A FESA DAQ FOR FAST CURRENT TRANSFORMER IN SIS 18

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Abstract

This contribution presents the development of the data acquisition (DAQ) system for the readout of fast beam current transformers (FCT) as installed in the GSI synchrotron SIS18 and as foreseen in several FAIR ring accelerators. Fast current transformers are reliable devices that offer a large analogue bandwidth and can therefore monitor bunch structures with high resolution. At appropriate sampling rates continuous measurements throughout repeated machine cycles lead to a large amount of raw data. The analysis of those raw data may range from simple bunch parameter calculations to complex longitudinal phase space reconstructions. Consequently, a new DAQ system must be carefully designed to allow for flexible acquisition modes or to allow for data reduction methods in special applications. The aims of the development are discussed and the status of the new DAQ is presented.

INTRODUCTION

A typical SIS18 synchrotron cycle at GSI consists of injection plateau, acceleration ramp, plateau at top energy and fast or slow extraction. Particles are injected at a kinetic energy of 11.4 MeV/u from a linear accelerator. Applying slowly increasing RF voltage at a harmonic number h=4, four bunches are formed and afterwards accelerated up to the maximum possible energy of 1 GeV/u. At top energy the fast bunch compression and extraction are done. The length of the total synchrotron cycle can range from half a second up to several seconds.

The main timing characteristic of the particles inside the bunch is the frequency of the synchrotron oscillations. In the SIS 18 this frequency at any point of the machine cycle is about 100-1000 times lower than the revolution period. Typical values range in the few kHz region. Hence, for the measurement of this frequency it is sufficient to monitor bunches at larger time invervals with minimal loss of information. From the previous paragraph, a list of general tasks can be extracted for the new DAQ system:

- Observation of bunch formation
- Calculation of bunch paramters (phase with respect to cavity RF or amplitude)
- Observation of RF manipulations (merging, splitting or compression of bunches)
- Injection optimisation by matching the frequency of the RF cavity to that of the bunches
- Fast tomographic reconstruction of longitudinal phase space

The DAQ system for fast current transformers should be employed in all synchrotrons or storage rings of GSI and FAIR. Hereby, the synchrotron SIS18 serves as test bench. Apart from the DAQ hardware, the development includes all required software such as graphical user interfaces and follows all FAIR specifications for DAQ systems to guarantee full integration into the accelerator control system.

The development was also driven by shortcomings of the existing acquisition and analysis tools. However, especially the tomography tool was very valuable in gaining practical experience and is therefore described in the next section. Then the attention is turned to the description of the new DAQ system and results of recent measurements.

TOMOGRAPHY IN SIS 18

Tomographic reconstruction of longitudinal phase space has become an important tool in accelerator physics [1]. The SIS18 analysis was implented using Mathematica software and the CERN tomography code.

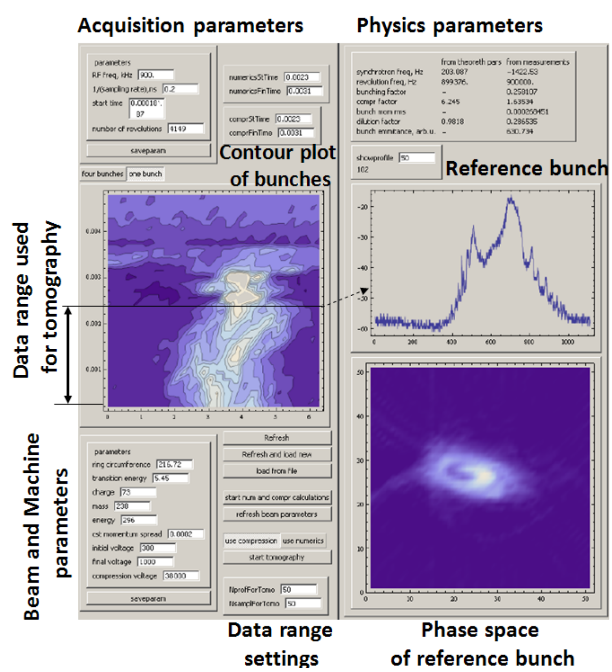

Figure 1: GUI part of the Mathematica code. The parameters given by user are: a) the Acquisition parameters to choose the data range for the contour plot, b) Data range settings to choose the input data for tomography, c) Beam and Machine parameters to prepare the input file for CERN tomography code. The reference bunch defines the time at which the phase space plot is shown.

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The phase space is derived from a set of longitudinal bunch profiles as illustrated in Fig. 1. This graphical user interface (GUI) allows to preview the raw data, define all necessary cuts and analysis parameters and to visualize the reconstructed longitudinal phase space. For the measurement, the FCT signal was connected to a 20 dB amplifier and digitized with a Lecroy 6050A oscilloscope at a sampling rate of 5 GSa/s. A raw data block of 24 MSa was stored locally for off-line analysis. There are several tasks which the analysis code has to perform: reading the binary raw data from the oscilloscope via LAN (in the GUI shown on the left as contour plot), processing data (which includes a cut to the required range and reduction of sampling rate if required), preparing of input files for tomography.

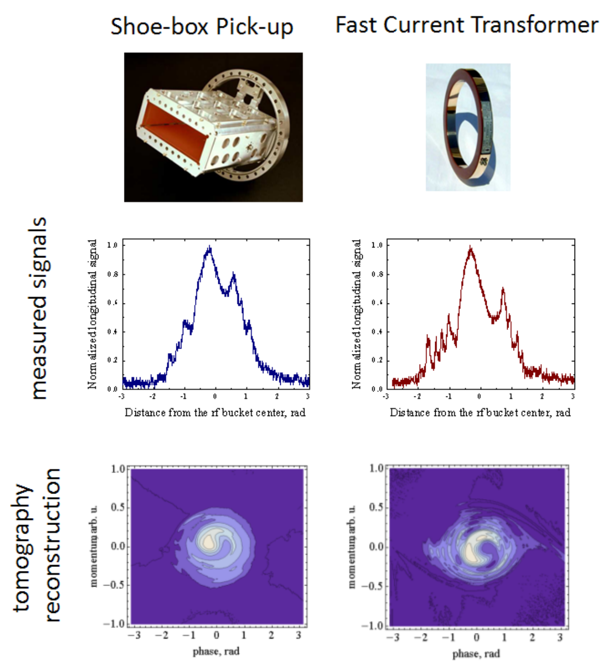

Figure 2: Comparison of the data from the wide band FCT and phase pick-up.

Measurements with a position pick-up and the FCT are compared in Fig.2 which presents pick-up and FCT on the left and right hand side, respectively. The signals at the centre were acquired at exactly the same time and show the detector responses to the same bunch. The number of data sample in both profiles are exactly the same. At the bottom the reconstructed phase space distributions are presented. The resolution in horizontal and vertical axes as well as the input parameters for tomography reconstruction were identical. The number of profiles was 811 in both cases, and on a single core processor the analysis required several minutes in each case. As can be seen the phase space reconstructed from the FCT is much more detailed than the one reconstructed from phase pick-up. In the present case, the fragmented parts of the distribution, called filaments, can be attributed to non-adiabatic capture [2].

LAYOUT OF DAQ SYSTEM

The SIS18 is equipped with a wide-band FCT [3] with an upper bandwidth of 650 MHz. The FCT signal is directly fed to a 20 dB amplifier at the output. In a second stage, a variable-gain Femto DUPVA-1-60 amplifier matches the signal level to the ADC input range in the electronics room. This low-noise amplifier has a frequency range from 1 kHz to 1.2 GHz. Its gain setting can be controlled remotely via a digital interface.

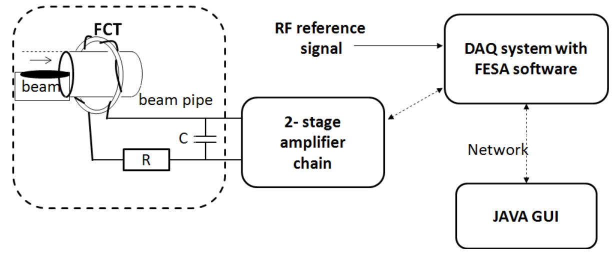

Figure 3: General measurements scheme of the FCT DAQ system.

The FCT signal is recorded by a 4 channel Struck SIS3350 ADC with 500 MHz maximum sampling frequency, 12 bit resolution, and 1 GByte on board memory [4]. This sampling rate may be a limiting factor in the tomography for bunches at top energies where the bunch length can be down to 200 ns, but is sufficient for all other routine tasks. With the available RAM 256 ms of data can be recorded with a single event trigger. The amplifier gain was controlled by a 32 channel Struck IO board. For measurements of the bunch position or phase with respect to the RF cavity voltage signal a reference timing signal is added to the ADC of the DAQ system. The schematic setup is shown in Fig. 3 and examples of FCT and reference timing data are shown in Fig. 4.

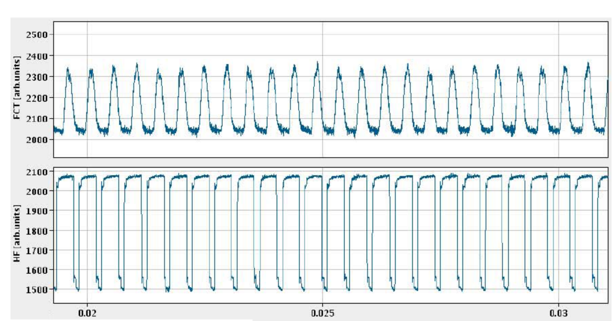

Figure 4: The FESA based FCT measurements showing the bunches measured in the SIS 18 (upper plot) and reference RF timings (lower plot).

A FESA (Front End Software Architecture) [5] class on the front-end CPU controls amplifier stage, reads out the ADC module and stores the data. FESA has been devel-

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oped by CERN and has been chosen as standard for beam instrumentation DAQ systems for FAIR. FESA is a framework to design, develop, deploy and test equipment software, called a FESA class. This realtime software runs on front-end computers and has access to the hardware of e.g. beam instrumentation devices and their electronics.

The GUI is designed in JAVA and based on concepts used at CERN. It consists of the JAVA API for Parameter Control [6] and CERN libraries. The existing prototype GUI can configure all main DAQ parameters such as start and stop events, delays, signal amplification, sampling rate and display the acquired data.

TEST OF MULTI-EVENT MODE

Since the time scale for longitudinal motion is 100-1000 times longer than the revolution period T_r, sampling of the entire SIS18 machine cycle results in an unnecessarily large amount of data. The DAQ system merely needs to acquire a sequence of single-turn data blocks at intervals larger than T_r, provided that these data blocks are synchronized to the radio-frequency signal. This data reduction is achieved in a multi-event mode by triggering the DAQ system on a rate divider output to which the RF master oscillator is connected. For this purpose, a single board electronics has been developed which can be controlled remotely via the FESA class.

For these measurements, the FESA class switches the ADC to the multi-event acquisition mode. The number of events and the acquisition length for each event are user-defined acquisition parameters controlled via the GUI. The maximum acquisition length of one event is 16 kSamples which is enough to provide a detailed acquisition of 4 bunches circulating in SIS 18. The maximum amount of events is restricted by the onboard memory. In the GUI the data are presented in a ”mountain range” plot. An example is shown in Fig. 5 for a sequence of 100 events or data blocks, acquired during the acceleration ramp at harmonic number $h = 4$ (four bunches in ring). Clearly, the formation of bunches and their time evolution can be observed in the raw data. In a next step the present hardware will be used to acquire data for tomographic applications.

SUMMARY AND OUTLOOK

The status of the present developments on the longitudinal diagnostics for SIS18 and FAIR synchrotrons has been presented. The new DAQ system is based on FESA and has been built with two aims in mind, routine machine tuning and dedicated beam physics experiments. The initial development phase was concluded by successful test measurements in SIS18. In the next phase, the analysis on the DAQ system will be enhanced in order to provide online trending plots of basic parameters such as bunch length or bunch position with respect to the RF timing. This includes online measurement of the synchrotron frequency derived by the bunch position oscillation. Cycle-by-cycle trending

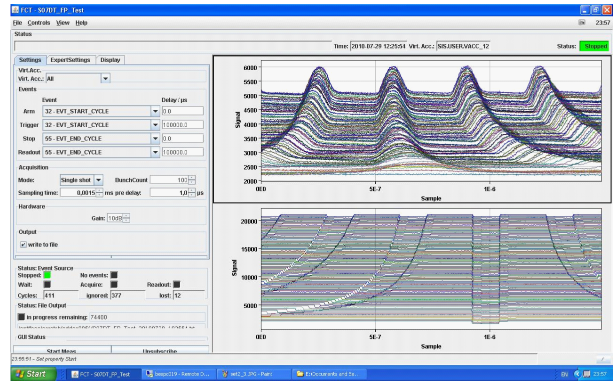

Figure 5: Beam profiles and RF reference timing measured during acceleration. The time between two consecutive events is 3000 revolutions. The vertical axis represents the time in arbitrary units along the machine cycle.

of critical parameters evaluated at specific times of the cycle (e.g. injection or flattop) are also foreseen.

Successful implementations of the tomographical algorithms on the Graphics Processing Units are well known worldwide. On a GPU a speedup of 1-2 orders can be achieved in comparison to a CPU. Based on previous experience with the SIS18 tomography software one can expect analysis times of a few seconds in typical applications. Thus, it is also planned to develop a FESA based longitudinal tomography software on a dedicated PC equipped with a GPU.

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