CERN

Controls architecture challenges for beam dump kickers

P. Van Trappen, E. Carlier, T. Fowler, W. Bartmann, B. Goddard, T. Kramer

FCC Week 2016

Rome, Italy

Overview

1. Conventional controls architecture
2. Specific FCC Dump requirements and proposals
   a) RAMS
   b) Physical size
   c) Radiation tolerant
   d) Triggering and retriggering
   e) Data analysis using AI
3. Summary & outlook

1.Conventional controls architecture

Using the LHC Beam Dump Kicker System (LBDKS) as an example. 15 HV pulse generators are needed for the required deflection, 14 generators will still ensure a full extraction.

- Controls architecture consists of 4 subsystems:
  - Beam Energy Tracking System (BETS) that controls and surveys the voltage (magnet deflection strength)
  - Trigger, Synchronisation and Distribution System (TCDS) that synchronises the trigger with the abort gap
  - State Control and Surveillance System (SCSS) that surveys all generator components and controls on/off
  - Internal Post-Operation Check (IPOC) that checks pulse parameters after each pulse
- Use of fail-safe techniques to ensure personal and machine safety:
  - SIL3 PLC modules (COTS)
  - Redundant GTO branches with redundant triggering modules per stack
  - Redundant triggering & retriggering system: FPGA surveying two redundant CPLDs, two cards per beam
  - Design and VHDL code has been reviewed externally
  - IPOC / XPOC verification of all redundant trigger signal paths

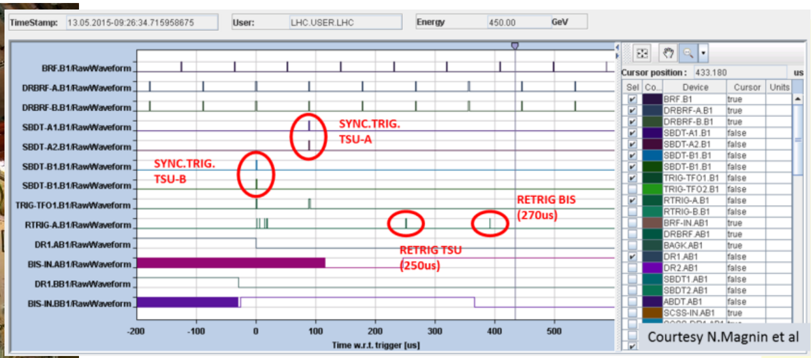
Redundancy is used to ensure a dump in all cases, all faults result in a (a)synchronous dump i.e. the fail-safe state. The redundancy does not increase availability.

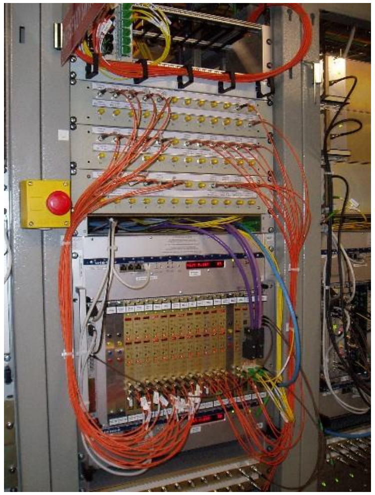
Table 2: Safety and false dumps trade-off.

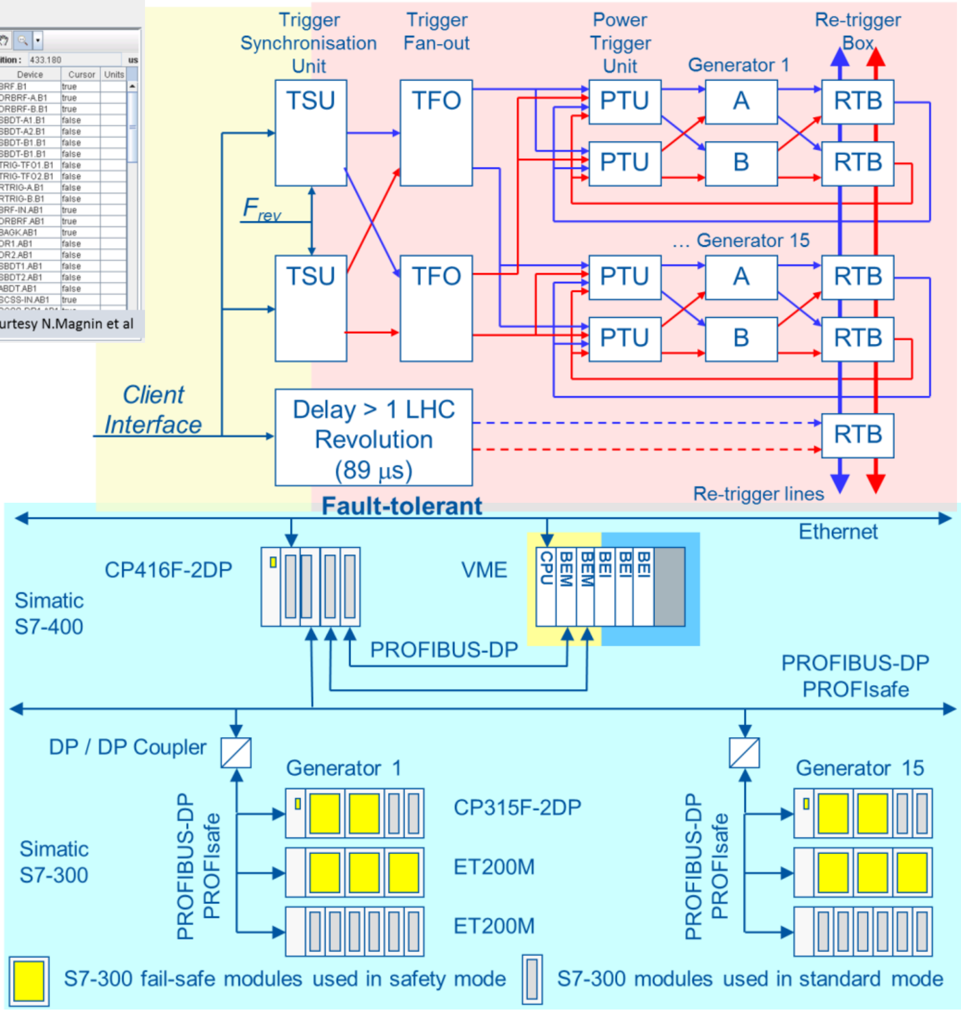
	Unsafety	False D.
Default	2.4×10^{-7} (> SIL4)	4.1
No dual branch	2.3×10^{-6} (SIL4)	3.0
No redundant TS.	4.7×10^{-4} (SIL2)	4.0
14/14 MKD	0.011 (SIL1)	3.9
No BETS	0.059 (< SIL1)	3.4
No RTS	0.32 (< SIL1)	4.1

R. Filippini et al.

1.Conventional controls architecture







2.Specific FCC Dump requirements

a) Reliability, Availability, Maintainability & Safety

Because of limited machine access, required accelerator performance and high beam energy (8.5 GJ!) however **a focus on RAMS** is needed more than ever.

This affects the FCC dump controls as follows:

- Perform **qualitative reliability analysis** for each part from the design phase on.
- Implement **system redundancy**: hot swappable HV pulse generators.
- Apply **Triple Modular Redundancy (TMR)** to critical parts.
- Accept operation in **degraded mode** where non-critical redundant paths are lost.
- Meticulously plan **preventive maintenance** during Technical Stops by leveraging advanced data monitoring.

2.Specific FCC Dump requirements

b) Physical size

Assuming the proposed layout with 300 extraction kicker magnets of ~30 cm length (ref. presentation T. Kramer). In this ~100 m the HV pulse generators and the controls will need to be fitted.

Looking at the rack space needed today, a different approach is required. The proposal is as follows:

- Return to custom-made electronics, generalised enough to allow design reuse (ohwr.org). One credit-card sized controller for all state control & surveillance.
- Integrate decentralised controls into the HV pulse generator.
- Decrease cables and interconnections.
- Combine software/hardware platforms as current System-on-Chips (SoC) allow for reconfigurable FPGAs and performant CPUs in one package.
- Investigate module powering (LV & HV)

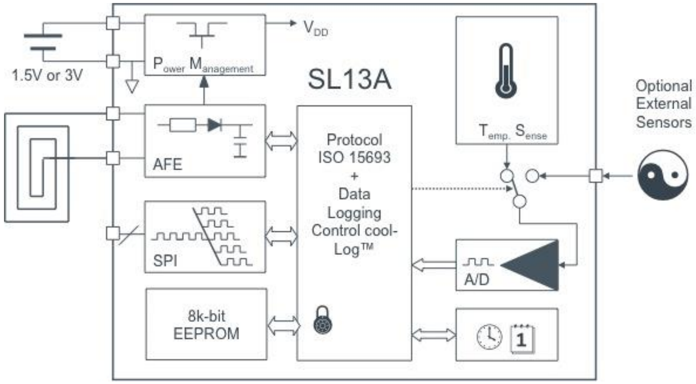
To be prototyped:

- Self-powered RFID sensors (analog/digital) to enable that integration.

2.Specific FCC Dump requirements

b) Physical size

Self-powered RFID sensors (analog/digital):



SL13A RFID Sensor Tag © 2016 ams AG.

farsens Medusa development platform for UHF RFID battery-free devices

Possible issues:

- Rad-hard
- EMC
- Accessibility

2.Specific FCC Dump requirements

c) Radiation tolerant

The transmission line's impedance affects the magnetic field rise time and a short cable length might be needed to reduce self inductance.

Depending on the layout (ref. presentation W. Bartmann) it is possible that the generator and controls have to be placed close to the circulating beam and hence accumulate high radiation doses and be more susceptible to HEH SEE.

Having the momentum collimation close to the generators is to be avoided at all costs.

Although this will limit the choice of technologies and components, not seen as a limiting factor for TE-ABT control electronics because:

- Proficient knowledge and database at CERN (TE-EPC, EN-STI)
- Decision making logic (CPUs) can be centralised away from the hot spots
- BUT this all depends on the TID and HEH flux levels – no data yet

2.Specific FCC Dump requirements

d) Triggering and retriggering

Triggering:

- Two possibilities: electrical or laser pumped thyristors (ref. poster J. Rodziewicz), synchronised with the abort gap(s)
- Pros and cons to be considered (FMEA)

Retriggering:

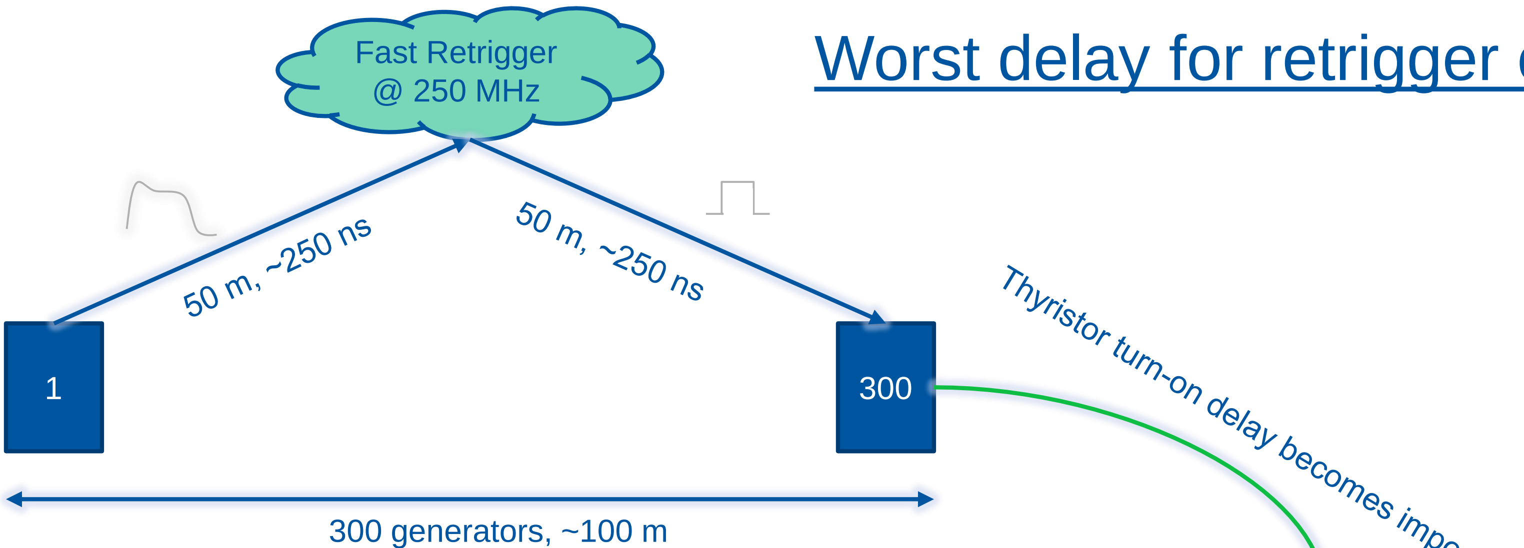
- Many generators but reduced length so signal transmission delays (~500 ns maximum) are acceptable.
- Two dump triggering strategies in case of erratic generator(s) firing (aka pre-firing):
  - An immediate asynchronous beam dump
  - A delayed synchronous beam dump using the following abort gap (beam < 1 sigma)
- Deciding logic needed, passive retrigger line (à la LHC) doesn’t suffice
- FPGA-based fast-retrigger system only marginally increases retrigger delay
- Thyristor turn-on delay becomes important for asynchronous dumps (ref. presentation B. Goddard.)

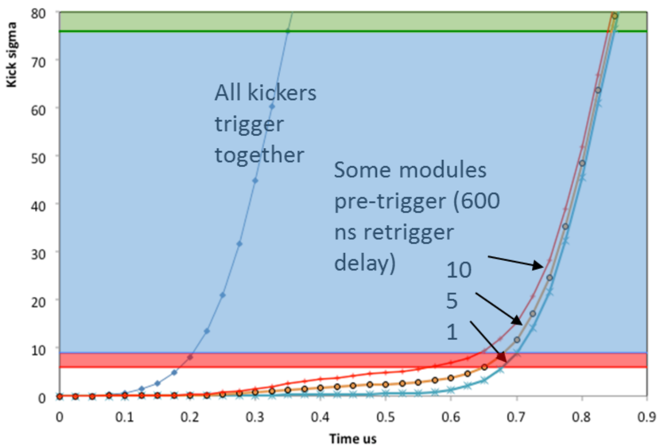
Worst scenario:

- Multiple modules pre-fire with no retrigger which will result in a beam dumped into the machine itself: collimators, protection, dipoles?, etc.
- Retrigger logic should hence be designed for failure rates < 10^-7.
- Looking at LBDS safety (2.4 x 10^-7) and SBDS retrigger failure rate /h (3.9 x 10^-5) should be feasible

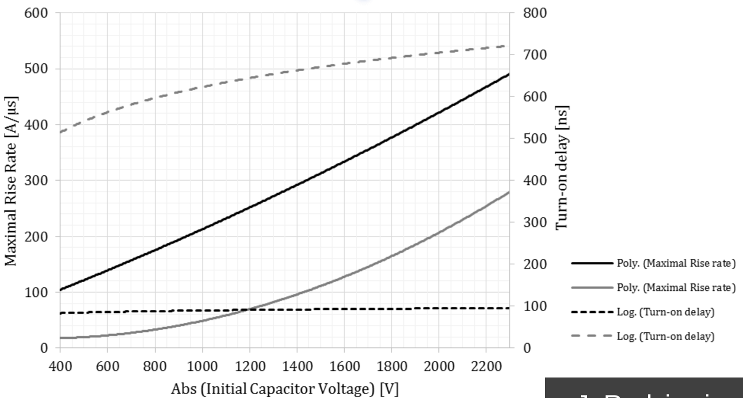
2.Specific FCC Dump requirements

Worst delay for retrigger case





B. Goddard



J. Rodziewicz

2.Specific FCC Dump requirements

e) Data analysis using AI

Lots of data logging, facing familiar problems:

- Too much data to program threshold and detection algorithms for every variable
- Failing components visible in data which is only analysed **after** the failure
- Unknown cause-effect relations between different variables

Artificial Intelligence (AI) can help, using *machine learning* and *deep* learning methodologies. Once a model has been developed and taught by using historical logging data, it can be used for:

- Online for warning generation (probabilistic model that does outlier detection)
- Offline with improved accuracy for helping expert with data analysis for problems that are not understood.

At this moment a possible collaboration with KUL (University Leuven) CS department is in the make. First master thesis could start September 2016.

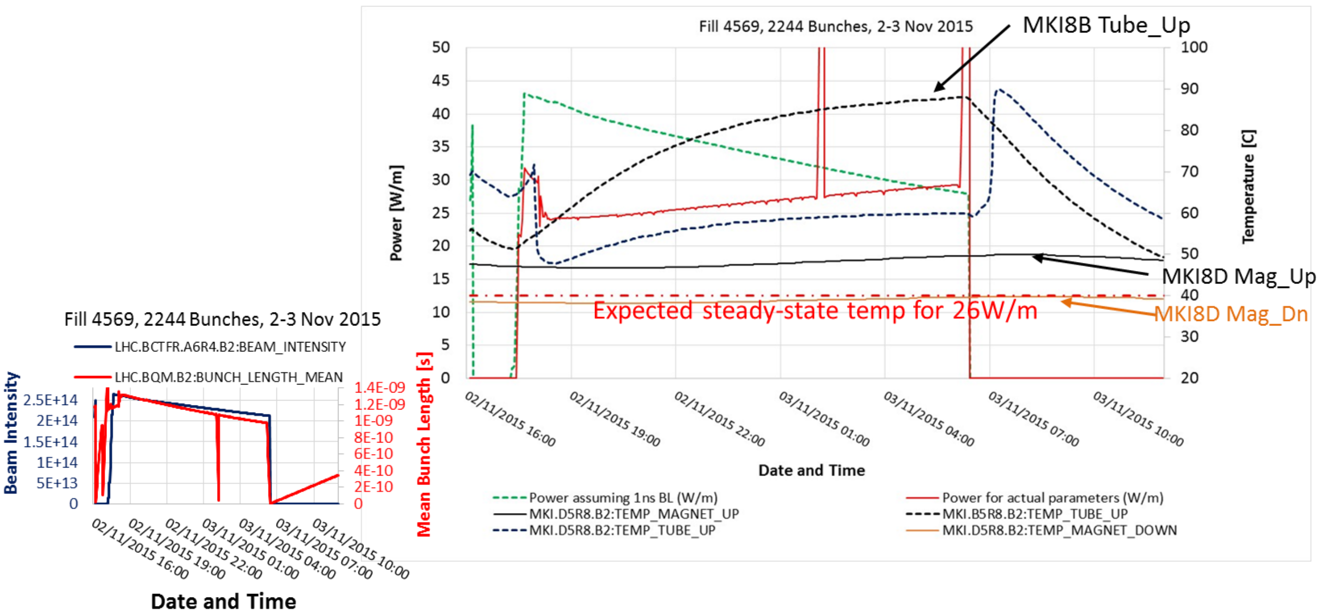
Examples:

- Causes of magnet flashover (voltage, vacuum pressure, beam induced heating, etc.)
- Effect of injection kicker synchronisation on beam quality

2.Specific FCC Dump requirements

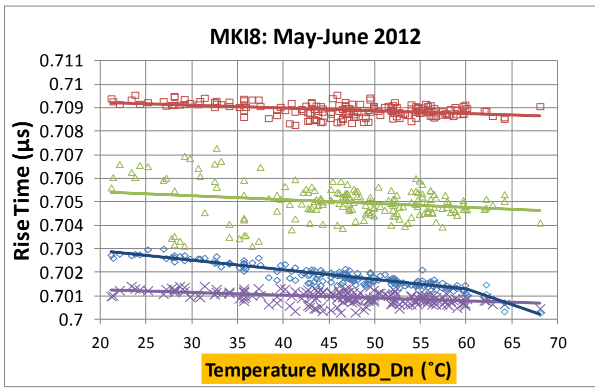
e) Data analysis using AI

First candidate for analysis: LHC injection magnets (MKI)



Magnet temperature vs. beam intensity

Difference between upstream and downstream of magnet



Ferrite yoke non-linearity

Courtesy of M.J. Barnes

3.Summary & outlook

Summary:

- Simply scaling the LHC controls won’t work
- Reliability and availability are the main concern, work in progress
- Focus on triggering & retriggering
- A deep learning model can provide many advantages

Planned for 2016:

- Obtain radiation dose vs. distance to find out rad-hard needs
- Reliability analysis Fast Retrigger system
- Continue laser pumped thyristor triggering research by exploring collaboration with the industry
- Collaboration with machine learning for data analysis

www.cern.ch