MACHINE PROTECTION BACKBONE

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Abstract

The LHC Machine Protection System needs to adapt to the Run 2 operational requirements. In addition, important upgrades and consolidations have been implemented on the MPS backbone during the first long shutdown. This paper summarizes the changes affecting Beam Interlock System (BIS), Powering Interlock System (PIC), Fast Magnet Current Change Monitors (FMCM), Quench Protection System (QPS) and Software Interlock System (SIS).

MAGNET POWERING INTERLOCKS

Electrical circuit definitions

Failures in the electrical circuits can have different consequences on the operation with beam. They depend on the operation mode of the accelerator and therefore on the magnet operating currents. The criticality of electrical circuits is defined in the PIC as:

- Essential: If circuits are required under any condition for beam operation, including safe beams (e.g. circuits defining the geometry of the machine). The PIC will send a beam dump request to the BIS in case of powering failures.
- Auxiliary: If circuits do not necessarily impact the beam in case of failures (e.g. orbit correctors that can be compensated by other circuits). In case of powering failures, the PIC sends a beam dump request to the BIS which will decide whether to dump or not the beam depending on the operation mode of the machine.

During the first LHC run some changes have been done to the list of auxiliary circuits. The eight skew quadrupole correctors RQSX3 located in the inner triplet regions had to be included in the list of auxiliary circuits of the PIC following an unexpected dump [1].

Run 2 operation means new powering requirements and circuits which were operating at low currents during Run 1 will become more critical for operation and therefore will need to be included in the PIC configuration [2]. The list of proposed changes agreed with BE-ABP is the following:

- ROD/ROF: They will be defined as auxiliary to avoid EMC coupling on neighbouring circuits.
- RCBCHS5.L8B1: This circuit was replaced by a normal conducting circuit during Run 1 due to a non-conformity and repaired during LS1. It will be defined as auxiliary for Run 2.
- RQS: Skew quadrupoles used to correct beam coupling will be included in the list of auxiliary circuits.
- RQT: Corrector quadrupoles defining machine optics will be configured as auxiliary.

Access restrictions while powering

After the incident occurred on September 2008, new rules were defined to access the LHC underground areas during periods of magnet powering. In order to avoid relying purely on procedures, two mechanisms have been put in place to limit the current on the power converters and to interlock powering if magnet currents exceed a safe limit when access is allowed. The latter relies on an interlock logic programmed on the SIS which receives the access status from the LHC Access Safety System (LASS). Since the link between the LASS and the SIS is currently based on the Technical Infrastructure Monitoring (TIM), it has been suggested to improve it by a more dependable solution.

During LS1 a new PLC has been installed in the CCR. It will be in charge of getting the access conditions through eight safety relays from the LASS and then will publish the access status to the controls middleware, including the SIS (Fig 1). This new mechanism will increase the availability of the longest and weakest link in the existing interlock chain [3].

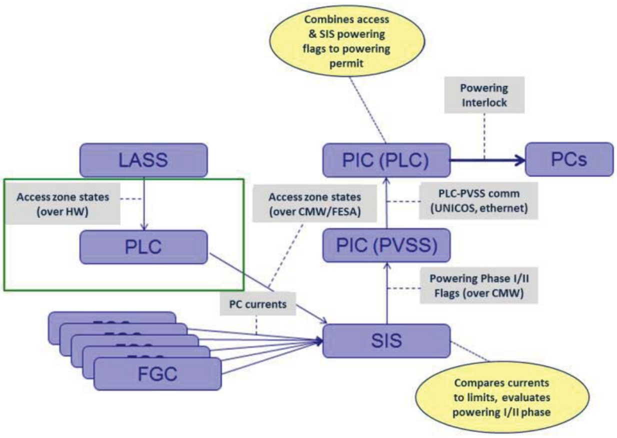

Figure 1: Layout of the Access Powering Interlocks

FAST MAGNET CURRENT CHANGE MONITORS

It is well known that one of the main root causes of beam dumps coming from magnet systems in the LHC is the electrical glitches affecting the CERN electrical network distribution. In 2012, a total of 24 events provoked FMCM triggers which lead to preventive dumps in order to avoid dangerous beam excursions. In most cases, these disturbances were only seen by FMCMs and no other equipment trip was recorded. An internal review of the system carried out in 2012 concluded with a set of recommendations, amongst them the replacement of the most sensitive RPTG thyristor-based power converters

(RD1 and RD34) [4]. During LS1, the design of the new switch mode converter, cabling and cooling infrastructure is being prepared. The installation of the two RD1 power converters will be carried out during the 2015-2016 Christmas break, while the two last RD34 power converters will be replaced during the 2016-2017 Christmas break.

BEAM INTERLOCK SYSTEM

LBDS retriggering link

Following a review on the UPS power distribution of the LHC Beam Dumping System (LBDS), it has been decided to implement an additional redundant triggering path directly from the BIS to the LBDS Retriggering System (RTS). This link is aimed at increasing the dependability of the LBDS and is based on two new boards (CIBDS) connected to the beam permit loops. The new hardware will trigger systematically a 250 us-delayed asynchronous beam dump request upon detection of the beam permit loop opening (see Fig 2). This link will be available from the beginning of Run 2.

The impact of the new retriggering channel on the machine safety and availability has been analysed through dedicated dependability studies [5]. Results show that the expected rate of both asynchronous and synchronous dumps can be considered as negligible for the overall MPS (see Table 1).

Table 1: Dependability of the LBDS retriggering line

Failure mode	Requirements	Dependability
Asynchronous	2 per 10 years	0.025 per 10 years
Synchronous	2 per year	0.011 per year

User systems

The existing user channel connections have been reviewed and new channels are foreseen [6]:

- LHCf detector: User channel remains disabled since 2010. If the detector is to be installed and used at unsafe intensity, the input has to be enabled on the BIS side.
- Fast Beam Current Change Monitors (FBCCM): A new interlock system will be operational from the beginning of 2015. However, the input will remain initially masked until we gain some experience.
- CMS magnet: Detector input has been updated to trigger in case of fast power aborts of the magnet solenoid.
- CIBDS: The two new boards will be connected to the unmaskable inputs of the BIS and will trigger upon requesting an asynchronous dump to the LBDS.
- TCDQ Beam 1&2: A maskable beam dump request will be triggered if the relative position of the jaw is above the interlock limits.
- Crystal collimator experiment: It will only be moved in safe conditions and included to the maskable inputs.

QUENCH PROTECTION

During LS1 the protection system for the superconducting circuits has been upgraded with the aim to improve the immunity to ionizing radiation and to extend its diagnostic capabilities. In the frame of the R2E campaign, the equipment in charge of the inner triplet protection has been relocated to low radiation areas (UL14/16 and UL557). In addition, new radiation tolerant hardware has been installed in exposed underground areas (i.e. RR13, RR17, RR53, RR57, RR73 and RR77) where relocation was not possible during the long shutdown.

Main circuit protection

Main circuits are equipped with quench heater strips to dissipate the stored energy within the magnets. Since quench heater faults can be dangerous for the protection of the magnet, an enhanced monitoring system has been developed to identify faulty heater circuits and to detect precursor states of potential failures. The new system acquires both discharge voltage and current using a sample rate of 192 kHz and 16 bits resolution. The implementation of the new hardware requires new protection crates which have been adapted to the new redundant UPS powering scheme. These crates are equipped with two external radiation tolerant 230V AC-DC converters which will be monitored by the DAQ systems.

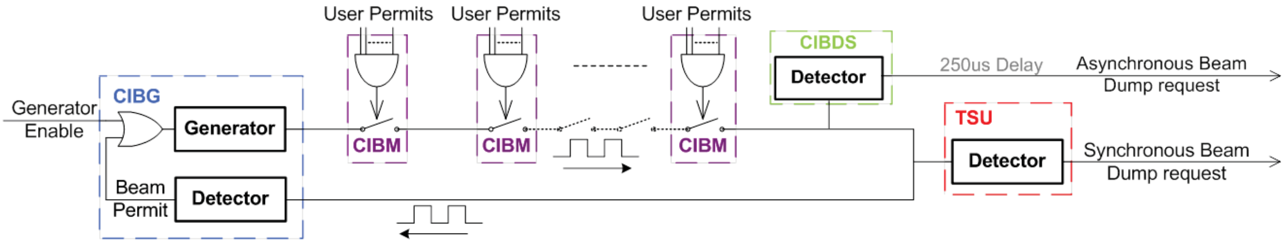

Figure 2: Layout of the Beam Permit Loop with the new CIBDS board to trigger an asynchronous beam dump request

In order to monitor the electrical insulation strength during fast power aborts, main dipoles and quadrupoles will be equipped with voltage feelers. Per sector a maximum of 54 feelers for the main dipole circuit and 55 for each of the main quad circuits will be installed with the goal to detect earth faults in the main circuits. In addition, all data will be logged in the logging database for data analysis.

With regard to the energy extraction (EE) systems, new arc chambers will be installed in the RQD and RQF circuits, which will allow increasing the maximum operational voltage of these circuits. In addition, the installation of snubber capacitor banks will be required to suppress voltage transients in the main quads. Furthermore, the EE resistors for the main circuits will be reconfigured for 7 TeV operation in order to reduce the maximum voltage across the switches and to avoid quench back [7]. Recommended values are represented in Table 2.

Table 2: EE characteristics of main circuits after LS1

Circuit family	R_{EE} (mΩ)	τ (s)	V_{EE},max(V)	dI/dtmax (A/s)
RB	2x83	103	900	-117
RQ	7.8	34	94	356

600A circuit protection

During Run 1 several 600A circuit families exhibited coupling-current induced quenches (quench back) during fast power aborts. In the end-of-run powering tests a reduction of the energy extraction resistor value was successfully tested in a RQTD circuit in order to increase the discharge time and to avoid quench back [8]. Based on this test and numerical modelling it was proposed to reduce the resistor value of the RQTL9 circuits to 0.4 Ω.

Operational improvements

Significant efforts have been done to improve operational software tools with the aim of facilitating the most common QPS tasks. The so called “QPS swiss knife” will provide remote power cycling capabilities. QPS settings and thresholds will be now stored in LSA database and the correct configuration of the protection systems will be guaranteed through the systematic execution of consistency checks.

SOFTWARE INTERLOCK SYSTEM

By the end of the Run 1, there were 52 interlock types implemented on the SIS. Due to the non-negligible number of changes applied to the different systems and to the new operational requirements a full revision of the interlocks will be required [9]. Three new interlocks will be added for:

- Embedded BPM collimators: Interlock on the beam offset with respect to the collimator centre.
- Abort gap monitoring: Interlock in case of excessive particle density in the 3us abort gap.
- Virtual beta* for transfer lines: Similar concept as for ring collimators. The SIS will publish the virtual beta* value associated with the optics.

In addition, some of the existing interlocks need to be updated, such as:

- Access Powering Interlocks: A new more dependable system has been put in place during LS1 and is ready for the restart of the powering tests.
- Particle type interlock: It avoids that protons are sent into a ring setup for ions and vice-versa. Particle type to be identified from SPS timing telegram.

SUMMARY

LS1 has served to implement quite some changes and upgrades to the MPS backbone which aim at increasing the machine dependability and to adapt to the new operational requirements. Consolidations will hopefully reduce machine downtime; especially from magnet powering systems mainly due to the reduced number of radiation induced spurious trips and electrical network perturbations.

Changes to the MPS will be validated following dedicated MPS procedures already reviewed by the Machine Protection Panel (MPP).

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