New Digital BPM System for the Swiss Light Source

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Abstract

This paper presents a new digital beam position monitor (DBPM) system which is currently under development for the Swiss Light Source (SLS). It is designed to provide sub-micron position data in normal closed orbit, and feedback mode as well as turn by turn information for machine studies and real time tune measurements. The self calibrating four channel system consists of a RF front end, a digital receiver and a DSP module. The same electronics will be used in all sections of the SLS accelerator complex. The system can be reconfigured in real time to perform different kind of measurements like: pulsed for linac and transfer lines, first turn, turn-by-turn, closed orbit, feedback and even tune mode for booster and storage ring. These reconfigurations only involve downloading of new signal processing software and will be performed via EPICS control system. An independent system for monitoring mechanical drifts of the BPM stations will be installed as well. The measured data will be permanently updated in a database and taken into account, when processing the final electron beam positions.

1 INTRODUCTION

The SLS is a high brilliance synchrotron radiation source presently under construction at the Paul Scherrer Institut (PSI) in Villigen / Switzerland. It is designed to supply highest brightness in the photon energy range from vacuum ultraviolet to soft X-rays and to provide flexibility to accommodate a variety of operation modes. Therefore, the SLS beam position monitor system has to ensure the adequate beam quality throughout the accelerator complex, consisting of a 100 MeV linac, two transfer lines, a full energy booster synchrotron and a 2.4 GeV storage ring.

In order to guarantee simplicity and uniformity of the system it was aspired to implement only one kind of BPM electronics for all SLS machine sections and operation modes. The most challenging requirements in terms of resolution and stability result from the necessity to reduce beam jitter to less than $\sigma/10$ of the vertical beam size in the ID sections of the storage ring. This corresponds to sub-micron beam position measurements, which have to be provided at a few kHz bandwidth, in order to successfully operate a fast (global) orbit feedback [1]. Concurrently, machine studies request snap shots of the beam orbit in turn-by-turn mode (TBT). Therefore, the BPM electronics has to deliver position data with more than

0.5 MHz bandwidth. A summary and description of the supported operation modes is given below. The technical specifications are listed in table 1.

- Pulsed Mode
  Intended for injector and transfer line BPM measurements. Assuming 3 Hz injection, one sample will be taken every 333 ms.

- Booster Mode
  Each BPM will provide position measurements throughout the acceleration cycle. Two orthogonal modes are envisioned. First, a single BPM measurement or a group of them is displayed in time domain. This allows tracking of positions as the beam is accelerated. Second, booster closed orbit is displayed at selectable time intervals.

- Turn-by-Turn
  User can select N (1024,…,8192) successive measurements to be taken per each sync. cycle. Time as well as frequency domain data formats are selectable.

- Closed Orbit
  Position measurements are taken continuously. Data is used for closed orbit (CO) display in control room.

- Feedback Mode
  Measurements are taken in the same way as in closed orbit mode and processed continuously to provide position information to global feedback.

- Tune Mode
  Data are taken in the same way as in turn-by-turn mode. However, software algorithm on DSP will calculate FFT and extract tunes.

Table 1: DBPM Specifications

Parameter	CO and Feedback	Pulsed and TBT
Dynamic Range	1-500 mA	1-20 mA
Beam Current Dependence		
full range	< 100 µm	-
relative 1 to 5 range	< 5 µm	-
Position Measuring Radius	5 mm	10 mm
Resolution	< 1 µm	20 µm
Bandwidth	> 2 kHz	0.5 MHz
RF and IF Frequencies		
Carrier RF	500 MHz	500 MHz
Carrier IF	36 MHz	36 MHz
Pilot RF	498.5 MHz	498.5 MHz
Pilot IF	34.5 MHz	34.5 MHz

2 DBPM ELECTRONICS

The newly developed DBPM electronics for SLS is a four channel system, which delivers high speed, medium precision and low to medium speed, high precision measurements. It consists of three major components: a RF front end, a digital receiver and a digital signal processor (DSP) module.
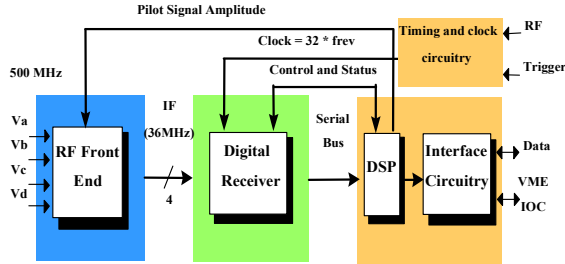

Figure 1: Block diagram of DBPM system for SLS.

2.1 RF Front End

The four RF front end channels tune to 500 MHz, the first harmonic of the machine. They get mixed to an intermediate frequency of 36 MHz and pass through a 5 MHz wide surface acoustic wave (SAW) filter. In order to equalise the gain of the four channels, a separate pilot signal is injected. It's frequency is 1.5 MHz below the frequency of the carrier signal but still within the SAW filter bandwidth. It's level is approximately 10 dB lower than the level of the signals from the four button pick-ups and used to set the total gain of each channel.

2.2 Digital Receiver

At the input of the digital receiver, the band limited IF signals are directly digitised by 12 bit analog-to-digital converters (ADC). Direct sampling at the IF frequency prevents the need of a second down-conversion stage in the RF front end and therefore reduces the problem of non-linearity associated with demodulation. The AD9042 from Analog Devices was selected for analog-to-digital conversion. It has a maximum sampling rate of 41 MHz, 100 MHz analog bandwidth and offers excellent linearity and stability, since the differential and integral non-linearities are $\pm$ 0.3 LSB or $\pm$ 7.3·10^{-5} FS and $\pm$ 0.75 LSB or $\pm$ 1.8·10^{-4} FS respectively. A/D conversion is performed at 31.25 MHz for the storage ring BPMs and 27.78 MHz for the booster BPMs. This means that under-sampling technique [2] is applied, which aliases the 36 MHz, band limited IF signals from the third Niquist zone down to 4.75 MHz for the storage ring BPMs 8.22 MHz for the booster BPMs respectively.

The remaining data processing, which include translation of the signals to baseband as well as filtering and decimation of the data streams, can now be done in a digital way. Both, filtering and decimation are important issues. They define the final system bandwidth, which in turn affects the measurement fluctuation and reduce the output data rate with respect to the input. The latter process reduces the requirements for the downstream digital signal processing. We have selected the HSP50214 DDC integrated circuit, which is a very flexible and fully programmable down converter.

2.3 Digital Signal Processor

The decimated data streams from the digital receiver are formatted, serialised and sent to the DSP module. We selected SHARC DSPs from Analog Devices, which are incorporated on the Wiese WS2126 DSP board. The DSP applies correction factors and calculates final beam positions. Moreover, incoming data are filtered and formatted for the desired operation mode, the pilot signal amplitude is adjusted and fast Fourier transformation is executed. In feedback mode, the DSP module calculates the orbit corrections and performs the communication to the adjacent sectors of the SLS storage ring. The sectors are connected via fast SHARC link ports (up to 40 Mb/s) in order to achieve a global correction scheme according to the SVD algorithm [1]. The complete DBPM system is fully integrated in the EPICS control system. This allows to select operation modes, displays beam positions in the control room, archives orbit data in an ORACLE database and constantly updates mechanical drifts of BPM stations, measured with the BPM position monitoring system (POMS), which is described in more detail below.

3 MECHANICAL ALIGNMENT

While the SLS DBPM electronics is designed to provide sub-micron resolution with high long term stability and low beam current dependence (see table 1), alignment and mechanical stability aspects of the BPM stations also become relevant for obtaining reliable and reproducible beam position readings and operating conditions for the users.

In the case of SLS, the vacuum chamber is supported by six BPM stations along a sector of the storage ring. The BPMs are rigidly mounted to the girders, following the SLS alignment concept for the magnets [3], which predefines the BPM centre within $\pm$ 25 μm with respect to the adjacent quadrupole axis. Final calibration to less than 10 μm will be obtained with the stored electron beam, applying the method of beam based alignment [4]. A complete BBA-cycle takes about 15 minutes and could be performed after every new start-up of the machine. During operation, any change in ambient temperature or any thermal load on the vacuum system leads to strong forces on the BPM supports, resulting in relative position changes of the BPM stations. This effect has been simulated for the SLS vacuum system and turns out to be in the order of 2 μm/°K. The resulting monitor movements override the alignment and initial calibration of the BPMs, which leads to false readings and corrections of the electron beam positions. It is obvious that this effect can be extremely critical when running a transverse feedback,

where beam positions are automatically stabilised in a bandwidth from DC to around 100 Hz. Therefore, the supervision of mechanical drifts will be accomplished by a set of absolute linear encoders, which are firmly clamped to the quadrupole magnets. These sensors serve as dial gauges, which monitor the relative movement of the BPM stations in respect to the adjacent quadrupole magnets. The system's resolution is less than 1 μm over a measuring range of ± 2.5 mm. The raw data from all 12 monitors per sector (6 vertical and 6 horizontal) will be locally interpolated, serialised and finally sent to a single VME card, which is providing the link to the EPICS control system. This way any mechanical drifts are continuously recorded and updated into a database. The information will be used for the final determination of the electron beam position.

A prototype version of such a mechanical position monitoring system (POMS) has been successfully tested at a BPM station at ELETTRA over a period of one week. The results are given in figure 2 and show substantial drifts of the BPM station at start-up of the machine, when closing the tunnel, after each beam dump and new injection cycle.
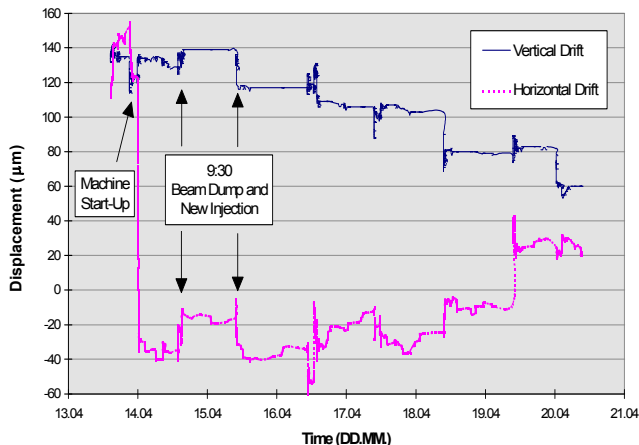

Figure 2: Horizontal and vertical drifts of a BPM station, measured at ELETTRA using a POMS prototype system.

4 PRESENT STATUS

Two prototypes of the RF front end module are being presently tested in laboratory environment with special emphasis on impedance match of all four RF inputs and determination of gain discrepancy between channels over the input dynamic range. So far the gain discrepancy of the four channels has been measured in the laboratory to be below ⊕ 0.1 dB over the whole dynamic range, which meets the original design specification.

After having demonstrated the under-sampling performance of the AD9042 [2], four one-channel digital receiver modules have been designed and successfully operated in the lab at PSI. A block diagram of the DR board is shown in figure 3.
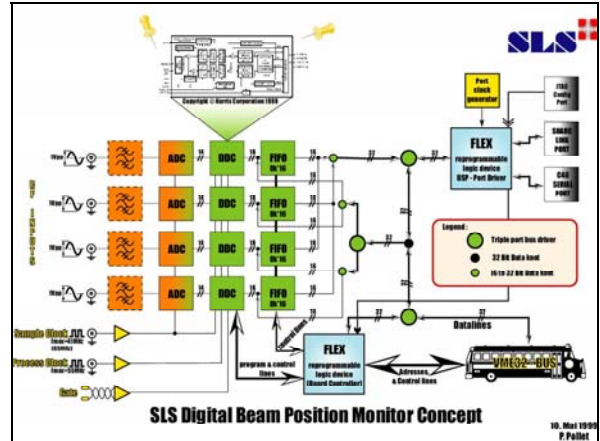

Figure 3: Block diagram of digital receiver module.

System integration tests with beam in feedback and turn-by-turn modes are scheduled for mid June at the synchrotron light facility ELETTRA in Trieste/Italy, already incorporating digital signal processing and EPICS interface via an IOC module.

Data formatting electronics for the linear encoders used in the POMS system, including interpolation and serialisation has been designed and successfully tested. A VME card, providing an EPICS interface via memory mapping is presently under design and will be tested at PSI early June.

ACKNOLEDGEMENTS

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