Report from HERA visit on machine protection issues

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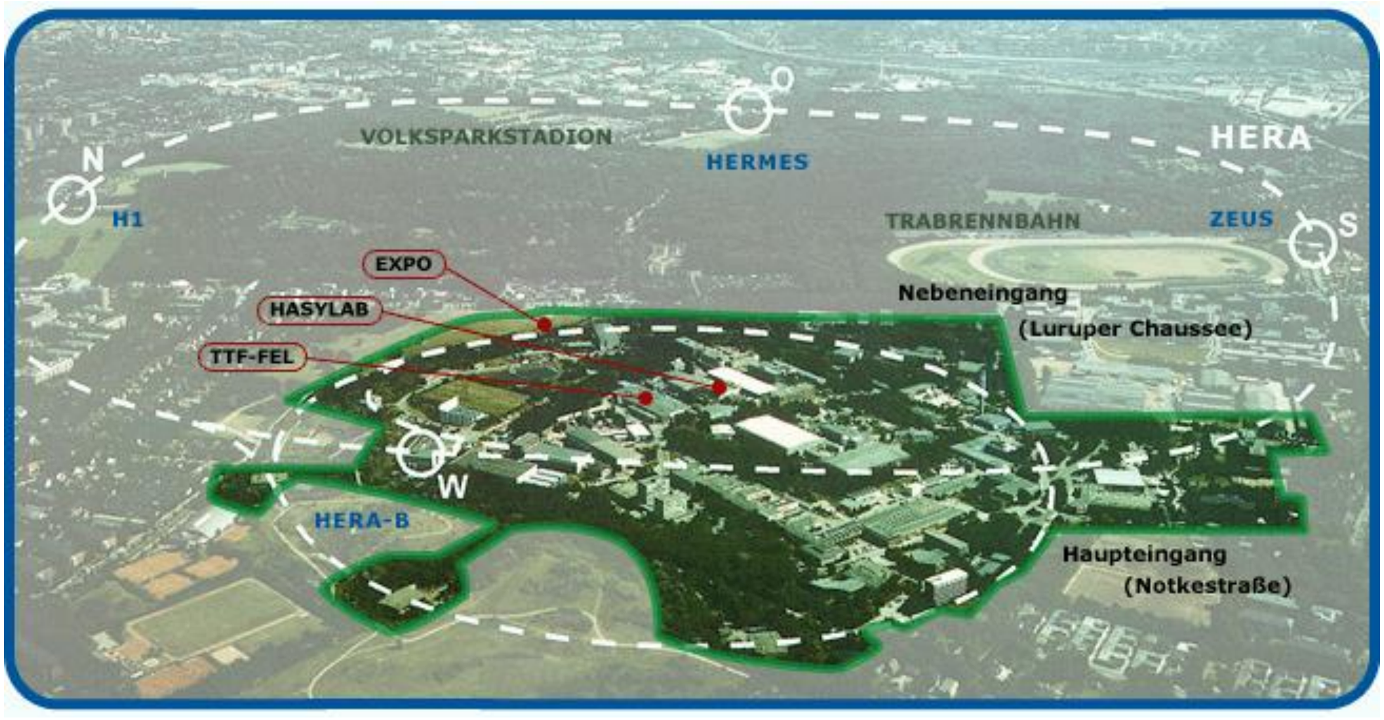
Written summary is available on the MPWG WEB page

HERA

- HERA is a 2 ring e-p collider of ~ same size than the SPS (6 km).
- Proton beam parameters :
  - Injection at 41 GeV/c.
  - Collisions at 820-920 GeV/c.
  - Proton beam intensity 100 mA in 180 bunches : $\approx 1.4 \times 10^{13}$ protons total.



HERA ALARM SYSTEM

- At HERA interlock clients are connected to the ‘alarm loop’ (current loop 1.6 A / 100 V).
- Initially : total transmission delay in the loop ≤ 1 ms.
- Clients can ‘manipulate’ the current in the loop : if the current drops below a threshold → beam dump.
- Beam losses are handled by 2 client systems :
  - Quench protection system :
    - Quench detection within ~ 10 ms.
  - Beam Loss Monitor (BLM) system :
    - One BLM (PIN diode) / quadrupole.
    - Integration / reaction time of 5 ms.
    - At high energy, the dump is triggered when 5 BLMs exceed the threshold level at the same time.
    - Dump levels depend on energy, but not on the loss duration.
    - BLMs are used to adjust the collimators (but also the exp. backgrounds).

HERA I – fast failures

- For HERA I, the machine protection systems were adequate.

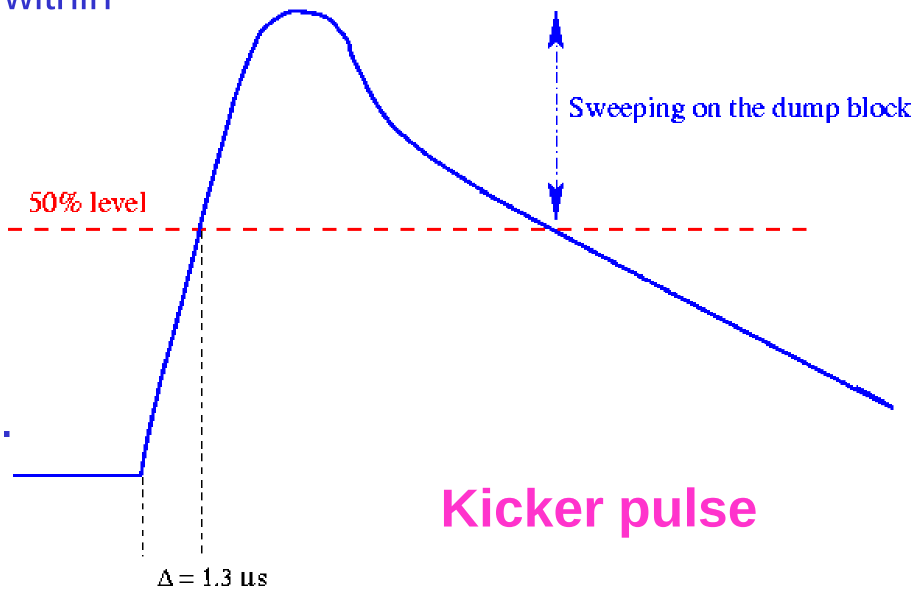
Fast losses / failures :

- 6 electrical circuits had time constants of ~ 20-100 ms.
  (warm quadrupoles)
- Fast losses (< 5 ms) were rarely observed and did not pose problems.

Beam dumping system

8 kicker magnets + internal dump block.

- Kickers with spark gap switch.
- Beam tracking with 1 DCCT (no redundancy).
- Pre-firing of 1 kicker triggers other kickers within 1 μs. No safety issue of pre-firing.
- 7 kickers can safely dump the beam.



Kicker pulse

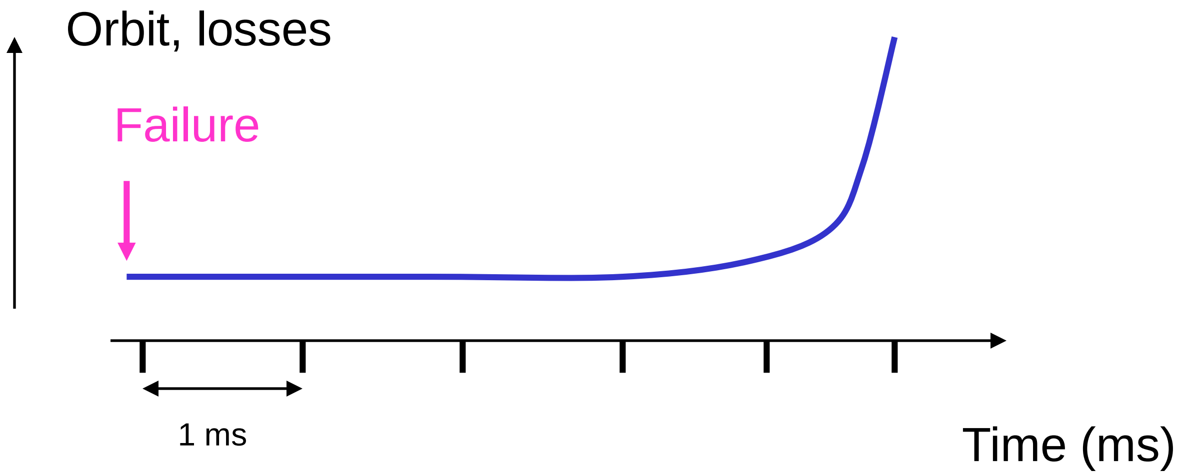
- Typically 1-2 pre-firing / year.
- Missing kicker was never observed.

Dump rates :

- One beam abort (by alarm system) per day.
- 1-2 aborts / week by the BLM system.

HERA II – fast failures

- For the HERA II upgrade (startup fall 2001) the number of critical circuits (insertion/low-beta quads) with short time constants (~ 20-100 ms) was increased from 6 to 14.
- The MTBF for those circuits was down to ~ 300 hours (aging / insufficient maintenance).
- Following a failure of such circuits, the beam is lost very rapidly (0.5-1 ms) after a short interval → cannot be caught by BLMs !!



Actions…

The situation was critical and was improved with the following actions :

- MTBF for the critical circuits was raised to ~2000 hours (inspection and revision of the PCs).
- The processing of some internal PC interlocks was reduced to 0.2 ms by generating interlocks directly from the thyristors (and not over the control PLC).
- An external current surveillance is under development.
- Delays in the alarm loop were reduced to ≤ 0.1 ms.
- A fast interlock on beam lifetime was developpped & put into operation.
- The delays in the beam dumping system were minimized.
- A BPM interlock will be implemented.

Expectation : when all actions will be completed there should be only 1 uncaught failure over 5 years.

PCs

Sources for PC failures :

- Connections.
- Temperature.
- External sources (electrical network).
- Aging.
- Water / humidity.
- Insulation.
- Air filters.

Improvements :

- Increased reliability with preventive maintenance (not just reaction on faults)
  - 1 day/month is now spent on preventive maintenance (comprise wrt not touching a running system…)
- Thermography with infrared cameras to detect hot/cold spots.
- Quality control by system engineers.

PCs

Electrical network :

- Sensitive to thrunderstorms within ~ 200 km.
- Regular (daily) power sags (10-20% for ≤ 120 ms) – part of the normal operation of the electricity grid. HERA PCs seem to be sensitive to such sags due to insufficient filtering.
- Tap changer movements on the main transformers lead to current variations of ~ 10^{-4} for some PCs → small (≤ 0.1%) beam losses ?

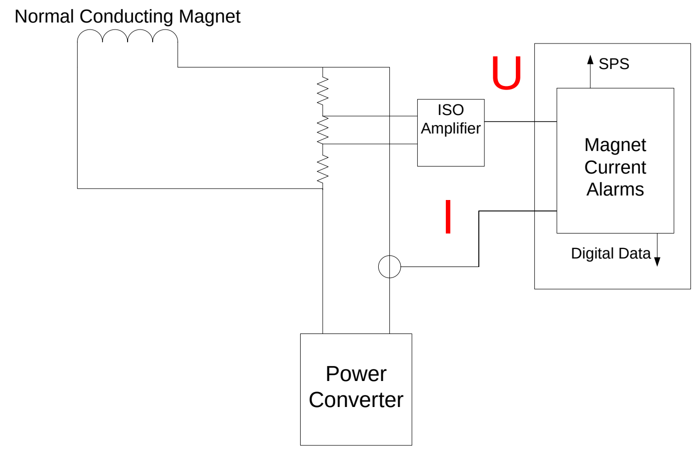
Interlocks :

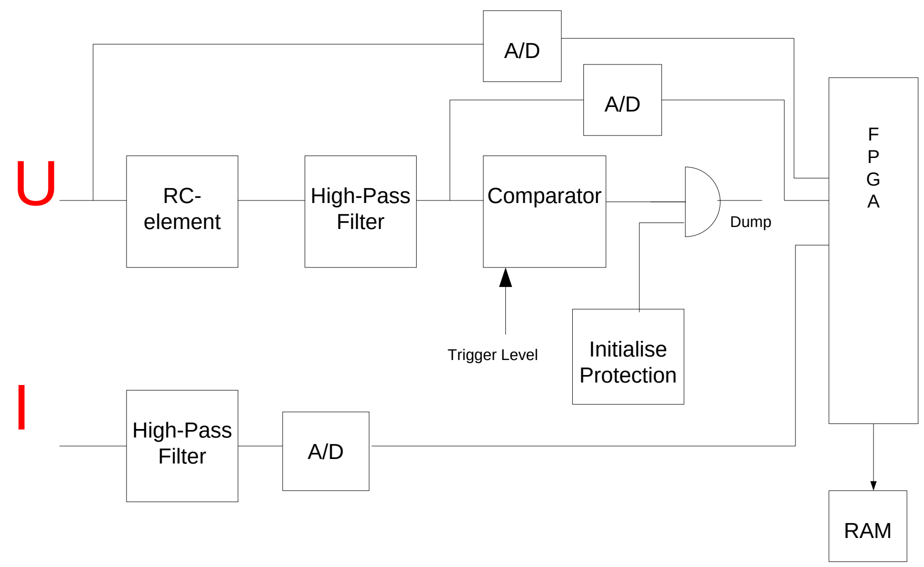
- Run the PC as long as possible to leave time for beam dump : optimization of control PLC timings and interlock generation.
- Detection of internal interlocks (and dump trigger generation) within 0.2 ms.

PC surveillance

- Voltage signal over circuit is used to simulate the PC current signal.
- High pass filter to extract high frequency (fast changes / transients) components.
- High frequency component compared to threshold → dump signal.
- Info is digitized and stored in FPGA for analysis.

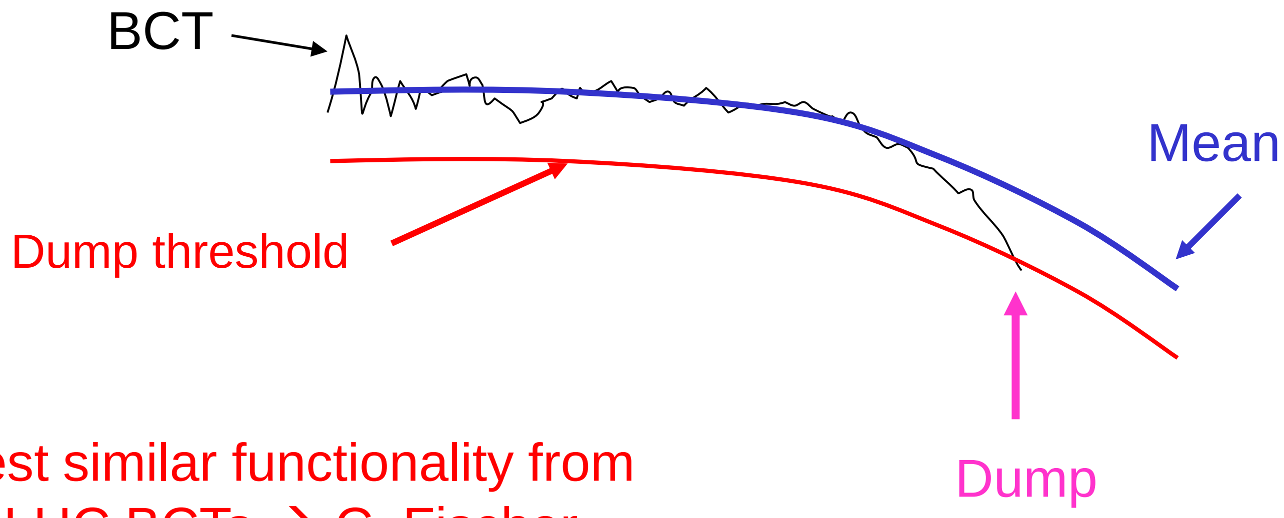
In the design phase ….





Beam intensity interlocks

- Fast interlock based on fast BCT signal (filtered at bunch frequency).
- Sum signal over one turn is compared to a moving sum + threshold.
- Maximum tracking rate of the mean is 0.7 mA/ms (1 ms ~ 40 turns).
- In operation…
- BCT sum signal resolution is apparently ~ 0.3%.



Idea : request similar functionality from the LHC BCTs → C. Fischer

BPM interlocks

- BPM interlocks were implemented at HERA from the beginning, but never used so far.
- The system is similar to the BLM system :
  - Each individual BPM (~ 100 / plane) can generate an interlock.
  - Response within a single turn.
  - Settable threshold: aim for ±3 mm.
  - Uses ‘healthy’ arc monitors.
  - Dump trigger : No. BPMs interlocks + No. BLM interlocks ≥ 5

    → ‘democratic’ system.
- Interlock is tested at the moment, but not activated.
- Open issue : reliability !

Collimators

Collimator use at HERA :

- Collimators are out at injection.
- Collimators are set to 10-11σ during the ramp (what σ ? Since it shrinks during the ramp….).
- Collimators are set to 7σ for collisions.
- Collimator setup is done with BLMs and experimental background signals.

- No attempt to use BLMs near collimators against fast losses :
  Frequent signal spikes due to transients that are not harmful to HERA.
- Beam tails :
  - Injection & ramp : ~ liitle tails.
  - Collisions : tails fill all space up to collimator openings.

Summary

– Even a rather ‘uncritical’ (wrt LHC) machine like HERA was caught struggling with fast beam losses that we are trying to anticipate.
– They seem to have understood the causes : warm magnets !

<u>Ideas for collaborations :</u>

– Installation of fast LHC BLMs near the HERA collimators to measure and understand fast losses of a fraction of the beam.
– Collaboration for the detection of fast magnet failures.
– Collaboration for the development of fast lifetime measurements.
– Collaboration on the understanding of fast beam losses.