AN ILC TURNAROUND FEED-FORWARD PROTOTYPE AT THE ATF

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An extract from BCD [1], 11 Instrumentation and Controls:

ILC Damping Ring to Main Linac: Turnaround trajectory feed-forward

- Purpose: correct for extraction kicker jitter.
- Correction plane: horizontal and vertical.
- Monitors: beam trajectory measured upstream via BPMs.
- Actuators: Two fast correctors per plane.
- Correction rate: bunch by bunch continuously during ~1ms, bunch spacing ~330ns.
- Feed-forward time: ~0.5µs.

In the latest ILC layout where the Damping Ring is situated around the Interaction region, a reverse turning of the beam from a RTML (a long Ring-To-Main-Linac transport line that is parallel to the Linac) into the Main Linac is necessary. So, a trajectory feed-forward system set just in this turnaround will be able to correct for generated in the RTML jitter as well as for extraction kicker jitter.

I propose a set-up at the ATF-2 that would model the ILC Turnaround Trajectory Feed-Forward:

An ILC Turnaround Trajectory Feed-Forward prototype at ATF-2:

- Purpose: a Turnaround Feed-Forward regulation error achievable (see below).
- Measurement plane: horizontal or vertical alternatively.
- Turnaround path: last turn in the DR and further through the EL.
- BPMs: one pair in the DR, two pairs in the EL.
- Actuators: one pair of strip line kickers in the EL.
- Beam: single bunch or two 330ns spaced bunches. Extracted beam energy is stabilised.
- Correction rate: for single bunch single correction repeated with extraction rate, for two bunches two bunch-by-bunch corrections repeated with extraction rate.
- Feed-forward time: ~0.45µs.

In addition, the prototype can be used as an instrument for measurements of:

A. Horizontal plane

- Instability of the Extraction Kicker.

B. Vertical plane

- Spurious vertical kick of the Extraction Kicker.

Extracted beam energy stabilisation residual error and turn-by-turn betatron jitter can be measured as well.

Purpose.

The purpose is to investigate how far one can advance in accuracy of the ILC feed-forward correction.

Assume the turnaround transfer matrix is stable.

1. The ultimate beam jitter correction residue limit is decided by the signal-to-noise ratio in the feed-forward system. Taking for instance a case when the amplitude function $\beta(s)$ in a drift is a slope with some values β_1 and β_2 in the upstream BPM1 and BPM2, one can obtain from [2] a condition to the required BPM position resolution σ_{BPM}:

$$\sigma_{\mathrm{BPM}} = \xi \cdot 2\sqrt{\varepsilon} \cdot \frac{1}{\sqrt{\frac{1}{\beta_1} + \frac{1}{\beta_2}}} \qquad (1)$$

where ε is the beam emittance, ξ is the ratio of the acceptable correction residue to the beam size. To be negligible, the residue should be, say, few 1/100 of beam size. This decides the BPM resolution about $1\mu\mathrm{m}$.

A feed-forward correction system dynamic range is decided by the upper limit of beam excursions due to supposed jitter of the extraction kicker and the RTML elements. Roughly, this limit can be taken as tenfold of beam size. So, the correction range comes to, say, 50dB. The upper limit decides the voltage/current range of the fast corrector.

The feed-forward system can also correct a constant shift or a slow drift of the equilibrium (average) trajectory. For this correction the system zero offset should be close to zero and stable within, say, 1/10 of the beam size. It counts to several micrometers. That is challenging.

2. One of the problems on a way of advance from an easily achievable correction range 20dB to about 50dB is achievement of correspondingly low gain compression. By other words, the feed-forward system gain that is ratio of the position/angle scale of the corrector pair to the position/angle scale of the BPM pair should deviate from a nominal value by less than $(-50)\mathrm{dB}$ within full voltage/current corrector range. Another problem is achievement of a gain stability that should be of same level.

As for fast corrector, a two-coarse/fine-channel power amplifier can be suggested as a solution of either problem above. Assume for simplicity that instead of each one corrector two adjacent correctors are used. One corrector is powered by a coarse nominal power amplifier, another one is powered by a fine low power amplifier. The coarse amplifier has a compression error, an unstable gain and a slow response. The fine amplifier as it is a low power amplifier has a fast response. This amplifier is used to correct for coarse amplifier compression error, to stabilise gain and to improve a response tail as well. This can be done individually for each bunch in the following way.

Take the fine amplifier input as difference between the coarse amplifier output (divided by the nominal gain) and the DAC output (delayed by a coarse amplifier propagation time). Then for a fine amplifier gain being equal to the nominal gain, the fine amplifier output would compensate the coarse amplifier error.

The outputs of both the amplifiers can be summed up and then fed into a single corrector. This arrangement has that advantage that a fine amplifier circuit becomes a local negative feedback. Taking the open loop gain that is actually the fine amplifier gain greater than the nominal gain an accurate and stable compensation can be achieved.

As for BPM, a bunch-by-bunch BPM described in [3] can be chosen as a BPM that provides high stability. In this BPM both signals from two pickup strip lines are processed in the same channel and are measured by the same ADC. It's expected that this will result in excellent scale stability and zero offset stability as well. As a pickup, a needle-like strip line pickup now under development in Daresbury Laboratory can be used. Its response is optimal for the BPM above.

3. Next problem is adjustment of the feed-forward system gain to the required value. The value is decided by the beam transfer matrix from the BPM pair to the corrector pair. The matrix can be found by a beam-based measurement that should be done with accuracy about $(-50)\mathrm{dB}$. More attractive looks a way where the gain being set to some approximate value, is automatically adapted on-line using a feedback algorithm built in the feed-forward digital processor.

For feedback, a reference pair of downstream BPMs is necessary. It measures a bunch-by-bunch feed-forward correction residue. For the jitter measured by the upstream BPM pair, and the residue jitter measured by the reference BPM pair calculate two sets of running differences

$$D_{\mathrm{up}\,n} = \chi_{\mathrm{up}\,n} - \chi_{\mathrm{up}\,n+1} \qquad (2)$$
$$D_{\mathrm{down}\,n} = \chi_{\mathrm{down}\,n} - \chi_{\mathrm{down}\,n+1}$$

where χ_n and χ_{n+1} are the coordinate/angle of a pair of bunches of number n and $(n+1)$, $n = 1, 2, \ldots$. Then a set of the correlation functions

$$C_n = \frac{1}{n} \cdot \sum_{i=1}^{\mathrm{n}} D_{\mathrm{up}\,i} \cdot D_{\mathrm{down}\,i} \qquad (3)$$

can be calculated. If the series C_n, $n = 1, 2, \ldots$ converges to zero, $\overline{C} = 0$, the gain is correct. Otherwise, the gain is changed by small increments/decrements and for each step $\overline{C}$ is calculated till $\overline{C} = 0$ is found. For a difference about $(-40)\mathrm{dB}$ between initial and final gain values, this adjustment procedure is expected be completed with a total series of bunches several hundreds.

With the gain found, the zero offset can be adjusted in similar way. Running sums are calculated:

$$S_{\mathrm{up}\,n} = \frac{1}{n}\sum_{i=1}^{\mathrm{n}} \chi_{\mathrm{up}\,i}$$
$$S_{\mathrm{down}\,n} = \frac{1}{n}\sum_{i=1}^{\mathrm{n}} \chi_{\mathrm{down}\,i} \qquad (4)$$

$S_{\mathrm{down}\,n}$ converges to the beam position/angle offset $\overline{S}_{\mathrm{down}}$ (assuming here that the reference BPM pair zero offset is zero). Changing the upstream BPM pair zero offset by increments/decrements and calculating for each step $\overline{S}_{\mathrm{down}}$, it is possible to adjust the beam offset to zero.

Prototype layout.

A prototype layout is shown in Fig. 1. As a pair of BPMs upstream of the Turnaround section, a pair of DR BPMs is used (shown as 1 and 2). As a pair of fast correctors downstream the Turnaround section, a pair of strip line kickers (5 and 6) in the EL is used. The Turnaround section itself is modelled by a DR part from the DR BPM pair to the Extraction Kicker, together with an EL stretch from the Extraction Kicker to the strip line kicker pair. Downstream the kicker pair, the reference BPM pair is there (7 and 8).

Signal processing should be done within the beam travel time 0.45µs, provided that with two (or for successive, like in the ILC) bunches spaced 0.33µs a pipeline processing is used.

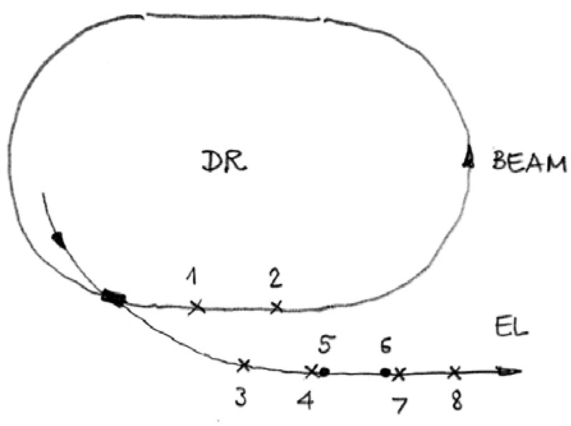

Fig. 1. Prototype layout.
The BPMs are shown as crosses, the kickers as dots.

ILC DR extracted bunch excursions due to supposed instability of the extraction kicker and the RTML are modelled using some set of standing betatron waves excited in the DR with its orbit correctors. On the last turn the particular wave propagates to the EL where it is compensated with the strip line kickers. The correction residue is measured with the downstream reference BPM pair.

A wave amplitude/angle range in the BPMs should be at least some NdB of the BPM resolution to allow residue measurement range down to $(-N)$dB. Note for the output corresponding to an amplitude/angle close to the upper limit the amplifier non-linearity should be also about $(-N)$dB.

The transfer matrices from the DR BPM pair to each EL BPM pair and to the kicker pair are measured using same standing betatron waves. To measure the matrix to the kickers, a pair of BPMs (shown as 4 (see below) and 7) that are close to the kickers is used. To diminish error due to possible instability of the Extraction Kicker, the matrices are measured as statistical means.

To have statistics, the feed-forward regulation for a particular wave can be executed repetitively for some number of extractions.

To diminish feed-forward regulation accuracy deterioration due to possible instability of the Extraction Kicker that is in this prototype merely some lattice element, an additional BPM pair (shown in Fig. 1 as 3 and 4) upstream the strip line kickers is used to find beam excursions caused by the Kicker jitter. For transfer matrices known the excursion can be propagated to the downstream reference BPM pair and used to find the feed-forward regulation net effect. This refinement is supposed to be done off-line of correction.

References

[1] http://www.linearcollider.org/wiki/doku.php?id=bcd:bcd_home#ilc_configuration_main
[2] A. Kalinin, A Beam Jitter Characterisation Task in Prospect for Beam Stabilisation on the ATF Extraction Line, a FONT internal note, November 2004.
[3] A. Kalinin, A Single Bunch BPM for ATF Feed-Forward, a FONT internal note, October 2005.