STUDY OF TRANSVERSE PULSE-TO-PULSE ORBIT JITTER AT THE KEK ACCELERATOR TEST FACILITY 2 (ATF2)

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Abstract

For future linear colliders the precise control and mitigation of pulse-to-pulse orbit jitter will be very important to achieve the required luminosity. Diagnostic techniques for the orbit jitter measurement and correction for multi-bunch operation are being addressed at the KEK Accelerator Test Facility 2 (ATF2). In this paper we present recent studies on the vertical jitter propagation through the ATF2 extraction line and final focus system. For these studies the vertical pulse-to-pulse position and angle jitter have been measured using the available stripline beam position monitors in the beamline. The cases with and without intra-train orbit feedback correction in the ATF2 extraction line are compared.

INTRODUCTION

The ATF2 final focus test beam facility [1] is the perfect testbed for diagnostic instruments and orbit control techniques to be used in the Beam Delivery System (BDS) of the future linear colliders. The ATF2 is currently progressing towards the achievement of transverse beam sizes of about 40 nm at the Interaction Point (IP). This is important to demonstrate the feasibility to produce the required beam spot size at the IP of the International Linear Collider (ILC) [2]. At the same time, R&D activities have also started to achieve the second ATF2 goal, i.e. the control of pulse-to-pulse orbit jitter to the nanometre level precision at the IP in multi-bunch operation. Both goals are crucial to achieve the required design luminosity in the future linear colliders. In this context, a two-phase intra-train Feedback (FB) system for position and angle correction has been installed in the extraction line of ATF2. This FB system is based on two kickers and three stripline Beam Position Monitors (BPMs), which allow the bunch-by-bunch measurement of x and y jitter in multi-bunch operation.

Several beam tests of the intra-train FB system at the ATF2 were performed during successive measurement campaigns in 2010, 2011 and 2012. 2010 results for 3-bunch mode train operation were reported in [4, 7]. The vertical position jitter was measured for the cases with and without FB correction.

In this paper, we present results from tests conducted during December 2011, operating with pulses in 2-bunch mode. In order to investigate the quality of the FB correction, the beam pulse-to-pulse vertical jitter were also measured using witness stripline BPMs, available downstream of the FB system. These measurements are compared with simulation results.

INTRA-TRAIN FEEDBACK SYSTEM

In the context of the Feedback On Nano-second Timescales (FONT) project [3], an ILC-like intra-train FB system prototype (FONT5) [4, 5] has been designed and tested in the extraction line of ATF2. A schematic of the FONT5 FB system elements in the ATF2 beamline is shown in Fig. 1. The key components of this system are: a pair of stripline kickers (K1 and K2), located with $\pi/2$ phase advance in between them, for applying beam position and angle correction in the vertical phase space; three stripline BPMs for registering the beam orbit (P1, P2 and P3); and additional electronic components, such as FB circuits, fast amplifiers and data acquisition devices.

The FONT5 system incorporates a digital feedback processor which allows the implementation of FB algorithms for simultaneous and coupled y and y' correction or, on the other hand, the configuration of two independent loops for y and y' separately.

It is interesting to point out that this FB configuration in the ATF2 extraction line is similar to that of the linac-exit bunch-bunch feedback system design of the ILC [6], and it fulfils a similar function stabilising the vertical orbit at the beginning of the BDS. The FONT5 system has been tested at ATF2 to correct the incoming pulse-to-pulse jitter (jitter that is correlated between bunches) for 3-bunch and 2-bunch train modes.

The three BPMs of the FONT system plus additional stripline BPMs (MQD14X, MQF15X and MFB1FF) have been instrumented to provide information of the transverse beam jitter along the ATF2 beamline. The monitor MFB1FF is placed in between the matching quadrupoles QM12FF and QM11FF, and provide us with jitter information at the entrance of the final focus system.

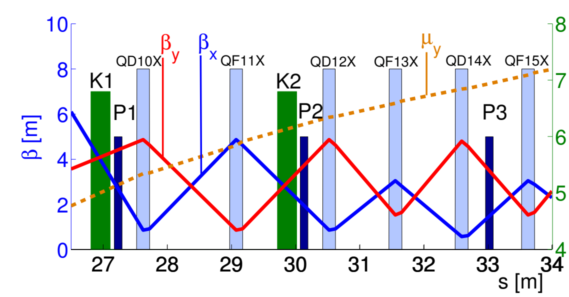

Figure 1: Schematic layout of the extraction line of the ATF2 beamline showing the relative locations of the FONT5 kickers (K1 and K2) and BPMs (P1, P2 and P3).

VERTICAL JITTER MEASUREMENTS

During the winter run period of ATF2 in 2011, the FONT5 intra-train FB system was tested to correct the vertical position and angle jitter in the extraction line of ATF2. The ATF2 was operated to provide 1.3 GeV bunch-trains with 2 bunches, and bunch separation of 187.6 ns. The FB system was operated in coupled FB mode in order to correct simultaneously y and y', interleaving the measurements with FB switched off and on. The FB system measures the first bunch position and corrects the second bunch.

To be effective the intra-train beam feedback requires extremely high degree of spatial correlation between the bunches. In this study the measured bunch-to-bunch position correlation was about 97%.

Position jitter measurements by the instrumented BPMs are shown in Table 1. This set of measurements for 1000 pulses corresponds to a test performed on the 7th December 2011. The positions at P2 and P3 were used to calculate the angle distribution at P2, and from this the rms angle jitter at P2 (see Table 2). The BPM resolution was estimated to be better than 0.5 μm for all the BPMs, except for MFB1FF, which appears to function more poorly, at around 2 μm resolution.

Table 1: Vertical beam jitter measurements by the FONT5 BPMs for each bunch in 2-bunch train operation. Data from 7th December 2011.

BPM	Bunch 1 σ [μm] (FB OFF/ON)	Bunch 2 σ [μm] (FB OFF/ON)
P1	1.27/1.44	1.22/2.5
P2	3.1/3.65	3.16/0.93
P3	2.75/3.09	2.76/0.76
MQD14X	3.59/3.73	3.23/1.5
MQF15X	1.55/1.53	1.48/0.84
MFB1FF	12.47/14.43	12.4/9.56

Table 2: Vertical angle beam jitter at BPM P2. Data from 7th December 2011.

BPM	Bunch 1 σ' [μrad] (FB OFF/ON)	Bunch 2 σ' [μrad] (FB OFF/ON)
P2	2.2/2.55	2.23/0.43

SIMULATIONS

Let us assume a beam pulse consisting of multiple bunches, each bunch centroid characterised by a vector $\mathbf{y} = (y, y')$ containing the information on vertical position and angle. If for each bunch an ensemble of y and y' measurements is performed over many beam pulses, the ensemble of a given bunch can be characterised statistically by the following covariance matrix:

$$\Sigma = \langle (\mathbf{y} - \bar{\mathbf{y}})^T (\mathbf{y} - \bar{\mathbf{y}}) \rangle = \begin{pmatrix} \langle y^2 \rangle & \langle yy' \rangle \\ \langle y'y \rangle & \langle y'^2 \rangle \end{pmatrix} , \quad (1)$$

where $\mathbf{y}^T$ indicates the transpose of $\mathbf{y}$. We will consider normal distributions with zero mean value: $\bar{\mathbf{y}} = \mathbf{0}$.

The rms position and angle jitter of the bunch can be defined as $\sigma = \sqrt{\langle y^2 \rangle}$ and $\sigma' = \sqrt{\langle y'^2 \rangle}$, respectively.

The evolution of the covariance matrix between two points s_1 and s_2 of a transfer line is given by:

$$\Sigma(s_2) = R\Sigma(s_1)R^T , \quad (2)$$

where R is the transfer matrix from s_1 to s_2. Here we consider only the 2-D transfer matrix in the vertical plane.

If Σ is known at a certain position and the optical lattice is known, then the position and angular jitter can be evaluated at any other point of the lattice.

Knowing the rms position jitter at P2 and P3 and the rms angle jitter at P2 we can obtain the value of the covariance $\langle yy' \rangle$ at P2. In this way, the elements of the matrix Σ are known at P2, and Eq. (2) can be used to evaluate the value of the position and angular jitter along the ATF2 beamline. Fig. 2 shows the position jitter propagation for bunch 2 in the ATF2 extraction line for FB OFF and ON. Simulation predictions are compared with measurement data. For the predictions we have used the actual current setting of the ATF2 magnets, such as they were set during the measurements. In general there is a good agreement between data and simulations. However, for FB OFF there is about 26% difference at MFB1FF between the measured point and simulation. It could be due to the reported poor resolution ($\approx$ 2 μm) of MFB1FF, although it needs further investigation.

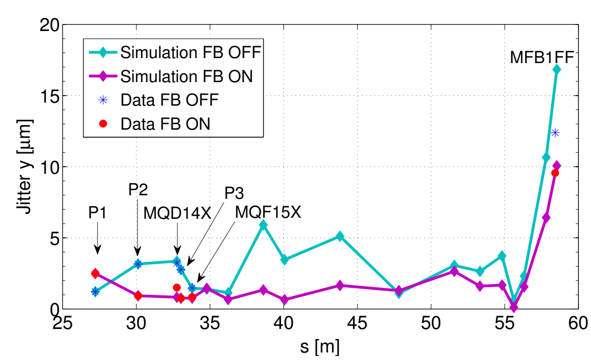

Figure 2: Position jitter propagation for bunch 2 along the ATF extraction line. The simulation predictions are compared with measurement data for the cases FB OFF and ON.

Tracking simulations of vertical offset distributions through the ATF2 beamline have also been performed in order to evaluate the vertical jitter downstream of the FONT region. For the initial offset distribution we have generated

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a bivariate normal distribution based on the information on rms position and angle jitter measured at P2 (Fig. 3). For bunch 2, the y-y' correlation factor of the initial distribution at P2 is $\rho_{\mathrm{P2}} = \langle yy' \rangle_{\mathrm{P2}} / (\sigma\sigma')_{\mathrm{P2}} = 99.5\%$ for the case FB OFF and $\rho_{\mathrm{P2}} = 75.5\%$ for the case FB ON. For this tracking study the code MAD [8] has been used. The simulation assumes no extra source of jitter downstream of the FB system.

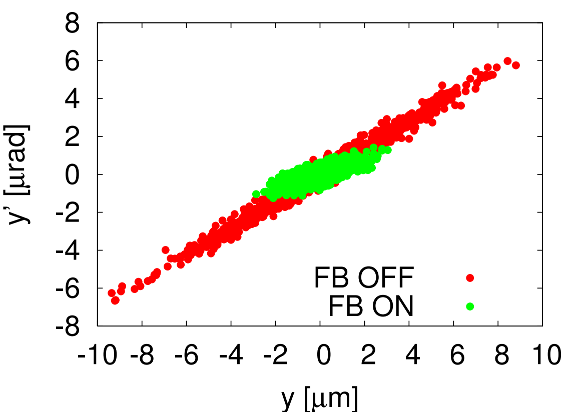

Figure 3: Initial offset distribution at P2 for the case with FB OFF (red) and FB ON (green).

Fig. 4 compares the vertical offset distribution at different witness BPMs (MQD14X, MQF15X and MFB1FF) and at the IP for bunch 2 with FB OFF and ON, resulting from the tracking of a distribution of 1000 events (pulse offsets) from P2. The tracking has been repeated 100 times and the position jitter has been calculated from the average over the 100 simulations. The results are summarised in Table 3. For instance, according to the measurements, with FB ON the position jitter is reduced by a factor 1.3 at the entrance of the final focus system (at MF1BFF). For the calculation of the position jitter at the IP we have considered the nominal ATF2 optics version v4.5, with nonlinear optimisation and $\beta_x^* = 10$ mm, $\beta_y^* = 0.1$ mm, available from the ATF2 lattice repository [9].

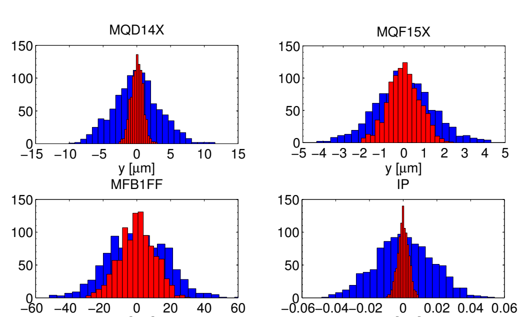

Figure 4: Vertical offset distribution at the stripline BPMs MQD14X, MQF15X, MFB1FF and at the IP for FB OFF (blue) and FB ON (red).

Table 3: Vertical beam jitter for bunch 2 with FB switched off and on at the witness stripline BPMs downstream of P2. Data from 7th December 2011. Measured data σ are compared with tracking simulation results. As a complement, the tracking results for angular jitter σ' are also included.

BPM	Measured σ [μm] (FB OFF/ON)	Tracking MAD σ [μm] (FB OFF/ON)	Tracking MAD σ' [μrad] (FB OFF/ON)
MQD14X	3.23/1.51	3.35/0.83	2.19/0.42
P3	2.76/0.76	2.77/0.76	2.21/0.42
MQF15X	1.48/0.84	1.47/0.77	0.61/0.89
MFB1FF	12.4/9.56	16.79/10.07	8.61/5.09
IP (nominal)	–	0.016/0.0031	110.05/85.99

CONCLUSIONS

An intra-train FB system has been tested at the ATF2 beam test facility with short ILC-like trains in 2-bunch mode. This FB system is placed in the ATF2 extraction line and corrects the incoming y and y' beam jitter. The FB system performs well, reaching a factor 3.4 position jitter reduction and a factor 5.2 angle jitter reduction at BPM P2.

In order to investigate the beam jitter propagation in ATF2 with FB OFF and ON, the jitter have been measured using three additional witness stripline BPMs downstream of the FB system. Simulations have also been performed, and are in good agreement with the measured data.

On the other hand, tracking simulations with the nominal ATF2 optics have shown that the intra-train FB system in the extraction line could help to stabilise the beam to below 10 nm at the nominal IP, assuming no lattice imperfections. These results are very encouraging and provide an important step towards the achievement of the ATF2 second goal.

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