NEW BEAM MONITORING INSTRUMENTATION AT ATF2, KEK*

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Abstract

A new stripline beam position monitoring (BPM) readout and processing system was installed and successfully tested over a two-week period at the Accelerator Test Facility (ATF2), at KEK, Japan during February 2010. The core analog processing board used in the system is a duplicate of that developed for, and in use at, the Linac Coherent Light Source (LCLS) at SLAC. The digitization, processing and control front-end were custom designed for ATF2 using a 14-bit 100-MHz VME digitizer and an EPICS Input / Output Controller (IOC) running on the VME controller. Control of the analog boards is via EPICS, which controls a serial-over-TCP / IP port server. Hardware for the readout of up to 14 BPMs with 3 spare analog boards was delivered. The goal of this installation was to provide better than 10 microns resolution, non-charge-dependent readout of the ATF2 electron beam with long-term gain stability compensation. These criteria were tested and successfully met. This design was found to be highly effective and to have many advantages, especially that it required minimal installation effort at ATF2.

INTRODUCTION

Twelve analog processing chassis are connected with cables to ATF2 stripline electrodes (Fig. 1). Each chassis has four inputs from Y+/- and X+/- striplines.

The 140 MHz output signals go to the VME 14-bit digitizers which have a 100 MHz sampling frequency. An EPICS IOC on a VME controller (Motorola MVME3100) receives and analyses the digitizer data, controls the analog processor gain, and calibrates signal power and calibration tone pulse width.

The port server communicates with the analog processing board via RS232 protocol. One trigger pulse initiates the calibration cycle in the time gap between the beam pulses. Another trigger synchronizes the digitizer's data conversion.

REQUIREMENTS

The main requirements:

- Resolution better than 10 microns.
- The measured beam position independent of beam charge. Operational ranges are ~ 0.15-1.5 nC (single bunch) with a dynamic range of +/- 3mm.
- Long-term gain stability 5%-10% over month timescales. The actual gain stability performance is still to be assessed.

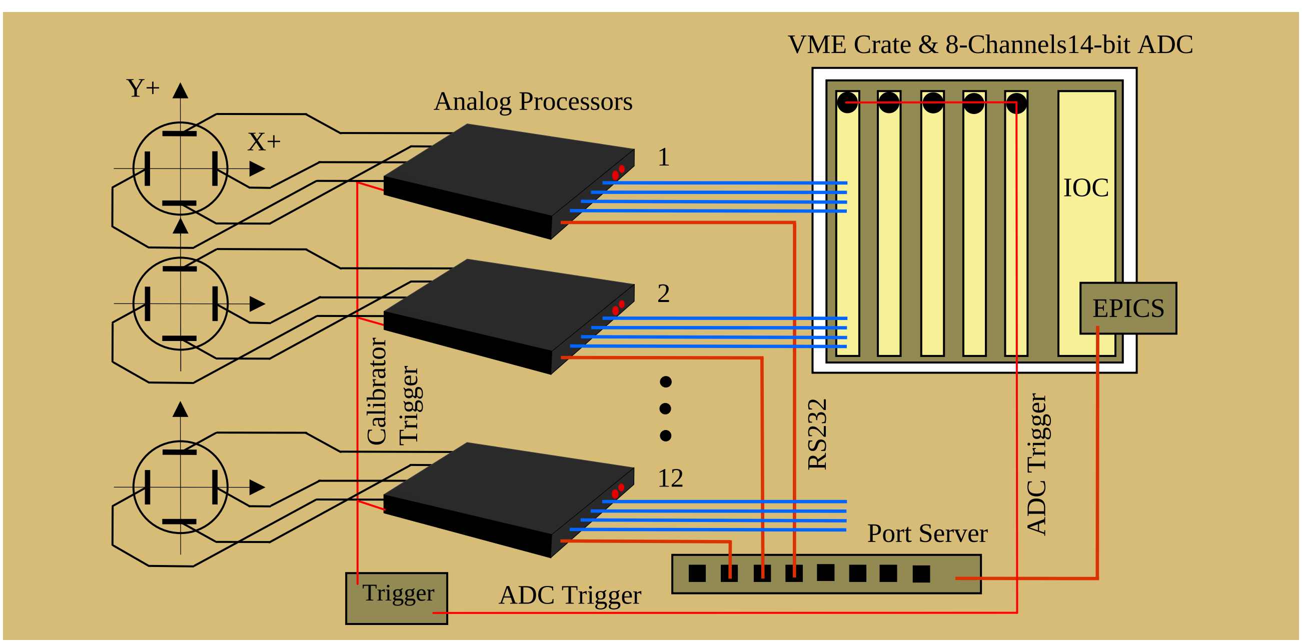

Figure 1: The ATF2 BPM processing system block diagram.

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BPM READOUT AND PROCESSING SYSTEM

The analog processing board or Analog Front-End board (AFE) originates from LCLS [1]. High resolution beam position monitoring processor electronics were designed a few years ago for LCLS for a single bunch of 0.08-8.0 nC charge. The LCLS processor consists of the AFE and 16-bit Analog-to-Digital Converter (ADC) boards, packed into 19-in rack mount chassis, 1U high. The ADC board has a microprocessor (IOC) and requires three network ports for communications. Fourteen chassis with the AFE but without the ADCs were built for ATF2. This design has many advantages.

Analog Processing Board

The AFE board has four analog processing channels, with three low-noise amplifies, three band-pass filters, two programmable attenuators of maximum attenuation 15 dB and 31 dB, a fast comparator and a switch at the end of the analog channel for overvoltage protection of an external ADC.

Input bandpass filters are centered at a frequency of 140 MHz with a processing bandwidth of 7 MHz. The analog channels input noise is very low, approximately 3 microV rms. The maximum gain is 34 dB with programmable attenuation of up to 46 dB in 1 dB steps. The calibrator (CL) sends short 140 MHz tone-bursts between the beam pulses alternately to the Y+ and X- striplines. The signal ratio of the two adjacent striplines calibrates the processing channels gain and cable loss. The programmable attenuator can vary CL amplitude over 31 dB in steps of 1 dB. The maximum power output is close to 2 W. The CL tone-burst duration is typically between 260 and 300 ns. The CL requires an external trigger pulse synchronized with the beam.

The fast comparators and a switch at the end of the channels (limiter) shut down the outputs if an overvoltage approaches, and prevents damage to the ADCs.

The LCLS processors show an average position resolution of 5 microns rms at a bunch charge of 220 pC in a stripline pickup of 1 inch diameter.

A Xilinx FPGA controls the programmable attenuators, CL and limiter. The FPGA supports two types of communications: RS232 and Queued Serial Peripheral Interface (QSPI). RS232 is used for the ATF2 BPM chassis.

ATF2 BPM Chassis Construction

The ATF2 BPM chassis is a 19” rack-mount unit, 1 U high. The enclosure size is 17” x 17”. AC Power input is 100-240 VAC, 47-63 Hz. On the rear panel there are four input SMA and two LEMO connectors, two fans and a power plug. The front panel has four output SMA connectors, “power on” LEDs, an RJ45 communication port and three fans. The enclosures are made by Protocase, Inc [2].

Digitizer

Eight-channel, 14-bit, 100-MHz VME digitizers (SIS3301) from Struck Innovative Systeme (Hamburg, Germany) are used in ATF2 for BPM signals processing [3]. With 140 MHz input signals and a 100 MHz sampling frequency, the digitizer under-samples the input waveform and the data aliases to 40 MHz. The advantages of using the external ADC are: flexibility of ADC selection, the ADC could later be replaced with a better one, for example one with more bits, a higher sampling rate, or higher analog bandwidth. The IOC runs in the local controller (VME for ATF2) and it requires only one network connection.

The SIS3301 has an analog input bandwidth of 70 MHz. At 140 MHz, the input signal is attenuated by 17 dB. This adds additional noise to the noise budget. As set up at ATF2, the corresponding digitiser 1-bit noise represents a resolution limit of about 2 microns. This is sufficient for the planned operation and can be improved in future by using digitizers with a higher bit-count or with increased input analog bandwidth.

Port Server

The RS232 port interface was used in preference to the QSPI one as readily available and easy to use commercial distribution hardware exists for this protocol. The Digi Port Server (TS 16) has 16 RS232 ports / serial-to-Ethernet [4]. These are used for programming the AFE, for setup, monitoring and control of the VME processor and for remote reboot control of the VME crate.

The AFE board has DB-9 connectors for RS232. Only three pins are used: Receive Data (RD) - pin 2; Transmit Data (TD) - pin 3; Ground is pin 5, so the AFE is Data Terminal Equipment (DTE) type.

EPICS Control Display

All setup, control and monitoring is done through a single Matlab Graphical User Interface (GUI) panel.

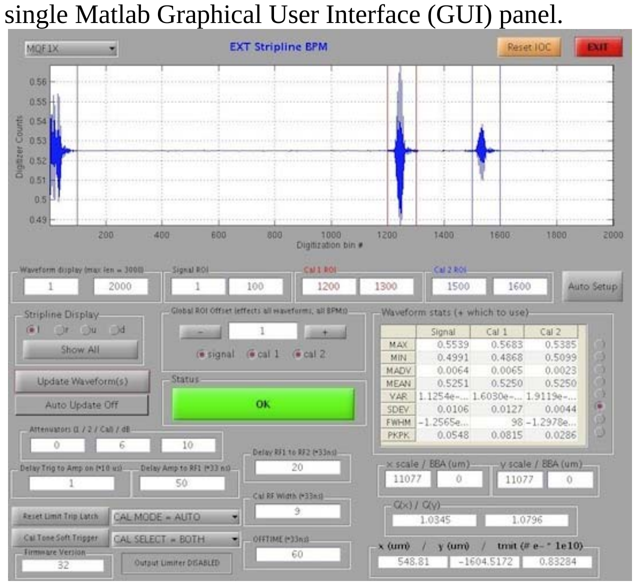

Figure 2: EPICS Control Display.

This principally allows for the selection of regions of interest for the main stripline signals and calibration signals. It also allows all other parameters supported by the AFE to be examined and changed. It displays the statistical analysis of the waveforms for use by the position algorithm and allows user selection of different ones. A simple standard deviation calculation for each waveform was found to give the best performance.

MEASUREMENTS AND DATA ANALYSIS

The BPMs were calibrated using dipole corrector magnets through the ATF2 beamline. To investigate resolutions, gain stability and charge sensitivity, one thousand continuous stable pulses were taken.

Resolution

The resolution was calculated for each BPM chassis. Y resolution is 6 microns or better, X resolution is 10 microns or better (Fig. 3). The resolution data below was calculated from a 1000 pulse run. A model-independent analysis technique using Singular Value Decomposition (SVD) was used to subtract the coherent pulse-pulse jitter from the accelerator, leaving the resolution-related jitter of the BPMs shown below. The horizontal BPMs in regions of the machine with large design horizontal dispersion show the worst resolutions, meaning that the applied technique did not succeed in completely removing all energy-related jitter. Hence the below should be considered as an upper-estimate of the resolution. The achieved resolution meets requirements and the best shown meets the expectation of 2-5 microns of jitter.

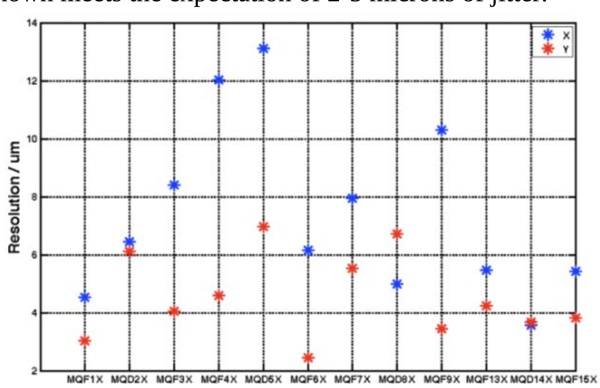

Figure 3: Estimate of the resolution for 12 BPMs.

Gain

Gain is stable. It was monitored over 24 hours (Fig. 4). The MQD5X BPM has a large gain imbalance due to a defective cable, it also exhibits far more gain drift than the other BPMs. The gain monitoring analysis system nicely deals with this however.

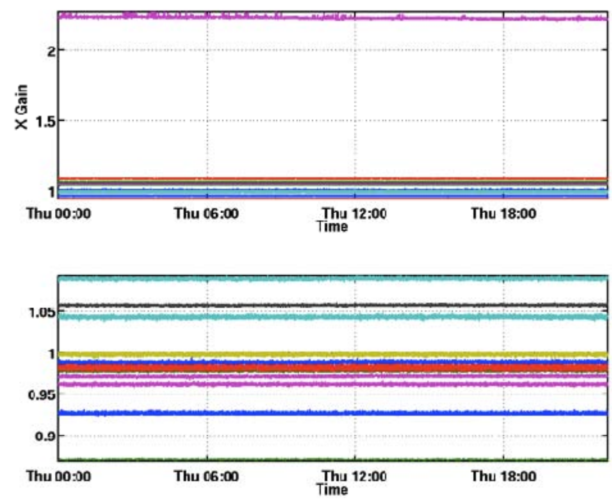

Figure 4: X and Y gains over 24 hours.

Beam Charge versus position

The position is mostly insensitive to the beam charge. Fig. 5 and 6 below show the data from two of twelve processors. The X and Y spreads are distributed horizontally. There is a very small tilt on the charge-versus-Y-position plot of MQD2X.

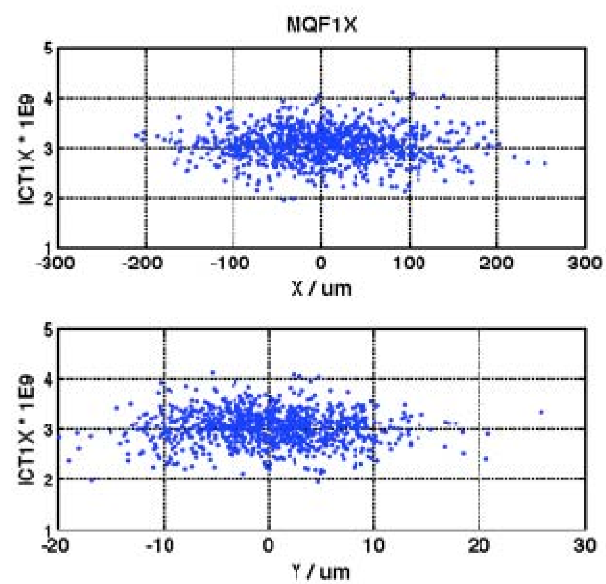

Figure 5: BPM MQF1X beam charge versus position, X and Y data spreads are distributed horizontally. There is no charge-position sensitivity.

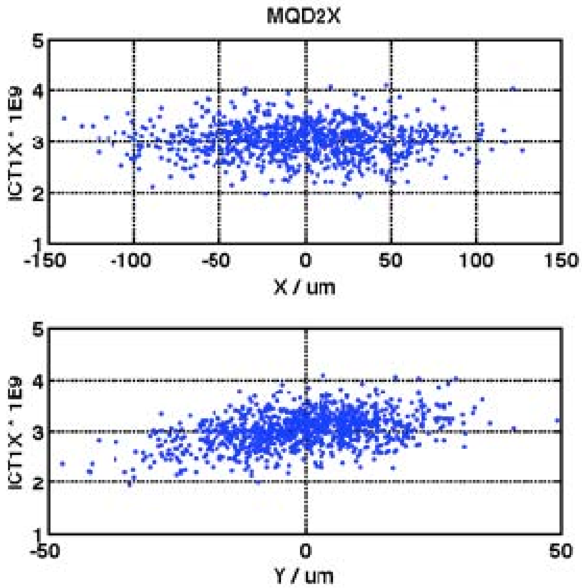

Figure 6: BPM MQD2X-Y has a charge-position tilt, negligibly small deviation.

Beam Based Alignment

Each BPM is attached to one of the quadrupole magnets in the extraction line of the ATF2. Quadrupole-shunting beam-based alignment (BBA) was used to align the BPM readout with the magnetic center of its associated quadrupole. This entails sweeping the beam across the magnet using an upstream corrector with the magnet at full and 80% of nominal strengths. The center of the magnet can be found from the crossing of the two orbits on a downstream BPM.

An example is shown in Fig. 7. It is hoped that the stability of this BPM system will allow for this BBA data to be valid for a long period of time enabling "golden orbit" restoration at the start of beam tuning shifts.

SUMMARY

- A new BPM readout and processing system was installed at ATF2, tested and available for use.
- Resolution 10 microns or better satisfies the requirements.
- Gain is stable over 24 hours.
- The measured beam position is insensitive to the beam charge.
- This design is very effective, required minimal installation effort. Each unit could be replaced relatively easily. A digitizer already supported by the existing control system was used.

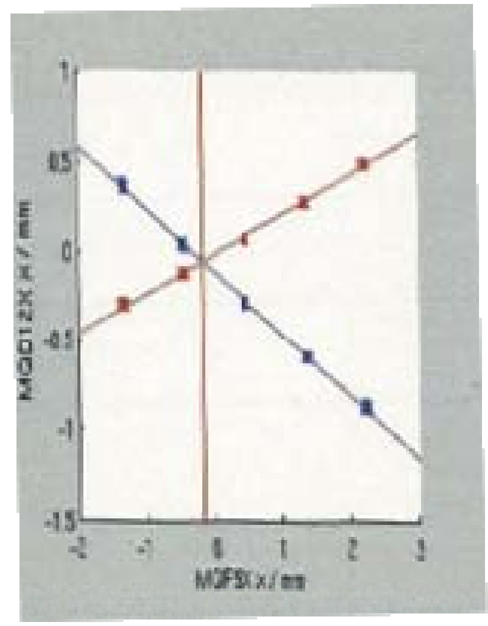

Figure 7: BBA results of QF9X quadrupole using MQF9X BPM and downstream MQD12X BPM and a quad shunting method.

ACKNOWLEDGEMENTS

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