Machine Protection Working Group

Minutes of the 53rd meeting, held 16th December 2005

Present: R. Steinhagen, J. Wenninger, E. Carlier, J. Uythoven, V. Montabonnet, A. Antoine, B. Goddard, R. Giachino, M. Lamont, B. Todd

Meeting Agenda:

- Closed Orbit and Protection [RSt]
- Triggering and re-triggering of the LBDS [EC]
- Direct IR6 Beam Dump Trigger [BG]

J. Wenninger began the meeting; there were no comments or additions to the previous minutes.

Closed Orbit and Protection [RSt]

R. Steinhagen made a presentation describing the results of a study, showing the possible impact of the Machine Closed Orbit on the Protection of the LHC. The Machine Closed Orbit is a single stable trajectory that particles can follow around each revolution of the machine; **R. Steinhagen** described how all *fast failures* of the LHC occur around a Closed Orbit. Worst case beam characteristics were chosen as a basis of the study, having the machine at Injection Energy of 450GeV, with a β of around 180 m, at this energy assuming nominal emittance gives a beam 3σ of around 3.42 mm.

R. Steinhagen described how closed orbit drifts alone are unlikely to damage the machine, as these are slow effects, which can be caught by beam loss monitors, however if a closed orbit drift is combined with another failure then the machine may be damaged in certain circumstances. An example of this is a local orbit bump combined with a fast failure, where a bump can be large enough to compromise the passive protection systems of the LHC, such as the beam absorbers or the collimators.

R. Steinhagen then continued to describe two methods to determine the aperture of the machine around the Closed Orbit.

The first method is to use the transverse dampers or Qmeter-kicker to increase the emittance of the beam until the point is reached where the edge of the beam touches an aperture limitation. At this point the ratio of the blown-up beam to the injected beam may be determined for example from the synchrotron light monitor, and the machine aperture can be determined. If this is $> 6.7\sigma$ then the closed orbit is safe, if this is lower, then the closed orbit is unsafe. This method is destructive in a sense, as the beam cannot be recovered from the blown-up condition. This method also tests the dynamic aperture of the beam, as the beam is uniformly blown-up and exposed to higher order magnetic effects, potentially reaching the dynamic limitations before the mechanical if the dynamic aperture is smaller than the mechanical aperture

The second method involves using the COD magnets to slowly adjust the Closed Orbit of the machine such that the edge of the beam reaches 6.7σ. If the observed beam losses are below a predefined threshold during this transition then the Closed Orbit is safe, if the BLM threshold triggers a beam-dump before reaching the 6.7σ value then the Closed Orbit is unsafe. This method requires in addition a measurement of the beam emittance, since the closed orbit amplitude that may be reached depends on beam size as well as on beam tails that may slightly vary from fill to fill. This method has the disadvantage of taking many 10s of second, but does physically measure the Mechanical Aperture, and allows the beam to be almost restored to its original state.

B. Goddard questioned whether the Aperture kicker could be used as a basis for the measurement of the Aperture, **R. Steinhagen** and **J. Wenninger** stated that the methods described here are far safer to perform. **R. Steinhagen** continued by saying that the use of an Aperture Scan should be limited to only when it is definitely required, when the beam Closed Orbit exceeds a predefined window, as the Aperture Scan takes a relatively long time and requires exclusive use of the machine. **R. Steinhagen** then described two different methods to determine whether an Aperture Scan is needed.

The first method uses the Beam Position Monitors, where the results of an initial Aperture Scan are used to determine correct Beam Position Monitor reference readings. During machine operation the measured value of position is compared to the reference values and an Aperture Scan is ordered if a potential Orbit Bump is detected.
The second method uses the COD magnets in a similar manner, an initial Aperture Scan is performed, and the results used to provide current reference values for the CODs, If these current values are exceeded during machine operation, then a potential Orbit Bump exists and an Aperture Scan is ordered. The tolerance of the actual value of COD current versus the expected value of COD current needs to be well defined, as the Orbit Feedback Controller uses the CODs to control the Closed Orbit and natural effects may cause a shift in this applied correction.

R. Steinhagen then continued to describe these natural effects, showing that the reproducibility of the Closed Orbit is around 1.1σ. **R. Steinhagen** then presented simple scenarios requiring an Aperture Scan: For example, if the Collimation Protection Aperture plus the natural effects is less than the Mechanical Aperture then a potential Orbit Bump exists.

R. Steinhagen then described how COD magnets could be a cause of orbit bumps, as a change of only 0.5A in a suitable pair of MCB may create an orbit bump of 1σ. It was also note that the current thresholds of the COD magnets needs to scale during the Energy Ramp of the machine, and during the β^* Squeezing, it then becomes much more difficult to separate correct COD magnet current changes from those causing Orbit Bumps. A preliminary conclusion from this is that Orbit manipulations up to 0.8σ seem to be safe within the machine's limitation, although this needs to be checked during LHC Startup.

R. Steinhagen then continued to describe the results of a study directed at the LHC Orbit Feedback Controller, as it was suspected that this could be a source of Orbit Bumps, essentially the OFC is designed to *avoid the creation* of local Orbit Bumps. **R. Steinhagen** showed the results of LHC BPM tests in SPS, where it was shown that the most likely failure of the BPM is to give no value for Beam Position, affecting the correction minimally. Spikes *have* also been observed. The OFC is tolerant of these BPM and COD failures it does this by double sampling at the BPM, and sanitising the BPM output value. For Example, if the BPM records the beam position as outside of the machine's Mechanical Aperture the result is obviously incorrect, results are also suspect if a large deflection is reported by the BPM from one sample to the next.

R. Steinhagen described the function of the OFC, where the correction to be applied to the CODs is determined by a Singular Value Decomposition algorithm. The number of Eigenvalues derived by the SVD algorithm determines the characteristics of the overall correction applied, small Eigenvalues correspond to local bumps, whereas large Eigenvalues to global structures. Performing corrections with a large number of Eigenvalues make the system more sensitive to errors in the BPMs. A trade-off has to be determined for those corrections which are accepted to prevent single BPM failures from causing too much disturbance in the OFC. The propagation of a single BPM failure onto the beam (yielding a small local bump ≈ "worst case") is expected to be less than 0.4 σ and the propagation of white (random) noise off all BPMs to be less than 0.02 σ.

J. Wenninger commented that the same process will be used in LHC as was used in LEP, where any suspicious BPM readings resulted in the questionable BPM not being used for analysis. He pointed out, using a 3 σ rejection criteria (see slides), it will be difficult to identify erroneous BPMs that are off by less than 3 mm w.r.t. their reference in the presence of a for example moderate global orbit r.m.s. of 1 mm. Ensuring that the system can adapt requires a very flexible implementation.

Triggering and Re-triggering of the LBDS [EC]

E. Carlier made a presentation introducing the trigger mechanism of the LBDS. Redundancy is heavily employed by the system to ensure that safety is maintained, the High Voltage generators are redundant as well as the trigger systems. The system is completely safe even when a HV Generator is missing, however, if a HV generator spuriously triggers, then the resulting Beam Dump is asynchronous to the abort gap and can result in machine damage, for example if the TCDQ absorber is not correctly set. **J. Wenninger** questioned whether the beam was dumped automatically following a failure in a Power Triggering Unit, **E. Carlier** clarified that it wasn't, the failure will be alerted to the machine operators. **J. Uytoven** clarified that this was not critical for the safety of the LBDS, as the triggers are redundant, and a 14 out of 15 arrangement is needed for the LBDS, a double failure is required in two systems before an unsafe state would be reached.

E. Carlier continued describing the fail-safe and fault tolerant approaches used in the rest of the LBDS. The inputs to the LBDS were then listed and the Central Beam and Cycle Manager was listed as a potential client for "Inject and Dump" mode. **Various Members** questioned whether the CBCM would be used for this, and what the requirements of Inject and Dump are. **B. Goddard** questioned whether the Inject and Dump warranted a full Post Mortem evaluation, which could take some time.

J. Wenninger and **J. Uythoven** clarified that the Post Mortem information should still be taken even if it is not to be fully evaluated every time. **E. Carlier** reminded members of the potential problem of a loss of power in the CCC. **Various Members** noted that this would result in an automatic beam-dump due to a loss of power in the CCC Beam Interlock Controller.

Action: Determine the Mechanism to Operate the LBDS in "Inject and Dump" Mode [BG, EC et al]

E. Carlier continued by describing the interface of the Beam Interlock System to the LBDS, where the presence of a 10MHz frequency was initially used to describe the BEAM_PERMIT of the LHC. **E. Carlier** noted that this was recently changed to a more robust surveillance of the 10MHz.

B. Goddard questioned why this was necessary. **B. Todd** replied that since the LBDS now integrates with the Beam Interlock System at such a low level it cannot be excluded that the 10MHz erroneously becomes more than 10MHz. **B. Todd** clarified that laboratory testing has shown that excessive attenuation within the fibre optic loops can lead to spurious outputs from receiver modules, generating a white noise that needs to be detected. **Various Members** of the group questioned the specification of the frequency detection. **B. Todd** said it was yet to be written.

Action: Write Specification for BIS to LBDS Interface [EC, BG, BP, BT et al]

E. Carlier continued the description of the LBDS, showing that a redundant pair of Trigger Synchronisation Units is used to trigger four trigger channels, in a *one out of four* arrangement, where an activation of any single channel will result in a Beam Dump being triggered.

E. Carlier then briefly described the re-triggering structure of the LBDS where either a spurious trip of any of the 14 triggering circuits is propagated to the remaining circuits, and where a loss of the Abort Gap Synchronisation automatically results in the triggering of the Beam Dump, using the timing of the Phase Locked Loop as it was for the previously detected abort gap. **E. Carlier** concluded by reiterating that the BIS interface with the LBDS, and the LBDS arming procedure were the key points of concern.

Various Members questioned what the preferred method of implementing the "Inject and Dump" mechanism was, **E. Carlier** pointed out that LHC timing is available in a rack, but care should be taken in generating an "Inject and Dump" event, as it should be sure that the CTG never spuriously gives this telegram.

Direct IR6 Beam Dump Trigger [BG]

B. Goddard made a presentation showing intended implementation of a direct link from a special Beam Loss Monitor in IR6 to the LBDS. This work stems as a result of the work by the Machine Protection Review in April 2005, where it was suggested that a dedicated link be setup to the LBDS from a special Beam Loss Monitor. **B. Goddard** explained that a small study had shown that a modified SPS Beam Loss Monitor could be used, with fixed thresholds well above expected values, and without tracking the LHC Beam Energy.

B. Goddard continued by describing that the foreseen implementation is four BLMs, and a single crate interfacing via a current loop to the LDBS, this is intended to trigger a Beam Dump in the case of a failure in the link from BIS to LBDS. It was requested that the MPWG verify this approach.

Action: Ratify BLM to LBDS direct link [MPWG]

AOB

J. Wenninger relayed a message from **B. Puccio**, asking whether the Interlocking of TI8 foreseen for Spring 2006 requires two interlock channels for the Beam Loss Monitors situated around the TED.

Various Members said it should make little difference, at the BLM after the TED should still see a particle shower. B. Goddard offered to verify this with data taken in the TI8 test in 2004.

Action: Verify that the BLM Interlock Channels Anticipated for TI8 2006 are Satisfactory [BG]

Next Meeting

Friday 17th February 2006 at 10:00 in room 866-2-D05

BT