The New Beam Position Monitoring System of ELSA

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Abstract

The **El**ectron **S**tretcher and **A**ccelerator (ELSA) is a cw electron beam facility operated by the University of Bonn. In the course of the upgrade of ELSA for the acceleration of a polarized electron beam the correction of the closed orbit has to be improved. In addition ELSA is used as a partly dedicated synchrotron radiation source with increasing demands for the position stability. The necessary measurement accuracy couldn't be fulfilled by the currently installed beam position monitoring (BPM) electronics.

The new developed BPM system consists of 32 stations with a rf processing module and a data acquisition and control module. The rf processing module switches the four input signals from a button type monitor to a common signal path using a multiplexer. All four button voltages are measured and processed by the data acquisition module that also controls the rf electronics and does the communication with the control computer of the BPM system through a field bus. Design issues and first results of the performance of the BPM system are presented.

1 INTRODUCTION

The stretcher ring ELSA provides a nearly cw electron beam to several particle physics experiments with an energy up to 3.5 GeV. In future ELSA will be used with a polarized beam for most of the time. During acceleration of the polarized beam depolarizing resonances have to be crossed, whose strengths increase with the rms-value $\langle z \rangle_{\rm rms}$ of the vertical orbit [1]. In order to reduce the resonance strengths the beam has to be centered in the quadrupole magnets. For the determination of these centers beam-based alignment [2] will be applied which requires a high relative position accuracy of the new electronics.

During one third of the operating time ELSA is used as a partly dedicated synchrotron light source. The increasing demands for beam stability of the synchrotron light users made a new design of a electronics necessary. This new BPM system was designed by the Research Centre Jülich and will be produced by the KFKI in Hungary. It is a decentralized system with 32 stations connected by a serial field bus with the ELSA control system. The rf processing of the 500 MHz signals, the digitalization and the preprocessing of the data is done by each station. The relevant parameters of ELSA and the specifications of the new BPM electronics are summarized in Table 1. Further details of the electronics can be found in [3].

2 PICKUP ELECTRODES

The pickup electrodes used at ELSA are capacitive buttons of the DESY II type mounted on the diagonals of the vacuum chamber. The BPMs are installed nearby the quadrupole magnets and are fixed to the ground to reduce chamber movements due to heating by synchrotron radiation. At 1 mA beam current the signal power is about -51 dBm for the fundamental frequency of 500 MHz.

In future new vacuum chambers with integrated BPM and water cooling will be manufactured. These chambers will be equipped with ESRF button electrodes produced by METACERAM, France. Due to their smaller cross section the received power is 10 dB lower compared to the DESY II electrodes.

3 ANALOG ELECTRONICS

The electronics consist of an analog part for the rf signal demodulation and a digital part for control of the rf signal processing electronics, the digitalization of the voltages and the communication over a field bus with the host computer. The analog electronics is a time multiplexed superheterodyne receiver [4]. Advantages of this processing scheme are that the measured position is not sensitive to thermal gain drifts resulting in a high accuracy and that the hardware is significantly cheaper due to the single signal processing path. The block diagram of the electronics is shown in Fig. 1. The signals from the buttons first pass a 600 MHz low pass filter to reduce the influence of the

Table 1: Specifications of ELSA and the BPM system

ELSA current range	0.1 – 250 mA
rf frequency	499.670 MHz
hor. / ver. button sensitivity	14.5 mm, 42.9 mm
gain	$>$ 106 dB
gain control	$>$ 80 dB
rf attenuator	0 / 30 dB (prog.)
max. input power	6 dBm
demodulator bandwidth	50 – 500 Hz
detector linearity error	≤ 5 ‰
hor. / ver. resolution at 100 mA	$\leq 2\ \mu$m, $\leq 6\ \mu$m
hor. / ver. resolution at 1 mA	$\leq 4\ \mu$m, $\leq 12\ \mu$m
multiplexer frequency	1 kHz
data transfer rate	1 MBit/s

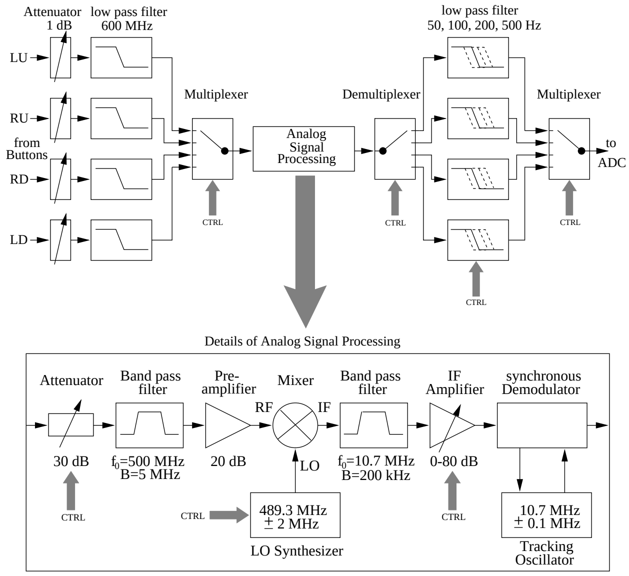

Figure 1: Analog part of the BPM electronics

higher harmonics of 500 MHz in the signal spectrum on the electronics. Attenuators before the filters can be used to compensate for different cable and button attenuations.

After that the four signals are multiplexed on the same analog signal processing path sequentially with a rate of up to 1 kHz. A 30 dB attenuator can be used to adapt to the different current ranges. After a preamplification of 20 dB the signal is down-converted to an intermediate frequency (IF) of 10.7 MHz with help of a local oscillator (LO). The frequency of the synthesizer can be changed in 50 kHz steps by the digital part of the electronics within a range of $f_{\mathrm{LO}} \pm 2$ MHz.

To make optimal use of the dynamic range of the demodulator due to beam current changes the gain of the IF amplifier can be controlled with a 12 Bit DAC. The synchronous demodulator uses a tracking oscillator locked to the IF frequency of the signal and demodulates the signal. Before sampling with a 12-bit ADC the signals are filtered by low pass filters. The filter bandwidths can be changed to 500, 200, 100 and 50 Hz. Narrower bandwidths are implemented by a low pass filter in software.

4 DIGITAL ELECTRONICS

A digital module (cf. Fig. 2) completely integrated into the system is used to control the analog part of the electronics. It consists of a micro controller with 32 kB RAM and 8 kB ROM, ADC, DAC, a digital I/O port and a serial opto-isolated port. The task of the controller is the readout of the ADC, the control of the attenuator and the gain DAC, the generation of the multiplexer timing and the serial communication with the host computer. The BPM stations are located in the ring tunnel of ELSA and connected by a 1 MBit/s serial field bus with the host. Up to eight BPM stations will be served by one serial bus using a master/slave protocol. The data will then be processed by a VME multi-

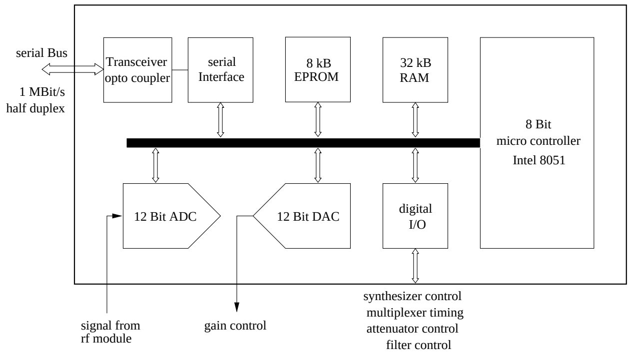

Figure 2: Digital part of the BPM electronics

processor system running VxWorks as real-time operating system. For the host communication a board based on a Motorola 68360 Communication Controller is used. Beam position data will be computed by a dedicated VME-CPU board and the closed orbit data sent over the local network to the control system of ELSA.

The sampling of the four button voltages makes it possible to use an intelligent gain control algorithm in the software of the micro controller. In the Automatic Gain Control (AGC) mode the highest of the voltages is amplified to a value of 90 % of the full scale value of the ADC and allows the optimal use of the dynamic range of the detector. Changes in gain are done between the sampling cycles. Furthermore the sampling order of the buttons can easily be changed by software to reduce the systematic effects due to current changes within a cycle.

5 CALIBRATION

One advantage of the signal processing scheme of the electronics is the simplified calibration procedure. The attenuation factors of the four channels of the electronics including the cables may be obtained easily using a fixed gain setting. For the reconstruction of the beam positions a model of the voltage dependency on the beam position was calculated using MAFIA [5]. The measured voltages are first corrected by attenuation factors of the four buttons, cables and the electronics. For the reconstruction of the beam position from the four voltages a combination of a look up table and a local polynomial fit is used.

For the determination of the absolute beam position relative to the magnetic center of the nearby quadrupole a k-modulation system was installed [6]. Each quadrupole can be current modulated with a modulation amplitude of 2 % at 1.2 GeV and a frequency of up to 100 Hz. BPM offsets were determined by measuring the oscillation amplitude induced by the current modulation for different beam positions (Fig. 3). First measurements showed that the determination of the zero position of a BPM defined by the magnetic center of a nearby quadrupole with an accuracy of less than 150 μm should be possible.

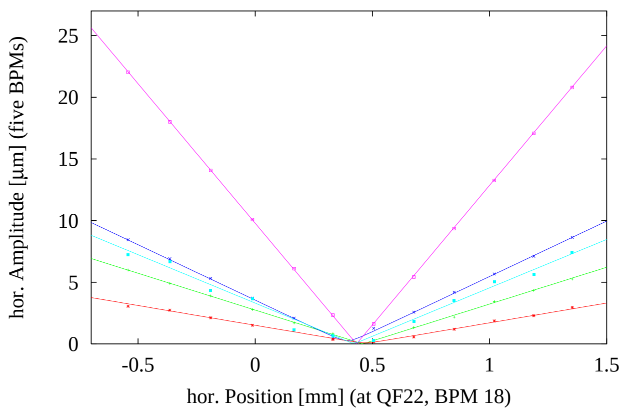

Figure 3: Example of the determination of the BPM zero position using quadrupole current modulation and a local beam bump

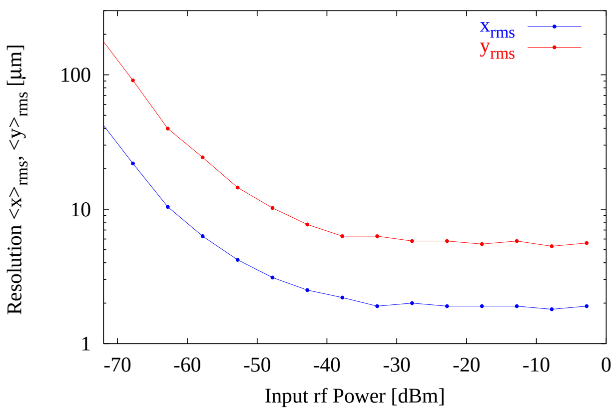

Figure 4: Measurement of the resolution for a bandwidth of 500 Hz

6 MEASUREMENTS

One of the important parameters of a BPM system is the position resolution. Measurements of the noise-induced resolution for different power levels were done using a synthesizer and a four way power splitter to simulate a central beam. Fig. 4 shows the rms-noise as a function of the input rf power at the electrodes for a bandwidth of 500 Hz. For the lower input powers the resolution is determined by the thermal noise and the noise figure of the electronics. For the higher input power the resolution is limited to 2 μm in the horizontal plane and 6 μm in the vertical plane due to the digitalization noise of the 12 bit ADC. The difference in the position resolutions is caused by the different plane sensitivities of the BPM. Better resolutions can easily be obtained by reducing the bandwidth with the integrated low pass filter.

Besides resolution the long term stability of the position is important. The long term stability was measured with the same experimental setup and was better than 2 μm during 24 hours.

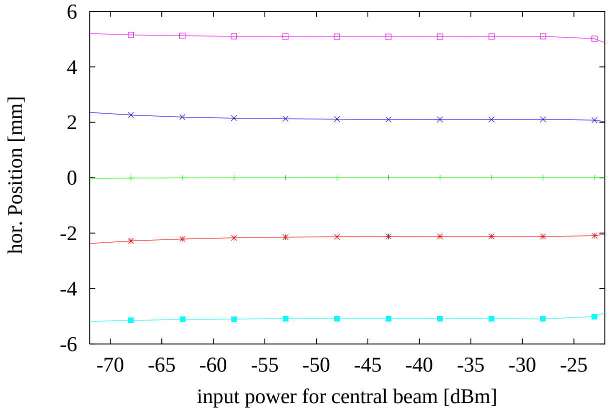

Figure 5: Position stability as a function of the input power for 0 mm, $\pm$ 2 mm, and $\pm$ 5 mm

Measurements of the position change with signal level were done on the BPM calibration facility of ELSA. It consists of an rf antenna inside a vacuum chamber with an integrated BPM. To simulate different beam positions the antenna can be moved by stepper motors with a resolution of 10 μm. The measurements of the position as a function of the signal level is shown in Fig. 5. In a broad range of approx. 50 dB, the change in position of a central beam passing the BPM is lower than $\pm$ 20 μm, for an offset of 2 mm from the center it grows to $\pm$ 150 μm. With the help of the switchable 30 dB attenuator the dynamic range can be further increased.

7 CONCLUSIONS

The first prototype showed the required performance and the complete system will be installed after manufacturing in the second half of this year. The position resolution should be sufficient to determine the zero position of the BPMs using beam-based alignment.

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