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BPM SYSTEM UPGRADE AT COSY

I. Bekman, C. Böhme, V. Kamerdzhiev, B. Lorentz, S. Merzliakov,
P. Niedermayer, K. Reimers, M. Simon, M. Thelen
FZJ, Jülich, Germany

Abstract

The beam position monitoring system of the Cooler Synchrotron (COSY) has been upgraded in 2017. The upgrade was driven by the requirement of the JEDI collaboration to significantly improve the orbit control and by the electronics approaching end-of-life. The entire signal processing chain has been replaced. The new low noise amplifiers, mounted directly on the BPM vacuum feedthroughs, were developed in-house and include adjustable gain in 80 dB rage and in-situ test and calibration capabilities. The signals are digitized and processed by means of commercial BPM signal processing units featuring embedded EPICS IOC. The decision path, technical details of the upgrade and performance of the new system are presented.

INTRODUCTION

The necessity of upgrading the COSY Beam Position Monitor (BPM) system arose from the requirement of the JEDI collaboration to significantly improve the beam orbit control and by the electronics approaching end-of-life. The upgrade affected all electronics sub-systems: amplifiers and their control, data collection and processing, networks, and the way measurement results are stored and presented. New sub-systems were added, for example, the calibration sub-system utilizing in-situ test signal generation and fine control of amplifier gain and as the main part - the Hadron Beam Position Processor Libera. Below the block-diagram (Fig. 1) and a brief description of the main components of BPM system are presented. 31 capacitive BPM are installed in the COSY ring. This number includes two BPM of the 2 MeV electron cooler which are also capable of measuring proton orbit. These are not affected by the upgrade presented here. Each COSY BPM utilizes 4 electrically isolated electrodes that make beam position measurements in both X and Y planes possible. The electrodes are connected via N-type vacuum feedthroughs to the amplifiers. Close to the amplifiers high precision ($4 \cdot 10^{-4}$) four-way splitters are placed to feed test signals from generators of the calibration sub-system into the amplifiers. The 116 amplified signals are transmitted from the tunnel via coaxial cables to eight Libera beam position processors [1] installed at 6 location in the accelerator hall (Fig. 2). The 19-inch racks house also the crates of the trigger system as well as additional crates accommodating the amplifier power supply and calibration sub-system. Newly developed graphical user interfaces based on Control System Studio allow for display of measured beam orbit and turn-by-turn data, amplifier gain control and calibration as well as provide additional software tools for display and control of Libera parameters, ADC data etc.

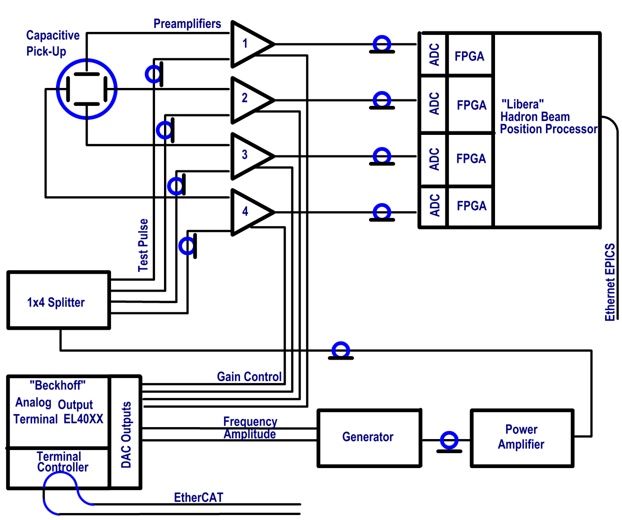

Figure 1: Block diagram of the new COSY BPM system. Only one pickup and corresponding electronics are shown.

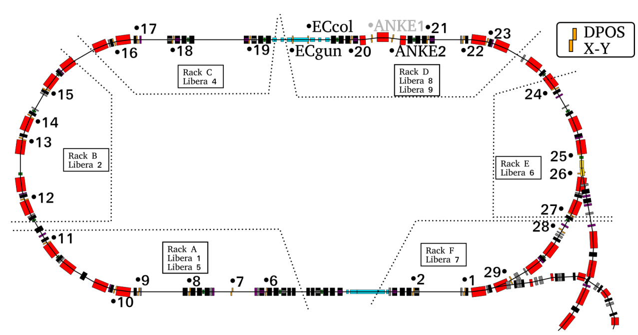

Figure 2: Operational BPM hardware around the COSY ring.

BPM AMPLIFIERS

The BPM amplifiers are housed in a 100·50·25 mm die-cast aluminum case and are installed directly on the vacuum feedthroughs. They are connected to the Libera beam position processors and the calibration sub-system. For analog signals RG214 coaxial cables are used. CAT 6 Ethernet cables are used to power the amplifiers and for gain control. Figure 3 shows the block diagram of a BPM amplifier.

Each unit consists of two stages: input stage and amplification stage. Table 1 summarizes the properties and performance of the input stage. The amplification stage is based on the variable gain amplifier chip AD8330 and features variable gain up to 80 dB. Control of the amplifier gain is done by means of commercial EtherCAT DACs.

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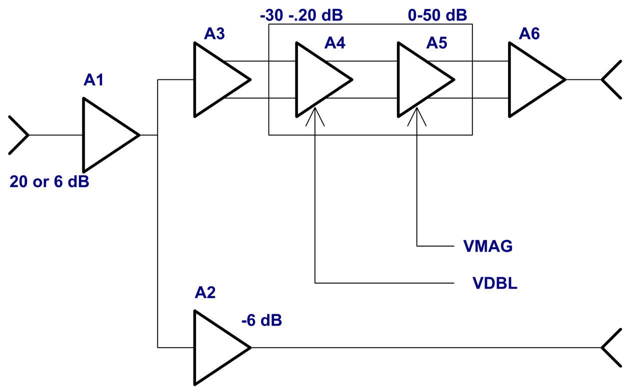

Figure 3: Block diagram of BPM amplifier. A1 - input stage (6 or 20 dB), A2 output stage (-6 dB), A3 - single to differential signal converter (0 dB), A4 and A5- 1st (0 - 50 dB, 0 - 1.5 V or 30 mV/dB) and 2nd stage (-30 - 20 dB, 0 - 4.8 V, nonlinear) of main amplifier, A6 - output buffer.

Table 1: Properties and Performance of the Amplifier Input Stage A1

Parameter	Value
Input impedance	500 kΩ
Output impedance	50 Ω
Gain	6 dB or 20 dB
Output Range	± 1 V at 50 Ω
Bandwidth	1 kHz - 80 MHz (-3 dB)
Temperature coefficient	0.05 % / °C
Input noise	1.4 nV / $\sqrt{Hz}$ at 10 MHz

LIBERA BEAM POSITION PROCESSORS

Based on the µTCA 4.0 platform, the commercially available LIBERA electronics [1] from Instrumentation Technologies digitizes the analog signals and provides several calculated data streams. The main purpose is the recognition of the single beam bunches and providing the calculated position of those. However, other data is available, like the 10 Hz averaged position data stream, the ADC raw data or the FFT of the bunch data. In the case it is not possible to acquire bunch-by-bunch data (insufficient signal quality or unexpected bunch shape like in case of barrier-bucket operation), a so called narrow-band analysis can be used. In this case the signal is highly integrated before trying to calculate beam position.

The available data can be sent towards the control system in several ways, out of the box the possibility for the EPICS or TANGO data communication is provided. Because of the larger user base, and therefore more software being developed, the usage of EPICS was chosen to slowly replace the proprietary data communication protocol used at COSY.

The LIBERA electronics needs further input signal references: a trigger signal, a RF frequency reference and a 10 MHz reference (based on central COSY clock) for synchronization between single units. These signals are generated on a central platform and then distributed to the units via equally long cables.

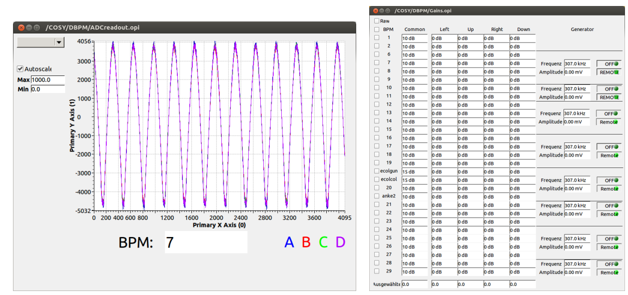

Figure 4: Control System Studio [2] graphical user interface views of raw ADC data (left) gain and generator control panel (right).

POWER AND CALIBRATION HARDWARE

The power and calibration modules for the 4 power sensors are packed in 19-inch crates. The sizes of all modules are 3 U, 8 TE, length 160 mm. Inside the crate Beckhoff EtherCAT DAC modules, which control the amplifier gains and the parameters of the calibration system are installed (see below). The calibration sub-system for one BPM consists of: 4-channel Beckhoff DAC, quartz synchronous generator, power amplifier and four-way splitter (the latter are installed in the tunnel). The generator is used for performance testing and calibration. It produces a series of Gaussian shaped pulses of different amplitudes (0–2 V) and frequencies (0.3–3 MHz). Frequency and amplitude control are done via EtherCAT remotely or using front panel controls locally. Precision of amplitude and frequency, as well as long term stability is better than 0.1 %. At the output of the generator a low pass filter of second order and a buffer amplifier based on OP LMH6639 is used. Power amplifier is based on the ADA 4870 operation amplifier. The device has a gain of 14 dB, and is capable to provide signals up to 10 V to four splitters with 50 Ω input impedance each. The main feature of the four-way splitter is the high accuracy of the power distribution between the 4 outputs. Input and output impedance of the device is 50 Ω, the attenuation from input to one output is 14,4 dB, flat. The maximum measured error of the attenuation for 30 splitters (120 channel) is $4 \cdot 10^{-4}$ (calculation error $2 \cdot 10^{-4}$). The second feature of the splitter is the possibility to work with 10 V input signal for a frequency range from DC to 300 MHz.

CONTROLS

The gain of the amplifiers and calibration generators is controlled by Beckhoff DAC modules using the EtherCAT communication protocol [3]. Modules listed in Table 2 are used per crate, with a total of 8 crates. The DAC modules provide adjustable current (EL41xx) and voltage (EL40xx) levels, which are converted to control signals delivered to the amplifiers and the generator modules. For each BPM amplifier two control lines are provided - a coarse common

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Table 2: Beckhoff Modules per Crate[1] of the BPM System

EK1101	EL4114	EL4114	EL4104	EL4114	EL4114	EL4104
EtherCAT Bus Coupler	4 Ch DAC Fine Gain (L)	4 Ch DAC Fine Gain (U)	4 Ch DAC Common Gain	4 Ch DAC Fine Gain (R)	4 Ch DAC Fine Gain (D)	4 Ch DAC Generator

[1]One crate being connected to fewer BPMs, there the last two DACs of type EL4114 are absent.

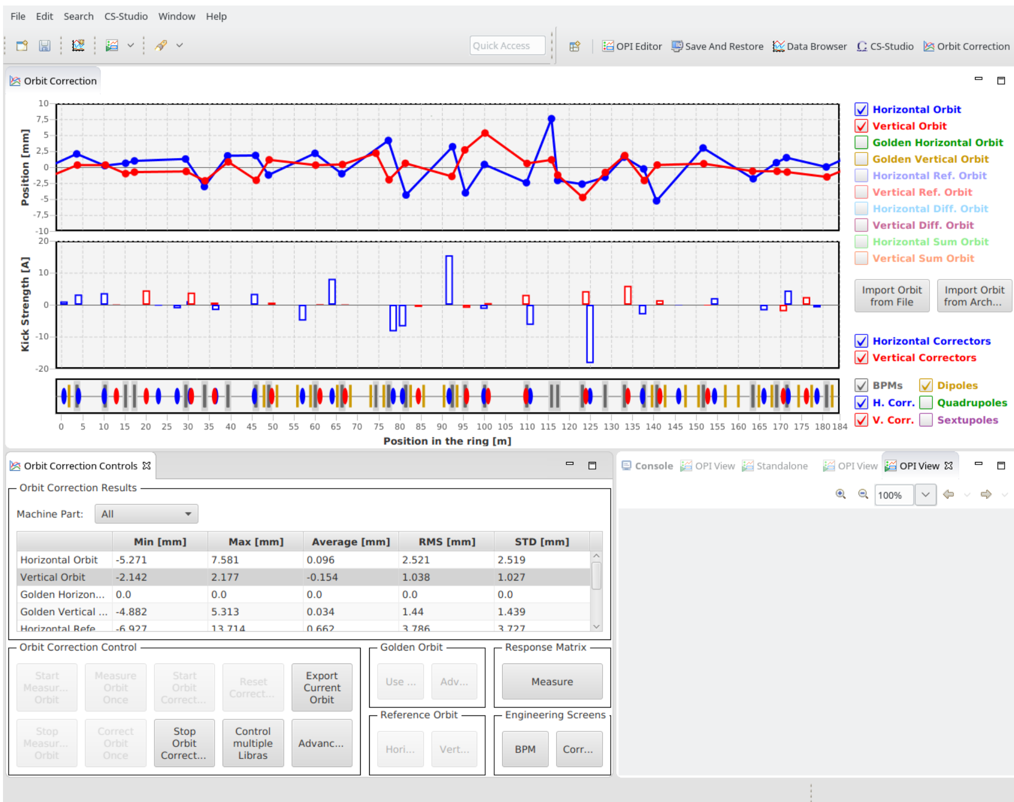

Figure 5: Screenshot of the orbit correction GUI. The measured beam orbit (10 Hz data stream) is displayed in the upper part.

gain for a group of up to 4 amplifiers and a fine gain to control individual devices.

The communication with the modules via the EtherCAT standard is realized by means of a specially prepared server with a separate compatible network card, modified Linux kernel, and device drivers based on EtherLab package running in a standard Debian distribution.

Libera, gain, and calibration generators are controlled and read out via EPICS [4] protocol and relevant values are being archived continuously. Several EPICS graphical user interfaces were implemented for ease of use by the operators and maintainers based on CSS software package.

GAIN CALIBRATION PROCEDURE

Preliminary calibration of a single BPM was performed with a sine generator. Gain parameters were scanned and data was read out from the ADC of Liberas via EPICS. The results are shown in Figs. 6 and 7. The precision of a given gain setting was determined to be on the order of 0.04 dB, the stability over 60 h was determined to be better than 0.01 dB.

SUMMARY AND OUTLOOK

The new hardware was successfully installed in July 2017. Since then the new system was routinely operated for orbit measurements and orbit correction. Minor issues were resolved and did not cause interruptions of beam operation. One-time calibration of the amplifier components is scheduled for the machine maintenance weeks in the Fall 2018. Currently the automatic gain calibration software is being commissioned. Once operational the feature should be used regularly and after every gain adjustment. It is expected that this would push the accuracy of measured beam position below 100 µm.

REFERENCES

[1] Libera Hadron, *Hadron Beam Position Processor*, User Manual, Version 1.01, Instrumentation Technologies, Velika Pot 22, SI-5250 Solkan, Slovenia

[2] Control System Studio Webpage, `http://controlsystemstudio.org/`

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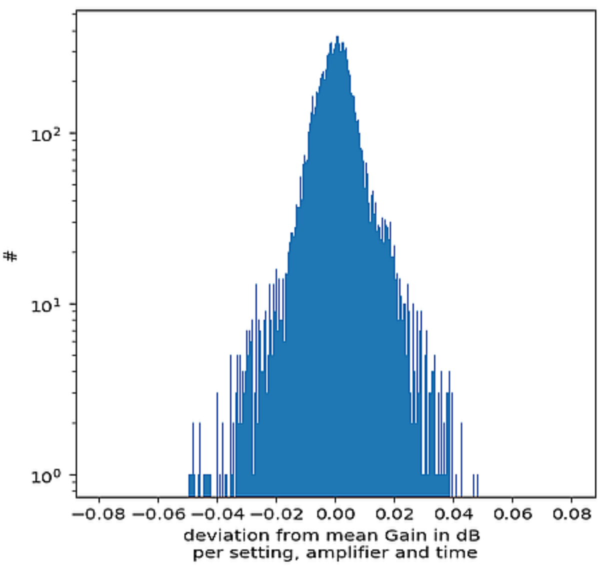

Figure 6: For gains below 57 dB for four different amplifiers both common and fine gain settings were scanned repeatedly in a calibration procedure. The plot shows statistical distribution of mean gain values per setting from which the precision over all settings can be estimated.

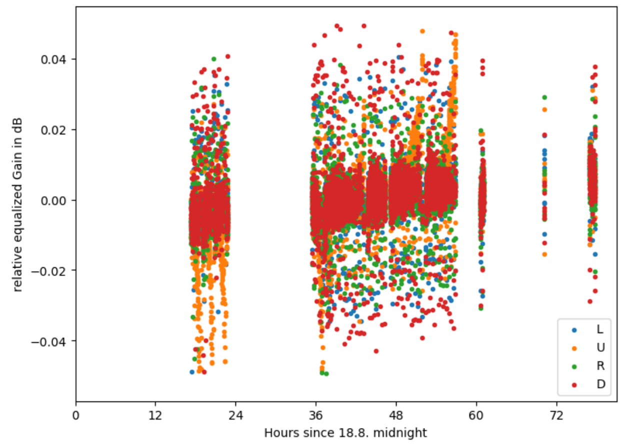

Figure 7: Repeated measurements for four amplifiers over several hours shows good stability.

[3] EtherCAT standard, `http://www.beckhoff.com/EtherCAT-System/`

[4] Experimental Physics and Industrial Control System (EPICS), `http://www.aps.anl.gov/epics`