Machine Protection Working Group

Minutes of the 18th meeting held on November 22nd 2002

Present: L. Arnaudon, R. Assmann, J.-C. Billy, E. Carlier, E. Ciapala, B. Dehning, G. Guaglio, B. Jeanneret, V. Kain, R. Lauckner, D. Macina, V. Montabonnet, B. Puccio, M. Sanmarti, R. Schmidt, L. Serio, J. Uythoven, J. Wenninger, C. Zamantzas, M. Zerlauth

Excused : F. Balda

Main topics of this meeting:

- Fast beam losses due to equipment failures (V. Kain)
- LEP2 and LHC RF interlock systems (L. Arnaudon)

Fast beam losses due to equipment failures (V. Kain)

V. Kain presented the results of her simulations on fast failures of dipole magnets and the consequences for machine protection. Magnet failures are modelled by an exponential decay of the current for power converter failures, i.e. $I(t) = I_{nom} \exp(-t/\tau)$, with a time constant τ given by the ratio L/R of the circuit inductance and its resistance. In the case of a quench, the current decay is given by $I(t) = I_{nom} \exp(-0.5(t/\sigma)^2)$, with σ = 200-400 ms. This time constant is typical for operation at 7 TeV. While for slow (~ adiabatic) changes the orbit perturbation can be obtained from an analytic formula, fast changes require a detailed turn-by-turn tracking. This is very important for the warm magnets with time constants of ~ seconds (τ = 2.5 s for the warm D1). Tracking of particles in a machine subject to a failure is done with a special program. Data on machine lattice functions, magnet parameters and the machine are required as input. The effects of failures are simulated by tracking particles and evaluating impacts on collimators…

As a first example **V. Kain** showed results for a quench of the D2 separation dipole. For the worst case first signals are observed on the collimators after ~80 turns and after ~120 turns an integrated intensity of 10^{11} protons has already hit the collimator. Such an intensity was considered some months ago to be the damage threshold, but in the meantime the collimators are required to sustain ~ one order of magnitude larger impacts. All results that are presented are therefore conservative, but the margins will not necessarily improve dramatically with more robust collimators.

As a second example, quenches or powering problems of the warm and cold D1 dipoles were considered. A powering problem on the cold D1 leads to detectable losses after ~150 turns and damage after 240 turns. In the case of a quench, the delays are reduced to ~60 and ~90 turns. The most serious case is the failure of the warm D1 in either IR1 or IR5 (τ = 2.5 s). For IR1 first losses are detectable after 8 turns, while the damage threshold is reached after 11 turns, leaving little time to react since a delay of 2-3 additional turns is required to dump the beam. The orbit change at the collimators is ~0.3 mm (or 1.3 σ) at the moment where the first losses are detected.

Finally quenches of a single dipole and of a whole sector were also considered. For a quench of a complete arc, beam loss can be detected after ~44 turns and the damage threshold is reached after ~50 turns for quenches in sectors 2-3 and 3-4. For the other sectors, the numbers are more 'relaxed'. This difference is most likely due to the fact that in IP3 the dispersion is not matched to zero because of the momentum cleaning. A momentum error therefore propagates more easily to the rest of the machine. For a quench of a single dipole, the delays are somewhat longer, 78 and 90 turns in the worst case.

V. Kain concludes that the fastest losses occur for powering failures of the D1 magnets. For such a failure, the reaction time available for beam loss monitors amounts to a few turns. **V. Kain** also wondered whether for quenches, there was a possibility to dump the beam early enough from the quench detection system since only ~10 turns are available to take a decision. Other failures need now to be considered as well, like vertical dipoles (for example warm orbit correctors), thunderstorms…

During the discussion **R. Schmidt** commented on the apparent difference between failures of the warm D1 in IR1 and IR5 (where the margins are slightly better). He noted that the collimators do not cover all betatron phases and that therefore the results depend on the closed orbit and details of the trajectories, the phase advances… **R. Assmann** pointed that one should always consider the worst phase advance, since one cannot assume that the phase are fixed forever: some margin is required for machine tuning and operation. He also worried about failures where all magnets in one insertion fail due to a power cut, which is quite a realistic scenario. **R. Schmidt** wondered what time is required to measure a current to the 10^{-4} level and whether such a measurement (under steady state conditions) could be useful. This topic should be addressed in the near future. Suggestions were also made to power the two dipoles in each insertion by 2 power converters and not just by one, since this will ~half the effect of a D1 failure. That option does not work however in case of a general power cut. **R. Schmidt** mentioned that a 'simple' solution would consist in increasing the time constants of the D1 circuit by adding an inductance. In practice this is however not so simple. **J. Wenninger** finally mentioned that for the SPS, a new interlock on the beam position is foreseen. This interlock system will sample the orbit over 1 μs and then apply a logic that still needs to be defined (how long to average, maximum excursion…). The system should be ready for tests in the next SPS run. This system will replace the existing analogue system which only surveys the horizontal position with a threshold of ~30 mm (the SPS aperture is very large in the horizontal plane) and a reaction time of ~2 turns.

LEP2 and LHC RF interlock systems (L. Arnaudon)

L. Arnaudon presented the design of the LEP2 RF interlock system and its evolution towards the LHC. The LEP2 RF system had a total of ~8000 interlock channels for 288 SC RF cavities. The interlock logic was entirely hardwired. Interlocks on Helium pressure and gauges were connected directly to the LEP beam dump. The good points of the LEP design were the reliable TTL logic, the modularity, the remote read-out and the very reliable protection. On the other hand, the communication was not very reliable, fault names were coded into the hardware and there was little flexibility. In addition there was no diagnostics for the beam dump (was added at a later stage) and there was no way to detect strapped (masked) interlocks.

The main points of the evolution of the system, in particular of the interlock modules:

- The modularity and the TTL logic are kept. The reaction time should be < 3 μs.
- Micro-controllers and FPGAs are used to gain more flexibility.
- Interlocks can be masked by software.
- New communication bus is used between modules and interlock controllers.

At the level of the software, fault diagnostics and remote download of the micro-controller programs are available. Many improvements are also made at the level of the interlock controller. A test system is already operational.

The LHC RF system consists of 16 cavities (and associated klystrons) with ~1000 interlock channels. Slow interlocks will be handled by PLCs (reaction time ~20 ms) and fast interlocks by the interlock modules. Time stamping will be based on GPS/IrigB. Supervision of the system will be done with a PLC. The system will be interfaced to the BIC. The detailed logic on how and when to fire the dump must still be defined. The system will be tested next year in SM18.

In the discussion **R. Schmidt** wondered if the opto-couplers used for the LEP2 system were reliable. **L. Arnaudon** said that the system was tested in every shutdown and that the experience with the opto-couplers was good. It was further asked what happens for the LHC after a RF trip, or if the beam is lost. A future discussion in the MPWG was proposed.

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R. Schmidt mentioned that a Workshop on LHC Performance is organized in Chamonix in March 2003. Two sessions will address questions related to machine protection and safe operation. On the 18th December, the LCC meeting will be devoted to the aperture in the beam dump channel. For that reason, he proposes to review this topic at the next meeting on 13th December, in particular since a number of private meetings were held on that subject.

B. Puccio reminded the audience that the choice for the interface between interlock system and clients must be made in the near future in collaboration with the equipment groups. The interface should be simple, fast, unique and reliable. Tests will be performed in the coming months in order to have a proposal for the spring of 2003.