Machine Protection Working Group

Minutes of the 12th meeting held on April 12th 2002

Present: F. Balda, E. Carlier, E. Ciapala, C. Dehavay, B. Dehning, R. Denz, J. Dieperink, F. Ferioli, V. Montabonnet, G. Mugnai, R. Rausch, R. Schmidt, F. Szoncso, J. Tückmantel, J. Wenninger, T. Wijnands, M. Zerlauth

Excused : B. Jeanneret

Main topics of this meeting:

- Radiation from super-conducting RF cavities in point 4 (J. Tückmantel)
- Reliability of the LHC beam dump kickers (J. Dieperink)
- Update on interfaces between Power and Beam Interlock Controllers and other systems (R. Schmidt)

Radiation from super-conducting RF cavities in point 4 (J. Tuckmantel)

J. Tückmantel presented some radiation hazards related to the LHC RF cavities at point 4. Installation of the 16 super-conducting RF 400 MHz cavities (8 per beam) is presently foreseen inside the ex-ALEPH cavern (see the layout LHCACSLA0012 shown in the presentation). Each cavity provides RF power to one beam, but the vacuum chamber of the other beam is also going through the same cryostat. The cause of the radiation issues associated to RF cavities is due to field emission. A 1 GV/m gradient can pull electrons out of a conducting surface even at normal temperatures. On a real surface, tiny objects, so-called 'emitters', allow field emission at much lower voltages, a problem that is more severe with super-conducting cavities because of the higher fields. Field emission increases exponentially with the voltage, it is therefore very sensitive to the running conditions in a SC RF cavity. The electrons that are extracted are accelerated to the surface where they deposit heat and generate bremsstrahlung photons with energies of up to a few MeV. A large fraction of the cavity surface is being swept by the electrons due to the time dependent fields. Field emission cannot be avoided completely and it disappears when the RF is stopped, the remanent radiation – if any – decaying very rapidly (short lived isotopes). To reduce field emission during normal running, the cavities are processed at high fields during periods without beam. The radiation levels that can be expected depend on the operation mode of the cavities.

- During processing, radiation levels of up to 1 kG/h can be reached during a period of hours or days. Processing is normally done during set-up, but exceptionally also between beam-dump and injection (luminosity runs).

- During normal (beam) operation, the radiation levels are of the order of some mG/h within a few metres of the cryostats.

The radiation levels will change rapidly when the fields in the cavities are changed. They will change erratically when emitter turn on and off. **J. Tückmantel** concluded that everyone around point 4 is concerned by this radiation. He added that the cavities would also emit a certain amount of light that could perturb measurements.

In the discussion **R. Rausch** said that he would check the location of the cable and optical fiber paths. Concerning instruments, **B. Dehning** indicated that the synchrotron light telescopes used for beam emittance measurements are pointing into the direction of the RF cavities. Finally **R. Schmidt** said that the 200 MHz Copper cavities (4 per beam) will probably not be installed at the LHC start-up, but **J. Tückmantel** insisted that those cavities will be required to ensure best possible capture at injection for highest beam intensities.

Reliability of the LHC beam dump kicker magnets (J. Dieperink)

J. Dieperink presented a first reliability analysis for the LHC beam dump kicker magnets. The system consists of 15 kicker magnets per beam, and 14 are required for a safe dump. Each magnet has 2 redundant triggers sources, power triggers and generators. The SIL allocation is based on the reference risk tables approved by the IAWG (see also F. Balda's presentation at the MPWG meeting of 14 December 2001).

A hazardous event is defined as a failure of the dump system itself, of the energy tracking system or of the dump synchronization when beam is present in the LHC and when there is an internal or external (access, machine protection) dump request. The different failures are

1. Incorrect energy tracking.
2. Generator failure (< 14 generators).
3. Dump system failure (no response to the dump trigger request).
4. Synchronization problem (spontaneous trigger or external synchronization).

The consequences of the failures on the machine for those 4 cases are either 'catastrophic' (cases 1,2 and 3) or 'severe' (case 4, leading to collimator damage). The tolerated frequencies of the failures are (so far)

- Cases 1, 2 and 3 ~ 1 / 100 years (classified as 'remote').
- Case 4 ~ 1 / year (classified as 'frequent').

The combination of consequences and frequencies implies that the required safety integrity level should be SIL3. For a low demand mode of operation, the probability of a failure should therefore be in the range of 10^{-4} to 10^{-3}, while for a high demand system, the failure rate should be in the range of 10^{-8} to 10^{-7} per hour.

There are 2 operating phases for the beam dump system

- **A**: *Ready-to-dump*, which lasts from injection to the actual dump, with a typical duration of some 10 hours or more.
- **B**: *Pulsing*, which lasts for ~ 100 μs during the actual dump process.

During phase A, a failure can cause, in particular cases, the loss of one or more kicker magnets. The reaction time of the surveillance system on the detection of an failure, by generating an internal dump request, is several tens of ms. With a high voltage decay time constant of ~ 12 s, it remains in most cases possible to dump the beam correctly with all kickers. Failing elements concern components for monitoring, power supplies… During phase B, a failure consists in an incorrect kicker operation.

The system has 3 clients that are responsible for forwarding the trigger requests: the beam interlock system, the access system and the MKD system itself (for internal triggers). Assuming that the failure rates are

- ~ 10^{-4}/h/kicker in phase A,
- ~ 10^{-4} to 10^{-5}/h/kicker in phase B,

~ 28 internal dump requests are expected per year and beam for ~ 1000 external requests. Furthermore, it is assumed that the mission time is ~ 10 hours and that following the system checks before injection, the dump system is 'as good as new'. Under those conditions, the dump system classifies as ~ SIL3 or above.

For synchronization failures, the mission time is only one turn and the expected safety level is above SIL3. The highly redundant re-triggering system is expected to be classified as SIL3 or above. Those classifications must however be evaluated in more detail with the new RAMS software.

J. Dieperink concluded that the different components of the system where all classified as SIL3 or better.

In the discussion that followed, **R. Schmidt** expressed his worry that the expected rate for internal beam dump requests of ~ 1 per week was too high. He also insisted that the problem of the damage to the collimation system in case of an unsynchronised dump is being addressed in the Beam Cleaning Study Group.

Following the meeting, **F. Balda** and **J. Dieperink** had a private discussion on the risk analysis. **F. Balda** pointed out that that the 'frequency of occurrence' of the initiating event should be used instead of the 'tolerated frequency'. This is logical since the risk reduction, expressed with the SIL, leads to the tolerated failure rate or failure probability. Nevertheless, if the initiating event is 'beam dump request', it is still important to point out how often the occurrence of such an event has catastrophic consequences in case of a Beam Dump System fault. In this case it is easier to get a correct estimation of the required SIL.

The initiating event in the Beam Dump Kicker System is a 'dump request', which certainly will be issued more than once per year. The events must therefore be classified as 'frequent' instead of 'remote', and SIL4 must be required for:

1. Incorrect energy tracking.
2. Dump system failures (no response to the dump trigger request).
3. Simultaneous dual generator failures, i.e. one generator fully lost during phase A followed by a failure of one of the remaining 14 generators during phase B.

In his conclusion **J. Dieperink** stated that the estimated SIL for Beam Dump Kicker System is above SIL3, but in fact, it is at least SIL4. This is true for all failures except maybe for the dual generator failures. If the frequency of a dual generator failure during phase A is more than once per year (high demand mode) SIL3 can just be obtained according to his calculations. But if this frequency is less than once per year (low demand mode) SIL4 can easily be obtained. The probability that during phase B one of the 14 remaining generators fails is less than 1.4 10^{-5} for a mission time of 10 hours.

Independently of whether the frequency is less or more than once per year, e.g. 10 per year, he believes that the target SIL4 is largely met even for dual generator failures.

J. Dieperink is of the opinion that the rules for the determination of the SIL in high demand mode, for non-repairable systems, is a little artificial and gives results that do not have much significance. The case described above is an example. **F. Balda** agrees to this point.

Finally **J. Dieperink** insists that the required SILs could never be obtained if the pulse generators would have only a single branch.

The slides of the presentation have been updated with a corrected version.

Interfaces of the Power and Beam Interlock Controllers to other equipment systems (R. Schmidt)

R. Schmidt gave an update on the status of the interfaces to the PIC and BIC, which differ through their demands on timing. For the PIC, where the delays (~ ms) are not very critical, current loops are used to transmit the signals. For the BIC on the other hand, the delays are critical (~ one turn or less) and a frequency signal will be used. The interfaces between PIC and PC and QPS systems are defined. The cables that will be used to connect PIC and BIC to other equipment will have total length of about 35 km.

Since the BIC has to interface with a very large number of systems, a single type of signal exchange is foreseen. The presently preferred choice for the BIC consists of a ~1 MHz signal carried by a twisted pair cable, two wires for the signal to be transmitted to the client equipment, and two wires that return the signal. Signal generation and detection will be done by the BIC, while the client system has to provide the switch to open/close the connection. In general one beam dump signal is used to dump both beams, but in principle the 2 rings can be handled independently. Preliminary designs exist now for the Beam Loss Monitor system and for the warm magnet surveillance system (PIC-warm), the later being the responsibility of the SL-MA group. The PIC-warm will handle the powering of the warm resistive magnets and forward one interlock signal to the BIC module.

B. Dehning mentioned in the discussion that in fact, current loops are also fast since the travelling time in the cable dominates and the use of a current loop adds little overhead. **R. Denz** confirmed that for the quench loop, the delays in the current loop are already limited to some ms by the relays used to open/close the loop. **E. Carlier** said that **G. Beetham** measured the delays of the current loop for the LEP beam dumping system with GPS clocks. Concerning the separation the rings and the ability to dump a single beam (in particular at injection) or to inject into one ring while the other is not ready (vacuum…), it was felt that this point requires further study.