LAYOUT AND SIMULATIONS OF THE FONT SYSTEM AT ATF2*

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Abstract

We describe the adaptation of a Feedback On Nanosecond Timescales (FONT) system for the final focus test beam line ATF2 at KEK. This system is located in the ATF2 extraction line, and is mainly conceived for cancellation of transverse jitter positions originated in the damping ring and by the extraction kickers. This jitter correction is performed by means of a combination of feed-forward (FF) and fast-feedback (FB) beam stabilisation. We define optimal positions for the kicker and BPM pairs of the FONT FF/FB system, and estimate the required kicker performance and BPM resolutions. Moreover simulation results are presented.

INTRODUCTION

The final focus test beam line facility at KEK in Japan, so-called ATF2 [1] will provide an unique experimental bed to investigate the performance of a compact final focus optics such as designed for the future International Linear Collider (ILC). The two major goals for the ATF2 facility are the achievement of a 30-40 beam sizes, and 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.

The ATF2 beam line will allow us to test ILC-like feedback and feed-forward systems for beam stability. To date, Feedback systems On Nanosecond Timescales (FONT) have successfully been tested in different beam test facilities (see for example [2]).

In this report we present the design and adaptation of an upstream FONT type system for ATF2. The goal is to investigate the performance and accuracy of a ILC intra-train feedback system correction prototype in order to achieve the required stabilisation of the bunch orbit at microm level. Additionally, this system will allow us perform bunch-to-bunch feed-forward (FF) corrections.

THE FONT LAYOUT AT ATF2

The FONT system at ATF2 will be placed in a dispersion-free section of the extraction line (see Fig. 1), and employs the following beam instrumentation:

- A pair of kickers (denoted as K1 and K2) for correction of vertical position and angle jitter originated in the damping ring (DR) and during extraction from the DR. K1 is located at $\pi/2$ phase advance downstream of the second extraction kicker, and K2 is at $\pi/2$ downstream of K1.

- Three beam position monitors (BPMs) or pickups, denoted as P1 (adjacent and behind of K1), P2 (adjacent and behind of K2) and P3 (at $\pi/2$ phase advance downstream of P2). The function of these BPMs is to reconstruct the FF matrix and the FB response matrix.

- Additional hardware includes electronics components such as BPM processor board, amplifier, FB board and the data acquisition devices (DAQ) [3].

Optimum positions of the FONT elements in the lattice have been chosen according to criteria of resolution tolerance, phase advance between elements and acceptable irreducible latency time.

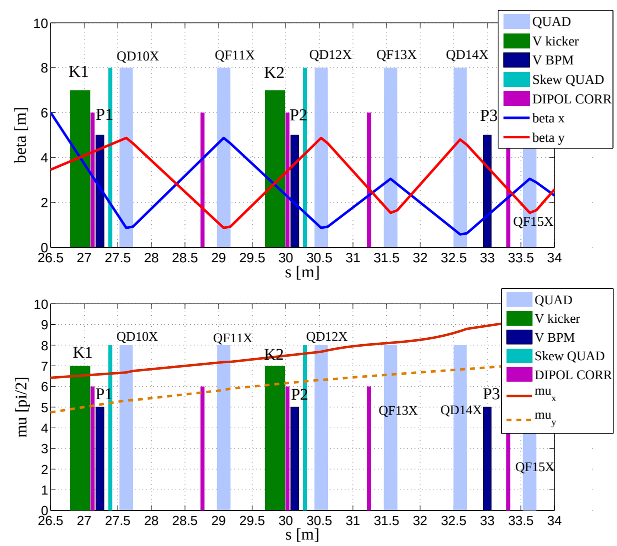

Figure 1: Layout of the region of the extraction line of the ATF2 optics version 3.8 where the FONT elements are located: kickers K1 and K2, and BPMs P1, P2 and P3. Top: transverse betatron functions $\beta_{x,y}$. Bottom: transverse phase advance functions $\mu_{x,y}$.

In this report we concern only about the y and y' corrections. However, if we consider also the correction in the horizontal phase space (x, x'), then an additional pair of kickers and other three BPMs are necessary.

To perform bunch-to-bunch FF/FB corrections we can use kickers with two strip-line electrodes. In this case, if a pulse voltage V is applied for both electrodes, then the kick angle is given by

$$\Delta\theta_{x,y} = 2g \frac{eV}{E} \frac{L}{d} , \qquad (1)$$

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where E is the beam energy, e the unit charge of the electron, L the strip-line length, d the distance between the electrodes (diameter of the aperture of the kicker), and g is a geometric factor, generally $g \approx 1$. The necessary pulse voltage should have a fall and rise time < 150 ns, i.e. the rise time should be lower than the bunch spacing, which in the case of ATF2 is about 150 ns (ILC-like beam bunches), to avoid crosstalk errors between bunches.

Some tentative design parameters for the kicker are shown in Table 1.

Table 1: Tentative parameters for the FB/FF kickers

Parameter	Value
Length L	30 cm ($\approx$ 35 cm with flanges)
Gap width d	15 mm
Kicker impedance	50 Ω
Maximum voltage	$\approx$ 3 kV (kick angle of ≈ 100 μrad)
Fall and rise time	< 150 ns (bunch spacing)
Strength error	0.5 %

To operate in micrometre level stability a BPM resolution $\lesssim 1$ μm is required. A resolution of the order of 1 μm can be achieved using strip-line pickups. The FONT type strip-line pickups have been chosen to have a length of about 12 cm (electrical length), and similar features as the spare linac BPMs from the SLC [4], consisting of four electrodes.

The BPM resolution depends on the beta functions at the BPM positions, and, in the case of the ATF2, it must correspond to a tolerable residue at the interaction point of about $1/20$ of the rms beam size.

POSITION AND ANGLE JITTER CORRECTION

In this section we study the feasibility and accuracy of the jitter correction and the residual jitter propagation after correction using the FONT kickers and BPMs. The kickers K1 and K2 are used to correct the jitter in the vertical phase space, and the BPMs P1 and P2 reconstruct the transfer matrix $\mathbf{R}_{\mathrm{K1}\to\mathrm{K2}}$ between the two kickers, taking into account that P1 and P2 are adjacent to K1 and K2 respectively. Here we only consider the 2×2 vertical linear sub-matrix in transport notation. The second BPM P2 and the third BPM P3 can fulfil the function of witness BPMs to measure both the position and angle residue, or be also used for FB algorithms.

Let (y_1, y_1') be the position and angle at the K1 position before applying the steering correction. If $\Delta\theta_1$ and $\Delta\theta_2$ are the angle increments caused by the kickers K1 and K2, respectively, then the vertical trajectory propagates to the P2 position as

$$\begin{pmatrix} y_2 \\ y_2' \end{pmatrix} = \begin{pmatrix} 0 \\ \Delta\theta_2 \end{pmatrix} + \begin{pmatrix} R_{33} & R_{34} \\ R_{43} & R_{44} \end{pmatrix} \left[\begin{pmatrix} 0 \\ \Delta\theta_1 \end{pmatrix} + \begin{pmatrix} y_1 \\ y_1' \end{pmatrix} \right] . \quad (2)$$

From the correction condition $(y_2, y_2') = (0, 0)$, the necessary kicker strengths (in angle units) can be calculated,

$$\begin{pmatrix} \Delta\theta_1 \\ \Delta\theta_2 \end{pmatrix} = \begin{pmatrix} -\frac{R_{33}}{R_{34}} & -1 \\ \frac{R_{44}R_{33}}{R_{34}} - R_{34} & 0 \end{pmatrix} \begin{pmatrix} y_1 \\ y_1' \end{pmatrix} . \quad (3)$$

However, errors in a real system (BPM rms noise, kicker strength error, element misalignment, etc) result in a residual jitter: $(\delta y_2, \delta y_2')$. This residual jitter propagates to the IP: $(\delta y_{\mathrm{IP}}, \delta y_{\mathrm{IP}}')$.

In order to fulfil the ATF2 beam stability requirements, the residual jitter at the IP should be less or about one $1/20$ of the rms beam size at the IP. If $\sigma_y^* \simeq 40$ nm, then $\delta y_{\mathrm{IP}} \lesssim$ 2 nm.

Simulation Set Up and Results

We have implemented the above correction algorithm using the tracking code Placet-octave, which is an improved new version of the code Placet including the program octave (a free clone of Matlab) [5].

For the simulations we have considered a normal random distribution of 100 initial vertical position jitters with a width of 40 % σ_y (rms beam size). This means a rms jitter of 0.46 μm at the entrance of the extraction line. The following errors have further been assumed: a BPM rms noise of 1 μm and kicker strength jitter of 0.5 % of the kick angle peak. On the other hand, concerning to the dynamic misalignment of the lattice elements, the so-called model K of ground motion [6] has been applied during a time of 10 s before the macroparticle tracking and orbit correction. This simulation set up allows us to study the jitter propagation along the ATF2 line, the accuracy of the orbit correction using the FONT kickers and the remanent residual jitter after correction, establishing limits for the beam stability at the IP position. For instance, Fig. 2 compares the jitter propagation along the extraction line before and after the correction. In the last case a considerable reduction of the jitter amplitude has been achieved. The corresponding jitter distribution at the IP is shown in Fig. 3. After correction the standard deviation of the jitter distribution at the IP is practically reduced by two orders of magnitude.

Sensitivity to Errors

In order to assess the error tolerance of the FONT elements, keeping the required beam stability, we have evaluated the residual position jitter sensitivity to the BPM resolution and the kicker strength error. Fig. 4 shows the obtained residual jitter at the IP versus the *BPM resolution*. Each point represent the average over 50 shots. The error bars correspond to the standard deviation. The shot-to-shot

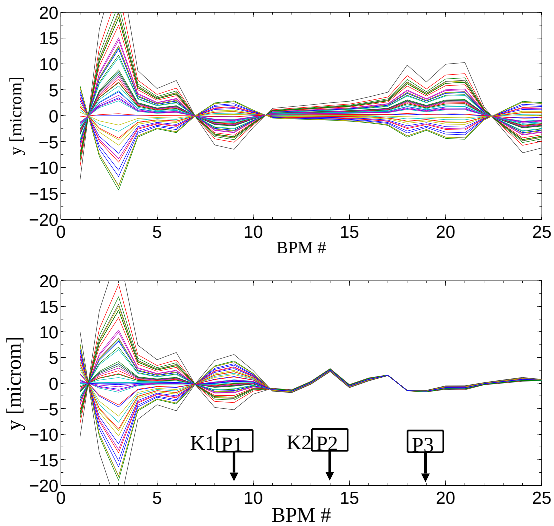

Figure 2: Jitter propagation along the ATF2 extraction region. Top: before correction. Bottom: after orbit steering correction by the kickers K1 and K2.

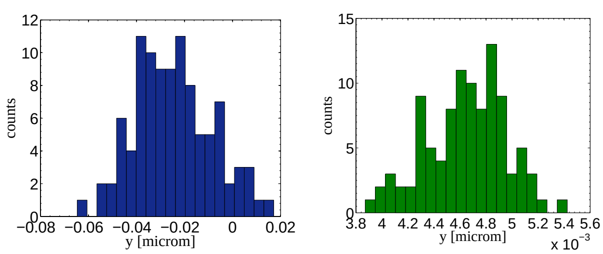

Figure 3: Jitter distribution at the IP, before steering correction (left) and after steering correction (right).

variation is very sensitive to the BPM resolution. If the tolerable residual jitter is quoted to be $\lesssim 5\ \%\ \sigma_y^*$, then the BPM resolution must be better than $1\ \mu$m. With $1\ \mu$m BPM resolution a control of beam position $\sim 10\ \%\ \sigma_y^*$ may be feasible.

On the other hand, assuming perfect BPMs, Fig. 5 shows the scan performed for *kick strength errors*. In this case, the acceptable kick error must be $\lesssim 10\ \%$ of the peak kick angle.

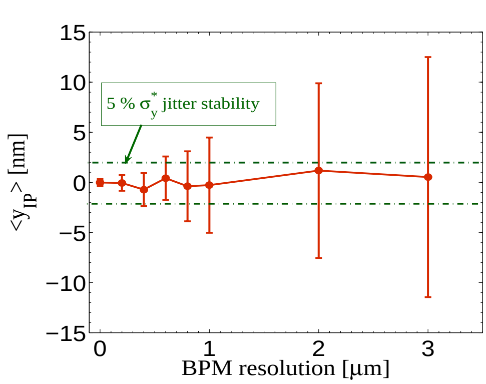

Figure 4: Vertical jitter at the IP versus BPM resolution.

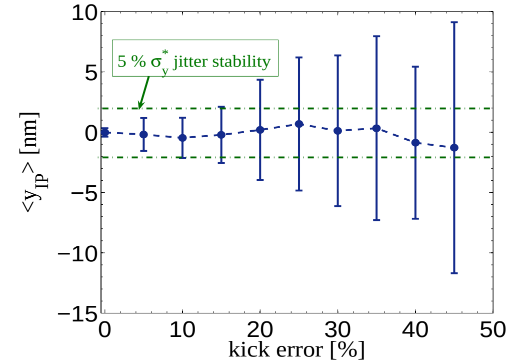

Figure 5: Vertical jitter at the IP versus the kicker jitter error.

SUMMARY AND OUTLOOK

In the framework of the Feedback systems On Nanosecond Timescales (FONT) collaboration, we present the adaptation of such a system to be installed in the ATF2 facility. The particularity of this system is that the feedback hardware can be carried over to feed-forward. The system is placed in the ATF2 extraction line, and consists of two kickers and three BPMs. A kicker is used to correct position jitter and the other one angle jitter. In this report only the jitter correction in the phase (y, y') has been considered.

Optimum positions of the FONT elements in the ATF2 optics lattice have been selected regarding the beta functions and the phase space separation. Moreover, some tentative parameters for the FONT kickers and BPMs have been estimated.

We have also set up a computer model of the FONT system at ATF2, based in the tracking code Placet-octave. This model allow us to perform multiparticle tracking simulations including different errors and imperfections of the machine, such as initial jitter, static and dynamic element misalignments. Simulation results with $1\ \mu$m BPM resolution show that the FONT system may be able to reduce by approximately two orders of magnitude the shot-to-shot jitter variation. In addition, simulation results have shown a maximum tolerable kicker strength error of about $10\ \%$.

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