Machine Protection Working Group

Minutes of the 62nd meeting, held 29th January 2007

Present: B. Todd, A. Gomez-Alonso, P. Pugnat, B. Goddard, J. Wenninger, D. Peters, J. Blanco,
F. Szoncso, L. Ponce, B. Dehning, D. Bocian, M. Sapinski, M. Zerlauth, B. Puccio, L. Serio,
J. Uythoven, E. Bravin, A. Castañeda, R. Schmidt, S. Le Naour, R. Assmann.

Meeting Agenda:

- Interlocking LHC Screens [BG]
- Secure Configuration of the Powering Interlock Controller [JB]
- Current Decay After A Quench [PP]

There were no comments or additions to the previous minutes.

Interlocking LHC Screens [BG]

B. Goddard made a presentation regarding the interlocking of LHC screens. **B. Goddard** explained that there are six screens in the beam dump lines for observation of extracted beam, and there are 13 screens for injection, for matching and steering. Screens come in two different types, 12 micron Titanium (Ti) and 1 mm Aluminium (AL_2O_3),. **B. Goddard** continued by describing the maximum allowed proton density limits of these different materials, the values are given without safety margin.

Ti	1x10^{12} p^+/cm^2 - circulating beam 1x10^{16} p^+/cm^2 - single shot
AL_2O_3	Not to be used with circulating beam 1x10^{15} p^+/cm^2 - single shot

B. Goddard then continued by showing some sample calculations for the maximum bunch intensity for the screens in various scenarios from one bunch to 2808 bunches, and from injection energy through to collision energy. Calculations show that none of the screens will be damaged by a single passage of 3x10^{12} protons at 7 TeV, corresponding to 17 standard bunches.

B. Goddard proposed that these results be used to define several conditions for interlocking the beam screens. Firstly it is proposed that the screens should not be allowed to move when beam is in the machine, a signal such as the Beam Presence Flag could be used to interlock the beam screens at the front end. **R. Schmidt** suggested that the Beam Permit Flag could be used as a basis for the interlock, as the Beam Presence Flag available in the LHC timing is not sent on a regular basis, and is not to be considered a Safe Machine Parameter. **J. Wenninger** proposed that the Safe Beam Flag may be a candidate for this interlock. **E. Bravin** noted that whichever signal is selected, in the final implementation a software comparison will be made, by asserting an inhibit-bit in the front-end, this is provided that sufficient resources are available in the controller FPGA. **E. Bravin** explained that the logic is simple: interlock if the screen starts moving, inhibit screen movement if beam is in the machine.

The second proposal is for explicit checks to be made by the sequencer prior to injection, ensuring that the screen positions are coherent with the proposed fill intensity and energy. **B. Goddard** noted that this implies a pre-definition of the mission expectation.

The third requirement is that once the machine mission is started a software interlock must observe the screen positions and force a beam dump if safe conditions are violated.

B. Goddard explained that the sequencer should check for safe conditions before the mission and the software interlock should enforce the conditions during the mission. **J. Wenninger** suggested that the set-up of the interlock be tailored so that an abort during the ramp is avoided.

B. Goddard continued by describing the limitations to inject and dump mode due to the screen damage levels. For example, screens can be used to set-up the injection, and aperture measurements in the injection and extraction channel.

B. Goddard explained that during the injection-setup the beam should be dumped after less than one full turn, this ensures that the screens only see a single event. To enable this fast response a dedicated hardware system will trigger the beam dump via the Beam Interlock System. To protect the screens against damage in other cases the maximum number of turns has to be strictly limited, and the beam must be safe. **B. Goddard** detailed that the maximum number of turns allowed with safe beam is ~100 for titanium screens and ~10 for aluminium screens. Around 1000 turns is allowed with a pilot beam, these figures have a considerable safety margin. **E. Bravia** noted that hardware counters were already foreseen in the beam screen front-ends that are designed to provide the turns based interlock. **B. Goddard** suggested that a higher-level approach may be more beneficial, avoiding the need to reconfigure many front-ends on an ad-hoc basis.

Action: Clarify the relationship between possible turn-counting in screen front-ends and the inject & dump controller – [BG et al.]

To add redundancy to the protection, a timing event will be used to break the beam permit a few milliseconds after the request number of turns. **B. Todd** explained that the permit loop generators have dedicated external 'start' and 'stop' trigger inputs for this function. **J. Wenninger** added that the LHC Safe Beam Flag will be forced false before injection of high intensity beam, to ensure injection is inhibited if some 'maskable' LHC systems are not ready.

Action: Clarify whether the systematic forcing of the safe beam flag false before injection has to be conditioned by the SPS intensity – and how – [JW et al.]

B. Goddard concluded that hardware based interlocks could be foreseen by using Beam Loss Monitors at each screen, with an appropriate integration time to dump the beam if losses above threshold are experienced. **J. Wenninger** said that in the CNGS the losses associated with the beam screen were not always local to the screen, they could appear further downstream. **Various Members** agreed that simulations were needed to show where beam losses would occur.

Action: Determine whether BLMs could be used as a direct hardware interlock for losses at screens – [BD]

Secure Configuration of the Powering Interlock Controller [JB]

J. Blanco made a presentation describing the steps taken to make a secure configuration of the Powering Interlock Controller (PIC). **J. Blanco** explained that there are 28 independent powering sub sectors in the LHC, with 36 PICs, installed in 33 racks. The aims of the PIC configuration protection are to ensure that the configuration and version information for each PLC is coherent and that changes to configuration can be made without affecting the hardware layout.

In case of a failure in the powering system, a beam dump is requested. If an electrical circuit is defined as essential, the beams will always be dumped. If an electrical circuit is defined as auxiliary, the beams will be dumped if the input to the Beam Interlock System is not masked, or the Safe Beam Flag is FALSE. For failures in the Auxiliary Circuits, only the PLC requests a beam dump. For Essential Circuits the beams are dumped via a signal from the PLC as well as via a signal from a CPLD Matrix - this provides redundancy, and significantly decreases the response time.

J. Blanco continued to describe that the configuration data is needed at three levels, and that five specific values of version and configuration information are required for the PLC and its associated Matrix:

SCADA	Requires all the information regarding the current configuration of the PLC and the Matrix. This is compared to the Database files.
Matrix	1. Requires a configuration which describes the connection of essential circuits. 2. Has a Matrix hardware version number.
PLC	3. Requires a ‘hardware’ configuration which describes the PLC I/O structure and the essential versus auxiliary circuit partition. 4. Has a ‘software’ code that is executed by the PLC. 5. Has a PLC hardware version number.

All of the configuration and code files have a CRC calculated and appended to them, these values are then used as a unique identifier for the files being used.

J. Blanco explained that the verification of the configuration is carried out using a simple process: The supervision software contains the expected values of all of the parts of the configuration; the actual values from the hardware are read-back and confirmed in the PVSS. **J. Blanco** described that the verification is carried out every time a PIC screen is opened in the PVSS application. In addition to this, every time a ‘give permit’ command is given, the three PLC related values are verified and every time a ‘give permit all’ command is given the three PLC and two Matrix related parameters are checked. If there is any discrepancy then the command is not carried out.

B. Dehning asked whether there was any intention to check the PLC program for Single Event Upsets, **M. Zerlauth** and **J. Blanco** explained that the configuration files don’t contain individual signals, and that the active read-back and comparison of the PLC program would be difficult considering the data involved. It isn’t foreseen as part of the process.

J. Wenninger queried whether it would be foreseen to actively regenerate the file CRC values, to detect any corruption during code download. **J. Blanco** said this would not be required as there are low-level mechanisms within the Profibus and data transfers that prevent this from happening.

J. Blanco then continued by describing that CVS is being used as a code repository and versioning system for the complete configuration data for all of the Powering Interlock Controllers. These files are validated during hardware commissioning, ensuring that the functionality described matches that which is required.

J. Blanco then continued by describing some failure cases, maintenance procedures and changes of operational parameters involving the configuration files. **R. Assmann** asked whether switching a circuit from essential to auxiliary was possible, **M. Zerlauth** stated that it was, but system experts would be the only ones with the know-how to do this.

J. Blanco concluded by saying that an engineering specification of the configuration management is in the process of being prepared and would be released to interested parties in the near future.

Current Decay After a Quench [PP]

P. Pugnat made a presentation regarding the expected magnet current decay of both MB and MQ magnets following a quench. **P. Pugnat** began by showing the time response determined by previous studies, with the time from quench to successful removal of circulating beam of typically 15ms.
P. Pugnat described that the decaying magnet field can produce a considerable kick on the beam that could mean 15ms is too long in case of fast magnet quenches.

When a magnet is detected as quenched, the magnet power supply is switched off; at this point the current decay is governed by the growing magnet resistance and the magnet inductance. At the same time quench heaters are fired to force more of the magnet to quench and to limit the maximum temperature in the magnet, this heating can take 20-120ms to propagate and start to become effective. To a first order approximation the magnet inductance can be considered as being time independent. For the two types of magnets that have been considered the inductance is: L(MB) = 110mH, L(MQ/2) = 5.6mH. MQ inductance is divided by two due to the fact that only one aperture must be considered.

P. Pugnat continued to describe that two factors play a major role in the magnet resistance increase during a quench:

1. The Residual Resistive Ratio (RRR), which is the ratio of the resistance of the stabilising copper conductor at 300K versus 10K, a lower RRR will make the current decay faster. It has been measured in LHC dipole magnets that the characteristic time corresponding to a current decay of 1‰ increases from 34 to 54 ms for a change of the RRR from 70 to 300.
2. The energy deposited during the quench and the volume that is quenched contribute both to the resistance increase and then to the current decay. Depending of the deposited energy, this can lead to a much larger change of time constants compared to the RRR effect.

P. Pugnat showed calculations made from experimental results, after change in current of 1‰ a corresponding dipole kick of 5.1 µrad and closed orbit deviation of 0.6mm could be expected. In the MB a change in current of 0.1‰ occurs after about 25ms, which is around the time which the heater could be expected to become effective. Experiments showed that the values for MQ magnets are roughly one order of magnitude faster as expected by the difference of inductances**.** Considering that the beam will be removed from the machine after just 15ms, this timescale is considered acceptable for 'slow' quenches, but 'fast' quenches due to beam losses have also to be considered.

P. Pugnat continued by citing experience from other High Energy Physics labs, starting with TEVATRON at Fermilab. At Fermilab, the duration between quench detection and the beam abort is the same as the one foreseen for the LHC. However, Fermilab have also experienced events that correspond to 'fast' quenches where the orbit was displaced only 2ms after the quench. This happened several times and was attributed once to a Roman pot which was accidentally driven into the beam leading to large beam losses. Fermilab did not use BLMs and relied on the QPS detection to protect the machine. Therefore they had to re-define their Quench Protection System detection parameters to react to this new category of quenches, by decreasing the detection time to 1-2ms instead of 16ms.

HERA at DESY has also recorded over 200 quench events, around two-thirds of which occurred within a timescale of around 5ms. The losses were due to failures of normal conducting magnets that led to a very fast magnet current decay. The BLMs at HERA have an integration window of 5ms and could not detect the failure in time and dump the beam. The quenches stemming from such beam losses could also be considered as 'fast' quenches.

P. Pugnat concluded that fast / massive beam losses resulting in 'fast' quenches will result in serious problems if Beam Loss Monitors do not react correctly. This could be countered by a change in strategy for the QPS, by increasing the sensitivity trading off availability of the machine, possibly starting with a short window for the quench validation time and increasing it progressively as understanding of the machine improves.

P. Pugnat also noted that further studies should consider the effect of the inductance change in case of fast quenches, as the current decay will further accelerated with a decrease of the inductance.

Various Members discussed the implications of these findings. **R. Schmidt** noted that this gives further emphasis to the use of sector tests and beam experiments to valid characteristics that can only be accurately realised in the machine environment. Other questions to be addressed are:

- What mechanisms could produce fast quenches and what beam loss is required?
- Is it possible that the BLM system would not detect such beam losses redundantly (e.g. by several BLMs)?
- What magnets are mostly exposed?
- Are there other redundant detection mechanisms (using Fast beam position change monitor, fast beam current decay monitor, ...) if detection by QPS is too slow?

Action: Study what could be done to decrease the time response of the QPS system, with a preliminary report to the MPWG in April 2007.

AOB

Next Meeting
Meeting 63, proposed 5th March, TBC.

BT