Review on machine protection and interlocks, 11 April 2005 – 13 April 2005

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1. Introduction to the LHC accelerator, the layout and its parameters – R.Bailey

For participants not familiar with the LHC, this presentation aims to provide an introduction to the machine and plans for start-up. Following a brief overall description of the accelerator, some details are given on the composition of the arcs and the insertion regions. After a look at the operational cycle, performance goals and associated parameters are presented. Finally, the present strategy for commissioning the machine to attain these goals is given.

2. Introduction to magnet powering and protection - R.Denz

After a short introduction to the powering schemes for LHC superconducting elements, the implementation of the related quench protection and energy extraction systems will be presented. The protection of LHC main magnets and circuits, the corrector circuits as well as the protection of the HTS current leads will be explained. In addition there will be a few remarks on the interfaces to the Machine Interlock System and the control and supervision of these systems. Finally some ideas for the test and hardware commissioning will be discussed.

3. Introduction to the review - L.Evans

4. Protection of the LHC – R.Schmidt

The energy stored in the LHC beams is unprecedented threatening to damage accelerator equipment in case of uncontrolled beam loss. Safe operation of the LHC requires correct operation of several systems: collimators and beam absorbers, beam dumping system, beam monitoring, beam interlocks, quench protection system and powering interlocks, etc. The time constants for failures leading to beam loss extend from some μs to few seconds. Failures during injection and extraction are prevented by interlocks and beam dilutors. When operating with circulating beam, it is essential to detect any unsafe situation and to properly extract the beam onto the dump blocks that are the only elements of the LHC that can withstand the impact of the full beam. The overall strategy of the LHC machine protection is discussed. The functionality of the systems with respect to machine protection is presented. Main emphasis is on the interfaces between these systems.

5. The role of the collimation system in protecting the aperture – R.Assmann

The LHC aperture is quite tight and must be well protected against beam loss, both from the beam core and the primary and secondary beam halos. Consequences of beam loss in the aperture can be benign (magnet quenches) or malignant (damage to equipment). The LHC aperture is introduced and the available margin for beam perturbations is discussed. The collimation system has been designed with the goal to first intercept and absorb beam losses. As a consequence beam-loss based detection of failures will (in most cases) first be possible at the collimators. The role of the collimation system in active and passive machine protection is explained and the various collimators/absorbers/diluters in the LHC are classified for their importance for machine protection.

6. Beam Dumping System - design and safety – J.Uythoven

The LHC Beam Dumping System is the only system which can safely dispose of the LHC beams. The system description is given, detailing the required functionality, the technical solutions chosen, the different hardware components and their performance specifications. Design choices for safety critical system elements and operational procedures are explained. System safety analysis results are presented, together with the expected availability. Commissioning aspects are briefly discussed.

7. Beam Dumping system - failure scenarios – B.Goddard

A failure of the LHC Beam Dumping System could have a serious negative impact on the performance of the LHC machine. The failure modes of the Beam Dumping System are presented, together with the expected occurrence rate and possible consequences. For the Beam Dumping System failures that are expected to occur during the LHC lifetime, the functionality and implementation of the foreseen dedicated protection devices and protection systems are described, together with the required performance. Analysis results for the most serious cases are presented. Finally, the requirements placed on settings for the movable protection devices with respect to the beam are highlighted.

8. Transverse damper – W.Höfle

The LHC transverse damper forms part of the RF system and will as such be connected to the beam interlock system through common links. The system will be used for injection damping and to provide feedback to stabilize the beams against transverse coupled bunch modes which could develop at the injection plateau and along the ramp. From the capabilities of the system limits are derived for the injection error and instability growth times that the system can handle. Moreover, the damper can be used for machine studies as beam exciter, and also for active abort gap cleaning by transverse excitation and subsequent interception of the beam by the collimation system. These possible uses are described together with their implications for the machine protection system, such as worst case failure scenarios including the expected time scale of beam losses as well as possibilities and limits of protection through interlocks inside the damper system.

9. Safe beam energy tracking – E.Carlier

Safe dumping of the LHC beam relies on accurate tracking of the LHC beam energy, since the strength of the dump system elements must scale with the beam energy to obtain the correct extraction trajectories. The LHC Beam Energy Tracking System (BETS) is responsible for the generation of the kick strength reference signals w.r.t. the beam energy of the extraction kicker high voltage generator power supplies. The system also performs continuous surveillance of the charging voltage of the different circuits within the high voltage generators and generates a dump request if the measured values are not within predetermined tolerance windows relative to the beam energy. In addition, the BETS will provide the calculated beam energy value to Safe LHC Parameters system (SLP) for the generation of the Safe Beam Flag signal and the distribution to other users. The architecture of the BETS, based on a modular approach, will be presented and the functionality of the different components included within the system described. Protection against possible failures within the BETS system itself will be discussed in more detail. Finally, validation tests of the complete BETS scheduled in 2006 in the SPS will be presented.

10. Interlocking strategy – J.Wenninger

The beam interlock system of the LHC is a central system for machine protection since it provides the interface between user systems and the beam dumping system. This presentation is focused on the main design concepts and overall architecture of the LHC beam interlock system. Interfaces to the interlock system users, to the beam dumping system as well as to LHC injector chain will be described. The general concepts of protection during the very critical injection process will be discussed.

11. The Architecture, Design, and Realisation of the LHC Beam Interlock System – B.Todd

The Beam Interlock System (BIS) forms the backbone of the LHC Machine Protection System, allowing 100's of distributed User Systems to inhibit beam operation and request Beam Dump from all around the 28 km circumference of the LHC. The time response of the BIS is in the order of only 100s of microseconds from any connected User System to the LHC Beam Dumping System. The rapid time response requirement of the BIS is coupled with very high safety constraints, dependability is a key issue, as whilst providing a secure and robust protection, it should not be a source of unnecessary beam dumps.

This presentation begins by describing the system level architecture of the LHC BIS, the sub-system technological choices are then explained. As safety is of the highest priority, the preliminary results of the BIS dependability analysis are then shown, and as a summary, the expected worst-case activation time of the system is demonstrated.

12. The LHC Safe Beam Parameters – B.Puccio

For safe operation of the LHC, several critical parameters must be generated and dependably distributed around the accelerator. These parameters are principally the SAFE LHC ENERGY, the SAFE BEAM FLAGS and the BEAM PRESENCE FLAGS.

The presentation explains how we intend to produce and generate the Safe Beam Parameters. It describes how we are going to ensure a safe and reliable transmission through the LHC and how the critical parameters would be received and checked by the involved systems.

13. Failures in magnet and powering systems – R.Schmidt

The most likely reason for the loss of the circulating beam is an incorrect magnetic field in one or more magnets. In this presentation a catalogue of failures in the magnet powering system will be presented, and the time constant for beam loss will be discussed. Most likely are quenches in the superconducting magnets, in particular at 7 TeV. Other failures are the discharge of magnets with a resistance in the circuit (after a quench, or due to a failure), a trip of magnet power converter, failure in the power converter controls system. An electric short in the coil of a normal conducting magnet has also been considered.

14. Objects that can move into the beam – R.Giachino

The beams in the LHC can be intercepted by many different types of objects moving into the vacuum chambers. These include devices designed for beam monitoring, machine protection and for data taking by the experiments. Moving these objects can only be permitted under certain conditions. Interlocks should prevent quenches or even damage in case of wrong actions. An inventory of such devices will be given along with the conditions under which they can be moved and the signals that are required to ensure they can only be activated at the correct times.

15. Fast kickers (tune and aperture) – J.Uythoven

The hardware parameters and the assumed operational scenarios of the LHC tune and aperture kicker systems are presented. From this the potential damage caused by the two systems is deduced. It is shown that especially the aperture kicker can lead to significant damage tot the LHC and an adequate interlock system is required. The proposed combined hardware and software solution, which has to guarantee a safe operation of the two systems, is presented.

16. Beam losses versus BLM locations at the LHC - S.Redaelli

Beam losses along the 27 km long LHC ring can now be predicted with longitudinal accuracy of 10 centimetres. Simulations are based on a multi-turn tracking of secondary and tertiary halo particles, as produced in the collimation insertions, and on a detailed model of the LHC aperture. The expected losses at the LHC in various operational conditions are compared with the proposed locations for the beam loss monitors (BLM's), which shall detect abnormal losses to damp the beam before sensitive equipment is damaged. The goal of this study is to assess the validity of the proposed BLM locations and to identify other sensitive locations for optimizing the performance of the BLM system.

17. Beam loss monitoring requirements and system description – B.Dehning

The LHC beam loss monitoring system is designed to protect the equipment against damage and quenches caused by lost protons. Proton initiated secondary shower particles are detected by ionisation chambers and secondary emission detectors located outside of the cryostat. The measured shower intensities are compared with energy and loss duration depending quench level values and a signal is generated if thresholds are exceeded. A single monitor will be sufficient to generate this beam aboard signal.

A summary of the system specification will be given and its implementation will be shown. Parameters characterising the expected and measured system performance will be discussed and the beam loss detection possibilities in the LHC collimation areas will be reviewed.

18. Beam loss monitors – realisation – C.Zamantzas

The BLM system is one of the most critical elements for the protection of the LHC. For this reason, its design must ensure a reliable, failsafe, secure and fast system. The complete system consists of: Detectors placed at various locations around the ring. Radiation tolerant tunnel electronics, the CFC cards, which are responsible for acquiring, digitising, and transmitting the data. Surface data analysis cards, the BLMTC cards, which receive the data via 2 km optical data links, process, analyze, store, and issue warning and abort triggers. Finally, on the far end, the Combiner cards at each crate collect those triggers together with status information in order to pass the abort signal to the Beam Interlock Controller system. In this presentation the BLM system will be explored giving emphasis at the strategies followed to provide and verify its design goals.

19. Magnet powering system and beam dump requests – M.Zerlauth

The objective is to safely extract the beam after quenches and failures in the powering or quench protection system. Failures could be detected by different systems, depending on the origin of the failure. The role of quench protection system, power converters and powering interlock systems will be discussed. Timescales for the extraction of the beams after different failure cases will be presented. Monitoring mechanisms to detect fast magnet current changes in critical electrical circuits will be addressed as a complement to the machine protection systems being presently in the baseline. This system will initiate the extraction of beams before the magnetic field in the magnet changes in a significant way. Combined failures could be equally covered by such a system, for example after a power cut due to thunderstorms.

20. Machine protection and closed orbit – J.Wenninger

Good orbit control is very critical for the LHC due to the tight aperture at injection and the stringent orbit stability constraints from collimators and absorbers. A real-time orbit feedback system will be used to ensure adequate orbit stability during all
operational phases. While the orbit feedback is important for operational efficiency, it cannot be used for machine protection directly. An interlock system based on redundant beam position monitors located around the beam dump extraction elements will be used to protect the beam dump channel from damage to due excessive orbit offsets. The same system will also provide an interlock signal for fast orbit drifts. The position interlock system will be discussed, in particular the complementary protection they provide to the beam loss monitoring system.

21. BCT for protection – D.Belohrad

At LHC the Beam Current Transformers (BCT) have an important role for machine protection. The BCTs will be used to derive to important signals that will be distributed with high reliability using the 'Safe LHC Parameter' system: the 'beam presence' flag and the 'safe beam' flag. Both signals are derived from the measured beam intensity in the LHC rings. This presentation will outline the present design concept to provide reliable intensity information to the machine protection system. Although the beam loss monitoring system will be the main instrument charged with detecting and acting upon the majority of failures that could lead to quenches or damage, a fast beam loss interlock using beam current transformers would increase the overall reliability of the machine protection system. Requirements and ideas for the realization of a fast loss interlock system based on BCTs will be discussed.

22. Performance of injection protection systems – V.Kain

For the last stage of the LHC injection process - extraction from the SPS, transfer through the transfer lines TI 2 or TI 8 and injection into the LHC at 450 GeV - the nominal intensities are over an order of magnitude above the equipment damage limit. Equipment failures or wrong settings resulting in beam loss will therefore cause severe damage to the extraction region of the SPS, the transfer lines or the LHC. Effective active (interlock) and passive (collimator) machine protection is essential. The protection level for various failures such as kicker erratics, power converter faults, etc. has been investigated for beam 2 with particle tracking including random machine and absorber setting imperfections. A full aperture model of the transfer line and injection region was taken into account. The requirements for active protection by surveillance of key equipment and passive protection (TCDI, TDI-TCLI) in terms of protection setting are presented. Results for grouped failures, where all magnet families trip which are connected to e.g. the same transformer, are also discussed. The risk levels for damage of LHC equipment at injection are given.

23. Ensuring required collimator settings – O.Aberle

The position of each collimator jaw in the LHC must be known at any time within very tight tolerances. To ensure this, a number of features have been implemented into the design of the collimator. The position and angle control for the jaws will be described from the mechanical point of view as well as for the electronics, controls and interlocks at the level defined up to now. A Collimation Controls working group is being set-up to address all the details.

24. Machine protection and LHC controls – M.Lamont

The critical components and interfaces of the machine protection system will not depend on the control system per se. However, controls are implicated in a number of areas. These include pre- and post operation checks, the need for efficient and accurate post-mortem analysis, and the need to maintain secure equipment settings which could vary with the beam energy and intensity. Other potential areas with implications for the control system include protection against false manipulations and software interlocks.

The various areas in which the control system is implicated are enumerated, and the importance of each evaluated. Possible implementations are suggested where appropriate; the areas requiring further attention are high-lighted.

25. Overall picture across the different protection systems, report from the working group on reliability – R. Filippini

A simplified model of the machine protection system which includes the Beam Interlock System, the Beam Loss Monitors, the Quench Protection System, the Powering Interlock Controller and the Beam Dumping System has been studied. The model provides quantitative results for safety and availability of the complete system. The importance of the assumed redundancy at the source of the dump request and the system regeneration is demonstrated.