A Fast VME Data Acquisition System for Spill Analysis and Beam Loss Measurement

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Abstract. Particle counters perform the control of beam loss and slowly extracted currents at the heavy ion synchrotron (SIS) at GSI. For these devices a new data acquisition system has been developed with the main intention to combine the operating purposes beam loss measurement, spill analysis, spill structure measurement and matrix switching functionality in one single assembly. To provide a reasonable digital selection of counters at significant locations a modular VME setup based on the GSI data acquisition software MBS (Multi Branch System) was chosen. An overview of the design regarding the digital electronics and the infrastructure is given. Of main interest in addition to the high performance of the used hardware is the development of a user-friendly software interface for hardware controls, data evaluation and presentation to the operator.

1. INTRODUCTION

For the control of slowly extracted ion currents with energies up to 1 GeV/u from the GSI heavy ion synchrotron into the high energy beam transfer line (HEBT), particle detectors and related technologies are applied. For the low intensities up to $10^6$ particles per second (pps) plastic scintillators, for the medium range between $10^4$ and $10^9$ pps ionization chambers (IC), and for higher ranges secondary electron monitors are used (SEM) [1]. While the scintillators, after discrimination deliver countable logical pulses, the secondary currents from the ICs and the SEMs are converted to logical pulses, close to the detector, by a large dynamic range current-to-frequency converter [2]. For the data acquisition, counting these detector signals, scalers can be used. Scalers are available with high performance at low costs per channel and are installed on densely packed VME-boards leading to a compact and modular setup. By means of voltage-to-frequency converters other parameters, like the stored current inside the synchrotron measured by a dc-transformer, can be taken into account. The main idea of the presented new data acquisition system is digitizing the counts of all detectors, independently from their dedicated application, in a VME system installed in the local-electronics room with a fine time mesh of about 1 ms using only standard hardware components. From the VME processor the reduced data is transferred to a nearby installed Linux PC via a 100Mbit Ethernet connection, where the flexible visualization and data storage is carried out. Using the X capability of LINUX, the information can be exported to any X-terminal located in the main control room.
particular, no additional hardware has to be installed there. This enables a well manageable organization of the required information.

Different types of information can be obtained from the measurement data: For a fast overview the total number of extracted ions per cycle can be displayed. This information may be used as a transmission control from SIS to the experimental area. For the alignment of the accelerator settings, the time evolution during a cycle has to be shown with a time resolution in the order of 1 ms. Comparative studies between different detector types can be used for calibration purposes. A smart selection menu provides a subset of detectors for a particular setting, which then is visualized. More complex analysis algorithms like integration, differentiation or FFT can be applied on demand. An overview drawing is shown in Fig. 1.

**Figure 1.** Principle scheme of the new data acquisition system. Analog signals from the synchrotron or the high energy beam transfer line (HEBT) are discriminated and counted in the front-end electronics. Power supply, front-end, back-end PC, and the exported X-display are all connected via 100Mbit Ethernet using the TCP/IP protocol.

2. HARDWARE

On the basis of practical experience a VME system was chosen. In this regime the modular concept and the commercial availability of the components is fulfilled. A CES RIO3 8064 real time processor provided with 128 MB DRAM performs the controlling of the data acquisition. Due to the fact that only count-rate-giving devices shall be observed, four VME SIS3801 32-channels Multiscalers have been installed. These scalers are providing 64 KB FIFO buffers leading to a save and incorrupt data acquisition. The maximum input rate is 200 MHz and the modules provide the possibility for individual channel selection using 32-Bit masking.
To debug and observe bus activities in the VME crate a CES8004AA VME/VSB display unit is used. For beam loss measurement using plastic scintillators the remote controlled VME 16 channel leading edge discriminator CAEN V895 was included into the setup. It provides easy remote threshold modification and adequate countable standard ECL pulses. Different sampling frequencies and precise timing are provided with a programmable VME SIS3807 4-channel pulse generator. To set the start and stop triggers, which means adjusting the acquisition gate depending on the heavy ion synchrotron cycles, a VME SIS3601 32-Bit output register is used. This module controls a programmable GSI timing interface unit, which is interpreting the GSI timing signals. In addition to all these VME devices some standard NIM modules such as Fan In/Fan Out, discriminators and mixed logic units are included. The hardware management and the operation via TCP/IP on the GSI local area network (LAN) is performed with a standard Intel processor based PC using Linux as the operating system.

3. SOFTWARE FRONT-END

The data acquisition software runs on the RIO3 PowerPC-based processor board with booting from a remote LynxOS real-time operating system server. The main idea of the newly developed software is providing a long-term monitoring of various detectors as well as a detailed time or frequency domain analysis of experimental data for short periods of time. It was found that the maximum sampling rate, which may be achieved in the current hardware configuration for continuous mode, is 1Msamples/s for one channel or 7ksamples/s for 128 channels in four modules. These rates are sufficient for the planned applications. Practically the value of 1ksamples/s per channel was selected. The structure of the software running on the processor board is shown in Fig.2.

The MBS (Multi-Branch System) is used as the base software for this application. This software was developed at GSI [3] and is utilized for medium and large sized detector arrays at GSI and a lot of other institutes since several years. It offers a stable and very flexible operation with a relatively small necessity of user programmed software arrangements. As MBS is designed for long period, multi detector data acquisition some modifications have been made to match the requirements concerning online visualization and bi-directional data exchange. Therefore, an additional TCP server thread has been implemented. The MBS controls the GSI VME trigger module, provided for the synchronization between the data acquisition and the accelerator events. The user editable MBS module ‘user readout function’ (f_user.c) provides all necessary initialization procedures, the basic data acquisition and analysis routines. Measured data from the scalers is summed up in constant time steps and then sent to the network client if it is connected. Meanwhile the original data from the scalers fills a fixed memory segment, organized as a shared memory area to provide access from other processes running on the same processor board. This gives the possibility to connect with other remote clients having access on the same data.
FIGURE 2. The user-readout-function (f_user.c) is part of the MBS (Multi Branch System) having access to the kernel. Being connected to the API, VME-hardware access, network service or inter-process communication is made possible.

To synchronize these processes a special LynxOS system message queue and a semaphore set controlling the shared memory access are initiated. These parallel running processes may be called as separate executables without interrupting the main data acquisition cycle. Assuming no impacts due to network limitations are present, the complete set of raw data may be temporary stored in the local memory for continuative analysis through the PowerPC or any remote Linux computer. While the standard readout process is creating a reduced data stream another user application may use the complete raw data set, which is stored in the shared memory at the same time.

4. SOFTWARE BACK-END

As the client remote computer a standard Intel Pentium 1 GHz CPU was chosen. The operating system is Linux Red Hat 7.2 with an installed KDE 2 window manager. This part of the data acquisition software was programmed in the Borland Kylix development environment. In principle every main function such as beam loss monitoring, matrix switching or spill analysis has to be considered as a user application, which is connecting to the front-end data stream via a TCP/IP client. This client is started inside the main program as a separate thread being responsible for the data transmission between VME crate and the Linux PC, compatible to the TCP/IP server on the front-end. This mechanism is based on a standard Linux socket library and uses network messages with variable data packet sizes.

The evaluator of incoming data at the back-end is implemented as an instance of an Object Pascal class. This class method provides some basic evaluation procedures like
calculating basic statistical parameters. The identification data such as physical module, channel number and the device-name etc. is stored in an appropriate data structure. To provide simple manipulation methods like storing data in files, refreshing data presentation, multi-channel data evaluation etc. a special list of objects has been developed.

5. APPLICATIONS

The main advantage of this new data acquisition system is the possibility to include several control operations, such as matrix switching functions and beam loss measurement into one single assembly. The most important functions are presented as follows:

5.1 Matrix Switching

The signals of most of the GSI HEBT (high energy beam transfer) detectors are collected in a designated electronic room. After discrimination the pulses are duplicated and sent to control system scalers and to a matrix switching unit. This crossbar function is used at GSI to display count rates of selected detectors in the main control room. The old system, a standalone 30MHz bandwidth analog solution is still working well. It provides a 64X4 matrix and it is placed in one rack at the SIS control desk. Due to the fact that this widely used device has reached its input channel limit and that more then 4 displayed channels are required a new way had to be found. In addition it is to expensive to update the old analog system to a bandwidth of the required 200 MHz.

The digital data acquisition system, which is discussed here, provides all the functionality of the old system but it is different from its data processing design. With using four 200 MHz SIS3801 multi scalers having 32 channels each, 128 inputs are obtained. Due to the modular design this amount may be increased anytime. The signals of all connected detectors are counted permanently in the VME part using the multi scalers with a sampling rate of 1kHz, but only the data of the selected detectors is used for visual display. The amount of the exported outputs is only limited by the display size. The count rates are displayed on a X-terminal in the main control room. For best view from longer distances within the control room a mode is prepared which displays the count rates in the biggest possible way in digital numbers. For more detailed observation, sitting in front of the terminal, the count rate distribution as a function of the cycle time, the digital value, and the logged end values as a function of cycles are displayed for each selected detector. This is also done in the way that the maximal window size per channel in relation to channel quantity is used.

5.2 Beam Loss Measurement

Having made several experiments [4,5] on beam loss detection to prevent permanent activation in the synchrotron tunnel in exposed areas and to increase
transmission to the experimental targets this project had to be moved from the state of improvisation to a regular beam instrumentation system. Blocks of 20x20x75mm$^3$ BC400 standard plastic scintillators coupled to fast multipliers Phillips XP2972 have been mounted at dedicated synchrotron sections such as extraction section and at the electrostatic septum. The amount of nearly 16 units will be installed during this development but further enhancement if necessary was taken into account. All monitors are observed permanently in the time-gate beginning with initialization of the synchrotron and ending with completion of the extraction into the HEBT.

The software provides a drawing of the SIS (Fig. 3) including the installed devices in which the user has to select the desired monitors. In small pictograms the final count-rates after each cycle and a simulated rate meter displaying the variation within the cycle will be shown for each detector.

![Sample drawing of the SIS with included detector icons showing the loss rates.](image)

**FIGURE 3.** Sample drawing of the SIS with included detector icons showing the loss rates.

Due to the fact that these pictograms may be dynamically added, removed or placed on custom position on the program window, the GUI may be easily adapted to the current environment setup. The pictogram set is organized as a list of objects, which properties may be saved and restored by using a separate setup file. These pictograms are based on a common parent class in which main features are defined. The basic class determines the mechanism of synchronization and data receiving from the beam loss data objects. The graphic objects have different shapes to visualize the various detector types. Logging and displaying the end values as a function of cycles while manipulating synchrotron settings provides the possibility to understand and to set the best conditions for transmission or lowest activating rates.
5.3 Spill Analysis and Calibration

For special accelerator experiments a tool was developed to observe the spill as a function of time. The spills of some detectors may be presented as graphs, supplemented with information like FFT, maximal count-rates and statistical parameters. Figure 4 shows in the top curve the currents in the SIS measured with a dc-transformer (a), and then the rate at the experimental target (b) giving information about the transmission, followed by beam loss monitors installed inside the SIS close to the electrostatic septum (c) and at the extraction section (d). During the spill some extraction parameters were not properly set, leading to a decrease in transmission as a function of time.

![Figure 4](image)

**FIGURE 4.** The spill analysis function showing selected detectors and mathematical conversions:
- **a.** SIS-DC-transformer
- **b.** experimental target behind the HEBT
- **c.** scintillator-beam loss monitor at the magnetic septum
- **d.** two scintillator-beam loss monitors placed left and right at the extraction tube.

Mathematical routines are used to calibrate the ion chambers with scintillators and secondary electron monitors. In the past this was calculated offline, but having access to every monitor including the SIS beam transformer a correlation between many kinds of detectors is now easily done.

To optimize the extraction parameters this online mode is very helpful. The graphs are getting updated cycle by cycle and are showing the behavior of the extraction
while editing the SIS hardware parameters. Comparing the count-rates of the HEBT detectors up to the target with the SIS beam transformer gives the transmission rate, which may then be optimized too.

An interesting use of this function is the observation of the spill time behavior. Due to several effects such as power supply ripples the resonant extraction may be disturbed leading to interrupted extraction behavior. To analyze such effects the sampling rate is increased up to 50 kHz for a maximum amount of 4 detectors. Then a spill structure analysis may be done. This kind of data acquisition was presented in [6]. Introducing the tool into the control system provides the possibility for new data storage and archiving routines.

5.4 High Voltage Power Supply

Since the SIS was commissioned in 1990 the amount of detectors such as scintillators, ion chambers, profile grids etc. has permanently increased. As these devices are all requiring high voltage power supply the maximum load of the existing devices was reached. Looking forward to future plans and particular projects like beam loss measurements a new powerful and expandable power supply unit was purchased. The decision to take the CAEN SY1527 was made due to the modular setup and the remote control function using TCP/IP and OPC server. The software design covers all the required functionalities such as observation and modification of voltage, current, trip-time and ramp-rate. A database for default settings, which can be loaded after shutdown periods, is provided.

6. OUTLOOK

This project has been started on March 2002. The system is yet not ready for implementation into the regular operating, due to debugging, long time tests and further ideas, which have to be added.

It is obvious that other operating features may be implemented into this system as long as they provide countable pulses.

7. REFERENCES