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STATUS AND PERFORMANCE OF BUNCH-BY-BUNCH FEEDBACK AT BESSY II AND MLS*

A. Schälicke†, P. Goslawski, M. Ries, M. Ruprecht, HZB, Berlin, Germany

Abstract

Bunch-by-bunch feedback systems provide an important component in the reliable operation of electron storage rings. Modern digital bunch-by-bunch feedback systems allow efficient mitigation of multi-bunch instabilities, and at the same time offer valuable beam diagnostics. In this contribution, setup and performance of the bunch-by-bunch feedback systems at BESSY II and the MLS are presented. Longitudinal and transverse instabilities are studied under different machine conditions. The developed data analysis techniques and experimental measurements are discussed.

INTRODUCTION

BESSY II is a 3rd generation light source, with a beam energy of 1.7 GeV. The maximal beam current is 300 mA. Since September 2012 it is operated in top-up mode, using the full-energy injector synchrotron to continuously replace lost electrons during user operation [1]. The Metrology Light Source (MLS) is a dedicated low-energy storage ring for metrology with synchrotron radiation [2]. It can also be operated in low-α mode for experiments with coherent synchrotron radiation. Typical beam parameters of standard user operation of both machines are listed in Table 1.

Table 1: Typical Beam Parameters

Parameter	BESSY II	MLS
Energy	1.70 GeV	629 MeV
Max beam current I	300 mA	200 mA
Circumference $2\pi R$	240 m	48 m
RF Frequency f_{RF}	499.6 MHz	
Harmonic number h	400	80
Synchrotron frequency f_s	4.4 kHz[1]	106 kHz
Horiz. betatron frequency f_x	1060 kHz	1115 kHz
Vert. betatron frequency f_y	928 kHz	1450 kHz

[1] The synchrotron frequency is reduced by Landau cavities from its nominal value of approx. 8 kHz.

For the reliable operation of the machine, the mitigation of coupled-bunch instabilities is essential. Both machines are equipped with digital bunch-by-bunch feedback (BBFB) systems [3, 4]. These systems are able to suppress transverse and longitudinal beam instabilities in a wide range of machine parameters, while offering excellent diagnostics opportunities [5–7].

* Work supported by BMBF and Land Berlin.
† andreas.schaelicke@helmholtz-berlin.de

BESSY II

The primary aim of BBFB system is the mitigation of coupled-bunch instabilities (CBI). The ability to measure and quantify the feedback strength via grow/damp measurement is essential in order to guarantee stable operation at all times.

Instabilities

At BESSY II coupled bunch instabilities occur under present operation conditions mainly in the horizontal plane. The dominant modes are typically low frequency modes, corresponding to a *resistive wall instability*.

For the measurement shown in Fig. 1, the horizontal chromaticity has been reduced form its nominal value of about 3 to approximately zero to evoke instabilities. At an increased feedback gain, the measured growth time is 1.0 ms and the damp times of the strongest mode is 0.25 ms (with a range from 0.16 ms to 0.41 ms for other modes).

In the longitudinal plane, the instabilities are typically weaker and greatly depend on the machine setting, such as the tuner position of the Landau cavities. In this measurement, the dominant modes are located around CBM 360. The measured damp time is 0.75 ms, while the growth time was 170 ms, see Fig. 1 right panel. The damp time was somewhat optimized by increasing the output gain by a factor of 8 compared to typical operation of the feedback. This shows that a damping time of just a few synchrotron periods is achievable, which is of particular importance for the proposed upgrade BESSY-VSR [8, 9].

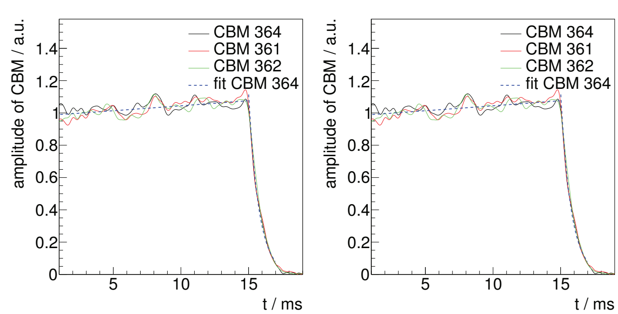

Figure 1: Grow/damp measurements at BESSY II. Left: Measurement in the horizontal plane during operation with near zero chormaticity. Right: Measurement in the longitudinal plane at nominal beam conditions.

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

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Transient Beam Loading

The nominal bunch pattern of BESSY II consist of

- a multi-bunch section of approx. 300 bunches,
- an isolated camshaft bunch in the middle of the bunch gap with a current of ~4 mA,
- and three so-called *slicing* bunches located in the middle of the multi-bunch train (or at the beginning of ion-clearing gap) with a current of 4 mA each.

These asymmetries in the fill pattern lead to transient beam loading in the fundamental and harmonic cavities, and thus to variations of synchronous phase and frequency over the bunch train. With the digital BBFB system it is easy to measure both synchronous phase and frequency for every bunch in the machine, which makes it possible to study the effects of transient beam loading. This is of particular importance in the context of the currently discussed upgrade option, called BESSY-VSR [8].

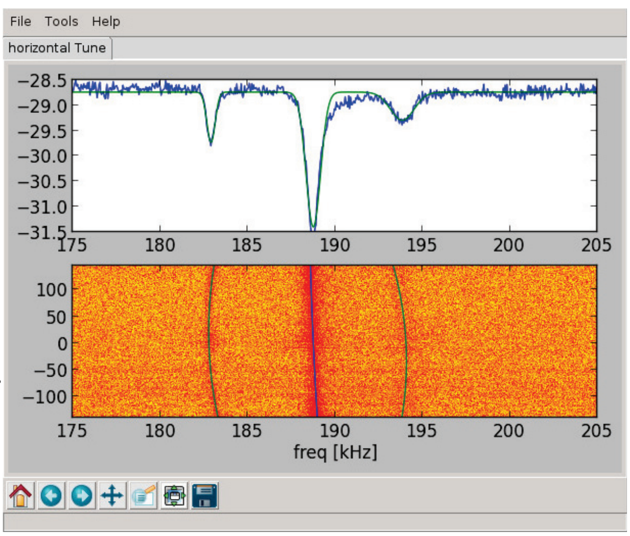

Figure 2: Control panel of bunch-by-bunch tune measurement in the horizontal plane. Top part shows averaged spectrum over all bunches, bottom part shows dependence over the multi-bunch part of the fill pattern. The side bands reveal a variation of synchrotron frequency over the bunch train due to transient beam loading.

For the continuous monitoring of the transient beam loading effects, the feedback system [3] is operated in the streaming mode. Therefore each unit captures bunch-by-bunch data samples of 20 ms length with a rate of 2 Hz. These data are transferred to a postprocessing computer with a data rate of 40 MB/s. The determination of bunch-by-bunch synchrotron frequencies is performed by averaging the measured tune spectra over a few seconds. Figure 2 shows an example of a horizontal tune measurement. The dependence of the synchrotron frequency on the bunch number is clearly visible in the side bands. The picture is particular sensitive to the tuning of the Landau cavities.

The bunch-by-bunch variations of synchronous phase is a default observable of the longitudinal BBFB system, since a well controlled phase is essential for stable feedback operation. The observed phase gradient is 80 ps over the bunch train, see Fig. 3. The results are in agreement with predictions.

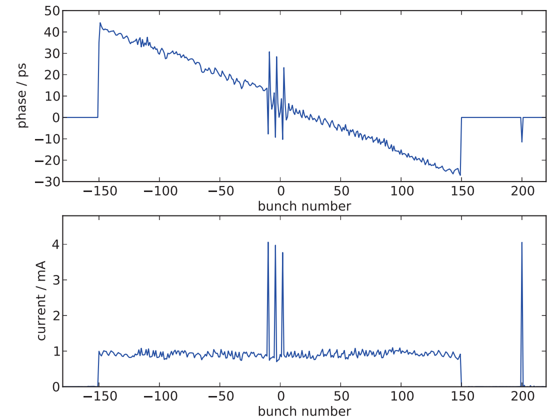

Figure 3: Top: Synchrotron phase gradient due to transient beam loading measured by the feedback system. Bottom: Typical hybrid-fill pattern.

MLS

The MLS is a ramped synchrotron, with an injection energy of 105 MeV and an final energy of 629 MeV. Other parameters are listed in Table 1. Due to the smaller circumference, the MLS is usually operated with a homogeneous fill pattern, i.e. without ion-clearing gap. This makes the machine more susceptible to ion-effects.

Instabilities

At the MLS, both transverse planes are typically stable, thus the use of the BBFB systems is not required. In the longitudinal plane, the coupled bunch instability is successfully controlled by the longitudinal BBFB. It is driven by higher order modes of the accelerating cavity. For positive momentum compaction, the dominating mode is CBM 43. Figure 4 shows the results of a current scan performed at the MLS with open feedback loop. The current was reduced in steps of 1 mA from 185 mA to zero and data from the BBFB was taken each time. The horizontal gap in the measurement is explained by a partial beam-loss during scraper operation. The threshold current can be read out easily at roughly 10 mA. Other CBMs become visible only at approximately 100 mA. If the momentum compaction is set to a negative value with an absolute value equal to the standard user setting, the dominating mode is CBM 37. This is in agreement with the expectation of the momentum compaction changing the sign of the growth rate. In addition it suggests that the width of the impedance driving the instability is larger than the synchrotron frequency, since the CBM 43 and CBM 37 appear as upper and lower sidebands of the same revolution harmonic.

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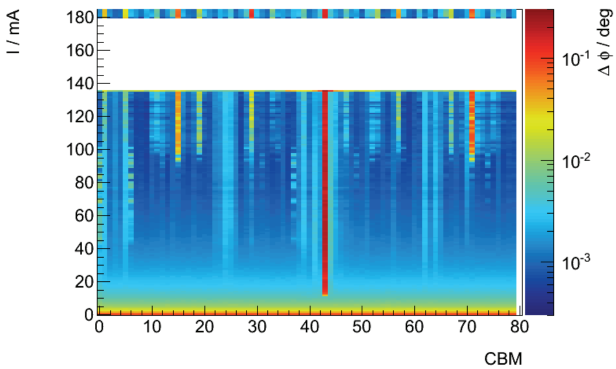

Figure 4: Measurement at the MLS showing the amplitude of the longitudinal coupled bunch modes vs. the total current stored in the ring. The dominating CBM 43 can clearly be seen. The horizontal gap is caused by a partial beam-loss during the scraper operation.

Beam-loss Data Analysis

Recently, emphasize has been put to the development of a fast beam-loss data acquisition. Therefore a logarithmic current detector is connected to a diagnostic stripline. Due to the usually very homogeneous fill pattern, a good sensitivity of 1-2 mA, and at the same time fast response times of only a few turns could be achieved. The ability to capture and analyse bunch-by-bunch beam-loss data is very valuable for the determination of the cause of beam-loss events. At BESSY II a similar system is in operation, capturing events with complete beam-loss, while covering a time domain of few nano seconds to a couple of milliseconds, see [4]. Figure 5 shows an example of a captured partial beam-loss event at the MLS, where the current dropped from 190 mA to 177 mA. The bunch-by-bunch data indicate that the beam-loss was initiated by a low frequency *resistive wall instability* in the vertical plane. After 3 ms the horizontal plane became unstable with higher order modes (CBM 49), leading to the beam-loss 2 ms later and a uneven fill pattern. The longitudinal instability (CBM 43) is likely caused by a shift in the synchrotron phase due to the abrupt change in beam current.

The detailed analysis of this kind of data is involved and constitutes an ongoing project. The aim is to deepen the understanding of instabilities at the MLS. The development of a system with similar sensitivity in order to capture partial beam-loss events at BESSY II is subject of current research.

CONCLUSIONS

Digital feedback systems at BESSY II and the MLS exhibit excellent performance also in difficult machine conditions. The measured damping times will be of special importance for further upgrade scenarios. The feedback systems also offer new diagnostics capabilities. This includes measurements of transient beam loading effects, and capture of bunch-by-bunch beam-loss data. Current work concentrates on exploiting these diagnostics, and the integration in routine operation of BESSY II and the MLS.

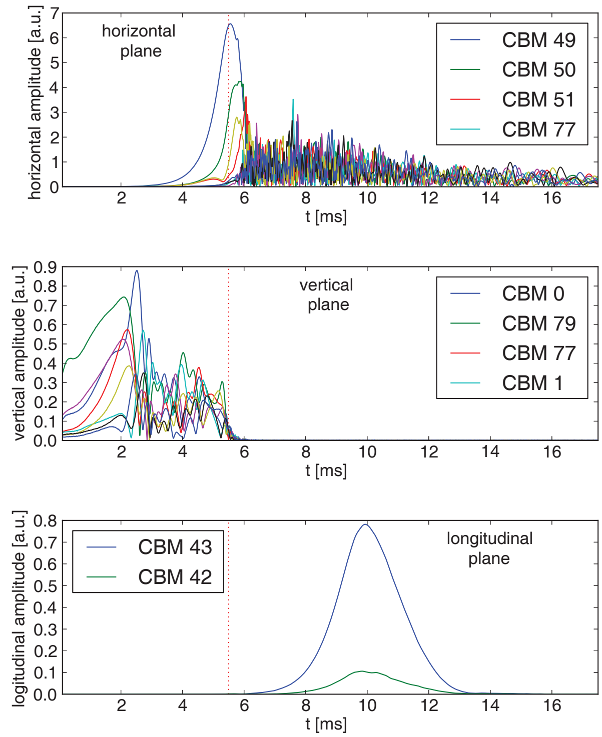

Figure 5: Captured partial beam-loss event at the MLS showing CBIs in all three dimensions. The beam-loss time is indicated by a vertical dotted line.

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