PERFORMANCE OF THE DIGITAL BPM SYSTEM FOR THE SWISS LIGHT SOURCE

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Abstract

The accelerator complex of the Swiss Light Source (SLS) is presently under commissioning at the Paul Scherrer Institute (PSI) in Villigen, Switzerland. The newly developed digital beam position monitor (DBPM) system has been successfully used to determine beam positions in the pre-injector LINAC, the transfer lines, the booster synchrotron and the storage ring. Instant and free selection of operation modes through the EPICS-based SLS control system allows to choose between single turn, turn-by-turn and closed orbit measurements. The operational experience and performance of the DBPM system is presented, based on measurements, taken during SLS commissioning. A monitoring system (POMS), which measures the horizontal and vertical mechanical positions of each BPM block in reference to the adjacent quadrupole magnets has been installed and first results, indicating transverse movements of the BPM blocks as a function of current in the storage ring will be presented.

1 INTRODUCTION

The DBPM system played a vital role during the commissioning of the SLS accelerator complex, which started in March 2000 and is still continuing until August 2001 [1]. The implementation of all available operation modes [2] from the beginning delivered beam position measurements in the LINAC, the transfer lines, the booster synchrotron and in the storage ring. In addition to simply visualizing the positions in the control room, the DBPM system is constantly delivering data to SLS beam dynamics applications [3]. This data transfer is arranged through a batch process consisting of up to 8192 x- and y-position and intensity readings, synchronized to the 3 Hz repetition rate of the SLS injector. The full programmability of the quad digital receiver (QDR) [2] as well as the complete integration of the DBPM electronics in the EPICS based control system, allows remote switching of operation modes for each sector of the booster synchrotron and storage ring individually. Optimization of injection and beam optics studies like measurement of tunes and chromaticities as well as “beta scans” have been performed in the high speed / medium resolution *turn-by-turn mode*. For determination of closed orbits, the system has been switched to lower bandwidth and therefore higher resolution. The application of a pilot signal in the RF front end [2] provides calibration of the electronics for any chosen gain setting. A self test mode can be applied to exclude mal-functioning of BPM stations and therefore improves reliability. Using the features and flexibility of the DBPM system resulted in a fast and efficient commissioning and provided complete understanding of the SLS accelerator optics.

2 PERFORMANCE CHARACTERISTICS

The following measurements have been taken in the laboratory and during SLS commissioning to determine the DBPM systems performance, to demonstrate first operational experience and to present some results from the SLS accelerators.

2.1 Resolution and Beam Current Dependence

While an AGC loop is presently not yet implemented, the full dynamic range of the DBPM system is covered through downloading of specific sets of pre-calibrated gain levels which correspond to pre-defined beam current ranges. These ranges are large enough to guarantee standard storage ring operation between adjacent injection (re-filling) cycles. The gain settings are chosen in such a way that the signal levels in the RF front end are always kept within the linear regimes of all electronics components and that the RF front end output is not exceeding 70% of the QDRs analog-to-digital converters input range (1 Vpp for presently used 12 bit AD9042 from Analog Devices). Minimum *turn-by-turn* resolution, which corresponds in case of SLS to 1 MS/s, has been measured to be in the order of 20 µm over a dynamic range of 5 mA to 700 mA. The minimum resolution at 15 kHz bandwidth corresponding to a so called "*ramp-250 ms*" mode, which was especially implemented for the booster synchrotron, has been determined to be < 3 µm and the resolution in the *closed orbit / feedback* mode, which operates at 4 kS/s, is < 1.2 µm. The increase of resolution from *turn-by-turn* mode over the "*ramp-250ms*" mode to the *closed orbit / feedback* mode goes - as can be expected - with the square root of bandwidth. In the latter two modes however, some low bandwidth noise floor can still be observed, which may be caused by phase noise in the RF front end. This issue needs be addressed (and solved) before the global closed orbit feedback [4] will be implemented. The sudden decreases of resolution whenever the gain levels of DBPM system are changed is a systematic effect and will be minimized as soon as the AGC loop is operational.

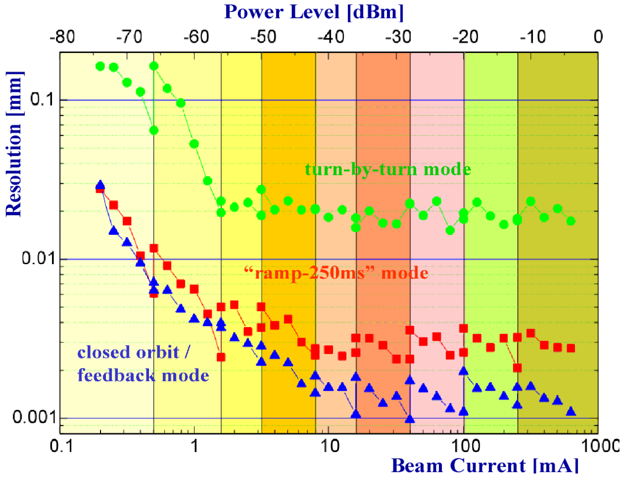

Figure 1: Measurement of DBPM resolution for different bandwidths: 500 kHz (green dots), 15 kHz (red squares) 2 kHz (blue triangles). Gain levels of the system are kept constant for the marked beam current ranges.

Beam current dependence has been measured in the lab for a centered beam by performing several measurement cycles over the whole dynamic range of the system with the same (constant) pre-calibrated gain settings as above. It was determined to be ± 5 µm within ranges of constant gain levels. At low signal intensities, position jumps occur, whenever a new gain setting is loaded. In these cases, the calibration routine still needs to be improved. Drifts of < ± 5 µm, in a beam current range between 7 mA and 700 mA, are within specifications of SLS.

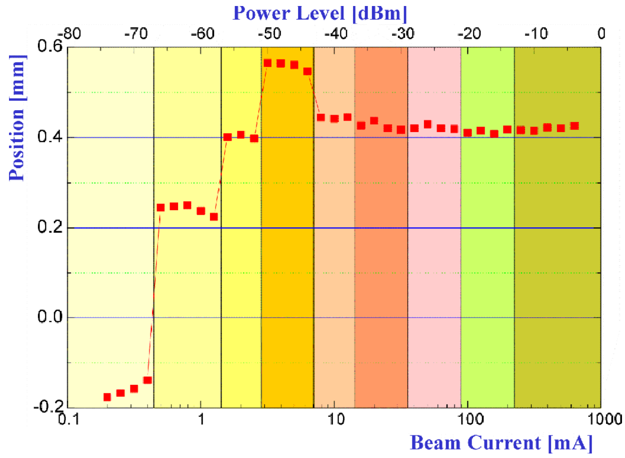

Figure 2: Beam current dependence over the whole dynamic range of the DBPM system in *closed orbit / feedback* mode.

2.2 Long Term Stability

Measurement of long term stability of DBPM electronics has been performed in the SLS technical gallery with a constant input power level of –12 dBm and a constant DBPM gain setting at the carrier frequency of 499.654 MHz over a time period of 24 hours. It resulted to be within ± 1 µm.

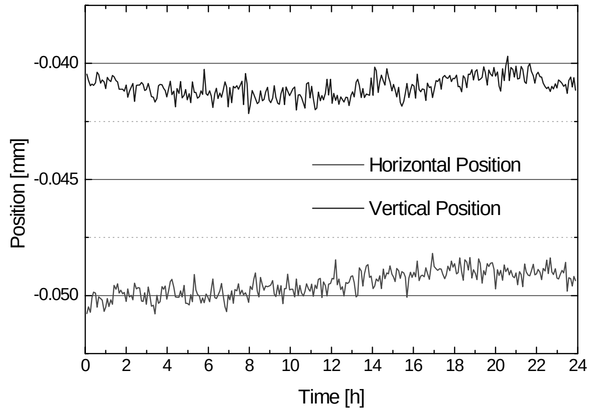

Figure 3: Long term stability of the SLS DBPM system was measured to be within ± 1 µm over a time period of 24 hours.

2.3 Measurements on SLS Booster Synchrotron

The SLS booster synchrotron which ramps up the energy of the electrons from 100 MeV to 2.4 GeV, is placed in the same tunnel as the storage ring (magnets are fixed at the inner wall of the tunnel). With its circumference of 270 m, it allows the use of quite small combined function magnets, which leave only space for a 20 by 30 mm elliptical vacuum chamber [5]. Therefore, the requirements for beam positioning as well as orbit and tune control in order to obtain good injection rates into the storage ring are quite challenging. Low injection losses and knowledge about beam parameters are especially important in the anticipated *top-up injection mode*, which should keep the beam current in the storage ring constant to a level of 10^{-4} of the nominal 400 mA. In this respect, the flexibility of the DBPM system is extremely helpful and all available operation modes have been extensively used during commissioning. The first turn(s) and turn-by-turn capabilities allowed optimization of injection, built-up of the ramp and single turn extraction. Tunes (predominantly the horizontal tune) have been determined and corrected throughout the acceleration cycle by continuously adjusting the trigger delay of the DBPM system, operating in tune mode. Orbits have been measured and could be corrected along the ramp down to rms values of about 400 µm, which is especially important at low energies, where emittances and therefore electron beam sizes are still rather large.

Figures 4a and b show horizontal and vertical beam orbits at booster BPM station ABODI-BPM-6C over a complete ramp for nominal injection with 0.5 mA beam current and for the future top-up injection with beam currents as low as 5 µA. For the small SLS booster vacuum chamber geometry, resolutions of 1.5 µm and 100 µm have been achieved applying equal gain settings.

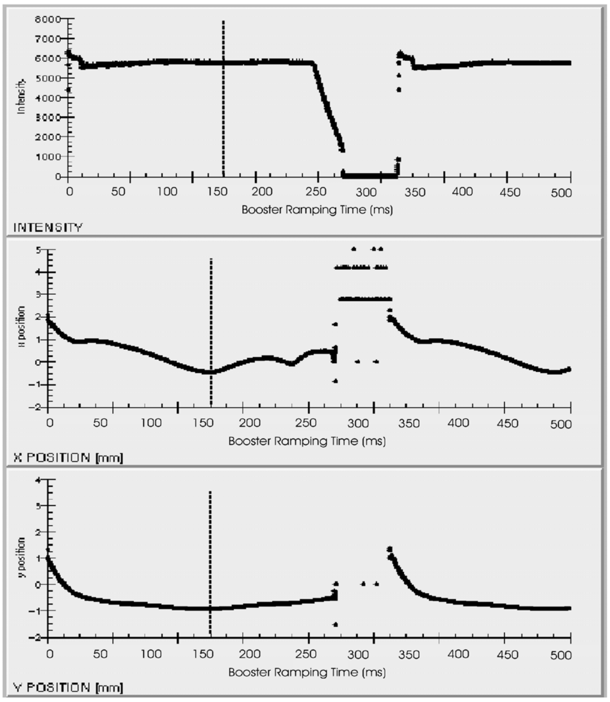

Figure 4a: Display of electron beam orbit along booster synchrotron ramp at BPM station ABODI-BPM-6C for nominal injection current of 0.5 mA. 1/E-damping of initial orbit correction is clearly visible in the vertical for not ramped correctors. Only during commissioning, the ramp was exceeded to 270 ms duration, corresponding to a deceleration of the beam down to about 300 MeV in order to minimize radiation losses.

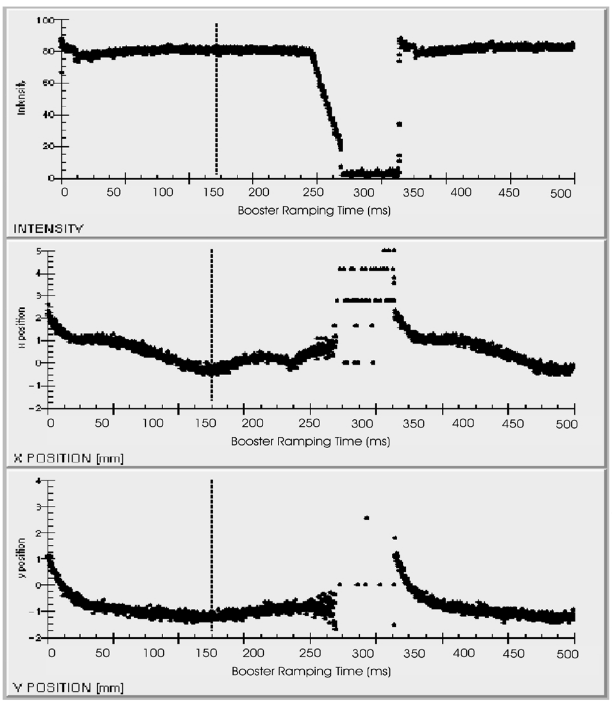

Figure 4b: Same measurement as above for low top-up injection current of 5 µA.

2.4 *SLS Storage Ring Measurements*

Likewise in the booster synchrotron, first turn(s) and turn-by-turn modes supported a fast and well optimized injection in the SLS storage ring. As already mentioned in the introduction, the direct connection of the DBPM system with the SLS beam dynamics applications over the EPICS based control system allowed automated tune, chromaticities and beta scans for good understanding of storage ring optics. Therefore, the machine modeling is extremely close to reality, which results in closed orbit corrections as low as 7 µm rms in the horizontal and 1 µm rms in the vertical! Displays of the corrected orbits are shown in figure 5.

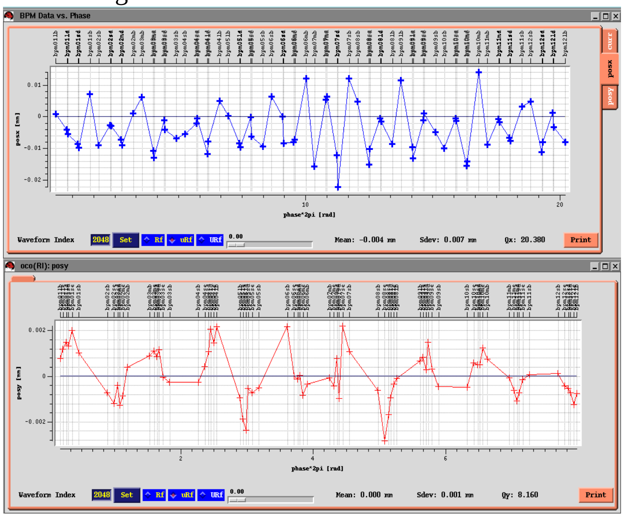

Figure 5: Horizontal (top) and vertical (button) orbit in SLS storage ring corrected to 7 µm rms respectively 1 µm rms.

3 MONITORING OF THE BPM'S MECHANICAL POSITIONS

At SLS, the final alignment of the BPM block positions will be performed by the method of beam based alignment (BBA). Since each quadrupole has its own power supply, it is expected to reach an accuracy of < 2 µm in reference to the magnetic axis of the storage ring. However, finite element analyses (FEA) show, that thermal loads or gradients, caused by changing beam currents in the machine, lead to a strong deformation of the vacuum chamber, resulting in position changes of the BPM stations in the order of 2 µm/°K. Figure 6 shows an example of such a FEA-simulation for a measured temperature distribution along sector 06 of the SLS storage ring. It is clearly visible, that the vacuum chamber is strongly bent between the BPM supports but still not touching the storage ring magnets, which leave 0.7 mm space to each side. The BPM supports, which are designed for stiffness in the transverse plane, move up to 3 mm in the longitudinal direction, while horizontal and vertical displacements are in the order of a few tens of microns.

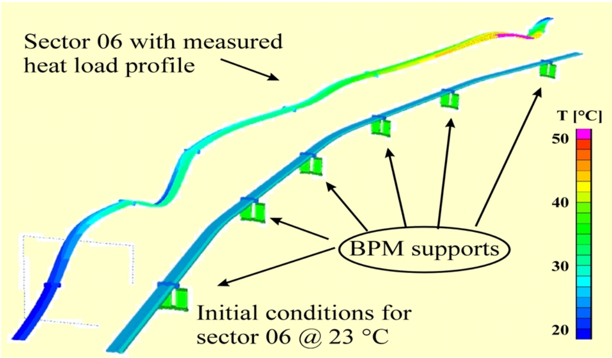

Figure 6: Finite element analysis of vacuum chamber movement in SLS storage ring for measured temperature profile along sector 06.

The mechanical drifts of the BPM supports in the SLS storage ring are constantly measured by a so called mechanical position monitoring system (POMS). It uses two linear encoders of the Renishaw RGH24Z50A00A type with 0.5 µm resolution for each BPM station. The sensors, which are rigidly attached to the adjacent quadrupole magnets, serve as dial gauges in the horizontal and vertical directions. The raw data from 12 encoders per sector are transferred via a SSI-serial interface electronics to a 32 channel VME-card, where the data can be read and written through memory mapping into the EPICS control system.

A snapshot during SLS storage ring commissioning is shown in figure 7, where daytime activities concentrate on injection and RF studies while the nightshift performed vacuum system laundry. The BPM blocks movements, which are measured by the POMS system, can be nicely correlated to the beam current (respectively heat load) in the storage ring and agree well with the FEA-simulations. Even with a well corrected orbit, movements are in the order of several tens of microns (maximum of 50 µm with 150 mA current change) are measured in the horizontal.

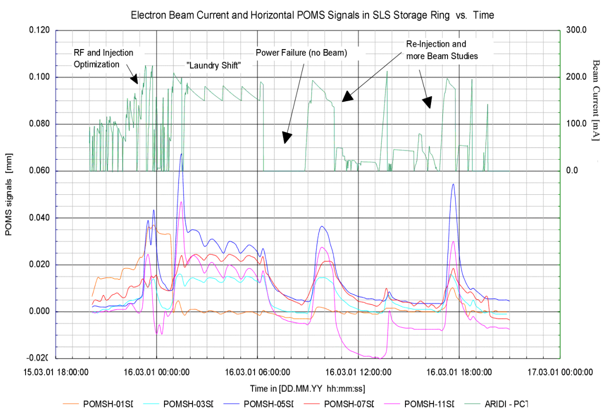

Figure 7: Horizontal BPM block movements and beam current in SLS storage ring during commissioning.

Since BPM readings are always relative measurements between electrode (BPM block) positions and electron beam positions, the POMS data will be taken in account for the final determination of "real" beam positions in the DSP part of the DBPM electronics. With this de-coupling of mechanical movements and electron beam motion, it is anticipated to keep a "golden" orbit throughout a machine run without any re-calibration of BPM centers by BBA. This approach should improve the reproducibility and stability of the SLS as a light source for the users.

4 CONCLUSIONS AND OUTLOOK

The DBPM system has reached and even exceeded the design specifications in all available operation modes and supported the successful and efficient commissioning of the SLS accelerator complex. Its complete integration into the EPICS based control system allows online re-programmability (e.g.: selection of operation mode) by the operators in the control room through a BPM control panel. Mechanical movements of the BPM blocks in the order of some tens of microns have been observed with the POMS system as a function of beam current in the storage ring.

TABLE 1. SLS DBPM system parameters

Parameter	Requirements	Achievements
Resolution turn-by-turn mode feedback mode	 < 20 µm < 1 µm	 < 20 µm <1.2 µm
Beam Current Dep. 5 - 400 mA const. gain ranges	 < ± 50 µm < ± 2.5 µm	 ± 20 µm ± 5 µm
24 h stability	± 2.5 µm	± 1 µm

DBPM features like an AGC loop and real time data transfer for the SLS closed orbit feedback still have to be implemented in the next few months in order to support SLS user operation, starting in August 2001.

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