Machine Protection (Review) Recap

Rüdiger Schmidt / Jörg Wenninger
Review on Machine Protection and Interlocks
April 2005

Risks when operating LHC with beam
Failures and beam losses
Protection systems
Strategy
Organisation
Conclusions
LHC Machine Protection includes many systems

What systems are for machine protection? Those systems that are required only due to high stored energy in beams and magnets

- Beam Dumping System
- Beam and Powering Interlocks
- Beam Loss Monitor System
- Collimation System
- Quench Protection / Energy Extraction Systems

Systems that are not for machine protection with hardware interfaces to the machine interlocks

- Beam instruments (BPM, BCT, screens, …)
- Vacuum
- Power converters
- RF and Transverse damper
- Access
- LHC experiments
- Kickers (injection, Q-kickers, aperture kickers)
LHC Machine Protection is across several projects and working groups

Projects
- LHC Beam Dump (B.Goddard)
- LHC Collimation (R.Assmann)
- Beam Loss Monitors (B.Dehning)
- Beam and Powering Interlocks (R.Schmidt)
- LHC Transfer Lines and Injection (V.Mertens)
- Quench Protection and Energy Extraction (R.Denz / K.Dahlerup-Petersen)

Protection issues are discussed in several working groups
- Machine Protection WG (R.Schmidt / J.Wenninger)
- Collimation WG (R.Assmann)
- Injection WG (V.Mertens)
- LEADE (Interface machine <=> experiments) (E.Tsesmelis)
- Electrical Engineering WG (K.H.Mess)
The challenge of LHC Machine Protection and collimation was addressed progressively

In the initial design (< 1995)
- Beam Dumping system
- (Initial) Beam Cleaning system
- Quench Protection system
- LHC Transfer Lines and Injection
- Beam Loss Monitors

Much later (~2001-2003)
- Beam Interlocks and Powering Interlocks
- Additional collimators to protect against various types of failures

Recently (~2003-2004)
- Monitor to detect fast magnet current changes
- Safe LHC Parameter distribution
- Beam position monitors for protection
- BCT for protection

Just starting: software / controls and machine protection
Outline of the review

- Introduction to LHC and machine protection
- Two session on core of machine protection systems (no other redundant systems)
  - Dumping the beam
  - Beam interlocking
- Session on events leading to beam losses
- Session on equipment surveillance and beam monitoring
  - BLMs can also be considered as a core protection system (some redundancy)
- Machine protection and operation
- For specific issues coming up during the review
  - Free slot: interactive session (closed)
- Executive session (closed session)
- Open summary session
Reviewers

- Mike Harrison (BNL) – chairman
- Marc Ross (SLAC)
- Vinh Dang (PSI)
- George Ganetis (BNL)
- Jerry Annala (FNAL)
- Reinhard Bacher (DESY)
- Coles Sibley (SNS)
- Roger Bailey (CERN/AB)
- Doris Forkel-Wirth (CERN/SC)
Organisers

Review organisation
- R. Schmidt
- J. Wenninger

Review programme team
- B. Puccio
- B. Dehning
- B. Goddard
- J. Uythoven
- O. Bruning
- R. Assmann
- V. Kain
- R. Bailey
- M. Lamont
- H. Burkhardt
Machine Protection Systems and (HW) Interfaces

- Beam Current Monitors
  - DCCT Dipole Current 1
  - DCCT Dipole Current 2
  - RF turn clock
- Access Safety System
- Beam Energy Tracking
- Beam Dumping System
- Injection Interlock
- Safe LHC Parameters
- SPS Extraction Interlocks
- TL collimators
- BLMs aperture
- BLMs arc
- Collimators / Absorbers
- BPMs for Beam Dump
- NC Magnet Interlocks
- BPMs for dx/dt + dy/dt
dl/dt beam current
dl/dt magnet current
- Screens
- RF + Damper
- LHC Experiments
- Vacuum System
- Operators
- Software Interlocks
- Powering Interlock System
- Discharge Switches
- Cryogenics
  - Quench Protection
  - Power Converters
  - AUG
  - UPS
- Timing
- PM Trigger
- LHC Beam Interlock System
- Essential circuits
- Auxiliary circuits
- Essential circuits

Energy flow:
- Beam Current
- Energy
- Timing
Beam Dumping System and Triggers

- Beam Dumping System
- Access Safety System
- DCCT Dipole Current 1
- DCCT Dipole Current 2
- RF turn clock
- Beam Energy Tracking
- Beam Dumping System
- Beam Dump Trigger
- LHC Beam Interlock System
- Powering Interlock System
- Cryogenics
- Cooling
- Power Converters
- Discharge Switches
- Timing
- PM Trigger
- Cryogenics
- Essential circuits
- Auxiliary circuits
- Safel LHC Parameters
- Energy
- Injection Interlock
- SafeBeam Flag
- BPMs aperture
- BPMs and absorbers
- BPMs for Beam Dump
- NLC Magnet Interlocks
- BPMs for dx/dt + dy/dt
d/dt beam current
d/dt magnet current
- Screens
- RF + Damper
- LHC Experiments
- Vacuum System
- Operators
- Software Interlocks
Beam Interlock System and Inputs

- Beam Current Monitors
  - DCCT Dipole Current 1
  - DCCT Dipole Current 2
  - RF turn clock
- Access Safety System
- Beam Energy Tracking
- Beam Dumping System
- Discharge Switches
- Powering Interlock System
- Essential Circuits
- Auxiliary Circuits
- Timing
- PM Trigger

LHC Beam Interlock System

- BLMs aperture
- BLMs arc
- Collimators / Absorbers
- BPMs for Beam Dump
- NC Magnet Interlocks
- BPMs for dx/dt + dy/dt
- dl/dt beam current
- dl/dt magnet current
- Screens
- RF + Damper
- LHC Experiments
- Vacuum System
- Operators
- Software Interlocks

Cryogenics
- Quench Protection
- Power Converters
- AUG
- UPS

Injection Interlock
- SafeBeam Flag
- Energy

Safe LHC Parameters
- Beam Interlock System and Inputs
- Beam Interlock System and Inputs
- Beam Interlock System and Inputs
Safe LHC parameters

- Beam Current Monitors
- DCCT Dipole Current 1
- DCCT Dipole Current 2
- RF Turn clock
- Access Safety System
- Cryogenics
- Quench Protection
- Power Converters
- AUG
- UPS

Beam Tracking
- Beam Dumping System
- BLMs aperture
- BPMs for Beam Dump
- TL collimators
- BLMs arc
- SPS Extraction Interlocks
- BPMs for dx/dt + dy/dt
dI/dt magnet current

Injection Interlock
- Energy
- SafeBeam Flag
- Operators
- Software Interlocks
- BPMs for dx/dt + dy/dt
dI/dt magnet current
- Screens
- RF + Damper
- LHC Experiments
- Vacuum System
- Operators
- Software Interlocks

Powering Interlock System

LHC Beam Interlock System

Safe LHC Parameters
- Current
- Energy
- Safe Beam Flag

Discharge Switches
- essential circuits
- auxiliary circuits

Timing
- PM Trigger

LHC Experiments

Vacuum System

RF + Damper

Operators

Software Interlocks

DCCT Dipole Current 1

DCCT Dipole Current 2

RF Turn clock

Access Safety System

Cryogenics

Quench Protection

Power Converters

AUG

UPS

Discharge Switches

essential circuits

auxiliary circuits

Timing

PM Trigger
Potentially dangerous events
- Injection process
- Circulating beam

“Failures”
- Slow (>few ms) SW changes
- Fast (<few ms) HW changes
- Single turn

Effect on beam

Priorities for review
- Beam Interlock System
- Beam Dumping System
- Beam Loss Monitoring
- Protection - from SPS to LHC
- Other Monitors for protection

Monitoring
- Settings monitoring
- HW monitoring
- Beam monitoring

Machine Protection System 'core'
- Beam Interlock System
- Beam Dumping System

Passive protection systems

Transfer SPS - LHC process

based on slide by B. Goddard
Programme

Getting to know the LHC
- Introduction to the LHC accelerator, the layout and its parameters by Dr. BAILEY, Roger
- Introduction to magnet powering and protection by Dr. DENZ, Reiner

Introduction to the review
- Introduction to the review, by Dr. EVANS, Lyn
- Protection of the LHC, by Dr. SCHMIDT, Rudiger
- The role of the collimation system in protecting the aperture by Dr. ASSMANN, Ralph

Dumping the beams
- Beam Dumping System - design and safety by Dr. UYTHOVEN, Jan
- Beam Dumping system - failure scenarios by Dr. GODDARD, Brennan
- Safe beam energy tracking by Dr. CARLIER, Etienne
- Transverse damper by Dr. HOFLE, Wolfgang
**Interlocking**
- Interlocking strategy by Dr. WENNINGER, Jorg
- Architecture, Design, and Realisation of the LHC Beam Interlock System by Dr. TODD, Benjamin
- The LHC Safe Beam Parameters by Dr. PUCCIO, Bruno

**Events leading to beam loss**
- Failures in magnet and powering systems by Dr. SCHMIDT, Rudiger
- Objects that can move into the beam by Dr. GIACHINO, Rossano
- Fast kickers (tune and aperture) by Dr. UYTHOVEN, Jan

**Equipment and beam monitoring - connected to the beam interlocks**
- Beam losses versus BLM locations at the LHC by Dr. REDAELLI, Stefano
- Beam loss monitoring requirements and system description by Dr. DEHNING, Bernd
- Beam loss monitors, realisation by Dr. ZAMANTZAS, Christos
- Magnet powering system and beam dump requests by Dr. ZERLAUTH, Markus
- Machine protection and closed orbit by Dr. WENNINGER, Jorg
- BCT for protection by Dr. BELOHRAD, David
Machine Protection and operation

- Performance of injection protection systems by Dr. KAIN, Verena
- Ensuring required collimator settings by Dr. ABERLE, Oliver
- Machine protection and LHC controls by Dr. LAMONT, Mike
- Will the machine protection systems let LHC safely operate? by Dr. FILIPPINI, Roberto

Conclusions

- Conclusions and recommendations by Dr. HARRISON, Mike
Objectives of the Review on Machine Protection and Beam Interlocks

Safe operation of the LHC in presence of the energy stored in each beam of up to 360 MJ requires using several systems: collimators and beam absorbers, beam dumping systems, beam monitoring, beam interlocks etc.

Machine protection will be important during all phases of operation: starting with the beam transfer from SPS to LHC, injection, ramp, squeeze and collisions.

Collimators and beam absorbers must be correctly adjusted, already during injection, when dumping the beam, but also when accelerating and during the store.

Failures are detected by beam loss monitors, by other beam instruments, by the quench protection system and other hardware related equipment. Beam dump requests are transmitted via the beam interlock system to the beam dumping system, and the beam is safely extracted into the beam dump block.
Objectives of the Review on Machine Protection and Beam Interlocks

The **overall strategy of the LHC machine protection** is discussed. The functionality of the systems with respect to machine protection is presented.

Main emphasis of the review is on the **interfaces between these systems during beam operation**.

The review will discuss **interlocking the LHC**, in particular the signals that are exchanged between different systems in the LHC as well as between LHC, SPS and the transfer lines between the two accelerators.
Questions to the reviewers

- Do you consider the overall strategy for machine protection adequate, and what could be the main risks?
- Are there mechanisms for beam losses not being considered that could impact on the strategy?
- Are the interfaces between the different systems clearly defined?
- Are there other protection devices that should be considered?
- Are there other input channels for the Beam Interlock System that should be considered?
- Will the protection systems have the required safety?
- Will the protection systems allow for efficient operation (availability)?
- Based on experience elsewhere: what is most critical and where have been surprises?
Outcome

I like to thank the reviewers for their interest, their very active participation (….long days), and for their very valuable comments

=> Mike Harrison
Reserve