
CERN

Internal Post-Operation Check (IPOC) System for Kicker Magnet Current Waveform Surveillance

PULse POwer for Kicker Systems (PULPOKS) workshop, 12.03.2018

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Plan

- IPOC Overview: software and hardware
- Usage examples:
  - LBDS kicker waveforms validation / calibration
  - XPOC / IQC: machine protection interlocking
  - MKI kicker waveforms validation / synchronisation
  - MKI ferrite yoke curie temperature monitoring
  - Study of closed loop: Thyrathron turn-on delay drift stabilisation
- Ongoing development examples:
  - Closed loop for thyratron delay drift stabilisation
  - Sparking detection system for HV GTO stacks

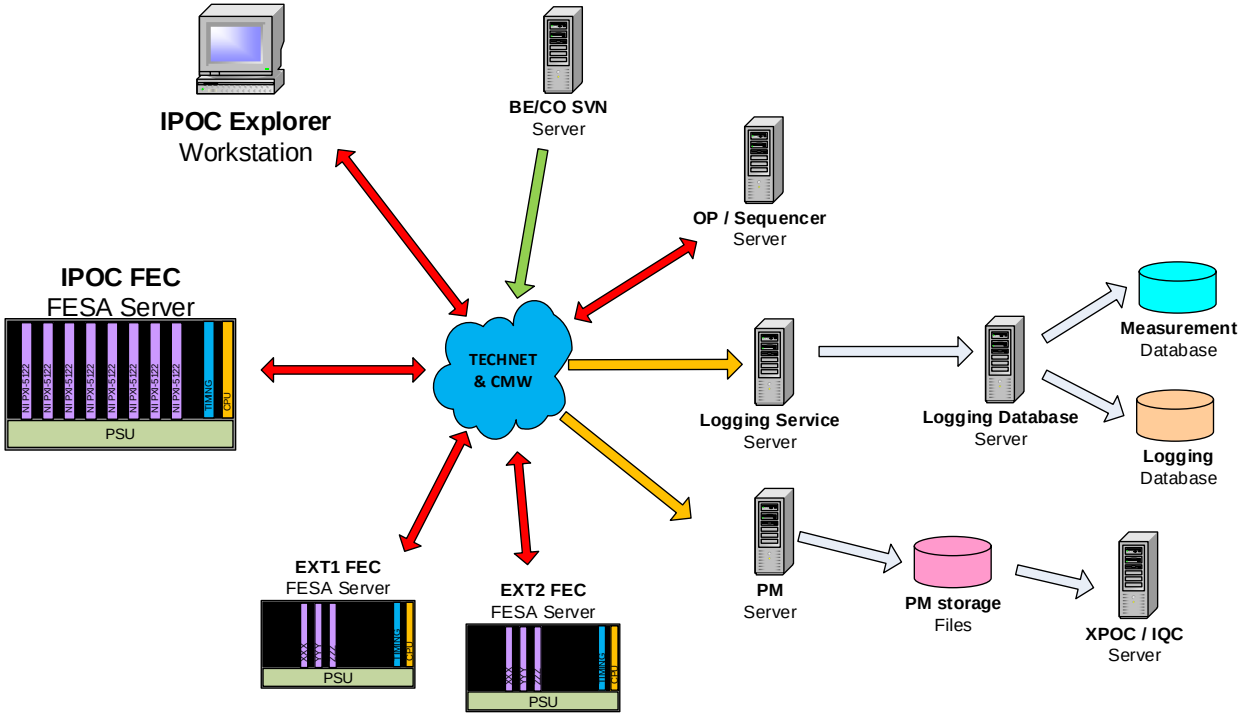
IPOC - System Functionalities

Main roles of Internal Post-Operational Check (IPOC) software are to:

- Control and monitor digitizer cards
- Acquire and analyse kicker current waveforms
- Publish waveforms and analysis results for Logging DB
- Save waveforms and analysis results into PM storage
- Interlock kicker system and block operation in case of problem detected
- Provide expert GUI for diagnosis and control

Developed for LHC Beam Dump System (LBDS) Post-Operation Check, now continuously deployed on new kicker systems at CERN.

IPOC - Integration in CERN Controls



Front-End Computers (FEC) contains:

- CPU running IPOC FESA server
- Digitiser cards
- CERN Timing card

IPOC-Explorer GUI Java application:

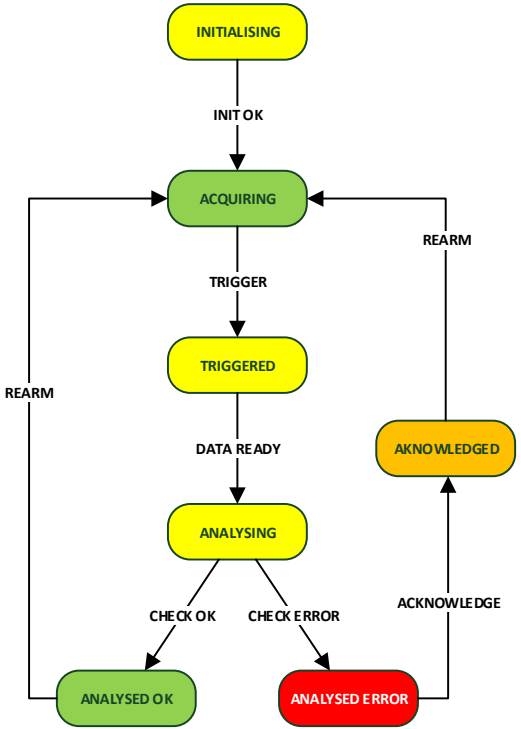
- Running on expert workstations for remote control and diagnosis.
- Access Logging DB for offline waveform analysis

OP / Sequencer to control the system

SVN server contains the IPOC configuration and limit files

Logging and PM servers to store waveform and analysis results

IPOC - Server States



INITIALISING: Initialise hardware, Analyser libraries, CMW subscriptions, etc…

ACQUIRING: Digitisers are acquiring, system ready to receive a trigger

TRIGGERED: Prepare new analysis session: Read waveforms from digitisers, collect CMW data, etc…

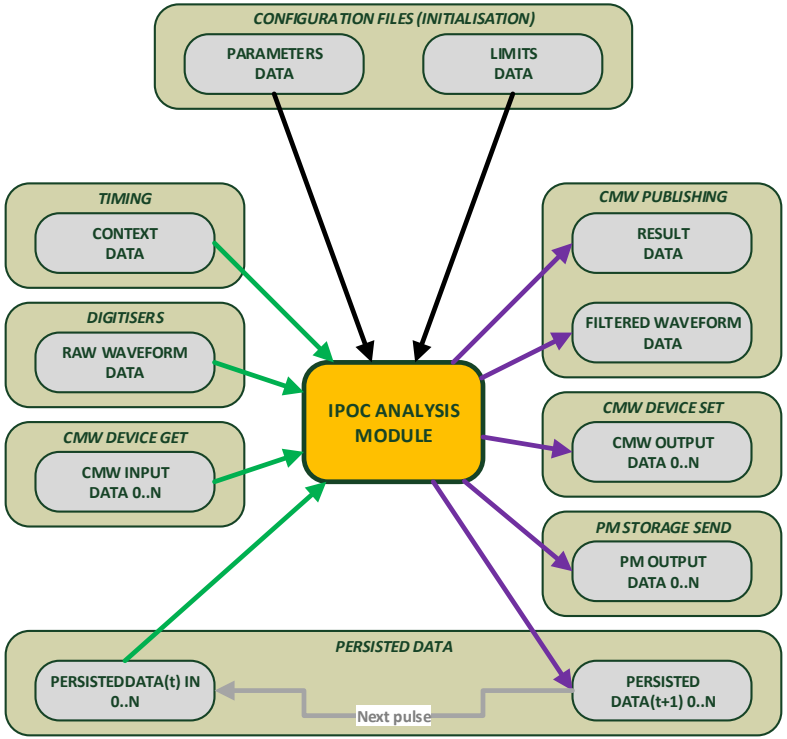
ANALYSING: All analysis modules are executed one after the other

ANALYSED OK: All analysis modules returned CHECK OK, waiting for REARM

ANALYSED ERROR: Some analysis modules returned CHECK ERROR
Acknowledge by expert is needed !

ACKNOLEDGED: Analysis error has been acknowledged, waiting for REARM

IPOC - Analyser Plugin API



Analysis Modules provided as plugin library (Linux SO):

C++ code can be developed by kicker experts, students, etc… without knowledge of IPOC system (Only IPOC Analyser API). No need to adapt IPOC server code to use new analysis algorithms, just configuration.

Configuration Data: XML files read from SVN at initialization.

- Analyser parameters and limits data

Input Data Collection:

- Waveforms from digitisers, Context data (beam info, etc…)
- Data from other CMW devices and persistent data

Output Data Collection:

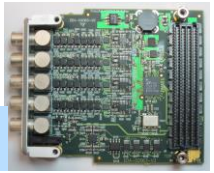
- Filtered waveforms and analysis results.
- Data to set to CMW devices, PM data, persisted data

IPOC - Hardware

Spectrum Instrumentation

National Instruments

Acqiris



CERN ohwr FMC-ADC

Front-End Computers (FECs): CERN control standards

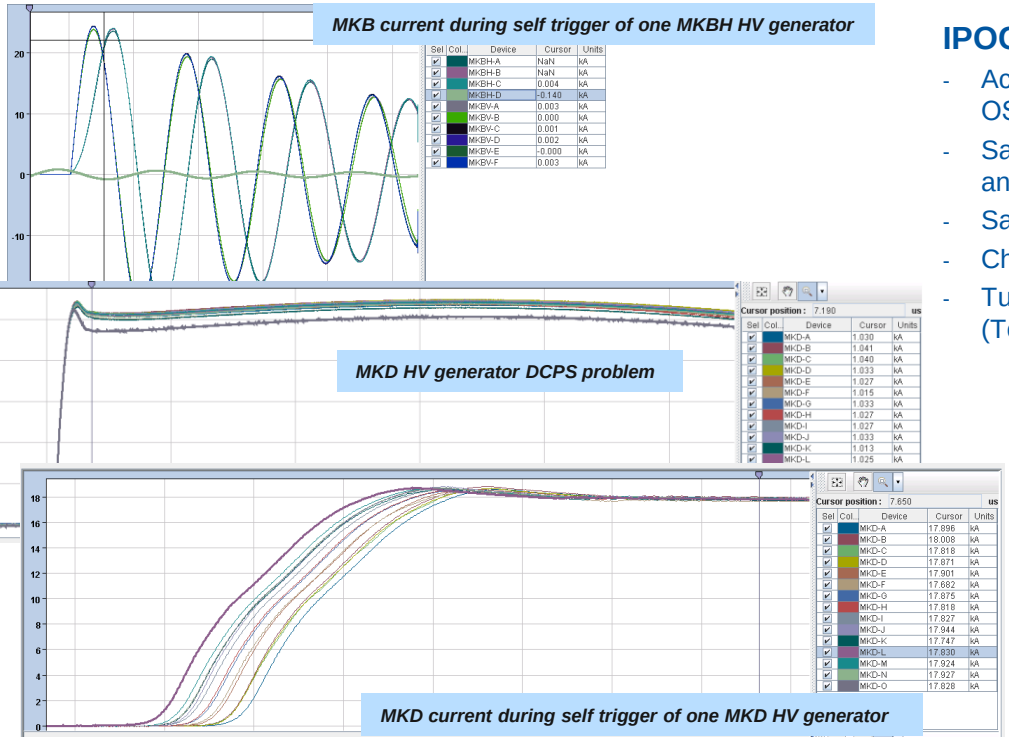
- Compact-PCI (cPCI slots, compatible PXI)
- Industrial PC (PCI / PCIe slots)
- PXIe (PXI / PXIe slots)
- VME64x (VME / VME64x slots)
- Future ones… uTCA?

All FECs are running Linux (SLC5/6, CC7 soon)

Hardware Abstraction Layer (HAL) allows for the support of:

- Various digitiser brands:
  - Acqiris / NI / Spectrum / CERN FMC-ADC / Future ones…
- Various digitiser bus formats:
  - PCI / PCIe / PXI / PXIe / VME / Future ones… uTCA ?
- Various digitiser bandwidth and dynamic:
  - From 8 to 16 bit
  - From 20 to 500 MS/s

Use Case - LBDS Magnet Currents



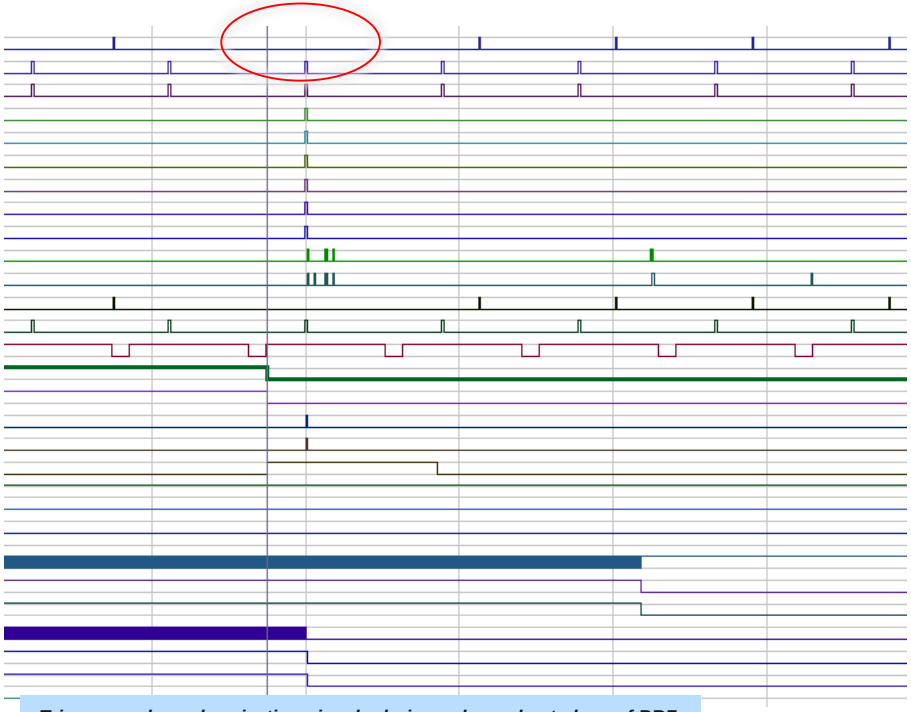
IPOC for MKD / MKB magnet currents analysis:

- Acquire and analyse waveforms (Rise time, delay, ref100%, OS1, OS2, max1, min1, max2, etc…)
- Save waveforms and analysis results to Logging for offline analysis => *Offline LBDS calibration*
- Save waveforms to PM =>*Online XPOC analysis*
- Checks that current waveforms are within limits
- Turn OFF HVPS in case of MKB IPOC error
  (To avoid magnet damage in case of sparking)

Example of faults detected by IPOC:

- Self trigger of MKBH generator
  (Residual current in magnet almost nil due to fault detection and trigger time)
- Self trigger of MKD generator
  (Retriggering of other MKD generators yielding in slower over rise time of MKD)
- Problem with HV generator power supply

Use Case - LBDS Triggers Synchronisation



Triggers and synchronisation signals during a dump due to loss of BRF

IPOC for Trigger Synchronisation and Distribution System (TSDS):

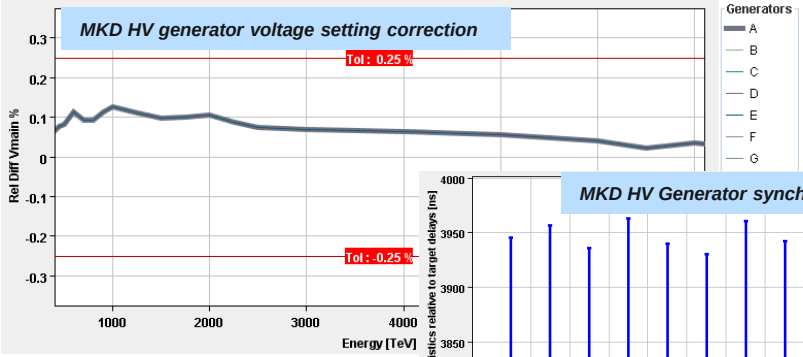
- Acquire and analyse digital waveforms (pulse edge time, transition times, delay between pulses, period/frequency, etc…)
- Check that all TSDS redundant signals are present and properly synchronised
- Save waveforms and analysis results to Logging for offline analysis
- Save analysis results to PM => *Online XPOC analysis*

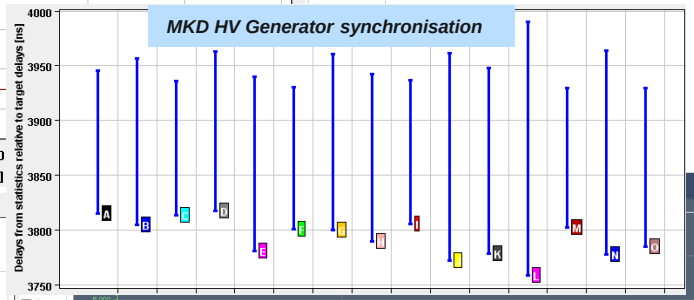
Example shown:

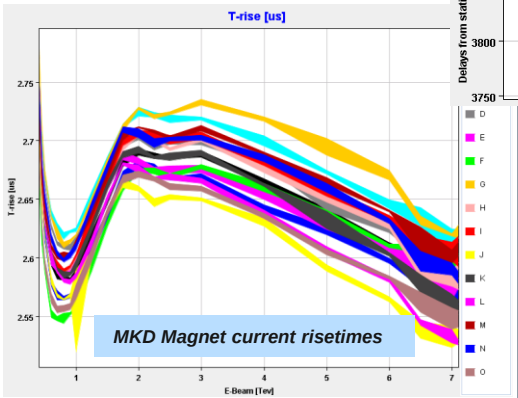
Dump on loss of Beam Revolution Frequency (BRF):

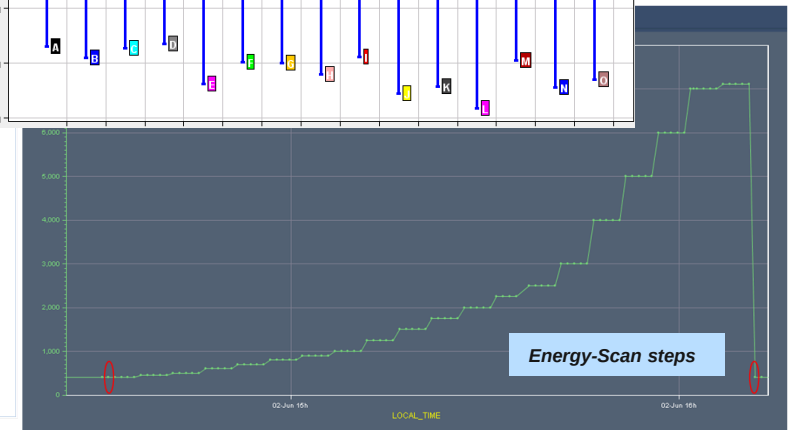
- RF resynchronization performed with LBDS armed.
  Missing BRF pulse => Dump requested by TSU cards
- No IPOC error detected, normal reaction and synchronisation OK
- Waveforms available for experts to analyse the event

Use Case - LBDS Calibration: Energy-Scan









Energy-Scan: Pulse 5 times at 21 voltages corresponding to energies from 400 GeV to 7100 GeV.

IPOC waveforms are saved in Logging DB for every trigger

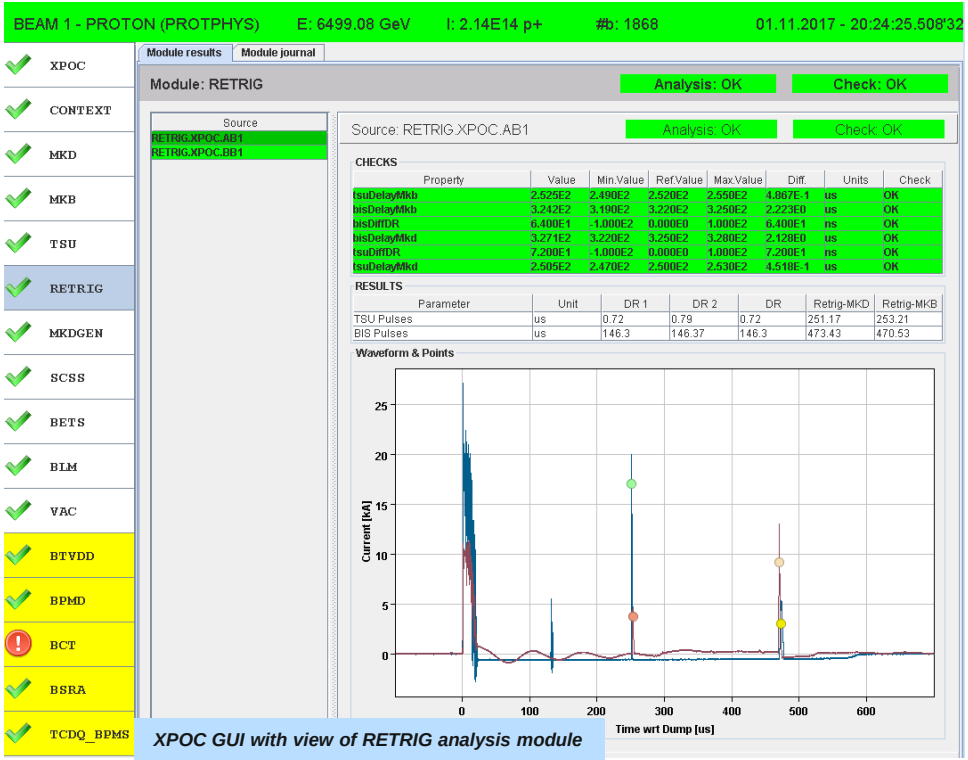
Offline analysis of IPOC waveforms:

- Statistics over 5 pulses: stability
- Use magnet calibration data to estimate overall magnetic field

Compute Calibration data:

- HV generators reference voltages wrt energy
- HV generators synchronization delays
- MKD/MKB XPOC limits
- Etc.

Use Case - XPOC



XPOC GUI with view of RETRIG analysis module

eXternal Post Operation Check (XPOC) is Post-Mortem (PM) Java server. It analyses every dump using data external to LBDS, like Beam Instrumentation data (BCTs, BPM, BLMs, BTVs, etc.)

It blocks LHC operation if any error is detected, kicker expert needed.

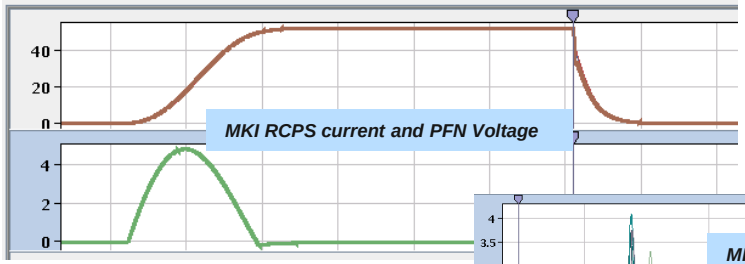
It also checks results from IPOC analysis:

- IPOC MKD/MKB magnet current amplitude and synchronization is checked wrt energy
- IPOC analysis results of TSDS are checked.

Example shown:

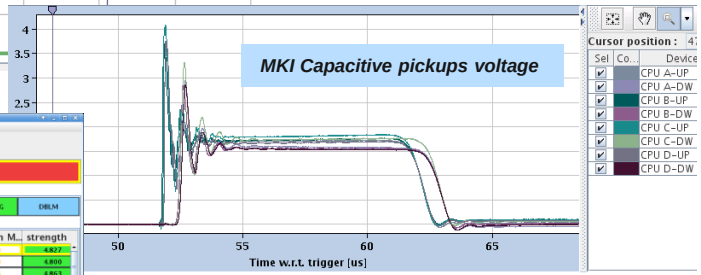
- IPOC waveforms and analysis results for the Re-Trigger line of LBDS are checked to validate the presence and correct synchronisation of all redundant trigger pulses.

Use Case - LHC Injection kickers (MKI)



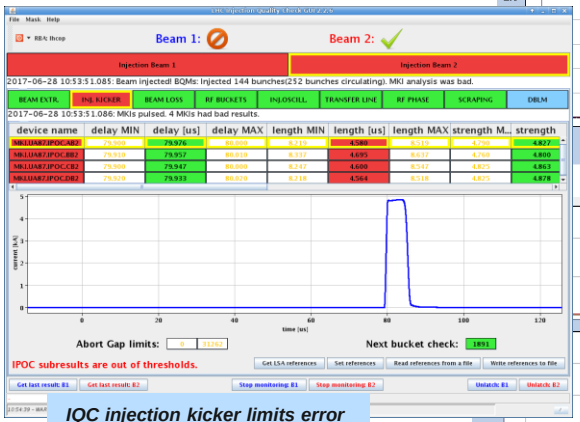
IPOC for LHC Injection Kickers (MKI) :

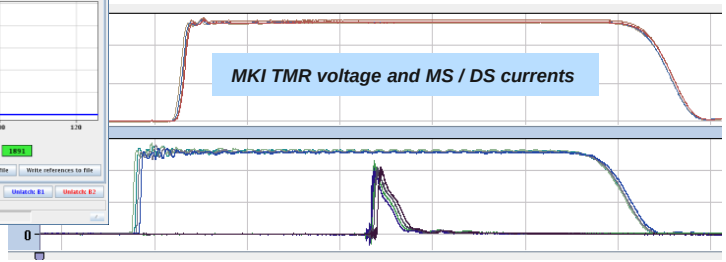
- Acquire and analyse waveforms of RCPS, TMR, MS/D, CPU, etc. (delay, length, rise/fall time, strength, etc.)



- Save waveforms and analysis results to Logging for offline analysis

- Save analysis results to PM for **IQC**



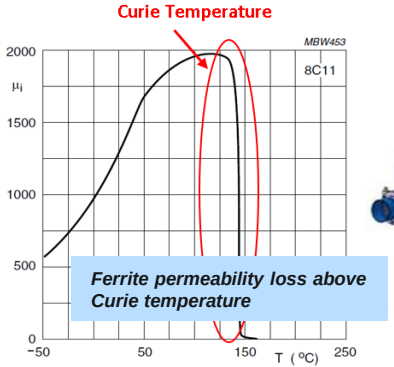


Injection Quality Check (IQC) is a PM Java server for LHC injection (like XPOC for LBDS).

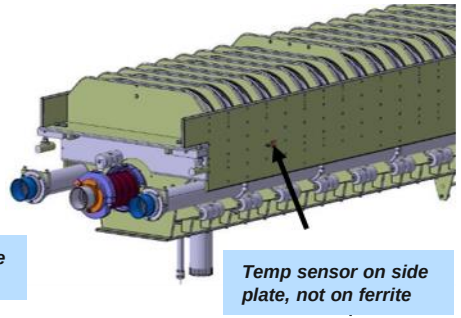
It analyses every injection using data external to MKI (BPMs, BLMs, Etc.).

It will also check IPOC analysis result of TMR waveforms, and block OP in case they are out of limits.

Use Case - MKI Ferrite Temperature Monitoring



Ferrite permeability loss above Curie temperature



Temp sensor on side plate, not on ferrite

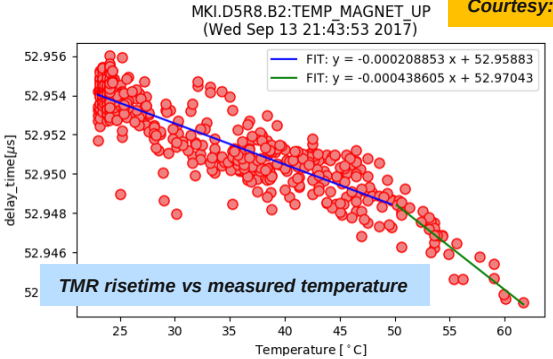
Courtesy: Agnieszka Chmielinska

Problem: MKI Ferrite yokes are heated by energy deposited by circulating beams. We have to ensure that yoke temperature is below Currie temp. before every injection.

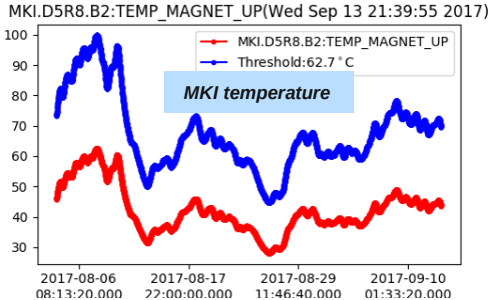
⇒ **OP (injection) blocked if temperature is above a defined limit.**

How to define limits for temperature measured on magnets:

- Ferrite temperature not measured directly, sensors are on side plate
- In case ferrite reaches Currie temperature, effect is visible on current waveform rise time and delay.



TMR risetime vs measured temperature

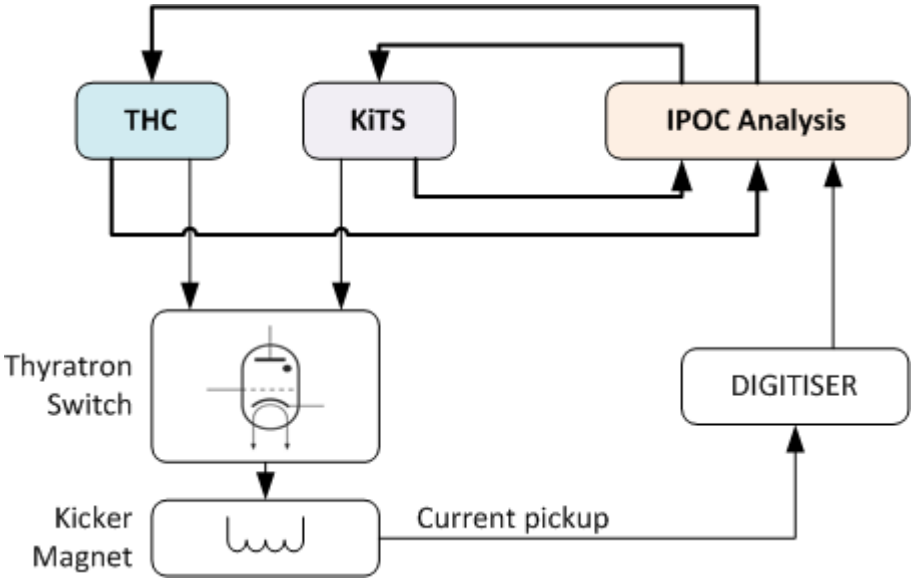


MKI temperature

Python service running 24/7 to process IPOC analysis results during MKI conditioning performed before every beam injection:

- Compute averages of rise time, delay and magnet temperatures, save results to Logging DB.
- When OP is blocked by temperature limit, experts check the trends of logged data.
- If MKI waveform OK => slightly increase the limits

Ongoing Dev - Thyratron drift stabilisation



IPOC can be used to implement closed loop systems

Example:

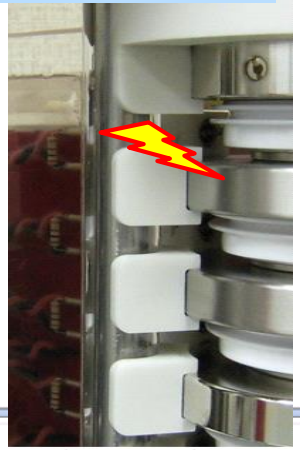
To compensate for Thyratron aging and temperature effects on turn-on delay.

- Analyser Input Data:
  - kicker magnet waveform from digitisers.
  - Thyratron Heater Controller (THC) settings from CMW Get
  - Kicker Timing System (KiTS) settings from CMW Get
- Analyse the waveform (rise time, delay), and compute THC and KiTS setting corrections.
- Analyser Output Data:
  - Sends corrections to THC and KiTS using CMW Set

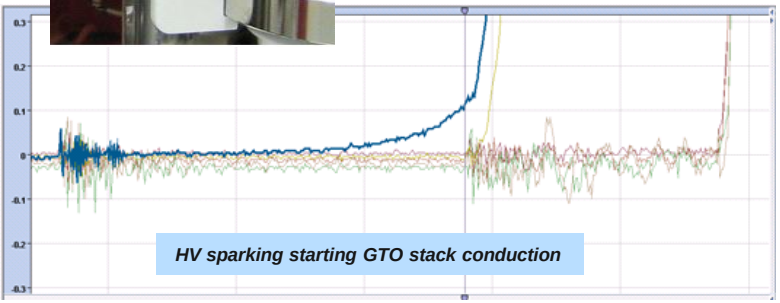
No measurements available yet:
Concept under test in software laboratory, planned for deployment on kicker test benches soon…

Ongoing Dev - HV Sparking Surveillance

Top of LBDS HV GTO stack



CERN ohwr SPEC card with With Rabbit interface



HV sparking starting GTO stack conduction

Problem:

LBDS HV generator GTO stack switches experience HV electrostatic discharges, yielding sometimes to self-trigger.

- Sparking visible on generator internal current pickups.
- Presence of dust in the generator is a risk factor
- Currently, sparking tests performed during TS, using scopes, to detect generators with high sparking activity, and clean or replace them.

Project:

Implement a continuous sparking surveillance system, and block operation in case a generator has high activity

- CERN FMC-ADC targeted, for FPGA custom firmware development.
- Many channels to acquire and monitor, problem: Synchronisation of many SPECS cards in the same FEC and on other FECs on large scale system:

=> Usage of **White Rabbit** is under evaluation.

Summary

IPOC is a generic waveform acquisition and analysis system:

- It uses analysis plugin modules for easy analysis algorithms development
- It contributes to equipment protection:
  - Interlock of kicker control system (Turn off MKB HVPS in case of error for instance)
  - Block OP in case analysis results are out of defined limits
- It is part of LHC Machine Protection:
  - Used by Post-Mortem applications like XPOC / IQC, that can correlate data from various IPOC systems and BI data .
  - Blocks OP in case analysis results are out of defined limits
- It is very useful for experts to diagnose kicker system failures or exceptional events
- Waveforms and analysis results are used by offline diagnosis or calibration applications.
- Project under development like closed loop system, sparking surveillance system

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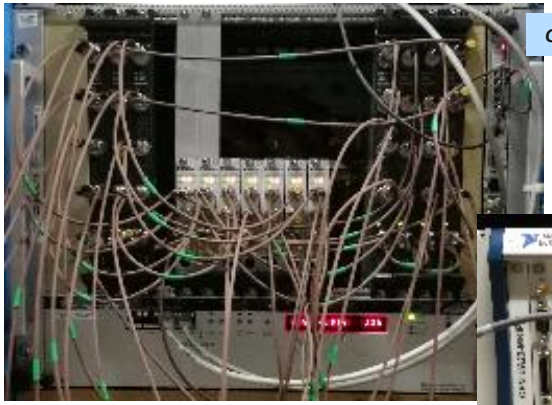
IPOC - Hardware



Compact-PCI FEC

PXIe FEC

Industrial PC FEC

Front-End Computers (FECs): CERN control standards

- Compact-PCI (cPCI slots, compatible PXI)
- Industrial PC (PCI / PCIe slots)
- PXIe (PXI / PXIe slots)
- VME64x (VME / VME64x slots)

Hardware Abstraction Layer (HAL) allows for the support of various digitiser brands and bus formats:

- Acqiris (Agilent / Keysight) =>PXI / PCI
- NI-Scope / NI-DAQmx => PXI / PXIe
- Spectrum Instrumentation => PCI / PCIe / PXIe
- CERN OHW FMC Carrier with FMC-ADC => PCIe / VME
- AdLink (Not used in operation)
- New brand / format to come?