ACCURATE BUNCH RESOLVED BPM SYSTEM

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Abstract

Operation of storage rings with multiple beams stored on different closed orbits as well as beam dynamics studies for complex fill patterns require accurate and stable measurement of the beam position for each individual bunch [1].

Analog BPM systems are usually optimized for measuring the closed orbit averaged over all buckets and many turns. Therefore no information about the position of individual bunches is supplied. The new bunch resolved BPM electronics, currently under development at HZB, is based on the analysis of RF-signals delivered by a set of four stripline / pick-up electrodes. These signals in combination with a low jitter master clock and commercially available DAQ cards allow to measure the bunch-resolved beam position with a resolution of a few micrometer.

Experiments performed at BESSY II and MLS demonstrate the performance of the setup and will be discussed.

INTRODUCTION

HZB operates two electron storage ring based light sources named BESSY II and MLS [2]. BESSY II is operated at an electron energy of 1.7 GeV with a maximum current of 300 mA distributed to 400 buckets. Whereas MLS is operated at 629 Mev with a current of up to 200 mA stored in 80 buckets. The main RF cavities of both rings operate at a frequency of about 500 MHz providing a bucket spacing of approximately 2 ns.

Different fill patterns and optics modes (i.e. low alpha) allow our users to work with optimal synchrotron light conditions at the beamlines. This flexibility of beam conditions leads to high requirements in the field of beam diagnostics.

For measurement of the average orbit the analog BPM system is used. The major advantage of this system is a high position resolution of about 1 micrometer for currents between 1 mA und 300 mA. Due to averaging, no external timing is required. The disadvantages is that there are no information about the position for each individually bunches and turns. In future upgrades of both storage rings this information may become necessary, therefore an alternative approach has to be explored.

DIAGNOSTICS REQUIREMENTS

What are the main challengers of bunch-resolved BPM diagnostic systems for the storage ring?

A) Capture the position of each individual bunch with an accuracy in the µm range.

B) Measurement results of the bunch position don't depend on temperature drifts.

C) The measurement data has to be linear with the orbit changes.

D) Large dynamic range of bunch currents from 10 µA to 10 mA.

E) The synchronous phase shift over the full fill pattern and small changes of beam phase with respect to the master clock should have no influence.

F) Cross talk between neighboring bunches due to ringing or reflections on the scale of 2 ns should be minimized.

G) Measurement results of the bunch position don't depend on orbit bumps (large displacements).

The following solution was found meeting all requirements.

A) A 14-Bit ADC with an analog BW of more than 500 MHz was chosen. The principle of under sampling allows to achieve a very good amplitude resolution. This technique is already being used in our fill pattern monitor “BunchView” [3].

B) The BPM signal will be multiplexed. So each of 4 signal channel has the same path of filter, amplifier and ADC. In other words only one active detector for all channels is used. This schematic has very good results in relation to thermal drift and aging of electronic parts.

C) A data acquisition card with a very linear 14 Bit ADC for a wide dynamic range of analog amplitudes is applied.

D) Linearity of the DAQ hardware will allow to apply normalization.

E) The approach of a sampling scope with 100 GHz is used for finding the maximum of the amplitude of the bunch signals.

F) A low pass filter (LPF) of about 750 MHz is applied to minimize the cross-talk to following bunches.

G) In the case of driving the orbit bumps it is important to have a good electrical separation between channels of the RF switch. The bad isolation between channels will be affected the X by change Y and vice versa.

The main component of the DAQ system is provided by using standard commercial equipment. A major advantage is the use of LabVIEW for controlling and

ISBN 978-3-95450-177-9

FPGA programming with straight forward implementation in the existing control system.

It shall be explicitly stated, that the presented approach is of bunch-by-bunch not turn-by-turn nature, i.e. averaging will be performed over multiple turns.

GENERAL SETUP

The basic layout of the system is shown in Fig. 1.

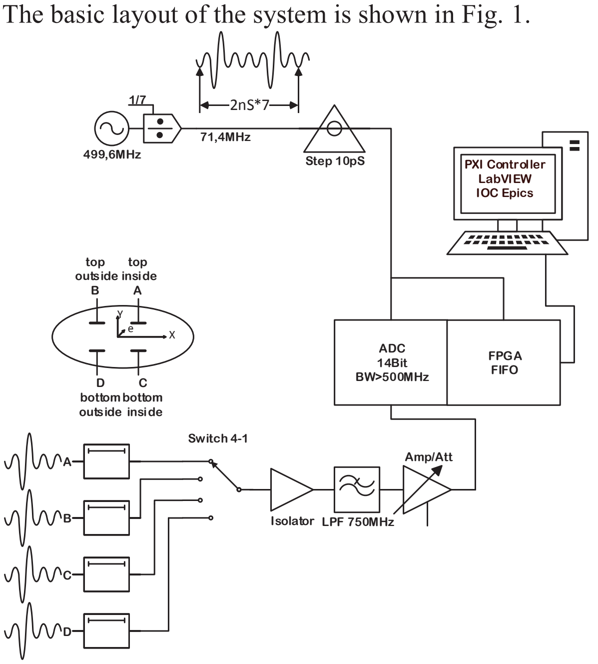

Figure 1: Block diagram of the bunch-resolved BPM system.

The signal induced from circulating electron bunches to striplines or button pickups will be adapted and connected to inputs of a RF multiplexer. It is important to connect the BPM pulse source and the input of switch connectors with high performance RF cable and with the minimum connect adapters to avoid the RF interference and thermal drifts between channels. In the case of RF reflections, the four to each other matched signals minimized the X, Y errors of the BPM measurement.

$X= [(A+C)-(B+D)]/(A+B+C+D)$

$Y= [(A+B)-(C+D)]/(A+B+C+D)$

The output of switch is connected to an isolator, it is a combination of attenuator and amplifier with a high directivity, defined as a difference between isolation and forward gains. So if there are impedance changes of filters or amplifiers or ADC do not influence the ideal out impedance of 50 Ohm of the RF multiplexer. Each of four BPM signal A, B, C, D has the same path of the RF detector. In the case of thermic drifts, no linearity of the detector (LPF, Amp, ADC) there are the same error for each channel.

The applied LPF has two functions. The first is the classical task of RF noise rejection. On the other hand, a special response pattern is generated with respect to the 2 ns bunch spacing. Therefore, the influence of a bunch signal to the next following bunch signal is minimized [3].

Different filters are applied for stripline and pickup detectors considering the different signal response.

The amplifier / attenuator matches the analog RF signal to the dynamic range of the ADC. For operation with high single bunch (SB) currents of up to 15 mA the signal has to be attenuated. Whereas small bunch currents, e.g. low alpha operation, require to amplify the signal.

The detected RF signal will be digitalized with the 14 Bit ADC and stored in the FPGA memory. In the first development stage we can average over 20 samples at BESSY II (400 buckets) or 100 samples at MLS (80 buckets) for each bunch while switching the RF multiplexer with 1 kHz.

The next steps will be to find a better agreement between the number of average and the switch frequency of the BPM system.

The master clock will be divided by factor of 7 and shifted with the digital delay to achieve a maximum amplitude, i.e. S/N ration. Therefore, the bunch-resolved BPM system samples every 7th bunch full fill pattern over 7 turns. The reduced sampling rate of 500 MHz/7 enables increasing the signal to noise performance of ADC and simplified the FPGA programming because of more relaxed timing demands.

In the case of phase drift of machine or phase bunch transients in the fill pattern it is possible to adjust the digital delay for the master clock. So a 5 bit of digital output of FPGA for control delay with 10ps steps is used. The available range of 320 ps (32x10 ps) is large enough to find the peak amplitude of the bunch's signal, as the synchronous phase transient at BESSY II is usually smaller than 200 ps. In addition, information about the bunch-resolved synchronous phase is extracted – see Fig. 2.

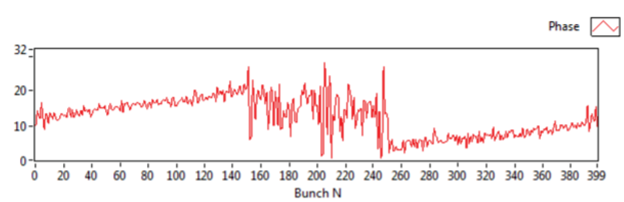

Figure 2: Longitudinal phase in units of 10 ps for a multi bunch fill induced by the gap at BESSY.

However, the additional sampling increases the computed time for the BPM data. The system is implemented in a NI PXIe chassis that includes an FPGA card with ADC, Switch card and a PXI Controller.

EXPERIMENTAL RESULTS

The first prototype of the system has been tested at both machines. The MLS features 80 buckets and is usually operated with a homogeneous fill pattern without gap.

ISBN 978-3-95450-177-9

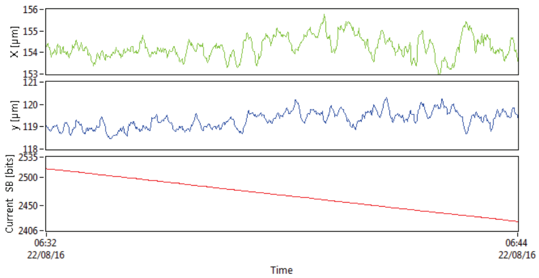

Figure 3: Position of one single bunch at MLS storage ring in decay mode.

For equally populated bunches a spatial resolution of better than 3 µm was achieved as shown in Fig. 3. Displacements of about 10 mm can be generated.

At BESSY II there is a complex fill pattern (bunch train of different intensity) with a gap and five strong SBs, as shown in the upper part of Fig. 4. The positions error is bigger, because of cross talk of strong SB signals to following bunch signals in the storage ring. This is the worst case for the BPM System. However, a spatial resolution of better than 100 µm for all fill bunches in the storage ring at BESSY is achieved – see Fig. 4 lower part.

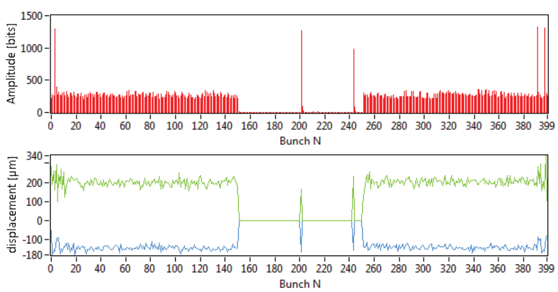

Figure 4: Fillpattern (over) and positions (under) of all filling bunches at BESSY II storage ring.

The first suprising result for orbit separation was achieved during low alpha operation of BESSY II. A significant displacement was observed for one individual bunch, which as intentionally excited for pseudo single bunch applications (PPRE-bunch) [4]. The data acquired by the system is shown in Fig. 5, while the excited bunch is depicted in red with a measured displacement of about 200 µm with respect to the reference orbit.

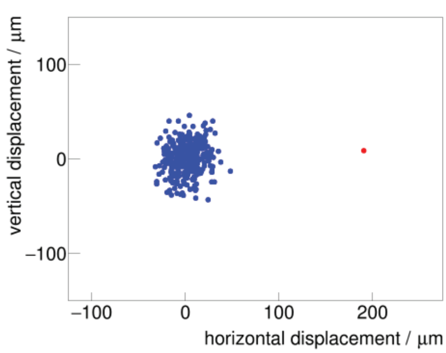

Figure 5: Spatial separation of individual bunches (PPRE bunch is marked in red]) in low alpha mode at BESSY II.

This phenomenon was later verified with other diagnostics and is in agreement with the expectations from beam dynamics.

A second experiment was performed during operation with resonance island buckets at both rings [5,6]. In order to estimate the coordinates of the transverse resonance island buckets only small change of the LabVIEW program is needed. For example of 3 horizontal islands it will be used the samples from 7*3 turns for estimate the coordinates X and Y for each islands. As if we have a 3 times "bigger" ring.

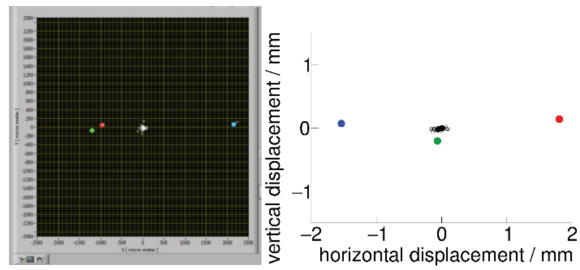

Figure 6: Orbit separation with 3 islands mode at BESSY II (left) and MLS (right). Both machines were operated with a homogenous fill pattern in the core beam, where one bunch was transferred to a single island [5]. The displacement of the stable, closed orbit of the island bucket was measured for the first turn (red), the second turn (green) and the third turn (blue).

Figure 6 shows the measured beam position during island bucket operation. A homogeneous fill pattern was used, where one bunch was repopulated to a single island bucket [5].

SUMMARY AND OUTLOOK

The availability to measure of BPM data of each bunch in the storage ring allows a better understanding of beam physics in the storage ring and can be used for multi beam operation in the future. The using of commercial card from NI with ADCs + FPGAs meets all technical requirements of the BPM electronics. The combination of the 4 good equalized analog BPM signals from pickups in the vacuum chamber and RF switch with high isolations give the opportunity create very good and stable analog RF signal for the BPM detector. In the card with 2 or 4 ADC it is possible to integrate of 2 or 4 BPM system with the same extern sample clocks. It reduces the costs for one BPM station and enables other interesting physical measurements.

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ISBN 978-3-95450-177-9