‘Pulse Current Monitoring for Fast Pulsed Magnets at BESSY II and MLS synchrotron light sources’

O. Dressler - PULPOKS workshop,12-13 March 2018,
CERN, Geneva, Switzerland

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- Stability Requirements of Pulsed Systems for Accelerator Operation,
- Hardware for Precise Pulse Current Measurements,
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- Improvement of 24/7 Accelerator Operation,
- PXI System Reliability and Long Term Availability,
- Realization of Pulse Current Interlock with RTO Oscilloscope,
- Summary and Outlook.

Pulsed Magnet Systems at Metrology Light Source

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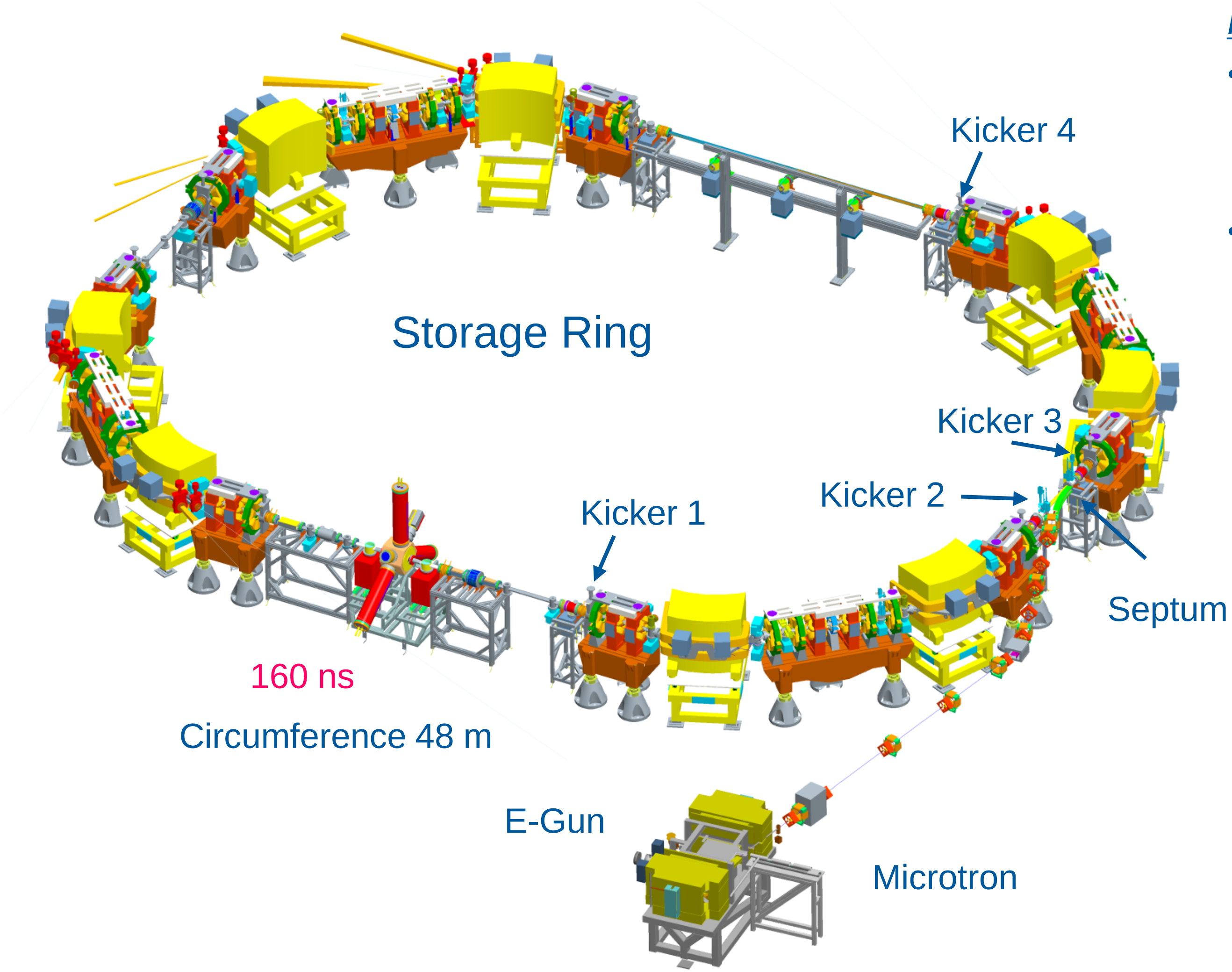


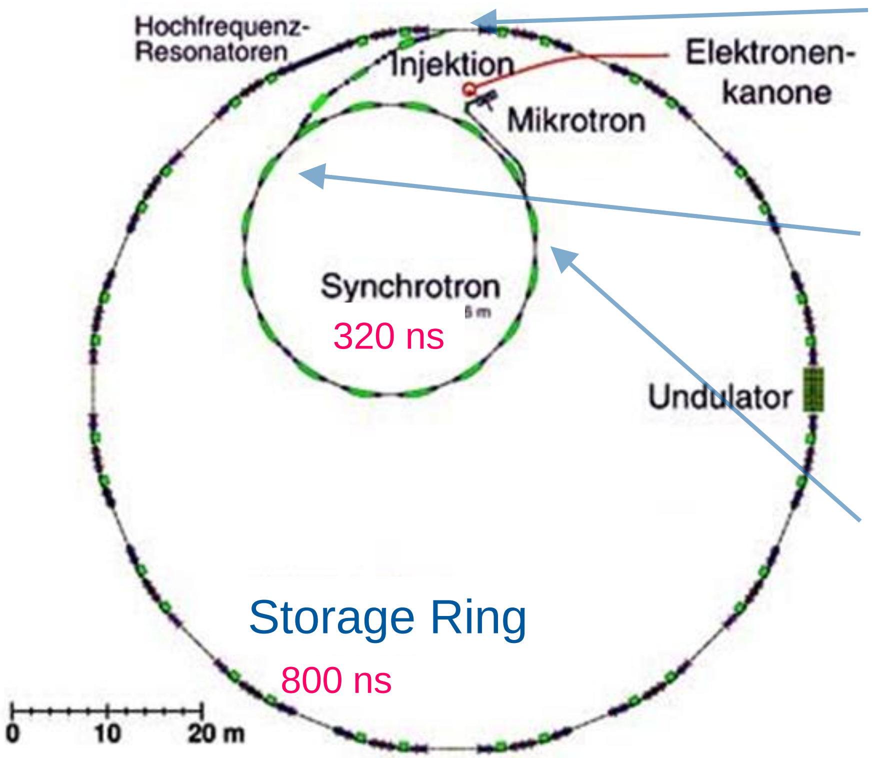
Injection elements:

- 4 Kicker systems (200V, 150A, 2.3μs, half-sine)
- 1 Septum system (150V, 1700A, 110μs, half-sine)

(Î - Peak current
U_L - Charging voltage
τ - Pulse length
all nominal values)

Needs every 6 hours a dedicated injection procedure to refill for user operations.

Pulsed Magnet Systems at BESSY II



SR Injection:

- 2 x 2 Kicker systems (15kV, 4.3kA, 5.5µs, half-sine)
- 2 Septa systems (1.5kV, 9kA, 45µs (60µs), half-sine)
- 1 Non-linear kicker (12kV, 2kA, 1.3µs, half-sine)

Booster Extraction:

- 2 Kicker systems (25kV, 500A, 350ns, square)
- 2 Septa systems (600V, 9kA, 250µs, half-sine)
- 3 Bumper systems (200V, 3kA, 250µs, half-sine)

Booster Injection:

- 1 Kicker system (12.5kV, 122.5A, 350ns, square)
- 1 Septum system (120V, 2kA, 120µs, half-sine)

SR Diagnostics:

- 2 Diagnostic kickers (15kV, 4kA, 1.6µs, half-sine)

Usually operated 24/7 in top-up-injection mode, where single shot injection efficiencies above 90% are required.

(all nominal values)

Stability Requirements of Pulsed Systems

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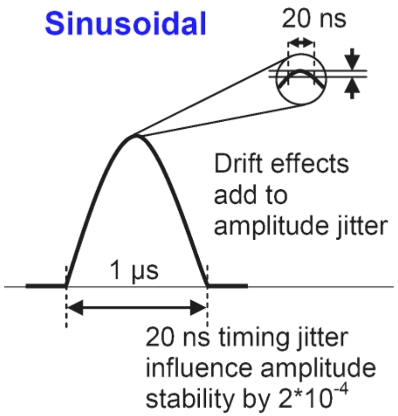
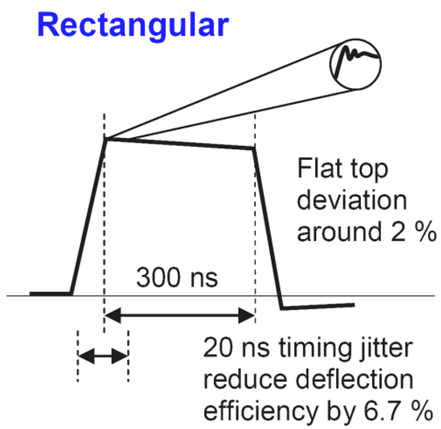




Amplitude and timing stabilities of pulser systems are specified in respect to requirements for accelerator operation.

Assumption: Pulse currents i(t) are measured as proportional voltage signals v(t) and assumed to resemble original value of pulsed magnetic fields.

Consider the transfer functions between above parameters!

Typical *values for:*

Amplitude stability **1×10^{-3}**

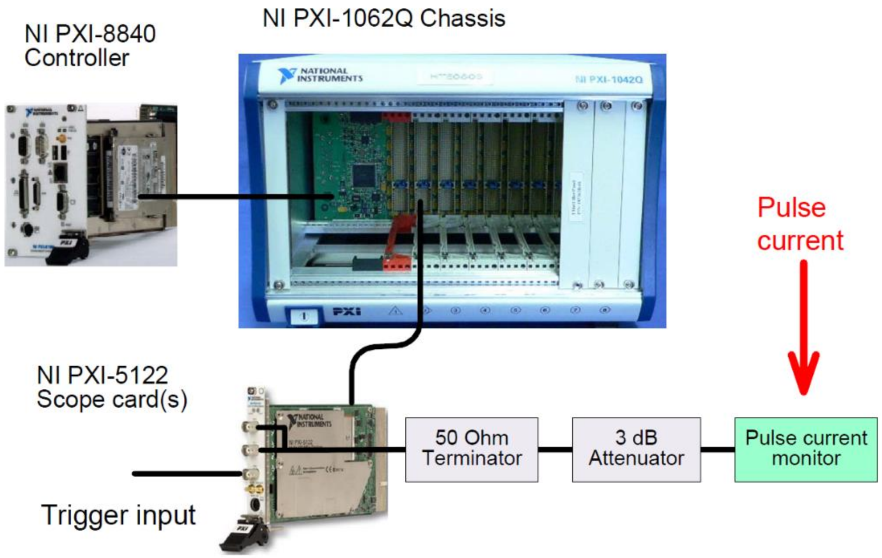
Timing stability **5 ns,** (20 ns),

Pulses are defined by:

Amplitude, FWHM, delay to a trigger event.

Moreover an array of 1000 values contains the information about pulse shape (Array, delta t, t0).

Hardware for Precise Pulse Current Measurements



Hardware realization of ‘EPICS Scope’ with NI PXI systems and scope card(s)

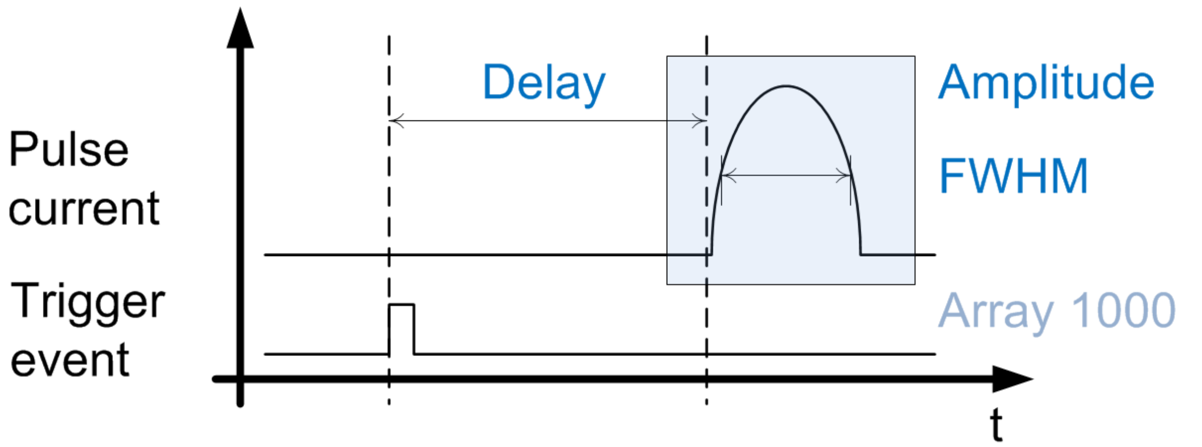
NI PXI technology applied:

- PXI NI-1062Q
- Embedded controller PXI NI-8840
- Oscilloscope card(s) PXI NI-5122
- LabVIEW program for signal measurement, analysis and communication,
- Consider longevity 24/7 for accelerator operations.

Preparation of measurement signals in disturbed environment:

- Insulation to HV potential,
- Signal attenuation and termination,
- Star like grounding concept to avoid loop currents,
- Common mode rejection on signal cable,
- Noise suppression on cable shield,
- 230 V~, 50 Hz power supply with no perturbations,
- Thermal issues in cabinet.

Precise Pulse Current Measurements



Achievable precision:

- Oscilloscope cards PXI NI-5122 have 14 bit and 100 MS/s (maximum)
- Channel ranges ±5 V and ±1 V
- Internal vs. external clock - nanosecond timing resolution could be improved with external synchronization.

Task: Attenuate signal externally to ~70 % of given voltage range for best measurement results.

Example of LabVIEW Program

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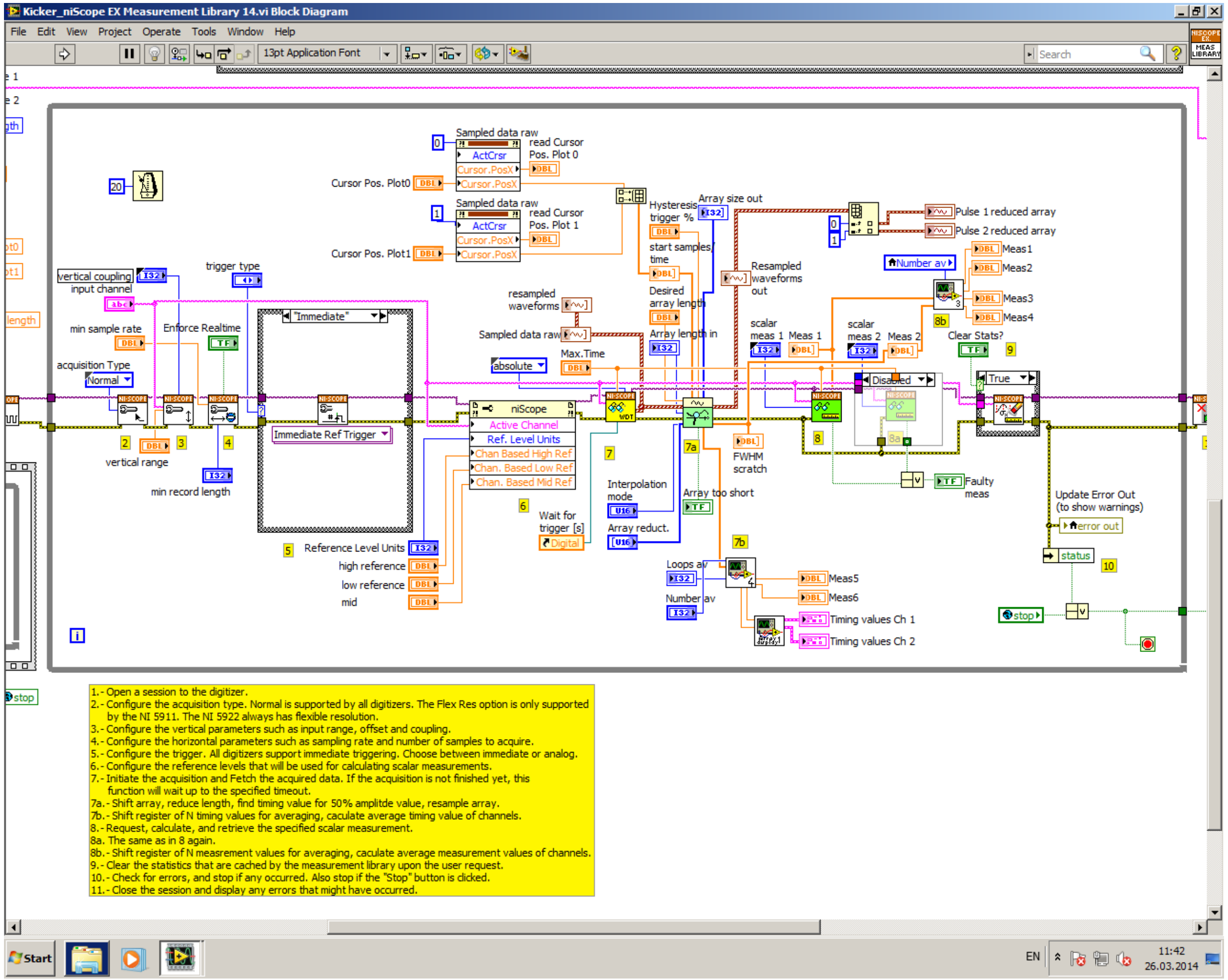
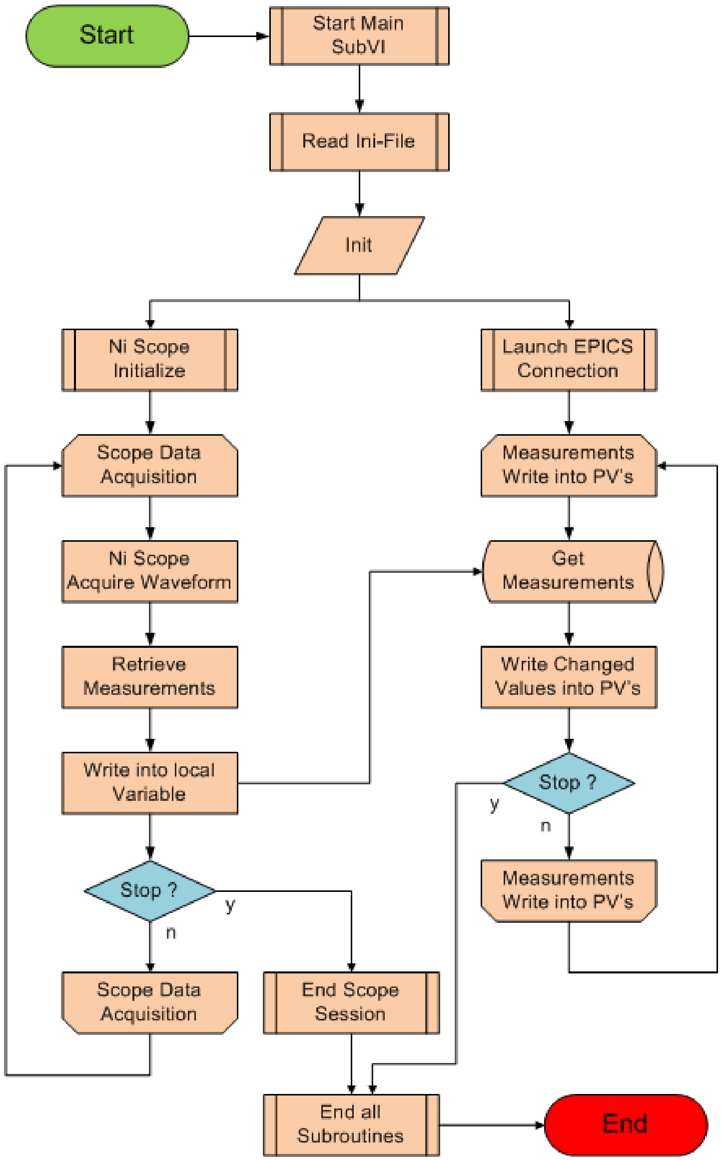


Example of LabVIEW program containing main subroutine.
The main program realizes:

- Read initialization,
- Initialization of scope card,
- Carry out data acquisition,
- Retrieve measurements values from data set,
- Transfer to local process variables (PV's),
- Write values into assigned PV's for control system,
- Since the program can be run in parallel sessions *(up to 5 scope cards run in parallel applications)*: Transfer to global variables for visualization in overlaid launch program.

Flow Chart of Pulse Current Measurement Program

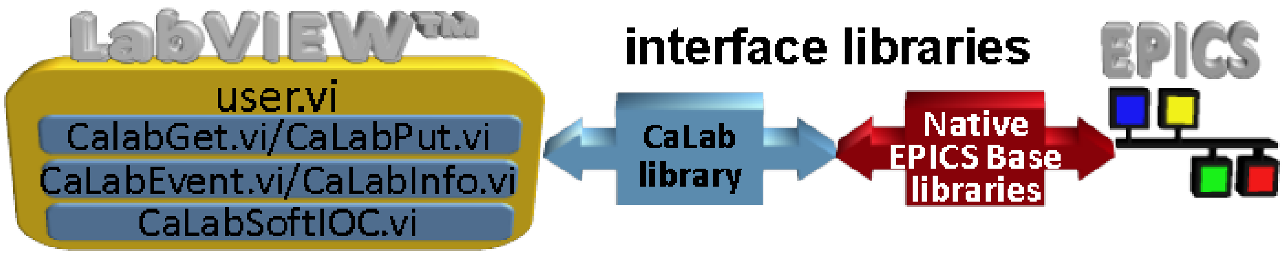
Data acquisition loop:
- High speed data acquisition.
- Fast waveform evaluation.
- Visualization in local LabVIEW front panel.



Data transfer by CA-Lab interface into EPICS process variables (PV's):
- Write 3 PV's containing *amplitude, FWHM, delay*.
- Write 3 PV's resembling the pulse current shape *start time, delta t* and *1000 array values*.
- One PV as *wait time* for next acquisition to show heart beat of system.

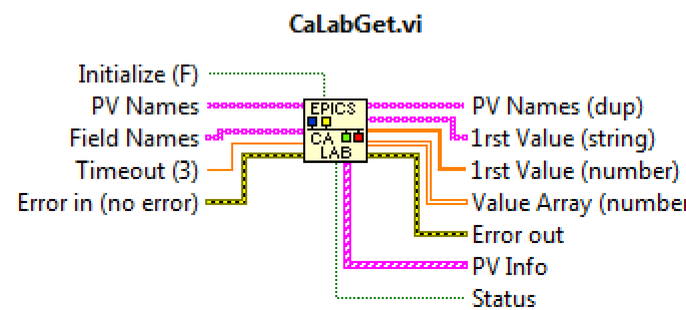
Interface with 'CA-Lab' from LabVIEW to EPICS

CA Lab is a user-friendly, lightweight and high performance interface between LabVIEW™ and EPICS.

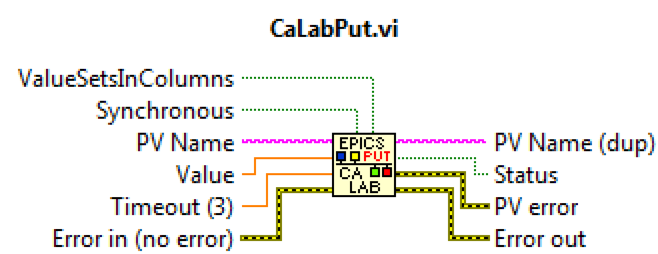


Examples:

CaLabGet.vi (Polymorphic VI)

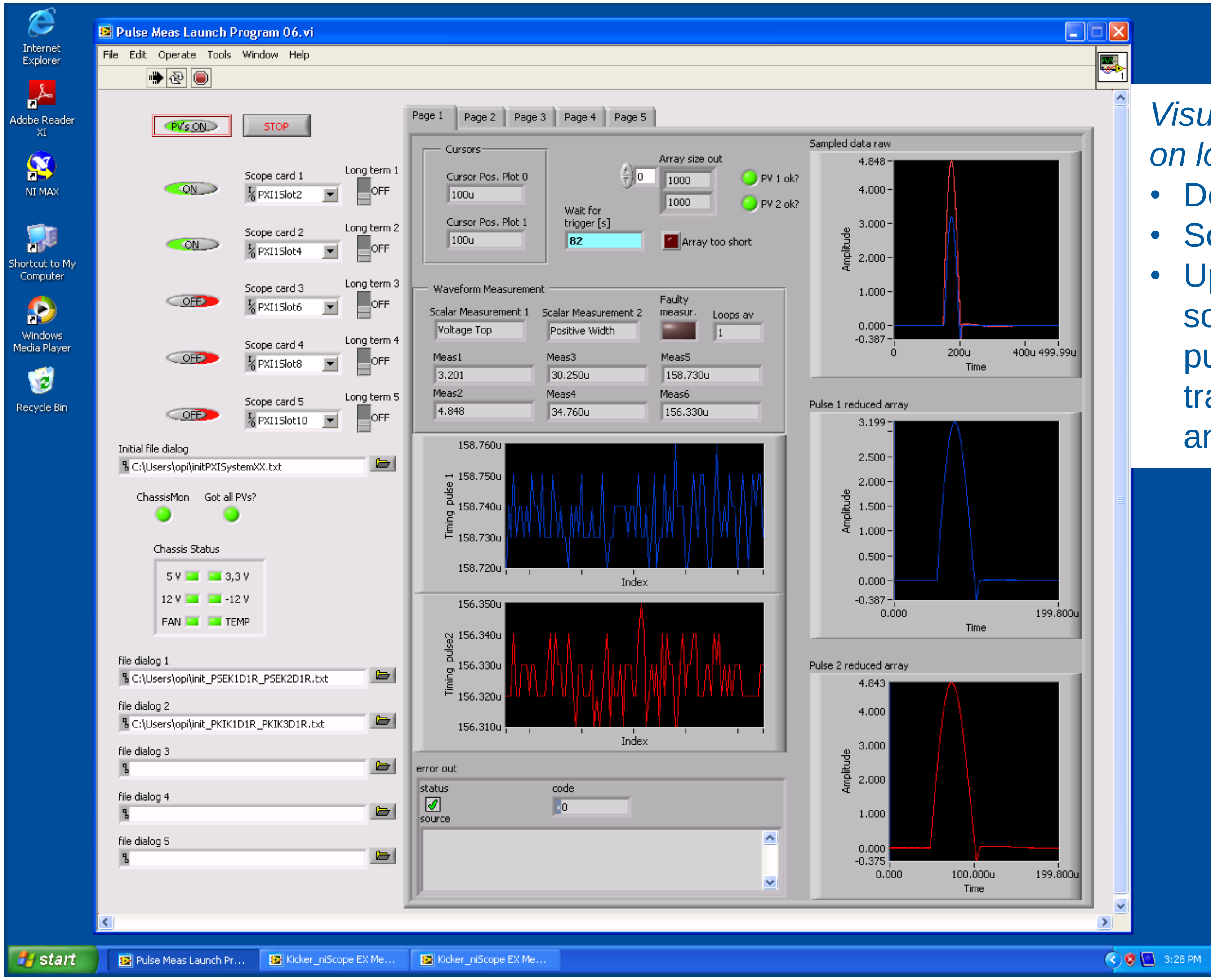


CaLabPut.vi (Polymorphic VI)



C. Winkler [Helmholtz-Zentrum Berlin]
www-csr.bessy.de/control/SoftDist/CA_Lab/

Visualization Front Panel on Windows PC

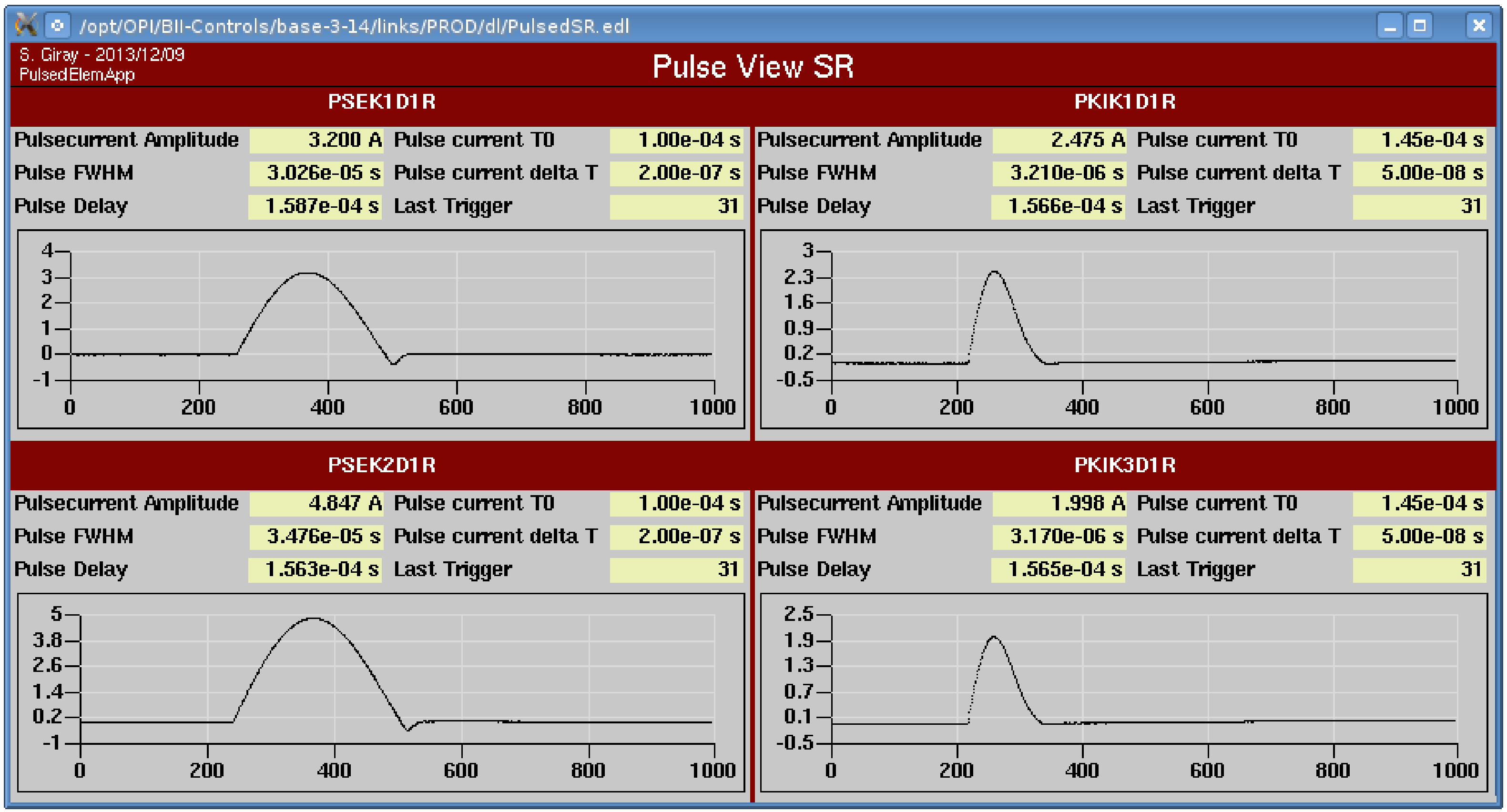


Visualization in launch program on local monitor or VNC viewer.

- Depiction of chassis status,
- Scope card slot,
- Up to five pages, one for each scope card containing: pulse shape monitor, transferred array monitor; and 6 measurements, etc.

Process Graphics in BESSY Control System

Instantaneous information for the BESSY operator inside the EPICS based control system about: Normalized pulse amplitude, FWHM, delay to a start trigger, counter for heart beat of the system.



Pulse Measurements vs. BESSY II Machine Parameters

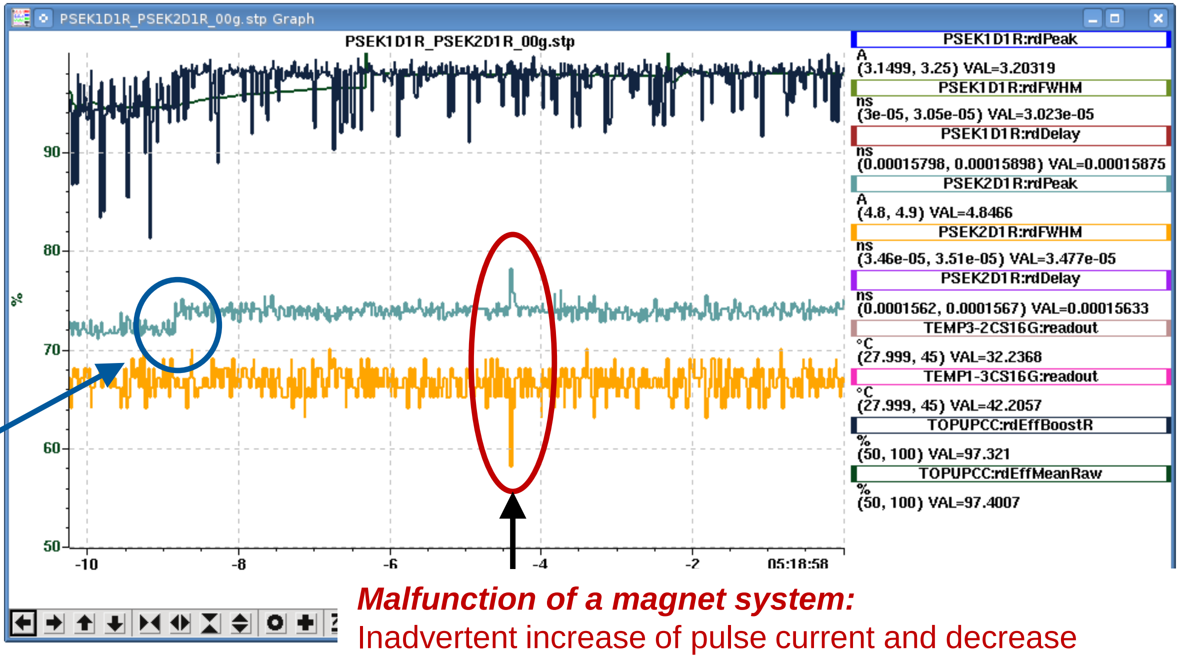
Measurements taken on SR injection septum magnet

Strip tool observed parameters:

Injection efficiency (%)

Pulse current amplitude (V)

Pulse current FWHM (ns)



Initiated by machine operator:
Increase of pulse current amplitude to restore top-up injection efficiency.

Malfunction of a magnet system:
Inadvertent increase of pulse current and decrease of FWHM, indicating changes in magnet. But in this case no negative effect on top-up injection efficiency observed.

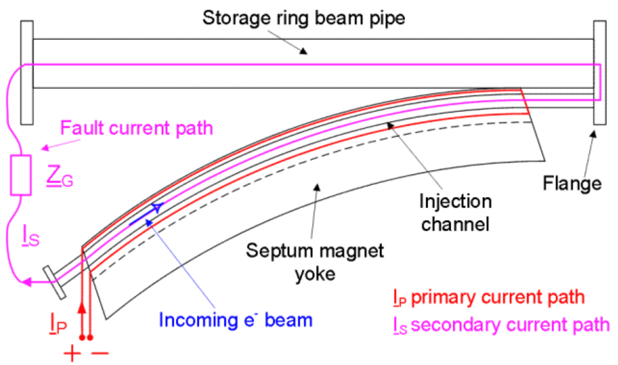
Required precision of pulse current parameters is better than 1 x 10^{-3}!

Availability of measurement values inside the control system environment enables:

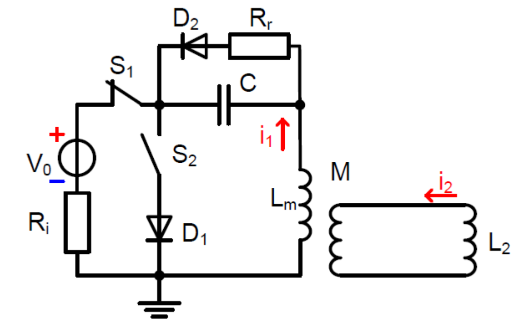
- Online shot to shot monitoring of system parameters during pulsed power system operation,
- Instantaneous correlation of observed accelerator events with of single component parameters,
- Data archive within the control system and long term availability, post mortem failure analysis.
- Also, possibility of slow feed-backs to stabilize beam position during injection process, etc.

Finding of Fault Conditions on MLS Septum Magnet

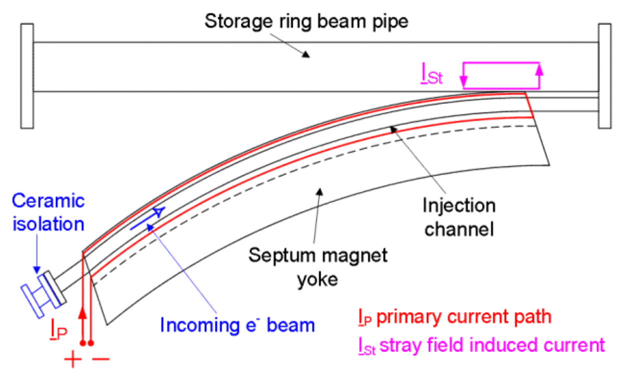
Schematics for Non-Isolated Integration



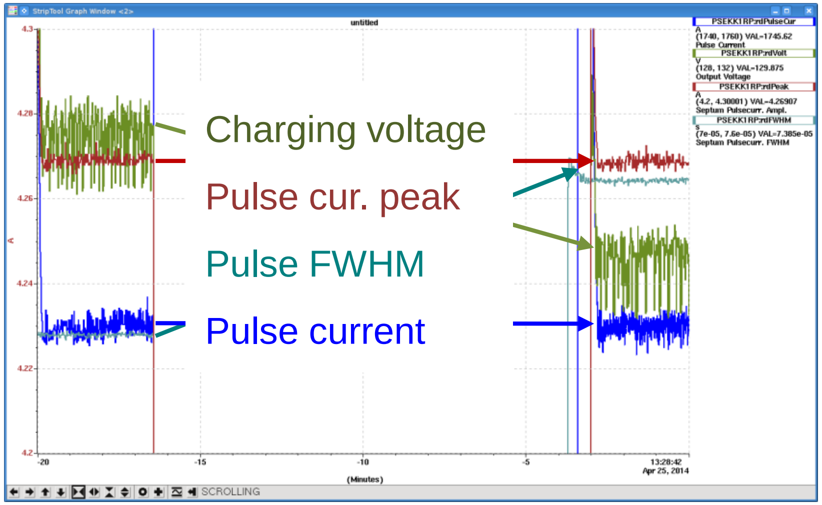
During the operation of a pulsed magnet, the relevant pulse current parameters suddenly changed. This effect was explained with i_2, an additional load current in equivalent circuit.



Ceramic Insulation in Transfer Line



Strip tool plot of septum pulse current parameters before and after removing the fault condition.



Explanation and comments:

24/7 accelerator operation became more reliable, because:

- The online visualization make events understandable,
- Faulty mechanical components (magnets) were unveiled, e.g. having design errors,
- Detecting instable HV power supplies, this effect could only be observed in simultaneous operation of different equipment,
- However, disprove suspicion on pulsed power supplies, which were sometimes accused, but often not being the cause of low injection efficiency or beam abortion.

The whole project realization to measure the pulse currents resulted in much more understood and stable accelerator operation, especially in Top-Up-Mode.
Fewer injection shots with less than 60% efficiency where produced which is an abortion criteria for Top-Up Operation.

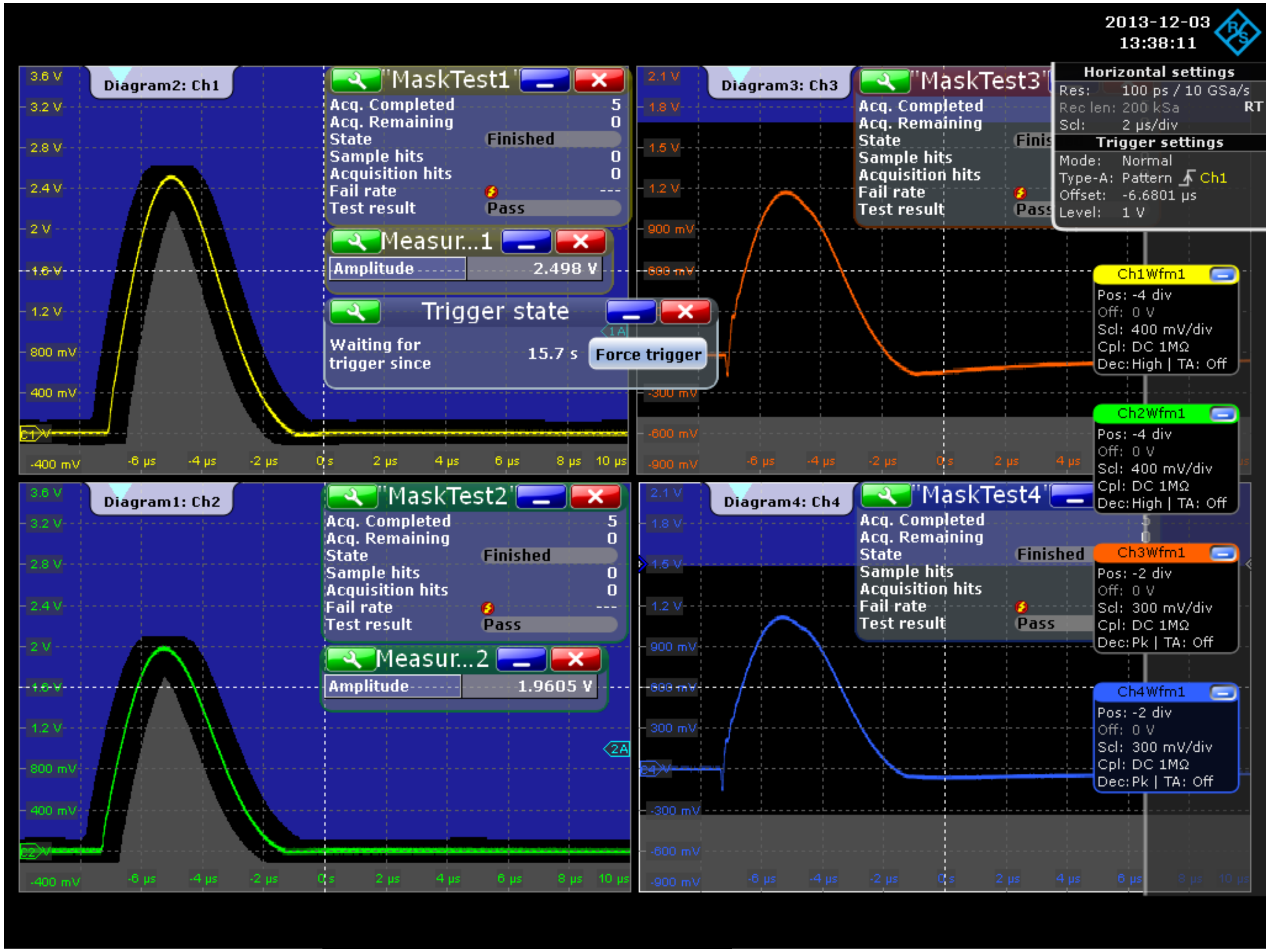
PXI System Reliability and Long Term Availability

Expectation and remarks:

- 24/7 operation,
- Reliable automated multi channel shot to shot pulse current measurement,
- Continuous data acquisition and analysis,
- PXI system monitor to gain information about the pulsed system performance and requirements for maintenance because of ageing,
- LAN network integration with high reliability,
- Transfer of data from controller via CA-Lab interface to EPICS based control system,
- Installation of equipment in EMI and dust polluted environment (not laboratory),
- Harsh conditions and temperature changes,
- Design life of an accelerator >20 years vs. few years of a PXI computer system?
- Limits of measurement system in current setup:
  It does not catch self-triggered kicker pulse currents!

Realization of Pulse Current Interlock on BESSY II Storage Ring Injection Kickers with Rohde and Schwarz RTO 1024 Oscilloscope

Pulse current K1 ‘Ground fault’ current on K1



Pulse current K3 ‘Ground fault’ current on K3

Methodology of Pulse Current Interlock

- Measurements of pulse currents on two SR Kickers,
  Print picture to internal scope hard disk if any of the masks are violated (left hand side scope pictures).

- Increased ground fault currents on two SR Kickers with mask violation *cause the scope to send a trigger (width 1 ms) to a rear BNC socket*.
  An external detection circuit gets triggered and opens an interlock loop on the kicker pulser control units and turns them of.

  The accelerator operator must send a ‘Reset’ command to the kicker power supply control unit to resume for operation.
  In addition, print picture to internal hard disk if any of the masks are violated (right hand side scope pictures).

- The scope screen is shown in the BESSY II control system with a VNC viewer.

Application Note by Rohde und Schwarz

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The R&S®RTO in accelerator physics

In accelerator physics, pulsed signals frequently need to be measured. The digital trigger and low noise frontend of the R&S®RTO digital oscilloscope make it possible to perform the high precision measurements needed to characterize the experimental setup. Several measurement functions specially developed for accelerator physics labs support detailed signal analysis.

© Soleil.

Your task

Experiments in accelerator physics, e.g. in synchrotron labs, often demand very accurate measurements of pulse parameters or of the jitter between two signals. This data needs to be measured during start-up and characterization of the experimental setup as well as during operation for continuous monitoring. For monitoring, the data needs to be stored and downloaded at a high update rate in order to catch every pulse of a free electron laser operating at e.g. 100 Hz.

T&M solution

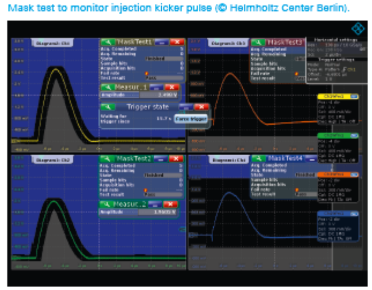
Researchers will appreciate the outstanding accuracy of the R&S®RTO. The low noise frontend and the 10 Gsample/s single-core monolytic A/D converter offer an effective resolution of > 7 ENOBs for precise measurement data. The 100 ps sampling resolution allows the detection of high-frequency signal components. The digital trigger architecture is the key to the low trigger jitter of 1 ps (RMS). The R&S®RTO-B4 oven controlled oscillator (OCXO) option improves the timebase accuracy to 0.2 ppm, which is important in order to minimize long-term drifts. The R&S®RTO performs measurements fast: 600000 mask tests/s detect signal deviations faster than ever before. Overall the R&S®RTO is perfect for precise measurements in many accelerator physics lab applications, such as in synchrotrons or free electron lasers.

Application

Beam quality safety interlock system

With the introduction of continuous top-up operation of synchrotron light sources, the injection process has to be fully automated. This requires major changes in the control system and drives the need for a new safety interlock system to prevent damage e.g. to the synchrotron. The R&S®RTO is the ideal tool for such safety interlock systems. Its fast mask test monitors the pulse that drives the injection kicker in a synchrotron. The R&S®RTO prevents damage to the synchrotron by stopping the injection process if the kicker pulses are not correct and the mask is violated. In addition, full remote operability is a big plus because experts can remotely support troubleshooting while having full access to the R&S®RTO.

Mask test to monitor injection kicker pulse (© Helmholtz Center Berlin).



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Test & Measurement
Application Card | 01.00

The R&S®RTO in accelerator physics

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Kicker Pulse Currents Monitoring with RTO Scope

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Evaluation of Kicker Pulse Interlock Conditions

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- ‘Positive interlock’ to protect kicker hardware
  (if turned off it does not obstruct operations),
- Protection of kicker hardware in case of increased ground fault current i.e. in case of kicker coil insulation breakdown,
- Online visualization of pulse current values for fast failure detection,
- Post mortem analysis with saved pictures on scope hard disk,
- Dual trigger capability for two pulse currents on channel 1 or 2,
  so recognizing missing of one of the both kicker current pulses,
- Improved of monitoring the injection kickers for top-up operations!

- But, is measurement real or just a disturbed pick-up signal?

Summary and Outlook

- Modular pulse current monitoring systems have been developed for online visualization of pulse current values to support the commissioning and operation of the both storage rings MLS and BESSY II.
- These pulse current monitoring systems are based on National Instruments PXI technology, and programmed with LabVIEW.
- The retrieved data is first processed, and then transferred by an in-house made ‘CA-Lab’ client software into the EPICS based machine control system. This gives the opportunity to correlate measurement to other machine parameters and also to archive data.
- Strategies to unveil unwanted operational conditions of the pulsed elements, e.g. instabilities or misfiring, were discussed.
- The systems are retained in continuous 24/7 operation since they were introduced. This results in better understanding of the pulsed elements, and so, in stable and uninterrupted operation of the accelerators.
  In general, it led into increased storage ring availability.