ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-WEPHA065

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

UPGRADED BEAM INSTRUMENTATION DAQ FOR GSI AND FAIR: OVERVIEW AND FIRST EXPERIENCES

T. Hoffmann, H. Bräuning
GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

Abstract

As construction of the FAIR accelerator complex progresses, the existing heavy ion synchrotron SIS18, the storage ring ESR and the high energy beam transfer lines HEBT have been upgraded to the future control system. Within this upgrade the beam instrumentation (BI) data acquisition (DAQ) systems have been heavily modernized too. These are now integrated into the control system with its White Rabbit based timing system, data supply (i.e. ion species, energy, etc.) and services like archiving. Dedicated clients running in the main control room allow visualization and correlation of the data and status of the BI devices. The DAQ hardware has been upgraded using new state-of-the-art components. With a trend to slowly phase out VME based systems, solutions based on standard Industrial PC for few channels as well as on the new µTCA standard for many channels have been successfully implemented. This contribution will give an overview over the upgraded BI-DAQ systems like current transformers and counter applications for ionization chambers, scintillators and more. It will also present first experiences during beam operation with the new control system, which started summer last year.

INTRODUCTION

While upgrading the control system of the GSI accelerators SIS18 and ESR within the last years, it was also necessary to modernize important BI-DAQ systems in parallel. This included the complete renewal of the data acquisition electronics, connection to the new White Rabbit based timing system and software integration. The goal was to design the DAQ in such a way that the solutions will be directly transferrable to the future FAIR accelerators.

The control system upgrade was a challenging issue as the established procedures for timing and software integration have significantly changed. Collaborations with CERN lead to a new, complete and useful control system infrastructure. Besides the FESA environment and the LSA settings management, the development and integration of the White Rabbit based timing system helped to achieve higher accuracy, better performance and high flexibility in the readout of BI systems.

CONTROL SYSTEM

The decision for FESA (Front-end Software Architecture) [1] as the lowest tier of the GSI and FAIR accelerator control system opened the way for the BI group to contribute directly with programming and integration of BI software into the control system. FESA is based on the classic client-server architecture, with the executable FESA classes acting as servers on the frontend computers (FEC). The FECs are operated with CentOS 7 Linux via PXEboot. Supported FECs are Intel based µTCA CPUs, Industrial PCs and in rare cases VME controllers. In addition, Siemens PLCs for slow controls are supported by FESA via the CERN made SILECS [2] interface tool. User access to all DAQ systems is provided by JavaFX graphical user interfaces, which subscribe to the relevant properties published by the FESA classes.

TIMING

The new White Rabbit (WR) based timing system plays the central role in the renovation of the BI DAQ systems. A detailed description can be found under [3]. The WR timing system is based on the IEEE 1588 2008 (precision time protocol PTP) standard and a network infrastructure similar required for Gigabit Ethernet. A timing master (TM) coordinates and synchronizes all FAIR Timing Receiver Nodes (FTRN) distributed in the field in the one-nanosecond range. The TM sends out event messages, which are then executed on time in the FEC. Each message consists of the exact time it is to be executed as well the timing group, event id, beam process id, sequence id and other information. The timing group indicates the part of the accelerator complex, for which the message is valid. While for example the SIS18 is a single timing group the HEBT is divided into several groups with each beamline segment between two switching magnets typically having its own group id. Events like beam extraction may be played in the timing group of the ring but not in the timing groups of the HEBT. Beam processes constitute the smallest unit in the operation of the accelerator, i.e. injection, acceleration, etc. Each beam process has its own id. The full accelerator cycle is given by a sequence of beam processes and has a corresponding sequence id. However, for a given beam from the source to the target, the number of beam processes and the beam process and/or sequence ids are usually different from timing group to timing group. This has to be taken into account in all BI applications which correlate the data of different devices along the beam path.

INTENSITY MEASUREMENTS

AC Current Transformer

The injection of the ion beam from the linear accelerator UNILAC into SIS18 is monitored by two AC current transformers (ACCT). Figure 1 shows the measured current for a single injection into SIS18 in the early phase of commissioning after a long shutdown. The upper graph displays the data from the ACCT in the transfer channel. It shows the approximately 40µs long macro-pulse from the UNILAC and its rather flat intensity distribution. The lower

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-WEPHA065

graph shows the data from the ACCT in the SIS18. At an injection energy of 12.8MeV/u the revolution time in the ring is about 4.4µs. The blue curve is the measured data, showing the increase of current in the ring. The red curve is the expected increase in ring current based on a 100% injection efficiency and the data from the upper graph. It is used as a guideline to optimize the injection efficiency.

Figure 1: ACCT measurement in TK and SIS18.

The DAQ consists of an Industrial PC (IPC), a 16-bit ADC M2i4963-exp (PCIe) from Spectrum [4], and an I/O card from AddiData [5]. The ADC is operated in the standard arm-trigger-readout cycle. It is armed at the start of the accelerator cycle. At this time any hardware settings like pre-amplifier gain are applied too. A dedicated beam injection event is used by the FTRN to emit the trigger pulse for the ADC. This event is guaranteed by the control system to come at least 100µs before the UNILAC pulse. The measurement time of 1ms also guarantees, that data after the pulse is measured. This is used for automatic baseline detection and subtraction. In addition, the FTRN generates a gate for the ACCT pre-amplifiers, which are active only during this gate. Also based on the injection event a software event is generated by the timing receiver after a delay of several ms, which triggers the readout of the ADC by the software.

The ADC uses a sampling rate of 10 MSa/s which is more than enough considering the 1 MHz bandwidth of the pre-amplifiers. Pre-amplifier gains can be set directly by the operators or automatically based on information provided by the control system like charge state, energy and expected number of particles.

DC Current Transformer

The intensity of the stored beam in the rings (SIS18 and ESR) is measured by a DC current transformer (DCCT). While the same DAQ hardware is used as described above, the readout is completely different, because the intensity is to be measured over the whole accelerator cycle which in case of the storage ring ESR can in principle be hours long. Thus the DAQ is not triggered as in the case of the ACCT but is free running. This is made possible by two distinct features of the M2i4963-exp ADC which are the availability of a continuous readout via DMA and the possibility to mix external logic signals into the ADC data stream. This second feature is essential in order to assign an absolute time to the ADC samples. By reducing the ADC resolution to 14 bit, 2 bits are available to reflect the state of two external logic signals at the time the ADC sample was taken. The start event of the accelerator cycle causes the FTRN to emit a logic signal of 100 µs length. The state of this signal is reflected in one of the two bits mentioned in the ADC stream. In addition, the FTRN issues a software event, which contains the exact timestamp of the event as given by the timing system. The DAQ then searches in the ADC data stream for the set bit and can thus assign an absolute time to this data sample. The time of all other data samples is than calculated based on the ADC sampling frequency. Still the synchronization is done on every start of an accelerator cycle.

In order to keep the amount of data manageable, the sampling rate of the ADC is set to 100kSa/s. In addition, using an averaging filter, data down sampled to 10kSa/s, 1kSa/s, 100Sa/s, 10Sa/s and 1Sa/s is kept available. The size of the data buffers is limited to 100000 samples. Thus at full sampling rate only 1s of data can be stored whereas at 1Sa/s data over a time span of 100000s can be displayed. For normal operation in SIS18 a sampling rate of 1kSa/s is used.

In addition, to the raw ADC data, the beam current (in A) and the beam intensity (in particles) are calculated and kept available for all sampling rates mentioned above. While the current is directly available based on the ADC value and the gain settings, the calculation of the particle number requires the ion charge state and the revolution frequency as a function of time. Both are supplied by the control system per beam process.

Besides the ADC data, the DAQ records all events in the ring's timing zone and matches them to the ADC data stream. This allows to divide the ADC data into the beam processes and send them to the client. Furthermore, any of the recorded events can be used to obtain a single value measurement of the beam intensity at this point in time as well as of a programmable time offset from the event.

Figure 2 shows a complete cycle (sequence) of the SIS18. The client is responsible for building the full sequence from the single beam processes send by the DAQ. Also indicated are a few dedicated events like injection and extraction. The upper graph shows the beam intensity i.e. the number of particles in the ring, whereas the lower graph shows the beam current. Directly after injection a loss in intensity can be observed which is also indicated in a decrease of the beam current. During acceleration the beam current increases due to the increasing revolution frequency. As can be seen in the upper graph, the number of particles in the ring is constant. Finally, after a short time the slow extraction starts and the number of particles in the ring decreases with the current decreasing proportionally.

In the mode described above and shown in Fig. 2 the data for each beam process is published at the end of the process, i.e. when the next process starts. This will be very inconvenient with long processes in storage rings. After some experiences with operating the ESR storage ring with the new control system will be gained in the next months, the implementation of a partial update is foreseen. This will

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-WEPHA065

Figure 2: DCCT measurement in SIS18. Shown are beam intensity (particles, top) and beam current (in A, bottom) as function of time for the full accelerator cycle. The spike at the right is a calibration peak which always shows a half full scale signal.

send for example every second the available data, even if the beam process is not finished yet.

Already implemented and maybe even sufficient for storage ring operation is a continuous update. The continuous update runs concurrently with the above described mode. It publishes the actual beam intensity and current with a rate of 10Hz independent on beam processes and machine timing.

Counters

The DAQ of many beam instrumentation devices can be based on counters. Either the devices directly provide a countable rate like i.e. scintillators or their output can be converted into a frequency with current-to-frequency converters (IFC) like ionisation chambers (IC), secondary electron monitors (SEM) etc. Using IFC or voltage-to-frequency converters (UFC), the DAQ is not limited to detectors but can also be used to acquire auxiliary signals like monitor voltages from power supplies etc. thus allowing the correlation of widely different sources. The advantage of counters is that they provide a high density of channels at moderate cost. Using latching scalers, the count rate as a function of time can be measured.

Several counter systems with up to 128 channels in a single system are used at the current GSI accelerators. While some systems are still VME based, a new µTCA based system for beam loss monitors (BLM) has recently been commissioned. The µTCA system uses the MTCA.4 compliant Struck SIS8800 scalers. Each scaler has 16 direct front channel inputs and 16 analogue inputs via a SIS8980 leading edge discriminator rear-transition-module to be used for example directly with the analogue signals from scintillator photomultiplier tubes.

Special efforts have been undertaken to control the required IFCs of ICs and SEMs in the beam line. A dedicated VME based digital I/O (V-DIO) was developed by MagentaSys [6] to not only set I/O functions, but to deliver remote power, to receive the differential detector signals over long distances and to convert them into NIM pulses for further counting. Currently these modules are used together with VME scalers in a crate consisting of 12 V-DIO modules with 4 channels each and two SIS3820 (32 channel) scalers controlled by a GE VR12 VME controller. In the future, it is planned to move the scalers to a µTCA system which will control the V-DIO modules via an USB-VME controller. First tests with such a setup are encouraging.

The counters are continuously read out like the DCCT described above. In fact, most of the DAQ logic like synchronization or sorting by beam processes is identical and placed in an external library. The only difference in synchronization is, that a scaler channel is used to count the synchronization pulse. Furthermore, due to the usually large number of channels the latching (sampling) frequency is limited to 1kHz which is sufficient for normal operating. A dedicated µTCA based expert system with a sampling frequency of up to 1MHz for a limited number of channels is planned.

Like with the ACCT and DCCT, where applicable, particle rates are calculated based on beam properties provided by the control system. For ICs and SEMs this also requires the calculation of the energy loss in the detector. This calculation is done only, when new beam properties from the control system are received by the DAQ software.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-WEPHA065

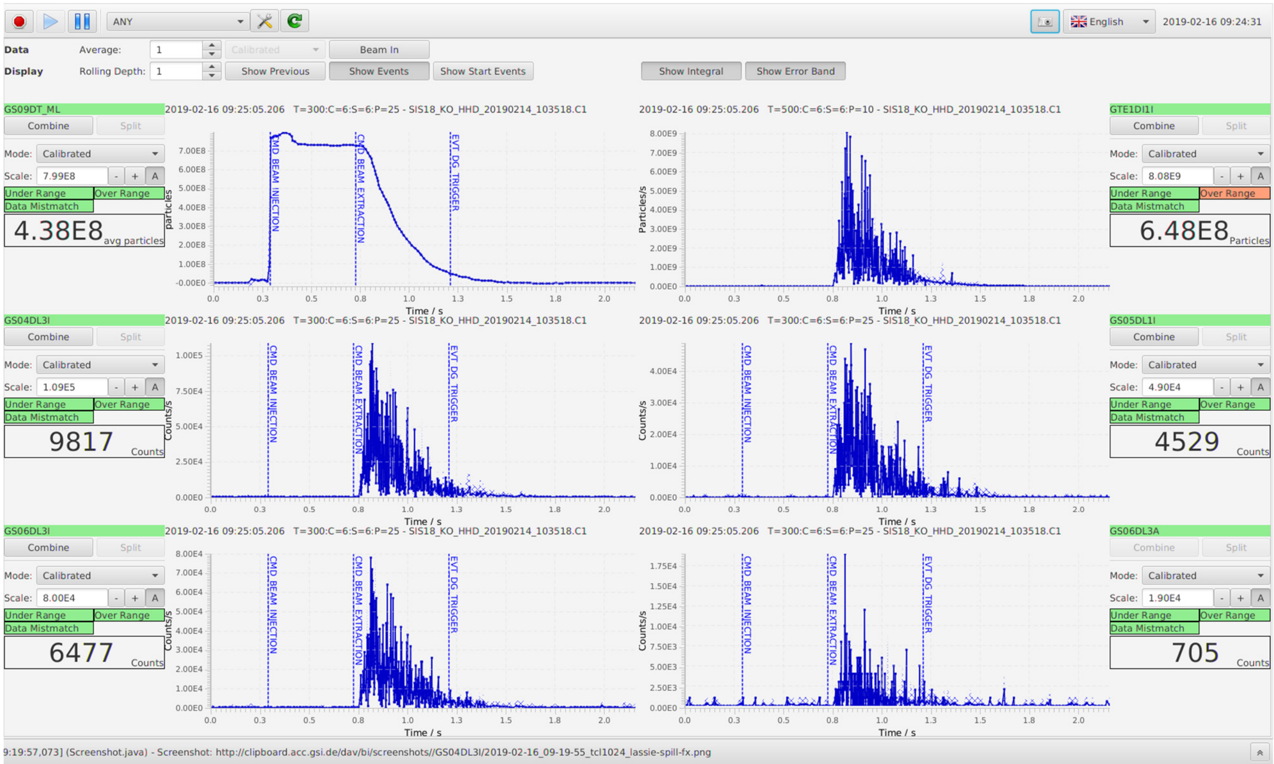

Figure 3: Synchronous visualization of different acquisition types (ADC, scaler) in LASSIE.

In contrast to the old DAQ the energy loss is now calculated using the Atima code [7] instead of a simple formula by Ziegler et al. [8].

Lassie

All the free running systems described above (DCCT, Counters) provide data as a function of time in a very similar way. Even the continuous update discussed for the DCCT is available in the counter DAQ.

LASSIE (Large Analog Signal and Scaling Information Environment) [9] is a JavaFX framework and collection of applications designed to show and correlate data from different free running systems. The core library handles tasks like subscribing to the various devices, sending manual settings, initiating self-tests and building the data for the full accelerator sequence from the various beam process data send by the DAQ. It is still flexible enough to deal with differences between different devices like ionization chambers providing the beam intensity in particles while BLMs just provide counts. The applications include the display of the data as a function of time (see Fig. 3), the monitor of the continuous update data, trending, display of integral values like counter sums over the cycle or maximum number of particles in the cycle and the analysis of time dependent data like FFT, cross correlation between two devices etc.

Figure 3 shows the time dependent data of different devices for a full SIS18 cycle. The upper-left graph shows the beam intensity from the DCCT discussed above and acquired with an ADC. The injection and extraction events are shown (see also Fig. 2). The upper-right graph shows the extracted beam in the HEBT measured by a plastic scintillator and a counter on the same time scale. As this device sits in a timing domain different from the SIS18 timing domain, ring events like injection and extraction are not send there and thus not displayed in the graph. The lower two rows show the in-ring beam losses measured by BLMs (count rate). The time correlation of the beam intensity in the HEBT and the BLMs with the start of the extraction from the SIS18 is clearly visible. Moreover, the integral data is shown indicating that the beam losses during extraction are rather small.

PROFILE

CUPID

The CUPID video imaging system [10] for beam profile measurement is operational since several years. Scintillating screens are observed by camera systems either in free run during slow extraction of the beam over several seconds or in triggered mode for fast extraction or pulsed beams.

The camera of choice is the IDS uEye UI-5240SE-M-GL GigE camera. It features an external hardware trigger, fast streaming via Gigabit Ethernet and is relatively insensitive to radiation. A dedicated control unit (CPS8) has been designed to provide power and trigger over long distances from the electronics room to the cameras in the tunnel. Different remote controlled lenses of fixed focal length like Linos MeVis Cm 16 or PENTAX C1614ER are used. With these lenses the iris aperture can be remotely controlled via a Siemens PLC system.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-WEPHA065

At locations with high radiation levels such as extraction beam lines, also radiation-hardened solid-state CID (Charge Injection Device) based cameras from Thermo Fischer Scientific, like the CCIR MegaRad3 (8726DX7), were installed. The images are acquired via Pleora iPort Analog-Pro external frame grabber units and send via Gigabit Ethernet to the DAQ.

As frame grabbers are free running with a fixed rate, the trigger functionality needed for fast extraction has been implemented by software. In this case the first frame acquired after a trigger event received by the DAQ from the FTRN is send to the clients, whereas all other frames are discarded. This introduces a jitter based on the frame rate of frame grabber and software delays in the DAQ. However, no adverse effects have been observed so far.

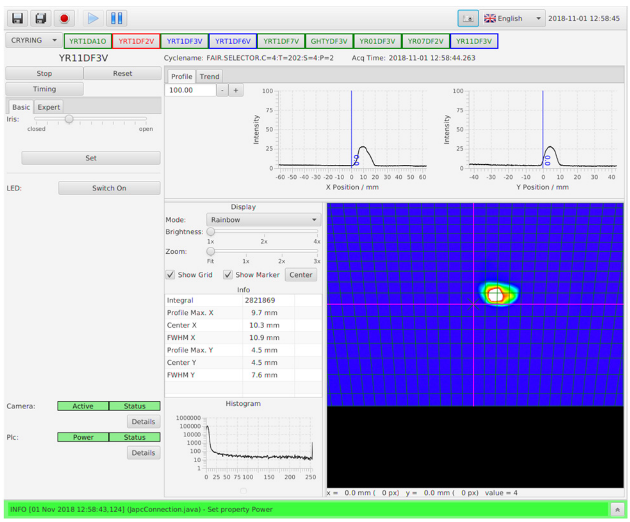

Figure 4: Video imaging with CUPID for beam profile measurement on scintillating screens.

Figure 4 shows as an example the beam spot on the scintillating screen in section 11 of the Cryring. Besides the image, the profiles and the intensity histogram are displayed. Values like position of maximum intensity, centre of intensity, and full width half maximum are calculated already by the DAQ and are also displayed. No effort is undertaken to correct the perspective distortion due to the 45° angle between camera and screen in the image. However, this distortion is indicated by the grid overlaid on the image as is clearly seen in Fig. 4.

OUTLOOK

Currently, the Fast Current Transformer (FCT) [11] systems for rings and beamlines are being redesigned. Again, a µTCA based DAQ system will be used. The main component is the state-of-the-art 2.5 GSPS, 14-bit FMC ADC from SIS [Struck] in conjunction with a corresponding FMC carrier. A SIS8164 I/O AMC module is used to control the Femto DUPVA pre-amplifier. The main difference of the triggered readout between the ring and HEBT applications lies in the data handling as the challenging amount of data in the ring, measured over many revolutions and synchronous to the rf, has to be managed. The HEBT FCT is basically a single shot system with a relatively small amount of data but requires careful trigger settings as only the start of the evaluation window of the kicker event is known and not the actual time the kicker fires. The hard- and software integration for the ring FCT is done and final tests with beam are targeted for the end of the year.

CONCLUSION

The most important BI systems were successfully ported to the FAIR control system standard. Essential was the provision of the WR timing system and the FESA framework. The use of contemporary hardware, e.g. µTCA, GbE cameras or high-performance ADC modules opened the way for a better performance and accurate high resolution data for beam diagnostic purposes. With this successful upgrade of the BI-DAQ systems a major step towards the final FAIR BI has already been achieved.

REFERENCES

[1] T. Hoffmann, G. Janša, and M. Schwickert, “FESA at FAIR - The Front-End Software Architecture”, in *Proc. 23rd Particle Accelerator Conf. (PAC'09)*, Vancouver, Canada, May 2009, paper FR5REP009, pp. 4794-4796.

[2] https://be-dep-co.web.cern.ch/content/silecs

[3] C. Prados, J. N. Bai, A. Hahn, and A. Suresh, “A Reliable White Rabbit Network for the FAIR General Timing Machine”, in *Proc. 16th Int. Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'17)*, Barcelona, Spain, Oct. 2017, pp. 627-632. doi:10.18429/JACoW-ICALEPCS2017-TUPHA091

[4] Spectrum Instrumentation, https://spectrum-instrumentation.com/de/m2i4963-exp

[5] http://addi-data.de

[6] https://www.magentasys.com

[7] H. Weick *et al.*, “Improved accuracy of the energy-loss code ATIMA for heavy ions”, in Scientific Report 2017 GSI Helmholtzzentrum für Schwerionenforschung GmbH.

[8] J.F. Ziegler *et al.*, "The Stopping and Range of Ions in Solids", Pergamon Press Vol.1, (1985).

[9] T. Hoffmann, H. Bräuning, and R. Haseitl, “LASSIE: The Large Analogue Signal and Scaling Information Environment for FAIR”, in *Proc. 13th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'11)*, Grenoble, France, Oct. 2011, paper MOPMN008, pp. 250-252.

[10] B. Walasek-Höhne *et al., “CUPID: New System for Scintillating Screen Based Diagnostics”, in Proc. 3rd Int. Beam Instrumentation Conf. (IBIC'14), Monterey, CA, USA, Sep. 2014, paper TUPD06, pp. 417-420.*

[11] O. Chorniy, H. Bräuning, T. Hoffmann, H. Reeg, and A. Reiter, “A FESA DAQ for Fast Current Transformer in SIS 18”, in *Proc. 2nd Int. Beam Instrumentation Conf. (IBIC'13)*, Oxford, UK, Sep. 2013, paper WEPF31, pp. 894-896.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.