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MODULAR STAND-ALONE PULSE CURRENT MEASUREMENT SYSTEM FOR KICKER AND SEPTA AT BESSY II AND MLS*

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Abstract

Pulse current measurement systems are introduced for all pulsed deflection magnets in the BESSY II and MLS storage rings which acquire data autonomously. The measured pulse currents are displayed locally or remotely as single values or graphs. The data acquisition systems utilize commercial PXI chassis by National Instruments (NI), controllers and 2-channel 14bit, 100MHz high-speed digitizer cards. Measurement routines are programmed with LabVIEW 2012. Special in-house custom made 'CA-Lab' client software provides interface for the independent systems to write values into pre-assigned process variables of the EPICS control system. The retrieved data can be displayed in the machine control system and stored in a data archive. This allows shot to shot assessment of the pulse currents for accelerator operation and troubleshooting as well as long term data evaluation in correlation with other relevant machine parameters.

This report also describes the set-up for the pulse current measurements and the structured programming for the data acquisition. Limits of the applied measurement technique and experience with the information gained for the accelerator operation will be explained.

PULSED MAGNET SYSTEMS

In both of the accelerators BESSY II and MLS, there are numerous very different pulse power systems installed for the injection process. Their specified nominal values differ quite a lot with respect to: required nominal voltage, peak pulse current and pulse shape / pulse length (Tables 1, 2).

These specifications reflect dedication of the systems in the accelerator chain, as well as applied pulsed magnet and pulser technology. The inherent pulsed magnetic field stabilities of the entire systems have direct impact on the stability of the beam deflection, and hence, to the efficient beam accumulation in the injection process. Understanding of these effects is important for the injection into the MLS storage ring. This deeper knowledge is essential for the injection into the BESSY II storage ring in top-up mode [1].

Table 1: Nominal Values of Pulsed Elements at MLS

Pulsed elements	Nominal voltage	Peak pulse current	Pulse shape
4x Inj.-Kicker Storage Ring	200 V	150 A	2.3 µs half-sine
1x Inj.-Septum Storage Ring	150 V	1.7 kA	110 µs half-sine

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Table 2: Nominal Values of Pulsed Elements at BESSY II

Pulsed elements	Nominal voltage	Peak pulse current	Pulse shape
1x Inj.-Kicker Booster	12.5 kV	125 A	350 ns rect.
1x Inj.-Septum Booster	120 V	2 kA	120 µs half-sine
2x Extr.-Kicker Booster	25 kV	500 A	350 ns rect.
2x Extr.-Bumper Booster	200 V	3 kA	250 µs half-sine
2x Extr.-Septa Booster	600 V	9 kA	250 µs half-sine
2x Inj.-Kicker Storage Ring	15 kV	4.3 kA	5 µs half-sine
2x Inj.-Septa Storage Ring	1.5 kV	9 kA	45 µs half-sine

Stability Requirements on Pulser Systems

The accelerator operation regularly requires very stable pulsed magnetic fields with respect to their amplitude and timing stability, represented in reproducibility of absolute values, low shot to shot jitters and long term drifts. It is assumed that there is a linear dependency of pulse currents and magnetic fields, particularly in steady-state with long term operation. Typical values of the amplitude stabilities are $\Delta I/I = 1 \cdot 10^{-3}$, for the pulse timing jitters $\Delta t = 10$ ns.

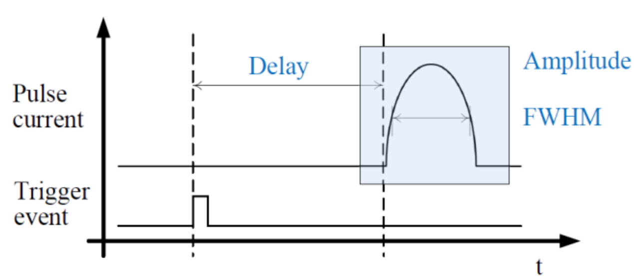

Figure 1: Trigger event and pulse measurements.

Precise Pulse Current Measurements

Pulse currents are either generated in lumped element networks, or more complicated, with pulse forming networks (PFN). It is believed that all the pulse currents can be coarsely characterized with measuring the peak pulse amplitude, their full width at half maximum (FWHM) and delay to an initiating trigger event. Furthermore, an array of 1000 values, together with start time and interval time, contains the information about the pulse shape (Figure 1).

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General Layout of Precise Pulse Measurements

Since the beam is deflected by pulsed magnetic field, the B-field is the quantity to be monitored. However, it is not possible to place a B-field probe into the same magnet gap were the beam is injected through without affecting the free aperture. In addition, the voltage induced in the probe pickup coil could be distorted. Therefore, it is assumed that the measurement of excitation pulse currents resemble the pulsed magnetic fields inside. State of the art pulse current transformers retain good shielding from electromagnetic interference (EMI), and hence are used as precise sensors.

The measured voltage at the output of such a sensor is proportional to the pulse current. To avoid interference with other signals, cable connections to the scope must be short and in a star like manner to avoid ground loops. Strip wound magnetic cores are added on coaxial cables for noise suppression and common mode rejection on input signals. Best measurement resolution and precision of the signal curves are achieved when input voltages are attenuated to ~70 % of the gauge range and 50 ohms terminated.

REALISATION OF THE PULSE CURRENT MEASUREMENT SYSTEMS

The aim of this development work was to realize the scope functionality inside the EPICS based control system [2]. The following description is one possible approach to cope with this challenge [3].

Nat. Instruments Hardware for 'EPICS Scope'

For the realisation of the 'EPICS Scope' application, National Instruments PXI technology is used. The main components for a measurement system are: one chassis with 230 V 50 Hz ~ power supply, one embedded controller and up to five scope cards (Figure 2). The chassis monitor card is added to watch the internal chassis voltages since thermal issues in the cabinets are of concern [4].

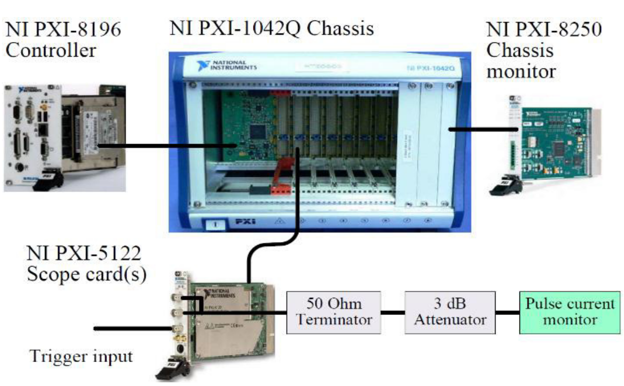

Figure 2: Hardware for pulse current measurements.

The Pulse Current Measurement Program

LabVIEW 2012 graphical programming language was used to reconfigure NI example programs as start-ups for the signal acquisition. The structure of the pulse measurement program is as shown in Figure 3. It starts with the Main VI as the launch program. It reads specifically structured text files to initialize the number of scope cards used, and then, initializes the subprograms for the applicable channel set-ups. There are as many subprograms started as scope cards are installed. Each program acquires data independently whenever it is initiated by an external trigger event (left hand side loop in Figure 3). The curves are then evaluated, the measured values retrieved and buffered in local variables.

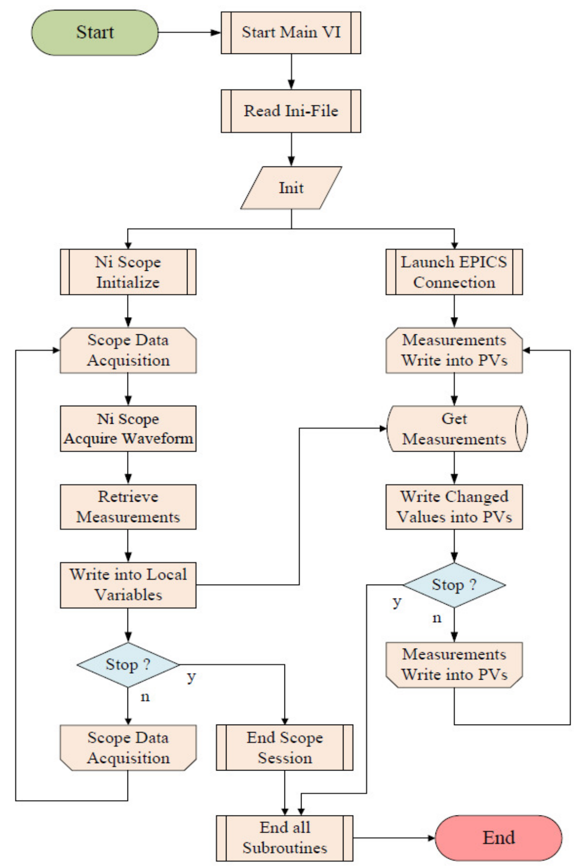

Figure 3: Flow chart of pulse measurement program

Values of the six measurements shown in Figure 1 and described underneath, are thereafter written into the second loop in the pulse measurement program (right hand side loop in Figure 3). This loop runs repeatedly every one second looking for value changes. If the value has changed, it is transmitted into the preassigned process variable in the EPICS control system.

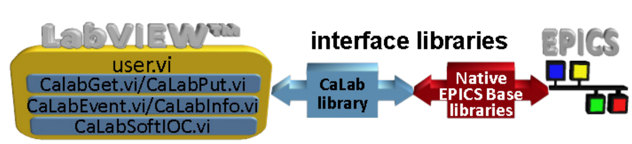

Figure 4: 'CA-Lab' interface from LabVIEW to EPICS.

Interface with 'CA-Lab' from Labview to EPICS

'CA-Lab' is the abbreviation for a special in-house made interface software between the LabVIEW programming language and the EPICS based control system. It is a user-friendly, lightweight and high performance software that permits easy reading and writing of EPICS variables [5].

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Display Front Panel Locally or by VNC Viewer

The ‘Main VI’ serves as the launch program on the local PXI systems. Its front panel possesses the functionality to start the compiled program set, reads the necessary ini-files and calls the number of the required sub-programs. The front panel permanently displays the measurements pre-sets for the scope cards, the acquired voltage curves and the retrieved values. For easy handling, channel ranges on the scope cards can be changed on the sub-program front panels while running the acquisitions. Finally, these adjustments must be transferred to the ini-files manually. These modification can also be done by a VNC viewer remotely.

MEASUREMENT SYSTEMS IN 24/7 ACCELERATOR OPERATION

Online Pulse Visualization for Operations

The PXI pulse measurement systems have become a useful monitoring system for every day accelerator operation. This online visualization observes and correlates events. For instance, suspicions on malfunctions of pulsed power supplies could be redirected to faulty components.

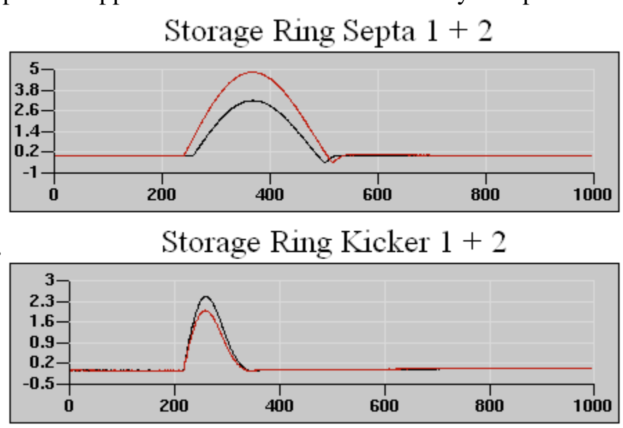

Figure 5: Process graphics of the storage ring septa and kicker pulses displayed in BESSY II control system.

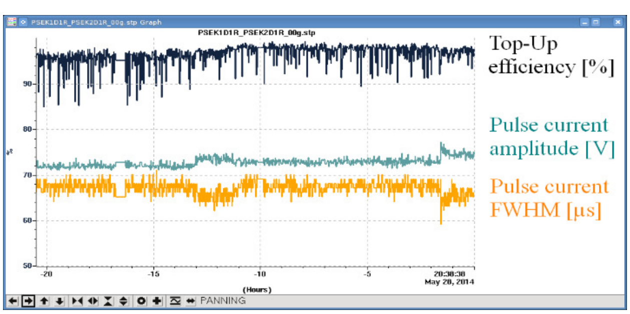

Figure 6: Pulse measurements vs. top-up efficiency.

Signals which are picked up locally and digitalized with high resolution and low signal distortion can be transported within the control system and displayed on monitor screens (Figure 5). This allows simple inspection and shot to shot assessment by the operator. The values of measured pulse properties, pulse current amplitude and its FWHM, can now be correlated with other relevant machine parameters by using long term graphs as display, also called ‘strip tools’. In the case of BESSY II, accelerator observing and tuning the injection efficiency in top-up mode operation is the major goal.

Archiving Measured Signal Data

The long term availability of data in an archive has enhanced trouble shooting of pulsed power systems. Also, post mortem analysis has helped to unveil components, e.g. with maintenance requirements or even design errors.

One example is shown by the graphs in Figure 6. It can be seen that the pulse amplitude and FWHM change a little only, very close to the designed system stability, but without affecting the top-up efficiency. This effect was explained as a small change of lumped circuit inductance.

System Reliability and Experience

Reliable operation has been observed since the autarkic working PXI measurement systems were commissioned at the beginning of year 2014, and this is expected to continue on. Even after power outages, in most cases, the systems rebooted and went back to operation automatically.

CONCLUSION

The implementation of the modular stand-alone pulse current measurement systems has had a positive influence to the improvement of the operational stability for both of the accelerators BESSY II and MLS. The online shot to shot visualisation and displays with long term graphs have improved trouble shooting capabilities. The archived data sets permit post mortem analysis aiming for fault finding and have resulted in deeper understanding of the pulsed system properties.

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