jitter at extraction. Here we do not have taken into account possible x-y coupling effects. A more complete study, considering x-y coupling and different machine imperfections, has to be done.

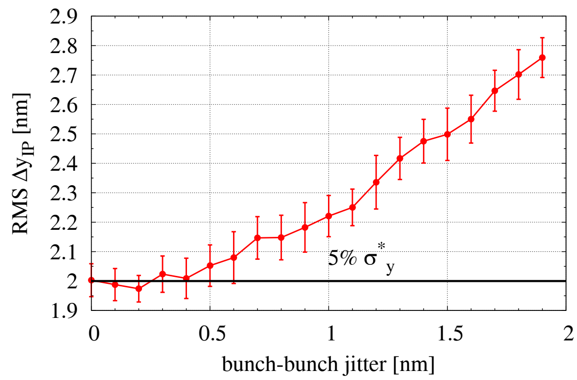

Figure 6: Third bunch RMS vertical offset at the IP versus bunch-to-bunch position jitter.

Final Doublet Position Jitter

The vibration of the final doublet (FD) quadrupoles is one of the main sources of beam jitter at the IP. The vertical displacement of these quadrupoles causes roughly the same beam position offset at the interaction point. The IP beam-based intra-train FB system can be considered as the last line of defence against such a jitter. Fig. 7 shows the RMS bunch displacement at the IP versus FD vertical position jitter. A three-bunch train operation has been considered in this simulation. The IP intra-train FB system corrects the second and third bunches. Notice that the third bunch is well corrected for a wide range of FD jitters: RMS $\Delta y_{IP} \lesssim$ 5 nm for FD vertical jitter $\lesssim$ 100 nm. In this way, the IP intra-train FB system can significantly contribute to relax the FD jitter tolerance.

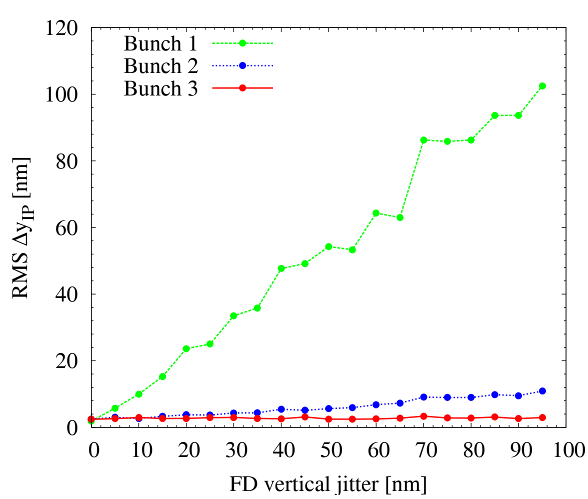

Figure 7: RMS vertical offset at the IP for each bunch in the train versus the final doublet position jitter.

DISCUSSION

The two beam-based FB systems described in this paper will play a crucial role in the achievement of the ATF2 second goal. This will be very important to demonstrate the nanometre level beam stability which is required at the IP of the future linear colliders in order to achieve their design luminosities. Simulation results have shown that, in principle, the ATF2 goal of 5% σ_y^* multi-bunch train stabilisation is feasible with a combination of two intra-train FB systems. Although this poses important technological challenges.

The FONT group [3] has recently succeeded in measuring and correcting beam jitter (in multi-bunch operation) with BPM resolution below 1 μm in the ATF extraction line. On the other hand, in the case of the IP-FB system the instrumentation noise is constrained by very tight tolerances. The desired 2 nm IP-BPM resolution poses a serious challenge. Further R&D efforts have to be done in order to reduce the IP-BPM resolution below 9 nm.

Another important issue of concern is the bunch-to-bunch jitter. To deliver a good FB response and then efficiently to correct the consecutive bunches in a train, the bunches must be correlated, i.e, the bunch-to-bunch jitter must be very small. We have evaluated a tolerable vertical bunch-to-bunch jitter $\lesssim 0.4$ nm at the IP. This imposes a tolerable vertical bunch-to-bunch jitter $\lesssim$ 12 nm at the extraction from the damping ring.

We have also simulated the IP-FB system performance in terms of correcting vertical beam displacements due to FD vertical position jitter, showing that an intra-train IP-FB system can significantly contribute to relax the FD vibration tolerance, and therefore it can help to relax the mechanical stabilisation requirements of the FD.

For the joint operation of both intra-train FB systems one may adopt the following strategy: using the 1st bunch as a pilot, the FB system in the extraction line can correct the 2nd and 3rd bunches; then, using a reference orbit measured from the 2nd bunch, the IP-FB system can correct the 3rd bunch position. This is extensible to multi-bunch operation for more than 3 bunches.

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