DRIFT CONTROL ENGINES STABILIZE TOP-UP OPERATION AT BESSY II*

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Abstract

Full stability of orbit and bunch-by-bunch-feedback controlled top-up operation becomes available to the experimental users only if the remaining slow drifts of essential operational parameters are properly compensated. At the light source BESSY II these are the transversal tunes as well as the path length and energy. These compensations are realized using feedback control loops together with supervising state machines. Key to the tune control is a multi source tune determination algorithm. For the path length correction, maintenance of beam energy and reduction of orbit deviations empirical findings are utilized.

INTRODUCTION

At lightsources, capabilities for user experiments rely on source point position, pointing stability as well as stable beam size and shape. These parameters transform to electron beam orbit and tune stability, typically controlled by slow (SOFB) and fast (FOFB) orbit correction feedback installations and by insertion device (ID) focusing feedforward compensations.

The intrinsic stability of the storage ring is greatly enhanced by the thermal equilibrium provided by top-up operation. In consequence correction amplitudes of beam guiding and shaping systems are drastically reduced, and beam quality can be better maintained by the described means.

Nevertheless, new constraints are imposed by the top-up injection permission, the technical solution implemented for FOFB and the stability requirement for efficiency of the Bunch by Bunch FeedBack (BBFB) [1] and for the amplitude of the resonantly excited bunch used for pseudo single bunch pulse picking. At BESSY II, additional control tools are needed to keep tunes, orbit and energy stable within required limits.

MOTIVATION

The ID-tune-feedforward system compensates the baseline tune shifts produced by gap and shift movements of any ID. This feedforward system interpolates empirically produced tables generated and iterated during measurements in dedicated ID-commissioning runs. Nevertheless imperfections and multiple IDs moving gaps and shifts at the same time would still cause significant tunes-shifts if not taken care of.

The purity of the camshaft bunch in the ion-clearing gap is controlled by a vertical knock out kicker. The resonant vertical beam excitation pulse during the gap around the camshaft bunch (see range marked blue in Figure 1) has to be very short to minimize perturbation of the camshaft bunch. So the kicker is active only for a few damping times at the injection shot. It has to be very efficient to prevent accumulation of charge in bunches to be cleared: If accumulated charge is cleared later when exact resonance condition is reestablished this might result in a shot injection efficiency below the allowed limits. Thus perfect matching of the excitation frequency and the vertical tune is needed to ensure excellent knockout efficiency.

Damping capability of the BBFB systems and the appropriate operational safety margin are well guaranteed as long as the tunes are constant.

Frequency and amplitude of the incoherent excitation for Pulse Picking by Resonant Excitation (PPRE) [2] have to match a specific frequency at the slope of the horizontal tune synchrotron sideband. Even tune shifts of about 500 Hz have severe impact on excitation effectiveness and stability of the PPRE bunch (see Figure 2).

Path length drifts were compensated by the slow orbit feedback (SOFB) by integrating the RF frequency into the horizontal response matrix and minimizing average horizontal corrector strength in the SVD calculation at each step. However, a straight forward implementation of this scheme was not possible with the fast orbit feedback system (FOFB).

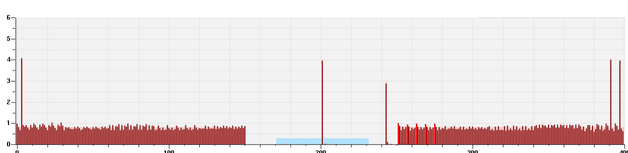

Figure 1: Fillpattern in standard multi- and single bunch hybrid mode, serving both average and timing mode experiments. A multibunch fill of 300 bunches including 3 bunches for fs-slicing experiments with an ion-clearing gap of 200 ns (100 buckets). A camshaft bunch at a fixed position in the center and a PPRE bunch close to the end of the gap - both for pseudo single bunch experiments. The blue region on both sides of the camshaft bunch is the cleared by resonant RF knockout during every injection shot.

TRANSVERSAL TUNE MEASUREMENT

Input Signals

Beammotion over a wide frequency range up to 1250 kHz is measured at a crossed stripline with a fast ADC/PXI system running LabVIEW. A processed FFT is provided to the control system in 3 partial ranges for each horizontal, ver-

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tical and longitudinal tune with a resolution of 80 Hz. The measurement system delivers a sliding average of FFT data within each partial range of the spectrum, at a 10 Hz rate.

For standard optics as well as low-α optics, the coarse region of interest of the measurement system has to be set up to properly contain the main tune as well as the synchrotron sidebands of the desired transversal tunes.

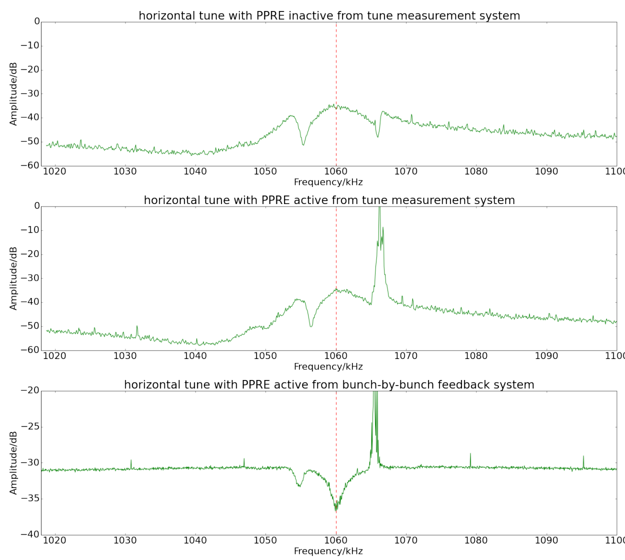

Figure 2: Typical horizontal tune spectrum - top: without PPRE excitation; center: with PPRE enabled; bottom: from bunch by bunch feedback with PPRE enabled.

The regular tune spectrum (top plot in Figure 2) has a slight asymmetry because the shifted tunes of high current bunches add a tilt to the spectrum.

Besides any possible unwanted distortions of the tune spectrum, there are inevitable additional types of beammotion e.g. due to the horizontal resonant excitation of the PPRE bunch (see Figure 1 and center plot in Figure 2). This excitation can make the actual horizontal tune impossible to determine by only analyzing the measured spectrum.

Tune-finder Strategies

A regular undistorted tune spectrum shows a peak at the mean tune of all bunches as well as two typically smaller peaks of synchrotron sidebands. In many situations, a simple peak finder is sufficient to identify the correct tune, but other non-tune-related beam motion may distort the spectrum and hence make the main tune hard to detect. Narrow-band distortions can easily be eliminated by removing outliers applying a smoothing algorithm to the spectrum. Since the main tune is not guaranteed to be the highest peak in the spectrum, a simple peak-finder often fails to identify the correct tune.

During pseudo single bunch experiments using PPRE, the motion of the excited bunch adds a major peak to the horizontal tune spectrum (see center plot in Figure 2). This may render a successful identification of the correct tune impossible, using the standard mechanism.

The horizontal BBFB system detects the motion of this bunch and delivers a spectrum showing the horizontal tune and sideband frequencies as notches and the excited PPRE bunch as a peak (see bottom plot in Figure 2) as the PPRE bunch is excluded from active damping. Consequently, switching tune-measurement to use the BBFB system as a source provides a stable and reliable determination of the tune during runs with PPRE enabled by performing simple notch-find on the selected region of interest within the horizontal BBFB system.

Depending on the scheduled optics and fillpattern, one of four algorithms is selected for each plane to determine the main transversal tunes from raw tune measurement FFT data. All these tune-finder strategies are working on a configured region of interest of the spectrum (see Figure 3).

Use BBFB peak- or notch-finder Used is if spectrum is distorted by active excitation e.g. during PPRE runs.

Simple peak search Finds the maximum value.

Peak search after smoothing While searching for the maximum value, this algorithm eliminates outliers by applying a simple smoothing algorithm with configurable windowwidth.

Area above threshold A simple pattern search (three equidistant peaks with the center one being the main tune) turned out to be a too simple approach to provide stable results. Instead, finding all identifiable peaks and selecting the one with biggest area below has proven to be a more reliable method. The threshold in this case is a minimum attenuation level att_0 where all relevant peaks are $att > att_0$.

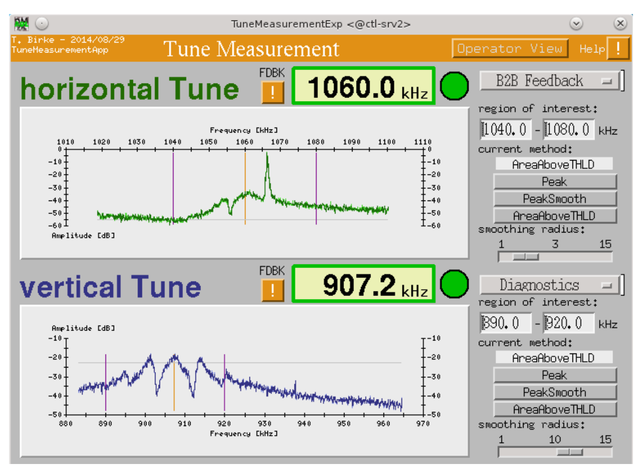

Figure 3: Tune measurement control panel - purple lines mark the regions of interest and a red line marks the identified tune for easy verification by operations staff.

Since injections appear as a major distortion in the measured beammotion, evaluation of FFT data and determination of tune values is paused for a configurable time during and after injections until the distortion is no more present in the smoothed spectrum.

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TUNE FEEDBACK

Once a reliably working tune measurement is established, it opens the possibility to setup a feedback system to keep the measured tune at its desired frequency. This way slow thermal drifts as well as residual tune shifts from ID movements can be compensated.

The transversal tune feedbacks are implemented to permanently monitor the motion of the measured tune as well as the difference from the configured target tune. Once, the difference exceeds a defined limit and tune motion is below a certain threshold, a configurable partial correction of the tune is applied. Subsequently, the resulting measured tune is checked for successful correction. If a correction was successful, further partial corrections are applied if necessary until the measured tune matches the target tune (see Figure 4).

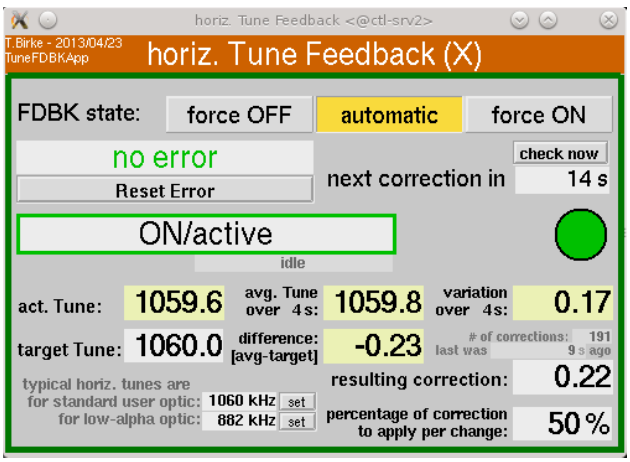

Figure 4: Tune feedback control panel.

User Level Configuration

The basic configuration parameter of the tune feedbacks is the target tune.

Some low-level configuration values control if, when and how any correction steps are performed. Tune corrections are inhibited temporarily

- For a specified time before and after injection shots, to not risk degradation of efficiency by applying a correction during an injection shot.
- When ring current does not exceed a minimum limit.
- If the measured tune varies more than a certain amount within the last few seconds, to not add additional noise.

Also configurable is the time delay between a adjustment step and the check for a successful correction.

To avoid applying additional noise, tune adjustments are performed at a maximum rate and only if a minimum step width is exceeded.

Error Handling

The following conditions lead to an error and the tune-feedback loop stops processing until error conditions are fixed and the feedback is reset manually. This measure is taken because distortions of the tune spectrum may cause the tune measurement to fail in identifying the correct tune. In this case, excess corrections may move the real tune to areas where subsystems relying on a stable tune won't work properly anymore. The tune may even approach a resonance, which could cause a partial or complete beamloss.

Error conditions are:

- Measured tune identified outside allowed window around target tune triggers a "*too much to correct*" error. The allowed window is small enough to not include the synchrotron sidebands.
- Correction step did not result in tune shift towards target tune causes a "*bad correction*" error.
- Variation of measured tune permanently exceeds a defined limit and hence leads to a "*measurement error*". The tune determinating algorithm could not identify a stable and reliable tune.

All these error conditions cause alarms to be signaled and an appropriate message sent to operators. Manual intervention and re-activation of TuneFDBK is necessary.

PATH LENGTH CORRECTION

Path length drifts are to be compensated by adjusting the RF master oscillator accordingly and hence keep the stred beam energy stable at a desired point.

Since FOFB cannot adjust the master oscillator directly, it instead uses corrector magnets to compensate for path length drifts and to keep the beam centered and stable. Over time excess strength in two corrector families accumulates.

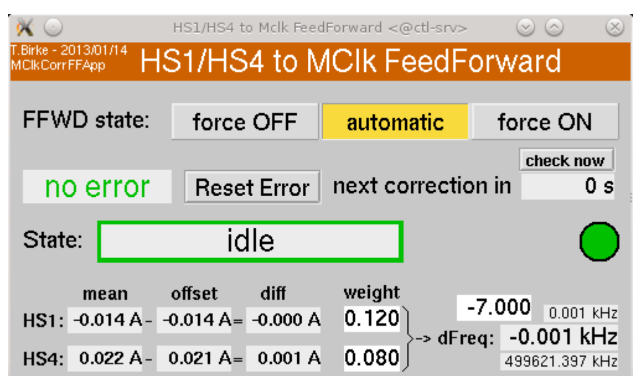

Figure 5: master oscillator FeedForward control panel.

A companion system for FOFB has been implemented, that transfers these excess corrector settings into RF frequency changes according to previously observed relations, and applies these changes "cautiously" (Figure 5). The relation between these corrector settings and the corresponding

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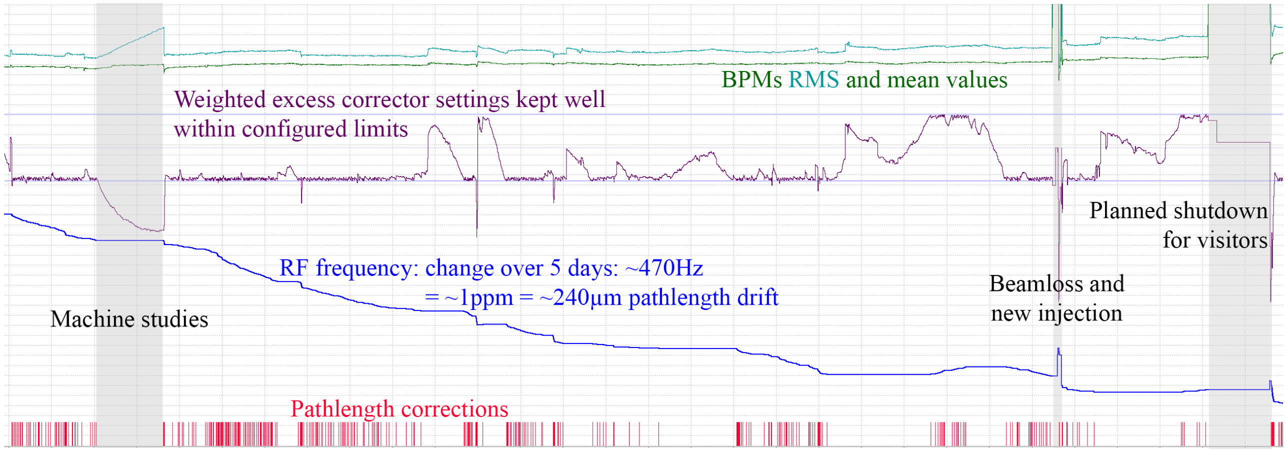

Figure 6: Plot of ~400 path length corrections over 5 days after one week of low current low-α operation. Shown are sum of the weighted excess corrector settings and the resulting RF frequency. BPM RMS and mean values are stable within ~1 µm.

RF change necessary, have been found empirically and is documented in [3, 4].

This companion system is implemented as a feedforward mechanism, that calculates the difference of the average corrector settings per family to a reference offset value. The results are weighted and transformed into a corresponding RF master oscillator change.

As the changes are applied, FOFB takes back the excess corrector settings applied previously.

Besides the influence of slow thermal drifts, driving undulators to small gaps and driving orbit bumps for PPRE experiments have the biggest share on path length changes (Figure 6).

Error Handling

After every adjustment of the master oscillator frequency, the corrector settings are checked. If FOFB did not respond to the RF change by taking back corrector settings, a "bad correction" error is raised, operators are notified by the global alarm handler and further corrections are stopped until manual reactivation.

Run Conditions

Some preconditions have to be met to allow path length corrections to be performed.

- FOFB has to be active and running
- ring current has to exceed 50 mA during multibunch and 11 mA during singlebunch runs
- the last injection shot was more than 3 seconds ago

Cautios application of changes is realized by scaling down the determined necessary frequency change (currently by a factor of 7).

A correction step is initiated as soon as the necessary change of the master oscillator frequency exceeds 1 Hz (RF frequency: 500 MHz). The real window width of ±7 Hz corresponds to a path length window of ~±3.5 µm.

CONCLUSION

The sketched setup of beammotion measurement, tune identification and tune-drift compensation has reliably stabilized operation at BESSY II. All other systems, that need stable tunes to work properly, benefit from basic beam properties.

Path length corrections have been applied flawlessly since FOFB is in use at BESSYII, and the resulting changes applied to RF master oscillator well reflect e.g. thermal drifts during accelerator startup and the seasonal and weekly changes of the outside temperature.

Performance and stability of top-up operation benefits from both drift control engines, and specialized setups for time resolved experiments heavily depend on these stabilized beam conditions.

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