FAST BEAM CURRENT TRANSFORMER SOFTWARE FOR THE CERN INJECTOR COMPLEX

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ABSTRACT

The fast transfer-line Beam Current Transformers (BCTs) in the CERN injector complex are undergoing a complete consolidation to eradicate obsolete, maintenance intensive hardware. The corresponding low-level software has been designed to minimise the effect of identified error sources while allowing remote diagnostics and calibration facilities. This paper will present the front-end and expert application software with the results obtained.

INTRODUCTION

The Transformer Integrator Card (TRIC) a new digital acquisition module, was designed to replace obsolete analogue integrators used to acquire the beam intensity from the Fast Beam Current Transformers (FBCT) in the CERN Proton Synchrotron Booster (PSB) and CERN Proton Synchrotron (PS) transfer lines.

The older Fast BCT acquisition electronics was, for the most part, analogue and provided poor facilities for remote adjustment and diagnostics. The output of the older FBCT system was essentially limited to a single value corresponding to a beam's total intensity. While the sample-to-sample reproducibility was within the 1% required for normal operation, the absolute errors could be considerable due to time-variations in the analogue electronics. Maintaining this system often required cumbersome expert interventions at the site of the installed hardware. This approach is outlined in Figure 1.

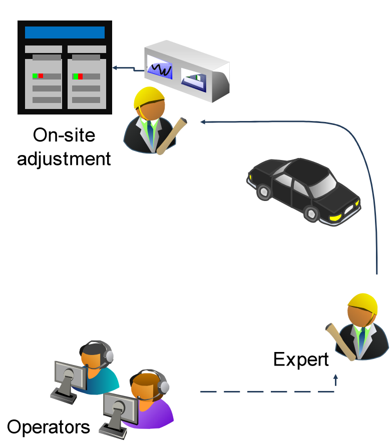

Figure 1: Interaction with old system.

The following outlines the main drawbacks of the old system:

- No ability to precisely time the acquisition to the beam signal, leading to the integration of additional noise in the measurement
- No ability to perform remote calibration or any remote diagnostics
- No possibility to discern and measure multiple isolated beam bunches and beams of multiple injections
- Parameters such as measurement gains had to be changed on-site via analogue potentiometers using a screwdriver
- The DC measurement offset had to be subtracted by the software. This made it impossible to compare the results from two distinct FBCT's in hardware and prevents the implementation of a hardware-only Beam Loss Watchdog. Reliability is therefore reduced due to this dependence on software and its associated complexity.

The new system was designed to address the above issues while maintaining or improving the satisfactory relative measurement accuracy.

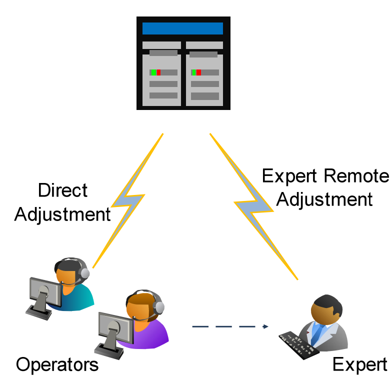

Figure 2: Interaction logistics for the new system.

TRIC HARDWARE SOLUTION

The TRIC is a VME-based acquisition module equipped with two analogue inputs each sampled at 200 MHz and subsequently processed by a large FPGA [1]. The TRIC card incorporates all the required functional elements for making reliable beam intensity acquisitions. The flexible and modular nature of the FPGA digital platform allows multiple data integration schemes which are explained below:

Parallel integrator – uses single window beam capture scheme with an accompanying offset capture. This integration is the most commonly used type for ordinary PS and PSB transfer line measurements. The

DC offset measurement can be specified to be performed at any time interval when there is no beam in the line.

Calibration integrator – single calibration window with accompanying DC offset capture as in the Parallel integrator above.

Bunch integrator – allows up to 32 possibly overlapping measurement gates to be defined and acquired using a single trigger signal. Each measurement has its own delay and capture length.

Multigate integrator – stores its values as a set of 1024 back-to-back capture gates with the same programmable gate duration. This mode provides an "oscilloscope" type overview and is extensively used in setting up timing parameters for the "single shot" integrators described above [2].

SOFTWARE ARCHITECHTURE

The software architecture for the new Fast BCT acquisition system is displayed in Figure 3. It consists of:

1. *BCTFPS*, a FESA acquisition server running locally on the Linux or LynxOS VME front end computers.

2. *BCTFPS_Monitor*, a Java based expert GUI application used for adjusting measurement parameters and validating acquired results.

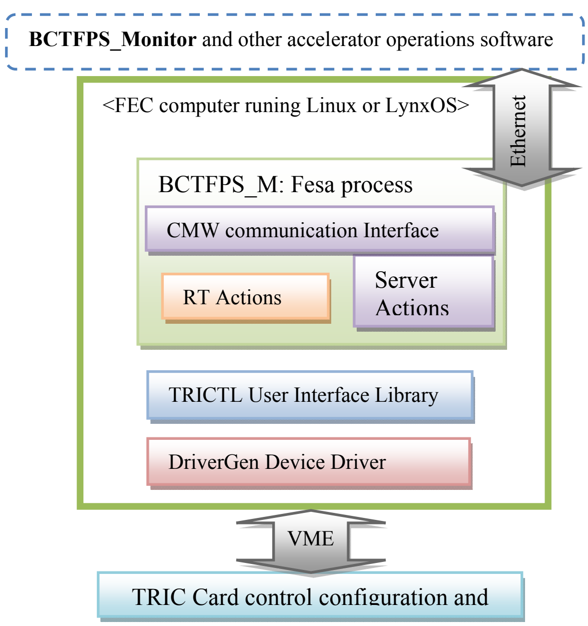

Figure 3: Software structure.

The *BCTFPS* is based on the FESA framework [3] allowing it to benefit from features such as real-time scheduling, beam-cycle synchronisation, user-notifications and use of a shared memory model.

Communication with the TRIC card is provided by a *TRICTL User Interface Library* where the register access to the TRIC hardware is made and data is decoded and pre-processed [4]. The low level hardware access is implemented using CERN's new standardized DriverGen driver platform.

The real-time part of the BCTFPS acquisition server consists of Prepare and *Acquire* actions triggered by PS or PS Booster central timing events linked to active elementary cycles. The following table summarises various steps taken during real-time actions.

Table 1: Functions Performed in Corresponding Real-Time Part of the BCTFPS Code

Real time SW Action	*Main functionality*
Prepare	✓ Reset integrators ✓ Configure each of the hardware integrators for the new cycle ✓ Select calibration scheme ✓ Setup cycle specific calibration parameters
Acquire	✓ Read timestamps, beam destinations and measurement status ✓ Read and store intensity measurements ✓ Scale *multigate* integrator values ✓ Compute intensity from raw data for verification ✓ Compute long term current statistics for the beam

INSTRUMENTATION EXPERT SOFTWARE

The *BCTFPS_Monitor* application (Fig. 4) is built for the adjustment of the timing as well as electrical and logical parameters for the low level *BCTFPS* acquisition server. It is coded using *Expert GUI* framework Java libraries developed by the CERN Beam Instrumentation Software Section [5]. The settings that can be applied are grouped into those applied for specific acceleration cycles and those that are common for all cycles. The integration gate length and its delay from the start trigger are, for example, settings which vary greatly from one accelerator cycle to another.

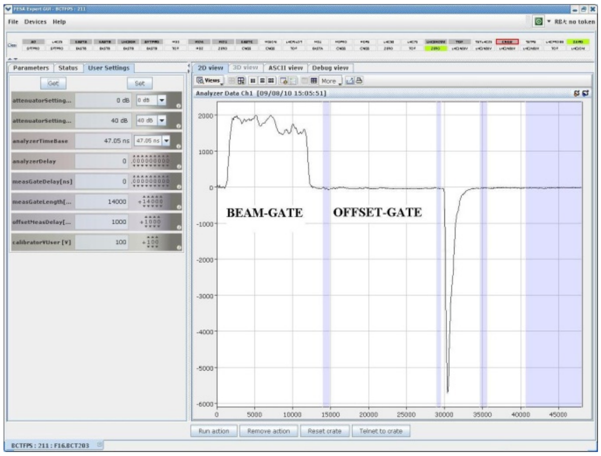

Figure 4: BCTFPS_Monitor GUI screenshot showing the beam intensity and negative calibration pulse with respect to the various integration gates.

The main part of the GUI is a large graph showing acquisition data from the 1024 data points of the *multi-gate* integration. The graph refreshes with every beam pulse passing in the transfer line. The beam acquisition and calibration pulse are superimposed on the acquisition gates using background colour cursors. The time base for the multigate integrator can be varied, achieving a 10ns resolution at its minimum setting. Figure 5 shows some of the shortest beam pulses extracted. The individual bunches of the *SFTPRO* beam cycle, ejected from the PSB, are <200ns long and spaced by ~300ns, and can easily be resolved using the smallest multigate integration time window.

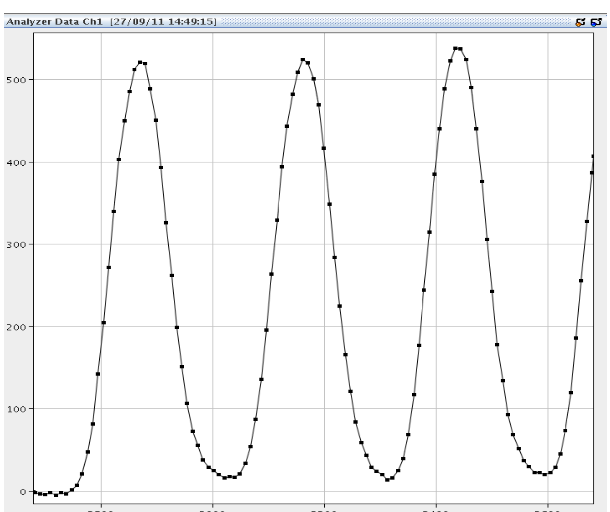

Figure 5: PBS ejected *SFTPRO* beam with *multigate* integration time increment of 10ns.

Increasing the increment acquisition time to tens, and even hundreds of ns, allows the expert to see the full picture for beams of longer duration. Figure 6 displays the same *SFTPRO* cycle at ejection from the PS, with the full 10μs beam pulse now visible.

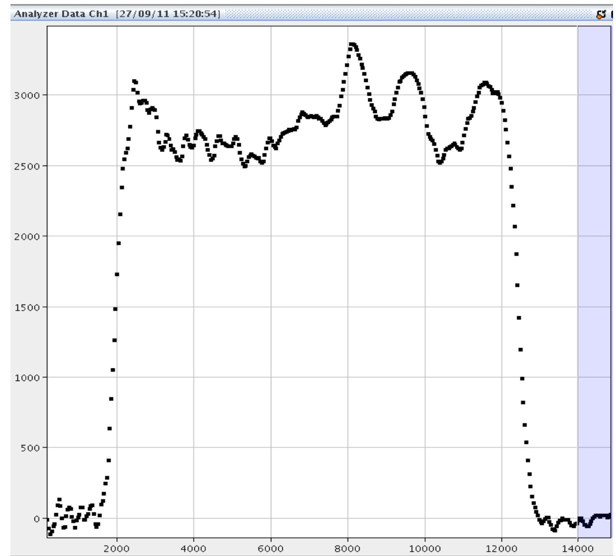

Figure 6: PS ejected *SFTPRO* beam with multigate integration time increment of 38ns.

MEASUREMENT REPRODUCIBILITY

The quality of the measurement data acquired by the new BCTFPS server was inspected with respect to different acquisition scenarios and compared to the old Fast BCT acquisition system. The first parameter studied was the relative error of the new system in the PSB transfer line compared to the intensity measured in the ring itself.

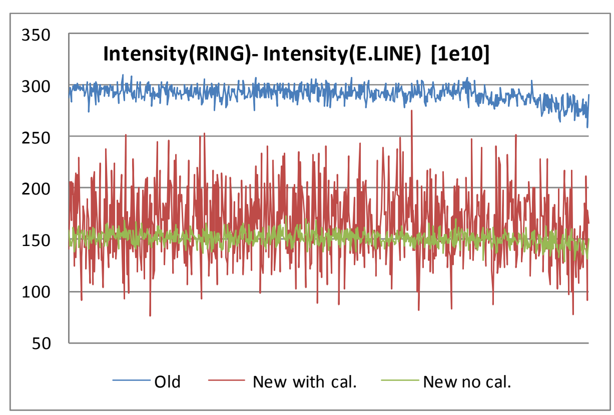

Figure 7: Comparison of the reproducibility for the old and new system. Using shot by shot calibration increases the noise on the measurement.

For the measurement in Figure 7, the average beam intensity was around 3e14 charges. The absolute value of the error is not important for the variation analysis, since the acquisition systems are not cross calibrated. It was seen that when the calibration was applied on a cycle by cycle basis additional noise was added to the final intensity result. This was found to come from the non-reproducibility of the calibration pulse. It was thus decided that rather than perform the calibration for each new measurement it was better to use a single constant calibration factor. This factor was to be determined and applied by the expert in the instrument setup phase by taking the mean value from many calibration pulses. Once the calibration factor was fixed the remaining errors in the intensity measurement came from the front-end electronics and reproducibility of the beam injection process. The drawback of the "fixed calibration factor" scheme is that the system is not 100% autonomous and maintenance free.

Unique calibration factors have to be maintained for each of the two acquisition channels and each of the three attenuation levels (0dB, 20dB and 40dB). To set-up these factors, the expert uses a dedicated feature of the *BCTFPS_Monitor* GUI (Figure 8). The steps are the following:

1. Enable active calibration routine after every beam measurement
2. Unselect the "Freeze" radio-button in current attenuation level.

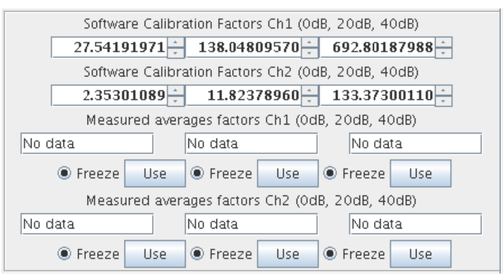

Figure 8: GUI panel for the calibration factor setup.

The system then starts acquiring calibration factors computed from the applied physical calibration pulses. The running sum of the 16 last measurements is displayed in the field.

3. Once the average is accumulated the Expert presses the "Use" button to subsequently set this value in a firmware register.
4. Disable active calibration and start using the new fixed calibration factor.

The quantitative improvement in the measurement reproducibility (i.e. less shot-to-shot variation) by using a "fixed" calibration factor has been significant. The following table displays the relative error of the total measured intensity for two distinct Fast BCTs [2].

Table 2: Reproducibility Error of old and new Fast BCT Acquisition Systems

Measurement System	BCT.BTTRA	BTY.TRA325
Original System	0.63%	0.23%
New system with Active Calib.	0.65%	1.2%
New system Const. Calib. factor	0.08%	0.22%

The last column showing BTY.TRA325 corresponds to the graph in Figure 8 above and shows how the relative pulse-to-pulse error was initially dominated in the new system by the shot-to-shot reproducibility of the calibration, returning to that of the old system once a constant calibration factor was applied. The downside of this solution is the fact that the new TRIC based system did not become totally maintenance free, as originally envisioned, since a periodic adjustment of the fixed calibration factor is now needed to correct for long term drifts in the acquisition electronics.

CONCLUSION

The new Fast BCT acquisition system has been significantly improved by new hardware and software. A highly modular digital integration module allows experts to cover many possible measurement scenarios by means of multiple integrator implementations keeping configuration settings limited and uncluttered. The additions of the on-board calibration circuit, as well as 1024 data point acquisition graph view, have greatly simplified instrument expert setup and maintenance procedures. The software solutions for both the front-end FESA server and the Expert GUI enable a seamless acquisition service to accelerator operations and a convenient parameter adjustment interface for the experts.

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