FAST ORBIT FEEDBACK AT BESSY-II: PERFORMANCE AND OPERATIONAL EXPERIENCES

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Abstract

At the 3^{rd} generation light source BESSY II the first phase of a fast orbit feedback system (FOFB) has been put into operation in September 2012. In this first phase the aim was to achieve noise suppression in the 1 Hz to a few 10 Hz range, mostly avoiding expensive upgrades to existing hardware, such as beam position monitors and the CAN based set-point transmission to the power supplies. Only the power supplies were replaced with newer, faster versions. This paper describes the capability of the phase I FOFB with respect to beam motion transient suppression, low frequency damping, high frequency noise generation as well as aspects of operational integration and stability.

INTRODUCTION

The photon beam stability requested by experiments at 3^{rd} generation light sources typically requires micron and sub-microradian electron orbit stability, where time scales range from hours to microseconds. BESSY has a long tradition in diagnosing and eliminating sources causing smallest beam motions. Thus in standard user mode the orbit, drift corrected by the slow orbit feedback (SOFB), has already reached a competitive level of stability [1].

But at a multi-user facility experimental activities generate irregular transients and noise spikes, that have to be suppressed as fast as possible. And for experiments averaging data as short as 100ms, beam motion in the frequency range 1 Hz to 50 Hz has to be kept as small as possible. Further more, in low-α mode, routinely offered at BESSY, any perturbation results in a typically exaggerated horizontal beam motion [2]. Consequently, in addition to the excellent base stability of the orbit, a “not-so-slow”, or even better, a sophisticated fast orbit feedback (FOFB) provides operational head-room and improved experimental capabilities.

IMPLEMENTATION STATUS

Two Phase Approach

The introduction of a FOFB system at BESSY has been split into two phases [3]. In a first functional set-up the worn out slow corrector power supplies have been replaced by fast modern devices. Express data lanes have been set up, collecting the 600 Hz parallel read-out of the old multiplexed beam position monitors (BPM) and distributing the corrector set-point on a dedicated reflective memory. The existing CAN bus attached power supply controllers could be utilized by a custom set point transmission, bypassing EPICS slow controls on dedicated CAN segments configured for data rates up to 200 Hz.

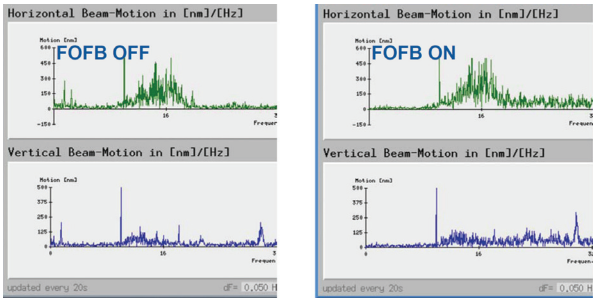

Figure 1: Simplified operators views with and without FOFB. In the current state the FOFB is most effective in the low frequency part (below 10 Hz booster line) of the beam motion spectrum.

From this set-up a possible follow-up phase II foresees a full replacement of the BPMs by fast, precise digital BPM units, an appropriate data and trigger distribution network as well as suited fast power supply controllers.

Phase I - Current Standing

The phase I implementation has been completed in mid 2012. System tests showed, that running the existing hardware near specification limits, a robust set-point throughput at 150 Hz with acceptable jitter can be achieved, allowing for a 4x averaging of the BPM readings. Thus, with proper control loop adjustments and additional fine-tuning, a system bandwidth of 30-40 Hz seems feasible.

Due to a lack of commissioning opportunities the system had to go into operation “raw”, i.e. as set up and assembled. Further developments targeted robustness and reliability, but the refinements of the control loop are still missing. In this state the clear improvements <10 Hz (see Fig. 1) are already a success. Additional improvements of the system bandwidth beyond 10 Hz are subject of current research.

OPERATIONAL ASPECTS

Caveats

The exclusive corrector access in “FOFB enabled” or “FOFB active” mode creates delicate operational constraints: feed-forward compensations (slicing bump clo-

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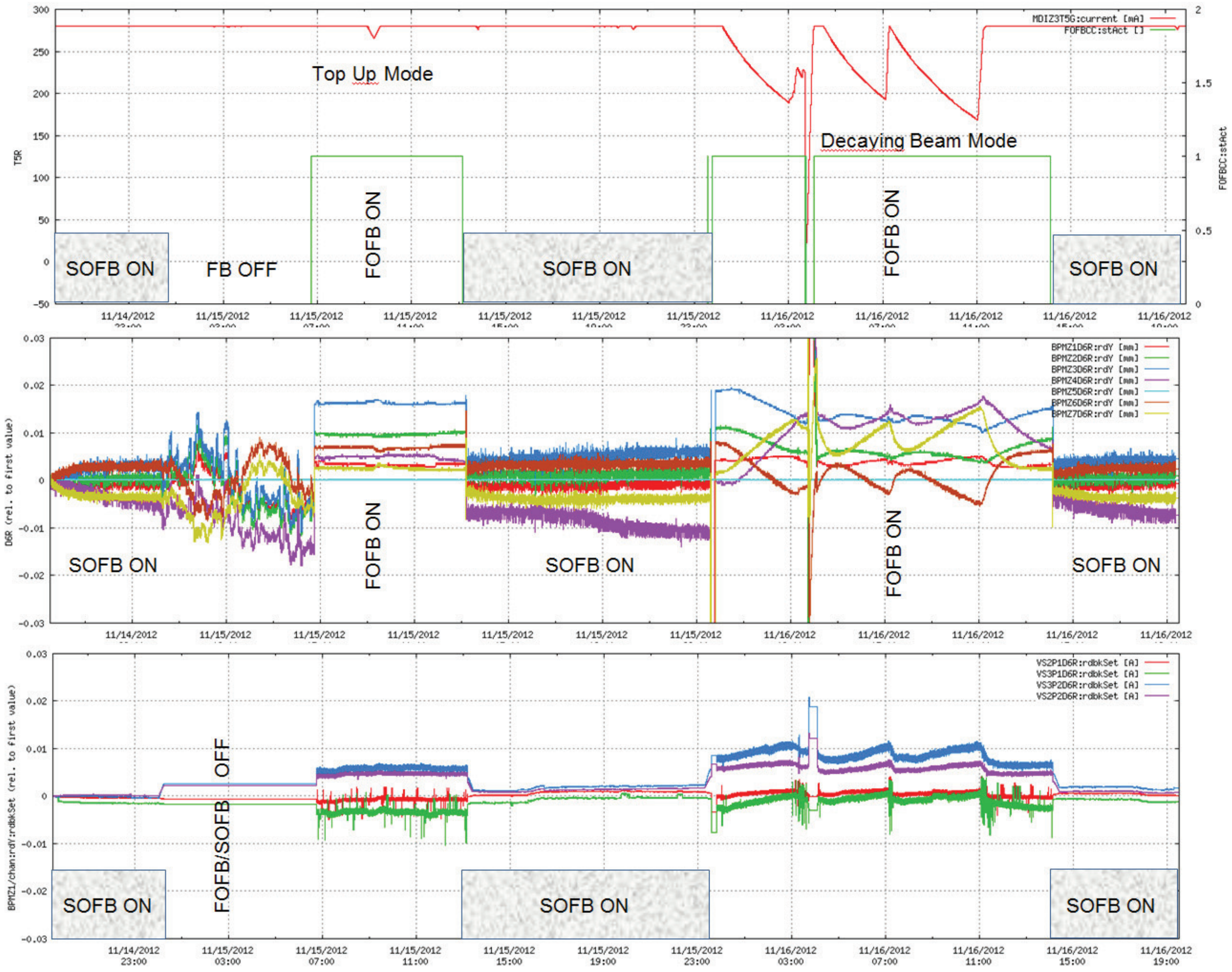

Figure 2: Sketch of the vertical orbit stability for the different combinations of SOFB/FOFB and top-up/decaying beam mode. **Top:** Beam current (red) and regions of all FB off, SOFB/FOFB on. **Middle:** BPM data of one sector showing the remaining beam motion in top-up mode for SOFB-only, FB off, as well as FOFB on. In addition the well known beam wander for decaying beam is clearly visible even with FOFB on. **Bottom:** Increased regulation activities of the correctors in the same sector in FOFB mode, compared to the SOFB case.

sure, wave length shifter field changes), formerly easily handled by offset values to the EPICS slow control setpoints, as well as save/restore or application program activities now require new operational procedures.

Top Up Operation

FOFB has been put into operation in parallel to the introduction of top-up as the new standard operation mode. The latter additionally stabilizes the beam on time scales connected to thermal equilibrium, that is at least helpful in mitigating any possible DC or beam wander problems of the FOFB (see Fig. 2).

General Behavior

Despite the differences in the slow and fast BPM data acquisition the "seamless" switching between SOFB and FOFB is feasible without specific provisions: resulting orbit jumps are on the few or even sub- μm level with negligible effect on the usable beam. Integration into the operators user interface features the same look and feel for both the SOFB and the FOFB.

For the path length correction it was originally planned to integrate the RF frequency into the horizontal response matrix and minimize the average horizontal corrector strength in the SVD calculation at each correction step, a method successfully applied in the SOFB.

Fast delivery of set-points to the master oscillator has to use the analog input. Here noisy frequency requests could cause phase jitter jeopardizing the required injection efficiency. As a measure of precaution a much simpler approach has been installed first: the appropriate RF frequency change is calculated from the excess average strength of the horizontal corrector families, according to previously observed relations [4], and "cautiously" applied (special care is taken to avoid frequency correction right at the injection shot).

Table 1: Integrated rms beam motion (0.02-300 Hz) with and without FOFB in its present status, comparison with 10% beam stability target in brackets (bandwidth ∼ 10 Hz). See R. Bartolini [5] for a facilities overview.

Mode	Horizontal	Vertical
FB OFF	$4\mu m(25\mu m)$	$1.5\mu m(2.5\mu m)$
300 mA Hybrid	$5.5\mu m(25\mu m)$	$3\mu m(2.5\mu m)$
13.5 mA SB	$9\mu m(25\mu m)$	$5\mu m(2.5\mu m)$
100 mA low-α	$9\mu m$	$4\mu m$
15 mA low-α	$14\mu m$	$7\mu m$

Exception Handling

Currently software interlocks on major deviations guarantee stable operation of the FOFB. A fast, hardware beam loss trigger attached to an extra BPM unit has been prepared, but was not needed so far. The FOFB runs well constrained with literally no built-up of DC effects - both short term and in multi-week operation.

PERFORMANCE

With respect to beam stability, operational robustness and additional capabilities in specific operational modes the FOFB behaves as expected. Problems of transients disappeared, basically no FOFB induced problems have been encountered, beside teething problems most of the few FOFB outages have been caused by non-FOFB component failures or mishandling.

Beam Motion

The multi-year, long-term operational reference of the 100ms averaged slow orbit data is maintained by the FOFB, now additionally kept constant to the bit resolution level, see Fig. 2 for details. Up to the 10 Hz booster line orbit perturbations are practically extinguished. On fast beam motion analyzers it can be seen, that even the tail of the horizontal injection shot perturbation is damped.

But beyond 10 Hz additional noise is visible, that needs to be understood and is currently under investigation. This is also evident in the resulting integrated rms beam motion, see Table 1, which is far from satisfying. Probably it has to be accounted to deficiencies in the set point data synchronization that need to be eliminated – even if some 2 μm originate from the 10 Hz booster synchrotron.

Operational Modes

The most obvious improvements in standard user mode (300 mA hybrid) are related to transient imperfections: due to the asynchronous set-point forwarding the femto second slicing beam separation bump could only be advanced at very low speed to enable the SOFB to keep the perturbation within 10 μm. Now with FOFB active it can be set at a speed of 20 μrad/s without measurable beam disturbance.

In single bunch (SB) decaying beam mode the huge dynamic range is the major challenge for the BPM measurement units. Now with top-up operation this issue lost relevance, the BPM signals are still more noisy compared to multi-bunch mode, but the FOFB is fully functional.

Figure 3: Orbit stability, two complete weeks of low-α operation. Light colors, noisy lines: Oct. 2012, SOFB only. Dark colors, smooth lines: May 2013, FOFB. Green: average position[-0.02 mm,0.02 mm], blue: rms deviation [0.01 mm,0.05 mm], red: alternating beam currents 100 mA high intensity/15 mA non-bursting mode.

In low-α mode the FOFB opens a new regime of horizontal beam stability, see Fig. 3. Both with respect to beam centering (average position) and orbit deviations (RMS) even at currents as high as 100 mA and unlimited changes of insertion device gaps the FOFB controlled orbit behaves as benignant as in standard user mode.

SUMMARY

Even the “raw”, unrefined status of the FOFB phase I system provides significant improvements: transients are efficiently suppressed, the over-all operability and reliability is convincing. Beam motion in the frequency range <10 Hz is reduced substantially.

Objective evidence as well as clear valuation of the achievements of the present FOFB set-up on user experiments is not easy to get and still pending. Accordingly the possible benefit of a FOFB phase II for the experiments performed at BESSY is not assessable yet.

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