Machine Protection Working Group

Minutes of the 37th meeting held on November 12th 2004

Present: R. Assmann, J.C. Billy, F. Bordry, A. Butterworth, E. Carlier, B. Dehning, R. Denz, R. Fillipini, E.B. Holzer, C. Ilgner, R. Lauckner, V. Montabonnet, B. Puccio, P. Pugnat, L. Ponce, A. Rijllart, F. Rodriguez Mateos, M. Stockner, R. Schmidt, J. Uythoven , J. Wenninger, M. Zerlauth

Topics of this meeting:

- Quench mechanisms and their time constants (P. Pugnat)
- Quench detection and its time constants (R. Denz)
- From quench detection to a beam dump (M. Zerlauth)
- AOB

Quench mechanisms and their time constants (P. Pugnat)

P. Pugnat presented an overview of the quench mechanism, with emphasis on the time constants that are important in the context of machine protection. Compared to RHIC and HERA, the margin of the LHC main dipole magnets is significantly smaller, implying that operation with beam will be more delicate than in those machines. In the absence of beam, quenches are due to the mechanical activity of the coil during the magnet powering. The measurements performed at SM18 show that the delay between the start of a training quench and its detection is in the range of 3-30 ms at top field. The time spread is of physical origin and depends mainly of the amount of energy which is deposited to provoke the quench and also of the quench location. For provoked quenches, this delay may reach up to 200 ms when the energy deposited in the low field region of the outer layer is just at the quench limit: the quench development and its propagation are then very slow. At injection, the delay to reach the detection threshold may exceed 5 seconds in case of symmetrical quenches. A quench typically propagates inside the magnet with a velocity of 1-4 m/s at the injection field and 20-30 m/s at the nominal field. The detection threshold on the induced voltage is 100 mV. Once the induced voltage exceeds this threshold, another 10 ms are used to validate the quench signal before firing the quench heaters to spread out the quench over the magnet. The quench heater delay, i.e. the time before heaters become effective, is in the range of 15-40 ms at high field, 70-130 ms at low field. The time spread is also of physical origin and the heater delay depends of the thermal coupling of the quench heaters to the outer layer of the coil. Eventually the bypass diode becomes conductive at high field 80 ms after the trigger, but the precise number depends however on the RRR (copper purity) of the conductors. Open questions concern possible effect on the beam of the field perturbations at the quench start.

In the discussion **F. Rodriguez Mateos** pointed out that in the String, the diode became conductive as soon as (~ ms) the heaters became effective. **P. Pugnat** said that results given come from measurements obtained on test benches with a single LHC main dipole connected to the power supply that is switch-off in the so-called slow power abort mode. The relevance of the results given to the case of the LHC machine configuration can be discussed. **R. Lauckner** wondered what could be the cause of field perturbations. **P. Pugnat** answered that this is due to the current redistribution which, at high field, is governed by the magneto-resistance of the copper used to stabilize the superconductor: during the quench. The current redistributes toward regions of lower field. **B. Dehning** asked if the quench frequency is correlated to the longitudinal position. **P. Pugnat** said that most training quenches occur in the magnet ends. **F. Rodriguez Mateos** wondered if there was a correlation between the quench delay and the location of the quench (inner /outer conductor). **P. Pugnat** said that such a study was effectively performed to analyse in detail the position of quench starts in order to give a precise feedback to the magnet manufacturers. **R. Schmidt** pointed out that beams induced quenches will mostly occur at the inner conductor since they are closer to the beam vacuum chamber.

Quench detection and its time constants (R. Denz)

R. Denz continued this series of presentation with an overview of the quench detection system. For the MB and MQs, there are 3 detection systems:

- Around 2000 local quench detectors with a voltage threshold of 100 mV and a delay of 10.5 ms.
- A main busbar protection system with 8 detectors.
- A protection system for the HTS current leads.

Each system is measuring the voltage continuously. When the voltage threshold is exceeded, a timer is retriggered. If the voltage remains above the threshold over a defined time period (see above), a quench signal is issued. The quench loop controller is informed by an internal current loop and sends out an interlock signal to the associated PIC. The quench loop controller is a micro-controller based detection system. The detection system consists of one controller in the even and another in the odd access point. Each controller is based on a redundant evaluation electronic. The entire system will be tested once per month.

For the insertion quadrupoles and the triplets, there are only 2 detection systems:

- Quench detector with thresholds of 100 mV and delays of 10 ms, both being programmable.
- Protection system for the HTS current leads.

Those systems interface directly with the PIC system.

From quench detection to a beam dump (M. Zerlauth)

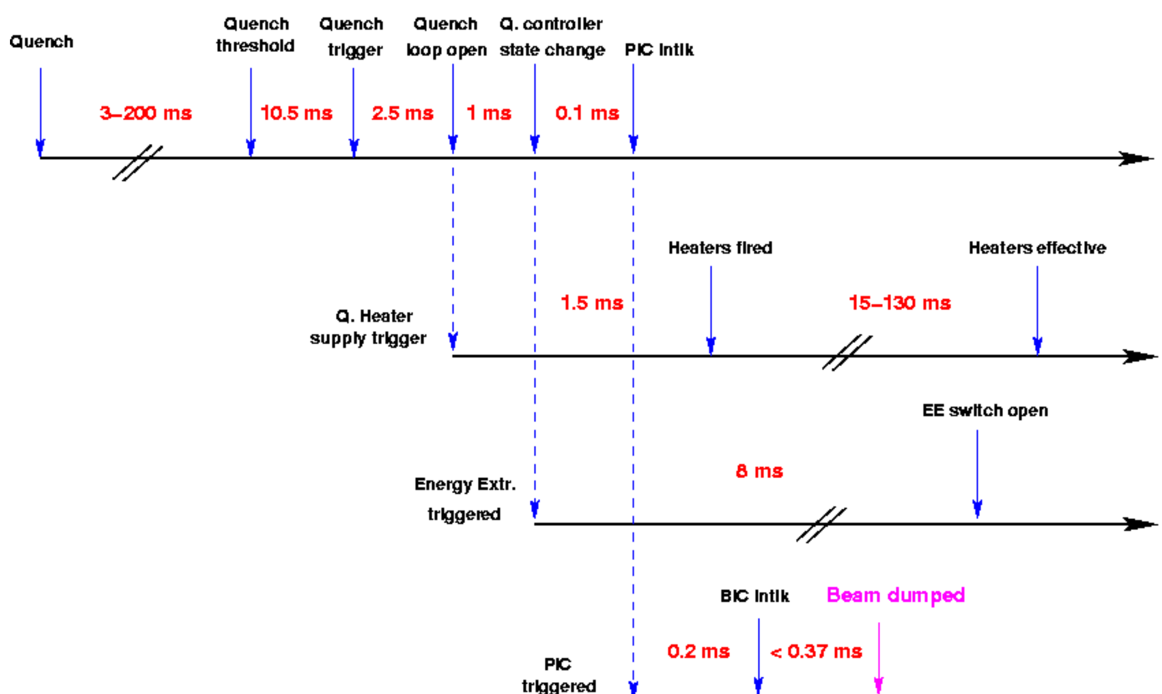
Finally **M. Zerlauth** discussed the internal delays of the PIC and the delays due to the BIC and to the beam dump synchronization. The PIC is based on a PLC controlled process, the RT process having a guaranteed maximum delay of 5 ms. For (beam) time critical circuits, a configurable hardware matrix is run in parallel to the PLC process to reduce the delay for the generation of an interlock signal to the BIC to less than 0.2 ms. After a maximum additional delay of < 370 μs, the dump action will be completed. With such a total delay in the PIC+BIC systems, the beams will be dumped in time before the energy extraction switches are opened and before the quench heaters become effective. The beam should a priori not see any significant change of field before it is dumped.

In conclusion, for the main dipoles and quadrupoles and for all other SC magnets, the QPC/PIC system will dump the beam before the BLMs see losses, providing redundancy to the BLM system. But the situation is different for the normal conducting magnets with time constants in the order of seconds. The interlocks for the normal conducting magnets are handled by a slow system. Presently only the BLMs provide protection against warm magnet powering failures. For that reason, a fast current (and voltage) monitoring is proposed, similar to what is presently done at HERA.

In the discussion **R. Assmann** wondered if the field changes are really sufficiently small until the moment with the QPS/PIC system trigger the beam dump system. **R. Schmidt** answered that before the heaters become effective, there is no real change of the field. **R. Assmann** also wondered about the criticality of the octupole circuits that are necessary to create sufficient Landau damping to stabilize the beams. He also proposed to apply the fast hardware matrix to all circuits. **M. Zerlauth** answered that the PLC provides all the diagnostics and that for this reason it is not desirable to replace the PLC entirely by the HW matrix. **F. Rodriguez Mateos** commented that the 8 ms delay of the EE system is actually not critical for quench protection: a delay of ~ 1 second was for example used at the String.

Summary of the different delays (J. Wenninger)

The drawing shown below summarizes the delays that were presented in the three talks (at top field):



AOB

J. Wenninger proposed to dedicate the coming meeting to a ‘post-mortem’ analysis of the interlock system for the TI8 and TT40 beam tests. The next meeting will be held in two weeks.