EXPERIMENT PROTECTION FROM BEAM FAILURES AND EXPERIMENT-MACHINE SIGNAL EXCHANGE

D. Macina, CERN, Geneva, Switzerland

Abstract

This paper briefly reviews the LHC experiment's protection from beam failures and the signal exchange that will be implemented for the LHC start-up.

BEAM FAILURE SCENARIOS DIRECTLY INVOLVING THE EXPERIMENTAL AREAS

The LHC protection from beam failures is described in several papers [1,2]. A dedicated workshop has been organized in June 2007 in order to address in detail scenarios which could involve directly the experimental areas. Talks and outcome of the workshop can be found in [3].

Unlike HERA, TEVATRON and RHIC, the LHC cannot be operated without collimators (except at injection with low intensity). In fact, the protons lost along the ring must be intercepted with very high efficiency before they can quench a superconducting magnet. This is done via the collimation system which defines the aperture limitation in the LHC. Collimators are located mainly in the cleaning insertions (IR3, IR7). A few additional collimators are located in the dump insertion (IR6) and in the experimental insertions. This has an important impact on the Machine Protection since, for most of the multi-turn failures, the beam will hit the collimator first. Hence, for most of the multi-turn failures, the experiments are protected by the collimators mainly located in the LHC beam cleaning insertions. However, a few scenarios (both multi-turn and single-turn) potentially dangerous for the experiments have been identified and listed in the following.

Failures at injection and extraction:

Wrong settings at injection

This failure is due to the wrong setting of one or more magnets located in the experimental insertion (in particular, the orbit correctors and the D1/D2 separation dipoles). This failure concerns all experimental insertions. A dedicated study for ATLAS [4] has shown that, depending on the type of error, the injected beam may hit/scrape the TAS and shower into the experimental regions, or directly impact the beam pipe. ALICE and LHCb are more exposed due to the fact that no TAS is foreseen in IP2 and IP8 and to the fact that these IPs have the added complication of a dipole magnet (associated with corrector magnets). Protection from these kinds of failures relies on the software interlock of the magnet settings, on the "probe beam flag" which will interlock the maximum beam intensity which can be injected into an empty LHC and the "pilot beam" procedure which foresees the injection of a pilot bunch ($5{\cdot}10^9$ protons) prior to the normal batch injection if the LHC is empty.

Error failures at injection (IR2 & IR8)

This failure is due to the wrong setting of the transfer line magnets or of the injection septum, a fast trip of the power supplies, failure of the SPS extraction kicker during extraction, etc. Protection from these failures is based on the response to magnet current surveillance and fast current change monitors and on passive protection from absorbers and collimators. In particular, the injection kicker failures in the LHC ring are caught by dedicated moveable absorbers like the TDI and the TCLI. These failures affect directly either IR2 (beam1) or IR8 (beam2). However, the injection failure can in principle affect the whole machine depending on the phase advances and the absorber/collimator settings.

Error at extraction (IR6)

This failure is related to the loss of synchronisation with the abort gap, an over-populated abort gap, the pre-firing of one of the 15 kicker modules or a failure in the energy tracking system. It is difficult to quantify the frequency of the pre-fire failure but it looks like once per year is possible. The downstream magnets and the adjacent Insertion Regions (IR5 and IR7) should be protected by dedicated passive absorbers (movable TCDQ and TCS, fixed TCDS and TCDQM). However, in case of problems during extraction coupled with TCDQ settings and/or orbit/optics errors, some beam loss may occur at the tertiary collimators (TCT) or triplets in IR5. The loss is difficult to quantify but a detailed analysis is ongoing (existing studies were done without taking into account the TCT/TCDQ, since introduced at a later stage). The abort gap (re)population is monitored via a dedicated instrument which could be connected to the interlock system (under discussion). This failure directly affects only IR5/CMS. However, there is the possibility that the mis-kicked beam passes through IR5 and IR3 and hits IR2 and/or IR1. In fact, the momentum cleaning collimators have a rather large aperture compared to the ones in the betatron cleaning insertion (aperture ~ 15 sigma in IR3 compared to ~ 6 sigma in IR7) and, therefore, the protection due to IR3 is less effective compared to IR7. This probability is expected to be low and it should be checked by simulation looking at the mis-kicked beam phase advance. The protection from this failure relies on the correct positioning of the above absorbers.

Failures during circulating beam

This concerns magnet failures including operational mistakes. It is usually slow and detected first in the aperture restrictions of the machine. The potential danger for the experiments (in particular the near-beam detectors like Roman Pots and VELO) is due to uncontrolled closed bumps since they could affect only the experimental areas. However, they build up slowly (BLM should trigger a beam dump early enough), they are extremely difficult to create at 7 TeV (less difficult at 450 GeV) and only critical if combined with a fast failure of one of the insertion elements. Therefore, the probability of this failure is considered very low. Protection from these failures relies on the tertiary collimators, on the fast current change monitors, on the Beam Loss Monitors (BLM) and on the experiment Beam Condition Monitors (BCM). If particularly dangerous bump scenarios will be identified by future simulations, ad-hoc software interlocks on the settings of the magnets may be envisaged.

COMMUNICATION CHANNELS BETWEEN THE EXPERIMENTS AND THE MACHINE

The communication between the machine and the experiments relies on the five communication channels which are described below.

Timing, Trigger and Control (TTC)

The overall TTC system architecture [5] provides for the distribution of synchronous timing, level-1 trigger, and broadcast and individually-addressed control signals, to electronics controllers with the appropriate phase relative to the LHC bunch structure, taking account of the different delays due to particle time-of-flight and signal propagation. Within each trigger distribution zone, the signals can be broadcast from a single laser source to several hundred destinations over a passive network composed of a hierarchy of optical tree couplers. For what concerns the machine interface, it transmits the LHC fast timing signals from the RF generators, i.e. the 40.08 MHz bunch clock frequency and the 11.246 kHz revolution frequency. In the experiments, this system is used by the Trigger Community.

Machine Beam Synchronous Timing (BST)

It is developed using the TTC technology to provide the LHC beam instrumentation with the 40.08 MHz bunch clock frequency, the 11.246 kHz revolution frequency and an encoded message that can be updated on every LHC turn and that is mainly used by the LHC Beam Instrumentation Group to trigger and correlate acquisitions [6]. The message also contains the current machine status and values of various beam parameters. The message is sent to the experiments [7] and used to provide the TTC with the “Machine Status” information to define the type of clock delivered (rising, stable, not guaranteed). Some experiments use it also to get the GPS absolute time and the beam parameters.

Beam Interlock System (BIS)

The Beam Interlock System (BIS) of the LHC provides a hardware link from a user system to the LHC Beam Dumping System, to the LHC Injection Interlock System and to the SPS Extraction Interlock System [2]. The LHC BIS is split into a system for beam1 and a system for beam2 and carries the two independent BEAM_PERMIT signals, one for each beam. The BEAM_PERMIT is a logical signal that is transmitted over hardware links and that can be either TRUE (i.e. injection of beam is allowed and, with circulating beam, beam operation continues) or FALSE (i.e. injection is blocked and, if a beam is circulating, the beam will be dumped by the Beam Dumping System).

The individual user systems must provide USER_PERMIT signals for beam1 and/or beam2 that are collected by the BIS through the Beam Interlock Controller (BIC) modules. The USER_PERMIT is a logical signal that is transmitted over a hardware link and that can be either TRUE (i.e. the user is ready and beam operation is allowed according to the user) or FALSE (i.e. beam operation is not allowed according to the user). To obtain permission for beam operation, i.e. BEAM_PERMIT=TRUE, all the connected USER_PERMIT signals must be TRUE. This condition is somewhat relaxed for the maskable user signals, where the USER_PERMIT signal may be masked only if the beam intensity is safe, i.e. below the machine damage threshold. The delay between reception of an interlock (USER_PERMIT to FALSE) and the moment where the last proton is extracted on the dump block varies between 100 and 270 μs depending on the location of the USER and the precise timing with respect to the beam abort gap position in the ring.

The BIS for the experiments is described in [8]. Special attention is paid to the interlocking of the movable devices since they are supposed to be positioned between 10-70 σ from the beam axis. Therefore, a wrong operation of these devices may lead to significant damage to both the devices themselves and the machine. In general, the movable devices are authorized to leave their garage position only during collisions.

It should be noted that the experiments will use the actual BIS only to dump the beam. In order to inhibit injection, they have asked to get an independent system which would not dump the beam at the same time. In fact, the injection inhibit will be based on the state of the detectors and it will not depend on the data from the experiment’s protection system. New hardware has been developed for the extraction systems and it allows for a direct link via optical fibers to the Injection BICs in SR2 and SR8. The new hardware will be used by the experiments to inhibit injection without dumping the beam [9].

Finally, a number of hand-shaking signals have been agreed between the machine and the experiments aiming at improving the communication during the LHC operation [8]. This should ensure a more efficient and safer beam operation. The hand-shaking signals will be sent through the DIP system.

General Machine Time (GMT)

This system synchronizes all CERN accelerators [10]. In particular, it distributes:

- The UTC time of the day.
- The LHC telegram: it represents a snap shot of the machine state and it is updated each second. Among the various parameters, it sends out the Safe Beam Parameters which are essential for building the interlock signals.
- LHC Machine events: an event is sent punctually when something happens that affects the machine state. Some are asynchronous that come from external processes, e.g. post-mortems, while others are produced from timing tables corresponding to running machine processes. The Safe Beam Parameters are also sent as events and supplied to the experiments via hardware. Part of the telegram information relevant to the experiments (like the beam modes, the machine modes etc) are also distributed via DIP.

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CERN Data Interchange Protocol (DIP)

This system allows relatively small amounts of soft real-time data to be exchanged between very loosely coupled heterogeneous systems [11]. All signals regarding the quality of beam collisions, data from beam instrumentation, and the operation status (mode) of the LHC are exchanged via this system. It should be noted that this system is highly flexible and data and signals to be exchanged may be added as the experience with the experiments and accelerator operation develops. The data already agreed between the machine and the experiments can be found in [12,13,14].

What else?

The transmission of additional relevant parameters is actually being discussed. In particular:

- The actual value of the SPS Probe Beam Flag [15] (default 10^{10} protons, maximum value 10^{11} protons). The experiments have requested the information to be provided as a Safe Beam Parameter even though it would be acceptable to get it via DIP for the start-up run in 2008.
- The background levels: the experiments should send to the machine two complementary normalized signals to help the operators in reducing the background levels whenever it is necessary. The information should be independent from data taking and sent at a rate of about 1 Hz.
- Information about the collimator settings, the filling scheme and the beam life-time is under discussion.

CONCLUSIONS

A number of communication channels between the machine and the experiments have been defined in order to protect the experiments from beam failures and to optimize the data taking and, therefore, the physics results. The commissioning of these channels is presently ongoing. Experience in the operation of the LHC may lead to an optimization of the present scheme.

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