ELECTRON BEAM DIAGNOSTICS FOR THE SWISS LIGHT SOURCE

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1 DIAGNOSTICS CONCEPT

The SLS accelerator complex consists of a 100 MeV pre-injector linac, a linac to booster beam transfer line (LBTL), a full energy booster synchrotron, a booster to storage ring beam transfer line (BSTL) and a 2,4 GeV storage ring [1]. The different operating modes of the machine - single bunch, multi bunch and top up mode - demand high flexibility and wide dynamic ranges of the beam diagnostics equipment in order to provide all relevant beam parameters in every part of the machine. Table 1 summarizes the diagnostic devices for SLS.

Table 1: SLS Beam Instrumentation Overview

Device	Linac and TLs	Booster	Storage Ring
FC	2	-	-
WCM	3	-	-
BCM	4	-	-
DCCT	-	1	1
HS, VS	2	-	2, 1
OTR	12	4	4
CTR	1	-	-
SRP	1	3	-
SR Beamline	-	-	1
BPM	-	54	72
Stripline	8	1	1
Tune Monitor	-	1	1
BLM	-	20	30

1.1 Current Related Measurements

Measurements of the electron beam intensity during the commissioning stage of the pre-injector linac will be performed by two Faraday cups (FC), one directly behind the electron gun and the other at the end of a diagnostics bypass behind the linac. Non-destructive monitoring of the transmission efficiency through the different parts of the machine will be accomplished with Bergoz beam charge monitors (BCM) in the TLs. The intensity and duration of the bunches behind the electron gun, which are specified to 1 ns full width, are measured and controlled with a wall current monitor (WCM). In case of transient beam loading effects in the linac, a second WCM in combination with a horizontal scaper (HS) limits the energy spread of the electron beam in a dispersive section of the LBTL and therefore define the macropulse duration and the filling pattern into the booster synchrotron.

Commercially available DC current transformers (DCCT) monitor the beam current in the booster and in the storage ring. They also provide lifetime information of the electrons circulating in the storage ring and allow current stabilization to 10^{-3} - 10^{-4} in the top up mode of the SLS.

1.2 Optical Measurements

Optical transition radiation (OTR) will be used in order to determine emittance and energy spread of the electron beam along the pre-injector linac and in the TLs. The OTR-monitors consist of very thin Al-foils, which are almost transparent to the electrons and which can be put into the beam by pneumatic actuators. Due to the superior spatial and temporal resolution of OTR in comparison with flourescent screens, time resolved measurements of beam parameters on a μs-scale are possible, using OTR interferometry in combination with synchronously gated CCD cameras [2].

The coherent part of the transition radiation spectrum (CTR), which is emitted in the far infrared, represents a very inexpensive and highly sensitive tool to optimize the bunching process in linear accelerators [3] and provides information about the length of the electron micropulses [4,5]. We will therefore use at least one of the OTR diagnostics stations behind the SLS pre-injetor linac for controlling the longitudinal phase space by simultaneously matching it to the optical and coherent part of the transition radiation spectrum.

The optical diagnostics in the booster synchrotron consists of three synchrotron radiation ports (SRP), used for non-destructive monitoring of the electron beam profile during the ramping cycle. In combination with fast, one dimensional CCD arrays, the SRPs allow tune tracking during the ramping cycle as well. Additionally, several OTR ports will ease the transverse matching of the electron beam into the booster during the commissioning phase.

In the SLS storage ring, a synchrotron radiation (SR) beamline will be dedicated for beam diagnostics purposes (12-S straight section). The final layout of the SR diagnostics beamline will be determined in the near future. Apart from emittance measurements, coupled-bunch instabilities will be studied and bunch purity in single bunch mode will be measured.

The localisation of electron beam losses around the storage ring facilitates the commissioning phase of the machine. Therefore several low cost beam loss monitors (BLM) of the Bergoz PIN-photodiode type will be installed in critical areas. Since they are movable and very small in size, they will also facilitate the optimization of the machine after installation of mini-gap undulators.

2 BEAM POSITION MONITORS

For non-destructive measurements of the electron beam position along the machine, 72 RF BPM button pickups will be located in the 12 sectors of the SLS storage ring and 54 BPM stations of the same type will be positioned around the booster synchrotron. Since top up injection mode is foreseen at SLS from the beginning, high sensitivity stripline BPMs will be installed in the pre-injector linac and along the TLs. For the sake of simplicity and for cost reasons one single BPM electronics should cover the different parts of the SLS accelerator complex. Moreover it should deliver very stable and accurate closed orbit (CO) position readings as well as turn-by-turn (TBT) position information in the storage ring.

2.1 Digital BPM Electronics

Multiplexing of pick-up signals to a common processing chain is the standard technique to obtain high stability and resolution. Wideband systems on the other hand use the log-ratio AM/PM, simultaneous 4 channel processing and other known and proven techniques.

The SLS digital BPM electronics represents a departure from these conventional approaches. The proposed electronics will be a four channel system, which accomplishes the requirements of providing excellent linearity and stability and keeping the gain in the four channels of the RF front end matched. Two new features are proposed to fulfill these great demands. The first one is use of a pilot signal, which keeps the gain in the four channels of the RF front end matched. The second one is direct intermediate frequency (IF) sampling and digital demodulation which offers excellent linearity and stability. The main features of the electronics are high resolution and programmable bandwidth that offers resolution for data rates up to 50 kS/s on one hand and TBT capability on the other hand. Table 2 summarizes the specifications of the digital BPM system for SLS and figure 1 shows the respective block diagram.

The four RF front end channels tune to 500 MHz, the first harmonic of the machine, and output four 70 MHz band limited signals. A gain control loop keeps the sum of the output voltages constant whatever the input signals are. The relative gain deviation between the four channels is less than 0.1 dB over the 1 to 400 mA dynamic range. As has been said before, a pilot signal with a different frequency than the carrier signal from the four buttons seems to be the adequate solution to equalize the gain of the four channels.

Table 2: SLS BPM Specifications

Parameter	CO and Feedback	TBT and First Turn
Position Measuring Radius	5 mm	10 mm
Dynamic Range		
uniform filling	1-500 mA	1-500 mA
single bunch mode	1-20 mA	1-20 mA
Min. Detect. Beam Current	0.01 mA	0.01 mA
Resolution	1 μm	< 20 μm
Beam Current Dependance		
1 - 500 mA	< 100 μm	-
relative 1 to 5 range	< 5 μm	-
Operator Display Rate		
x and y positions for CO	2 Hz	-
1024 successive meas.	-	0.5 Hz
1024 point FFT	-	0.5 Hz
Sampling Rate	32*f_{rev}	32*f_{rev}
Bandwidth (software adj.)	< 40 kHz	$f_{rev}/2$
Max. Measuring Rate	50.000/s	f_{ref}
Max. Throughput	50.000/s	-
Delay (40 kHz BW)	10 μs	-
RF Frequency	500 MHz	500 MHz
IF Frequency	69.6 MHz	69.6 MHz

The 70 MHz band-limited signal is sampled with a wide band 12 bit analog-to-digital converter (ADC). The sampling of the 70 MHz band-limited signal occurs at a rate of 32 times the revolution frequency; 33.3 MS/s and 34.8 MS/s for storage ring and booster respectively. We decided for under-sampling to eliminate the need for a second down conversion stage. The data stream from the ADCs is sent to four digital downconverters (DDC). Each DDC consists of four signal processing elements: a digital tuner, two fixed coefficient decimating filters and a programmable coefficient decimating filter. The ADCs and DDC are commercially available products.

The decimated data streams from the digital DDCs are serialized and sent to a DSP which can perform multiple functions. It scales the input samples and applies corrections, calculates position and current, filters, formats data for desired application, adjusts the pilot signal amplitudes or calculates fast Fourier transforms.

2.2 Tune Measurements

At SLS we need to measure tune of the booster synchrotron and of the storage ring. Initially we planned to use a dedicated spectrum analyzer with tracking generator, which is connected to a power amplifier that drives a transverse kicker. By sweeping appropriate frequency span, one can obtain transfer function of the beam containing both tunes. However, inspired by the wide-band nature of the new digital BPM system, we decided to base our tune measurement on the latter.

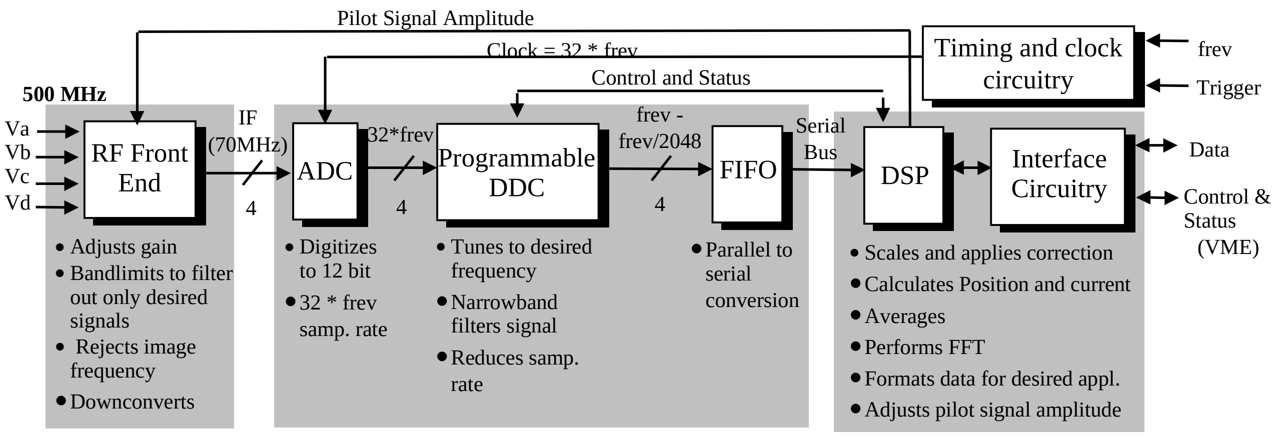

Figure 1: Block diagram of the digital BPM electronics for SLS

The concept is to transversally excite the beam with white-noise. If the spectrum of the noise is wide enough, both horizontal and vertical tunes can be measured simultaneously. The transverse beam motion is captured by a dedicated BPM station which performs Fast Fourier Transformation (FFT) on a large series of samples. This set-up offers great flexibility and cost reduction since the detecting electronics uses the same hardware platform as the BPM system.

2.3 BPM Alignment Concept

Since µm resolution seems to be the state of the art for todays BPM electronics, the aspect of the mechanical alignment and stability of the BPM stations becomes more relevant for obtaining reliable and reproducable operating conditions in high performance synchrotron light sources.

Following the SLS alignment concept for the magnets on the girders [6], the storage ring BPM chambers will be mounted on precisely machined supports, which directly fit in alignment rails of the storage ring girders. With the same machining tolerances in the order of ± 15 µm for the BPM stations and the magnets, the BPMs are expected to be aligned within 50 µm with respect to the magnetic axes. By taking additional offsets and errors from the electrical chain of the BPM system into account, the initial positioning error of the monitors will be less than 0.5 mm in reference to the magnetic axes of the adjacent quadrupoles. This uncertainty of the BPMs positions will be sufficient for commissioning the SLS storage ring.

The high precision calibration of the BPM stations to the magnetic axes of the quadrupoles will be done with the stored electron beam, using the method of beam based alignment (BBA) [7]. The monitor positions should then be defined with the resolution of the BPM system (a few µm). Nevertheless operational experience on existing synchrotron light sources show that thermal effects, which are mainly due to changes of the ambient temperature in the storage ring tunnel or caused by different thermal loads on the vacuum chambers cause drifts of the BPM stations of several hundred microns [8]. FEM calculations for the SLS vacuum system confirm these observations and show that even extremely rigid support systems will not yield to a sufficient fixation of the BPM chambers [9]. Instead of following the conventional approach of rigidly attaching the BPM station to the adjacent quadrupole, at SLS, we will allow the drift of the BPMs and simply monitor the movements of the chambers by using photosensors with sub-micron resolution. The actual mechanical positions of the BPM stations will finally be taken into account when the electron beam position is calculated in the DSP part of the digital BPM system. This low cost solution guarantees reliable BPM readings even during the start up phase of the machine and independent of the applied operating mode.

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