Machine Protection Working Group

Minutes of the 54th meeting, held 17th February 2006

Present: B. Dehning, B. Goddard, R. Hall-Wilton, C. Ilgner, V. Kain, A. Koschik, D. Macina, V. Montabonnet, L. Ponce, B. Puccio, R. Schmidt, L. Serio, R. Steinhagen, M. Stockner, B. Todd, J. Uythoven, J. Wenninger

Meeting Agenda:
- Positioning of LHC BLMs [L. Ponce]
- Update on Software Interlock System [J. Wenninger]
- Interface between the Cryogenics System, the Powering, and Beam Interlock System [L. Serio]
- AOB [J. Wenninger]:
  1. Transfer Line Interlock System
  2. TOTEM Movement Inhibit

Positioning of LHC BLMs [L. Ponce]
In her presentation, **L. Ponce** discuss the results, strategies and guidelines for the positioning of the Beam Loss Monitors (BLMs) in the LHC (see slides for details).

The analysis of optimal locations for BLMs is subdivided into three steps:
1. Identification of likely loss locations based on beam dynamics and cleaning in the LHC. Data supplied by the collimation team: R. Assmann et al.
2. Simulation of the secondary shower created at the primary impact location to identify the likely local shower maxima outside the magnet's cryostat (using GEANT3, L. Ponce).
3. Simulation of the detector response of the spectra registered in the left and right detector (GEANT4, M. Stockner)

The BLM location analysis is based on samples of 500 protons per loss location. As a initial working assumption, the protons are considered as mono-chromatic and with an impact angle of 0.25 mrad. The analysis shows that generally two shower maxima are expected: The first about 1 m behind the location of the primary impact and the second after the first magnet free region. The later location may be explained by the fact that the secondary particles can propagate freely in this region and are intercepted due to the change of aperture with respect to the next magnet. The simulated losses are about a factor two higher for main quadrupoles (MQ) with respect to losses inside the main dipole (MB) magnets. Consequently, the quadrupoles are primarily equipped with BLMs.

The angle of 0.25 mrad is considered to be the most likely impact angle for primary particle loss. The sensitivity with respect to the impact angle has been studied and it has been found that a changing impact angle rather affects the amplitude than the location of the observed shower maximum. For small angles, a doubling of the impact angle causes the maximum shower amplitude to change by about 20%. An additional uncertainty may arises due to the transverse position of the primary impact inside the vacuum chamber. A loss in the 'top' and 'innermost' part of the chamber result in an about 40% smaller amplitude with respect to losses in the 'outermost' part. Top and innermost differ by only about 10%.

The main topology of the loss pattern in the main quadrupoles seem to be understood and relates to the aperture change in the transition between magnets and maximum beam size inside the magnet. However, more detailed analysis require higher statistics of the primary impact location (presently based on 500 protons).

The general guideline for BLM positioning is driven by the optimisation constraints of measuring the likely losses caused by magnets transitions and beam size in the quadrupole centres, the minimisation of the uncertainty on the ratio between deposited energy inside the magnet coils versus by the BLM measured energy and discrimination of Beam 1 and Beam 2 losses.
Based on these constraints, each main quadrupole will be equipped with three BLMs for each beam. As a consequence of above likely loss locations, the first BLM will be placed about 1 m behind the MB-MQ transition, the second about 0.5 m behind the MQ centre and the third about 1 m behind the MQ-MB transition (see also MPWG minutes #41).

The presented BLM positioning scheme shows a good discrimination of a about a factor 10 between Beam 1 and Beam 2 losses and seem to be well suited for the arc and dispersion suppressor regions. However, due to mechanical integration limitations arising due to for example the hydrostatic levelling system and magnet supports, the ideal BLM location is in certain cases compromised and has on a individual per magnet basis to be shifted to the next possible mechanical locations. The BLMs will be fixed with stainless steel stripes to the magnets.

The study of an imperfect LHC cleaning system with a simple orbit error scenario revealed new loss location that need additional BLM coverage (e.g. MB.C13R7). In first order, the ion loss locations seem to be similar as for protons. However, due to for example the electron capture by pair production, an additional likely loss location in MB.B10.R2 has been identified and need additional BLM coverage. Due to the ongoing BLM integration, further studies should be provided soon in case additional BLM coverage of special magnets is required.

First results on the correlation between the energy deposition in the coil versus energy deposition outside the magnet seem to be qualitatively reasonable. The analysis does not include the BLM efficiency yet. In contrast to the other analysis that only accounts for particles that left the magnets and that were done using 500 protons, this analysis is presently limited to 10 impacting primary protons due to the numerical tracking limitations of GEANT3 of the secondary particles in the magnets' coil. The numeric limitation arises due to the large ratio between the secondary particles that are tracked and absorbed in the coils and the actual escaping shower particles. The ratio exceeds about two orders of magnitudes. It is evident, that for a more precise quantitative analysis including rare particle production and their absorption inside the magnet, a higher statistics of primary impacting protons are needed. Hence, **L. Ponce** stresses that in order to overcome these shortages a migration of the used analysis code to GEANT4 is needed. The migration is presently paused by the available magnet descriptions that need to be updated or potentially recreated due to incompatibilities between GEANT3, GEANT4 and other equivalent tools.

The BLM positioning scheme for the arc and dispersion suppressors is well established and consists of three BLMs per quadrupole and per beam. The BLM locations in the insertions regions are being finalised and based on similar rules as for the arcs.
Additional loss location have been identified while studying simple cases of an imperfect collimation system and ion operation. The presented analysis are based on predictions Beam 1 loss location that have been mapped to suit the positioning of BLMs for Beam 2. However, a detailed analysis and

verification of the loss locations for Beam 2 would be favourable. Further, for a better prediction of the coil versus BLM energy deposition ratio a higher statistics of primary protons would be needed.

Interface between the Croygenics System, the Powering, and Beam Interlock System [L. Serio]
L. Serio presents the cryogenics interface with the Powering and Beam Interlock System (see slides for details). In his presentation, he introduces and assesses strategies that use the cryogenics permit to issue a beam dump and energy extraction in case of failures of the Cryogenic System in order to early capture and to prevent quenches.

The Cryogenics-System, segmented according to the machine layout, is one of the largest systems covering about 25 km of the LHC circumference. It consists of more than about 3000 control loops required for controlling the temperature of power converters, magnets, beam screens and the Cryo-System itself. It is closely entangled with magnet and beam operation through various interdependencies.
The LHC cryogenic system issues a permit connected to the Powering Interlock System (PIC) that is required prior to powering the superconducting magnets. Though a fault of the Cryogenics System may cause a magnet to quench or a pressure rise in the vacuum chamber and thus indirectly cause a beam abort, the Cryogenics System does presently not have a direct input to the Beam Interlock Controller (BIC) nor another possibility to directly dump the beam.

The present surveillance of the Cryo-System includes the monitoring of

- the temperature of the superconducting magnets, beam screens, helium transfer lines, their liquid helium level and the pressure of the quench tanks (empty/filled),
- the DFB's boxes and relevant parameters such as the minimum required liquid helium level and current lead temperature,
- the temperature of the superconducting links (DSLs),
- the liquid helium level inside the LHC RF tanks,
- the state of the eight refrigerator plants and
- the state of Ethernet (Technical Network) communications.

The above monitored systems need to satisfy individually given thresholds prior to give a powering permit ('CRYO OK') for the magnets. It is important to note, though the Cryo-System gives the required permit prior to powering of the magnets, an absence of the Cryo-Permit during operation does (presently) not necessarily dump the beam.

The motivation of connecting the Cryogenics System is driven by the possibility of a un-manned cryogenic operation and the recovery time that can be larger in case of a quench than if the machine is pre-aborted in a controlled way.

From the Cryogenic System point of view, the minimum recovery time is given by the available cooling power of the system.
The required recovery time is about 2 hours after a fast magnet ramp down from 7 TeV. In case of a quench, depending on the operational magnet current and number of elements quenched, the recovery time is at least about one hour and can be as large as about 48 hours. For example: If the main dipole current is below 3 kA, the system could recover within one hour for one to three quenched cells. For intermediate currents between 3 kA and 9 kA the recovery time is within two and about three hours depending on whether one or up to three cells quenched. For nominal currents the required recovery times are about 4.5 to 6.5 hours.

It is important to note, that in principle the LHC could run for several minutes in case the Croyogenic System's permit conditions are not met. An 'CRYO OK' does not protect equipment but ensures a ensures that the required conditions are met prior to powering the magnets. In the absence of the Cryo-Permit the machine could run up to several minutes.
However, it is clear that it may be favourable to use the additional input of the Cryogenics System and to pre-abort the beam and to discharge the magnets in a controlled way in order to minimise the maximum required recovery time.

L. Serio presents three possibilities of how the Cryogenics surveillance could be used to issue a pre-warning and to pre-abort the beam in order to avoid quenches:

1. The Cryo-Permit is used as an indication that is authorised by an operator prior to an initiation of a beam abort and energy extraction. This may maximise the machine availability but is not an anticipatory measures for quench prevention and could lead to recovery times of the Cryo-Systems of about 5 hours in certain quench cases.
2. The Cryo-Permit may be used to slowly discharge the magnets in case the temperature and liquid helium surveillance shows an exceeding of tolerances. This scheme is likely to avoid quenches and minimises the quench recovery to few minutes. However, though majority voting of sensors is used to minimise the impact of single sensor failure onto the availability, this scheme may still possibly increase the unavailability the machine due to false triggers.
3. The Cryo-Permit may be used for a fast discharge the magnets. In contrast to the second option this scheme will capture more likely potential quenches on the expense of a minimum recovery time of about two hours but similar to case 2 may also increase the machine unavailability due to false triggers.

The advantage of the second and third proposal is that it could be used for an un-manned cryogenic operation and free operators for other tasks on the expense of additional down-time due to false triggers.

L. Serio proposes that for hardware commissioning the first option, the operator authorised power discharge in case the 'CRYO OK' is withdrawn, and to move to the second or third option once a reliable operation of the Cryogenic System is established and the false triggers of sensors is minimised.

The common opinion of the present MPWG members is that the schemes seem to be sound. Further studies are required.
ACTION: L. Serio, R. Schmidt

Update on Software Interlock System [J. Wenninger]
J. Wenninger presents the status of the Software Interlock System (SIS) that will stepwise replace the SPS SIS and finally be used for he LHC (see slides for details). The schematic layout of the SIS has been presented during the MPWG meeting #49 held earlier.

The present SIS implements a logical tree with a configurable number of branching levels and branching knots and a data acquisition layer in the lowermost part of the tree.

The data acquisition from the concerned equipment systems is encapsulated in Individual Software Interlock Channels (ISICs). Their state is typically checked once per cycle, potentially to up to about a Hz. Their logical signal passed to the first next higher branching level.
The branching knots in the upper part of the tree consists of Logical Signal Interlock Channel (LSIC).

Each LSIC implements a specific interlock logic using the input of the lower branches that have to be met and passes its result to higher branches. Based on the final condition of the uppermost branch, an interlock signals will be issued. The state of all LSIC state may be re-evaluated synchronously at approximately one Hz.
The first SIS prototype, including user interfaces, has been finished.
For an optimum exploitation of the pre-accelerator chain, the SIS will use the general machine timing system to stop individual beams. The interlocked beams are matched to the following geographical destinations:

- FTARGET
- CNGS
- LHC1-TI2
- LHC2-TI8
- SPS_DUMP (not extracted, internal SPS dump)

The SIS is using the software input of the hardware Beam Interlock Controller (BIC) of each of the interlocked destinations to remove the BEAM_PERMIT that is send to the extraction, injection or dump kickers. It is foreseen to monitor the status of this software input link through a 'watchdog' mechanism inside the BIC front-end itself.

The SIS needs a synchronisation to SPS machine events in order to access beam instrumentation and for data integrity and update checks. This synchronisation could be implemented either using a dedicated timing card (CTRI) inside the SIS front-end computer or through software signals relayed from somewhere else. For reliability reasons, **J. Wenninger** proposes to use a dedicated timing card for the SIS as been already foreseen for the orbit, tune, chromaticity and other beam-based feedback controllers. The present MPWG members support the use of a dedicated timing card for the SIS.
ACTION: V. Baggiolini, CO-Timing, CO-IN

Am extended version of the SPS SIS is foreseen for the CNGS tests and the TI8 this years and later the LHC sector tests.

AOB:

Hardware interlock buttons for the SPS BICs [J. Wenninger]:
Buttons with a direct hardware links to the SPS BICs and to the machine timing system to inhibit the production of given beams are being installed in the SPS island (see MPWG meeting #49 for details). There is one button to dump the beam in the SPS, one button to inhibit extraction from LSS4 and one button to inhibit extraction from LSS6.
The following list of buttons is used to inhibit the production of the specific beams in the pre-injector complex using the timing system:

- Inhibit all beams
- Proton inhibit
- Ion inhibit
- MD beam inhibit (inhibit all beams marked as MD beams)
- Inhibit beams with destination SPS_DUMP
- Inhibit beams with destination FTARGET
- Inhibit beams with destination CNGS
- Inhibit beams with destination LHC1-TI2
- Inhibit beams with destination LHC2-TI8

Transfer Line Interlock Test Specification [J. Wenninger]:
J. Wenninger has prepared a preliminary version of the specification of the proposed interlock tests for transfer line and send out for comments. The next advanced draft is foreseen to be circulated in the beginning of March.

List of in the SPS transfer lines interlocked equipment [J. Wenninger]:
J. Wenninger compiled a list of presently interlocked equipment in the transfer lines and inquires whether a formal approval is required or simple publishing of this document would be sufficient. The list encompasses about 464 devices plus some warm interlocked magnets (WIC), girders, septum magnets and kicker surveillance.

TOTEM Movement Inhibit [J. Wenninger]:
The TOTEM experiment requested an inhibit of Roman Pot movements by operators during data-taking while 'stable beams' is declared.

Follow-up of last LEMIC meeting [D. Macina]:
The CMS experiment is in favour for a software solution for the interlock implementing the inhibit of injections into the LHC. **D. Macina** points out, that in case a hardware based solution would be requested, a proposal would be needed soon.

It was decided not to mix the TOTEM and CMS beam permit signals. Additional inputs (BIC crates) will be provided.

Next Meeting: 17th of March, 10:00, 866-2-D05
Agenda:

- Analysis of thunderstorms (M. Zerlauth)
- BLM settings (C. Zamantzas)
- AOB:
    - Collaboration with ETH-Zürich

Minutes submitted 9th of March, 2006
<u>Happy Birthday MPWG!</u>