BUNCH-BY-BUNCH FEEDBACK AND DIAGNOSTICS AT BESSY II

A. Schälicke, F. Falkenstern, R. Müller, HZB, Berlin, Germany

Abstract

At the light source BESSY II new digital bunch-by-bunch feedback systems [1] have been put into operation in January 2013, replacing the existing analog as well as the obsolete digital systems. From the first days of operation the new system successfully suppresses transverse and longitudinal beam instabilities in wide range of machine parameters. The system offers also many new diagnostics opportunities. In this contribution first operational experience, the developed data analysis techniques and experimental data will be presented.

INTRODUCTION

BESSY II is a 3rd generation light source, with a beam energy of 1.7 GeV. Typical beam parameters are listed in Tab. 1. In the past year the facility has seen an number of improvements in order to react to steadily increasing user requirements concerning beam quality and beam stability. Since September 2012 it is operated in top-up mode, using the full-energy injector synchrotron to continuously replace lost electrons during user operation [2]. In addition a faster orbit feedback has been commissioned successfully reducing beam orbit disturbances up to 10 Hz [3].

In January 2013 new digital bunch-by-bunch feedback (BBFB) systems [1] have been put into operation, replacing the existing analog as well as the obsolete digital controllers, while reusing established amplifiers and transverse and longitudinal kickers [4, 5, 6]. From the first days of operation the new system successfully suppresses transverse and longitudinal beam instabilities in wide range of machine parameters. The system offers also many new diagnostics opportunities, these include the analysis of instability modes, measurement of the feedback loop gain, and determination of the transfer function. In addition the analysis of the input data stream allows a passive determination of machine properties like betatron and synchrotron frequencies as well as the longitudinal phases for every bunch.

Table 1: BESSY II Beam Parameters

Parameter	**Value**
Energy	1.70 GeV
Total beam current I	300 mA
Circumference $2\pi R$	240 m
RF Frequency f_{RF}	499.6 MHz
Harmonic number h	400
Synchrotron frequency f_s	4.4 kHz
Horizontal betatron frequency f_x	1060 kHz
Vertical betatron frequency f_y	928 kHz

The integration of external triggers permits the analysis of post-mortem data and the characterization of beam-loss events, as well as monitoring of the injection process.

FEEDBACK OPERATION

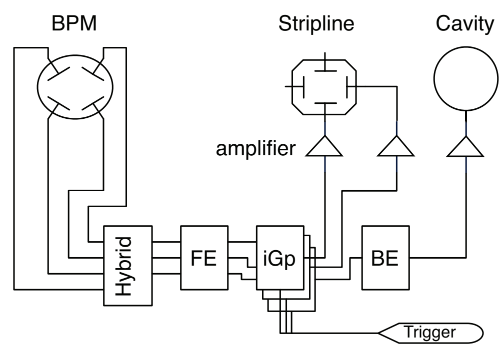

Figure 1: Bunch-by-bunch feedback overview: beam position monitor (BPM), Hybrid network, front-end receiver (FE), 12-bit integrated giga-sample processor (iGp12), back-end electronics (BE), HF power amplifier, kicker stripeline/cavity.

A schematic view of the updated configuration of the bunch-by-bunch feedback systems is given in Fig. 1. The transversal and longitudinal beam signals are derived from the 4 pickups of a beam position monitor (BPM) using a hybrid network. An analog front-end receiver (*FBE-LT* [1]) is used to adjust amplitude and phase of the 1.5 GHz signal from the hybrid network and converts the input to the baseband. The central component of the feedback system consists of three digital *iGp12* processing units, with fast 12-bit ADC (operating at 500 MHz), 32 tap FIR-filter and DAC [1]. For the transverse feedback the *iGp12* is directly connected to the power amplifier driving a 1 ns stripline. The DAC signal for the longitudinal feedback is used to modulate the carrier frequency of 1.5 GHz in the back-end part *FBE-LT* unit. A dedicated longitudinal kicker cavity is driven by a 4-port power amplifier [5].

The *iGp12* unit allows storing of bunch positions for all 400 buckets for up to 32000 turns (ca. 25 ms). In order to fully exploit the diagnostics capabilities of this system two external triggers are connected. A fast beam-loss signal is used to trigger data acquisition on unexpected beam-loss events. A dedicated memory region on the *iGp12* stores 480 turns (ca. 0.4 ms) prior to the beam-loss event. An injection trigger signal is used to study the impact of injection process on the stored beam.

ISBN 978-3-95450-127-4

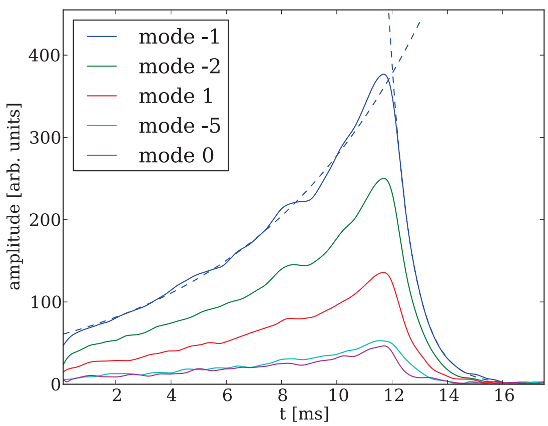

Figure 2: Grow/damp measurements in the horizontal pane at BESSY II in nominal operation mode.

Commissioning

The new digital feedback system has been commissioned during the first week of 2013. The commissioning procedure included: the determination of front-end phase and attenuation, ADC and DAC timing, back-end phase and the filter coefficients. Due to tight time constrains all three systems had to be installed within a couple of days. Special emphasis was put to the adjustment of the DAC output to the response function of the power amplifier. The iGp12 unit includes two shaper coefficients, extending the 2 ns pulse by weighted contributions to preceding and following pulses. By careful optimization of shaper coefficients the bunch-to-bunch isolation could be improved from 12 db to 18 db leading to an optimal utilization of the amplifier bandwidth. The procedure is documented in [7].

From its first day of operation the new feedback system showed excellent performance. At BESSY II coupled bunch instabilities occur under present operation conditions mainly in the horizontal plane [8], as illustrated in Fig. 2 with a typical grow/damp measurement. The dominant mode in this measurement is “-1” corresponding to a *resistive wall instability*. The measured grow and damp times are 6.5 ms and 0.8 ms resp.

The feedback also demonstrated good damping capabilities in more challenging conditions, like reduced chromaticity in both planes, horizontal and vertical, or modified bunch patterns.

BEAM DIAGNOSTICS

A big advantage of a digital system is the capability to store and analyze the input data (see e.g. [9, 10]). This includes the possibility to passively measure tune spectra of the complete beam and also of a single buckets. Due to the specific bunch pattern at BESSY (see Fig. 3), different buckets exhibit different tune spectra. An example is given in Fig. 4. Obviously there is a large difference between multi-bunch area (bucket 258–400 and 1–146) and

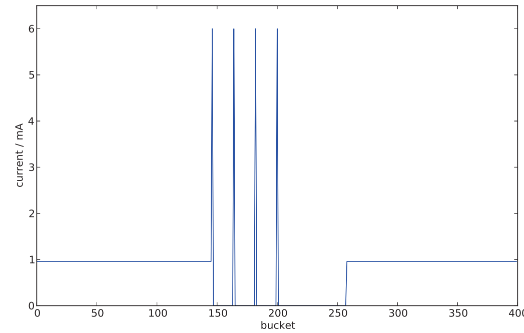

Figure 3: Typical hybrid-mode bunch pattern for BESSY II storage ring.

high-current bunches (bucket 147,165,183 and 201). In addition the visible shift in the side bands indicates a change of the synchronous phase over the multi-bunch train, see Fig. 5. The current dependence can be studied explicitly during dedicated commissioning times. Figure 6 gives an example of this kind of studies. It is shown that with increasing current the frequency of the dominant resonance is increased in steps of 4 kHz.

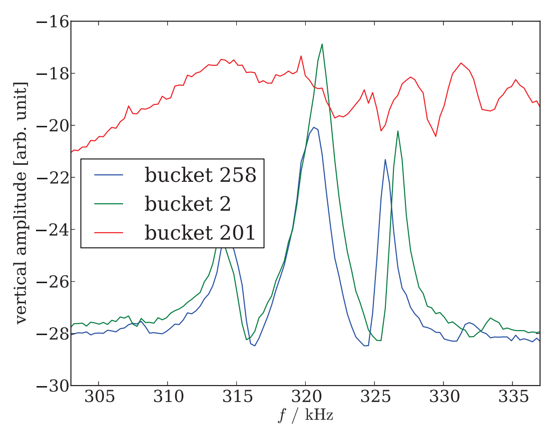

Figure 4: Vertical tune spectrum as measured by the BBFB system for two bunches in the multi-bunch train (bucket 2 and 258), and one high current bunch.

Instabilities

The primary aim of BBFB system is the mitigation of coupled-bunch instabilities [8]. The ability to measure and quantify the feedback strength via grow/damp measurement (Fig. 2) is essential in order to guarantee stable operation at all times. In addition the measurements of unstable beam conditions (i.e. feedback off state) can help in understanding the origin of instabilities and their mitigation. In Fig. 7 a rare longitudinal beam instability is depicted. This is a narrow resonance at 6.63 kHz. Its is only observed under certain beam conditions, and only affects a number

ISBN 978-3-95450-127-4

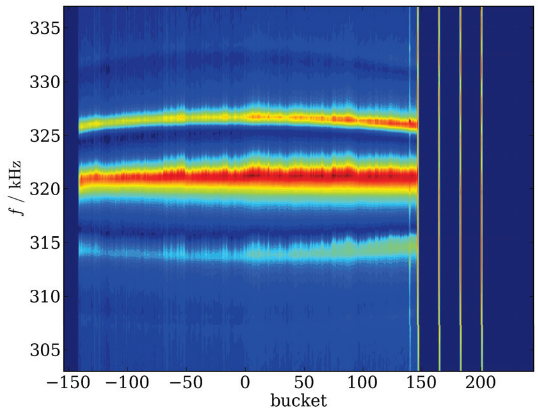

Figure 5: Vertical tune spectrum for all buckets. Buckets above index 250 are mapped to the negative axis in order to show the multi-bunch area continuously.

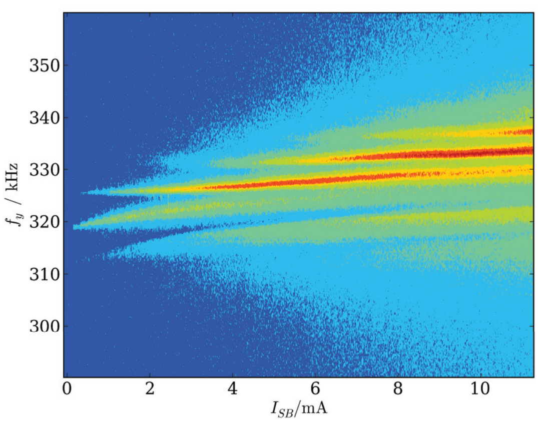

Figure 6: Vertical tune spectrum vs. single-bunch current.

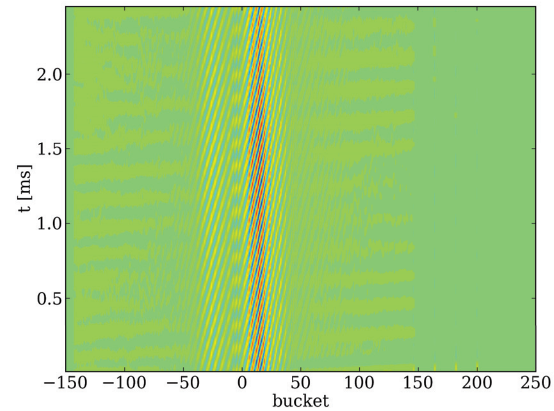

Figure 7: Longitudinal instability affecting the middle of the bunch train, $f = 6.63$ kHz.

of bunches in the middle of the bunch train. The origin is not yet understood, but the feedback system is well able to control this instability.

Post-Mortem Data

The feedback system at BESSY II is connected to two external triggers. The first is connected to a fast beam-loss monitor signal, which is used to trigger data acquisition of unexpected beam-loss events. Fig. 8 illustrates the capabilities to characterize beam-loss events in very different time domains: 30 ns (unwanted kicker pulse), 90 μs (RF failure triggered by a hardware interlock signal), and 0.8 ms (quadrupole failure). Thus, the feedback system is now an important instrument for the diagnosis of otherwise unclear beam-loss events (i.e. no clear hardware failure).

Injection Studies

Since September 2012 the BESSY II storage ring is routinely operated in top-up mode, using the full-energy injector synchrotron to continuously replace lost electrons during user operation. Due to the constant heat load on mechanical and optical components in combination with an increased average intensity the quality of the photon beams is superior to the operation in decaying mode. Since BESSY was not designed for operation in top-up mode, a number of safety measures had to be put in place. These include an interlock for the injection efficiency to be above 90%, limits on minimal injection interval to be 10 s, and a life-time requirement of at least 5 hours.

The BBFB system is a useful tool to monitor the effects of the injection procedure on the stored beam [11]. Therefore a dedicated trigger signal is provided. Fig. 9 illustrates the induced beam disturbances during a typical injection process in the vertical plane. The observed orbit jitter is quite large. The aim is to use the data from the feedback system to reduced the impact on the stored beam while keeping the injection efficiency above 90%.

SUMMARY

Beginning of 2013 a new completely digital bunch-by-bunch feedback system was put into operation. From the very first day the system enabled BESSY to be operated with chromaticities near zero with the clear benefit of improved lifetime (∼1h) since all emerging instabilities have been reliably suppressed by the newly well tuned BBFB-systems within a wide range of beam conditions. The capabilities to store and analyze the input data adds new diagnostics capabilities to the BESSY facility. The incorporation of these new features into the standard operation procedure is topic of current research.

ACKNOWLEDGMENT

Special thanks goes to Dmitry Teytelman (Dimtel Inc.) for his outstanding support and useful advise in any aspect of the feedback operation and data analysis. The authors also like to express thanks to the colleagues at BESSY II, without whom this work would not have been possible.

ISBN 978-3-95450-127-4

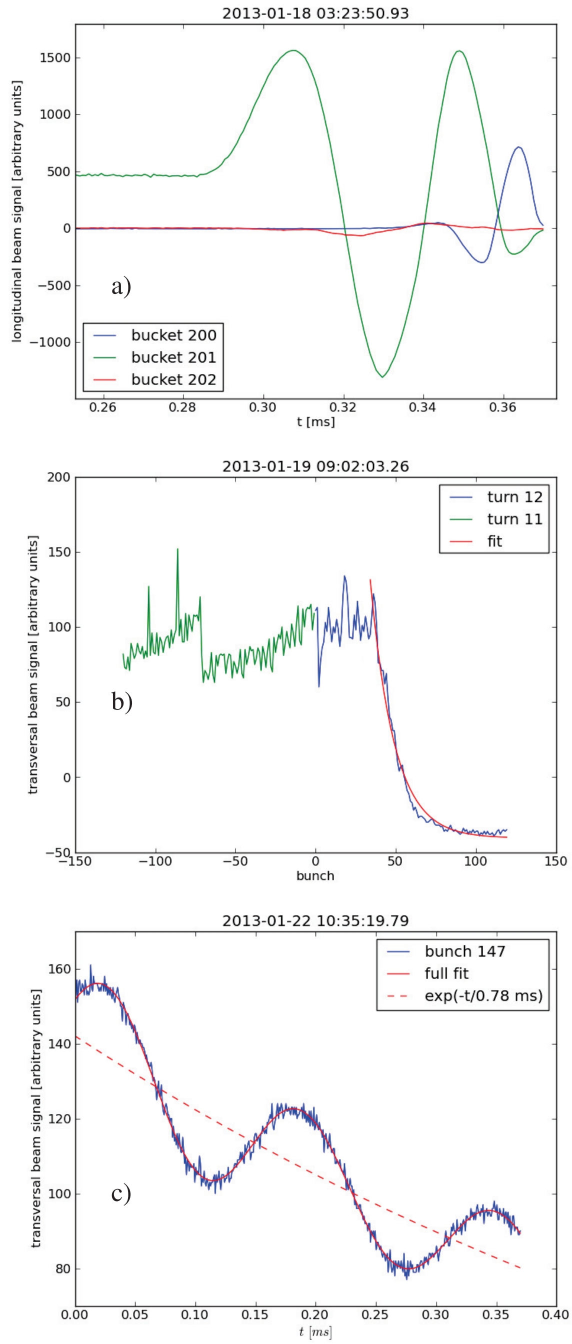

Figure 8: Post-mortem data of beam-loss events: a) RF failure triggered by a hardware interlock signal, b) unwanted kicker pulse, c) quadrupole failure.

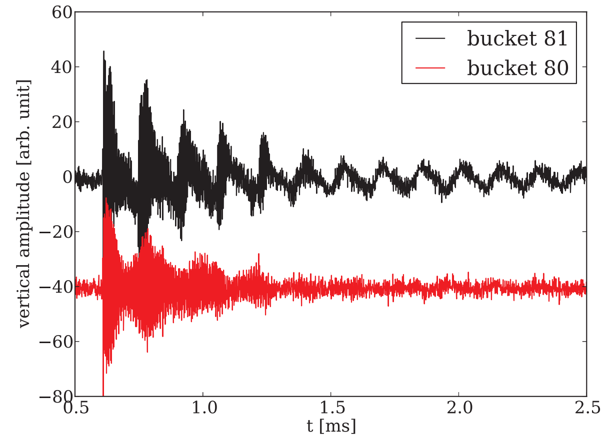

Figure 9: Vertical beam disturbances during top-up injection for the injected bunch (bucket 81) and a neighboring bunch (bucket 80).

REFERENCES

[1] Dimtel Inc. `http://www.dimtel.com`

[2] P. Kuske, et al., "Preparations of BESSY for Top-Up operation", EPAC 2008, Genoa, WEPC037, (2008), `http://www.JACoW.org`

[3] R. Müller, et al., "Fast Orbit Feedback at BESSY-II: Performance and Operation Experiences", IPAC 2013, Shanghai, WEPME002, (2013), `http://www.JACoW.org`

[4] S. Khan, et al., "Commissioning of the BESSY-II Longitudinal Feedback System", EPAC 2000, Vienna, Austria, WEP3A06, (2000), `http://www.JACoW.org`

[5] S. Khan, et al., "Longitudinal and Transverse Feedback Kickers for the BESSY II Storage Ring", PAC 1999, New York, USA, TUA33, (1999), `http://www.JACoW.org`

[6] S. Khan, T. Knuth, "Performance of Bunch-by-Bunch Feedback Systems at BESSY-II", PAC 2001, Chicago, USA, TPPH087, (2001), `http://www.JACoW.org`

[7] D. Teytelman, "Optimization of Bunch-to-Bunch Isolation in Instability Feedback Systems", IBIC 2013, Oxford, UK, MOPC26, (2013). `http://www.JACoW.org`

[8] S. Heifets, D. Teytelman, "Beam-Ion Instability", Phys.Rev. ST AB 8 (2005) 064402.

[9] M. Höner, et al., "Beam Diagnostics by Using Bunch-by-Bunch Feedback Systems at the Delta Storage Ring", IPAC 2013, Shanghai, MOPME008, p. 485, (2013), `http://www.JACoW.org`

[10] C.-Y. Yao, et al., "Application of Z-Transform to Noise Response Modelling of a Bunch-by-Bunch Feedback System", IPAC 2013, Shanghai, WEPME056, p. 3058, (2013), `http://www.JACoW.org`

[11] D. Teytelman, F.-J. Decker, "Injection Diagnostics using Triggered Bunch-by-Bunch Data Acquisition", DIPAC 2007, Venice, Italy, WEPC07, (2007), `http://www.JACoW.org`

ISBN 978-3-95450-127-4