# WHAT WE WILL DO FOR BEAM PREPARATION IN 2009 : BEAM INTERLOCKS

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*Abstract*

A large fraction of the LHC Machine Protection System was commissioned in 2008 in view of the first LHC run, and first attempts to automate test sequences were implemented. This presentation will outline the commissioning plans for the MPS system in 2009 based on the 2008 experience. A possible planning of the tests will be presented, including scheduling issues and compatibility with HWC. Controls requirements will be outlined. MPS tests with beam will be discussed.

## INTRODUCTION

The LHC Machine Protection System [1] is a complicated system because it has many elements, see Fig. 1. It is also a complex system because the elements interact in space and time. Finally the LHC, due to its size, has a very large phase-space for failures. The components of the LHC MPS are however glued together by a Beam Interlock System (BIS) that has a very simple function: to transmit an dump request with highest possible reliability to the LHC Beam Dumping System (LBDS). Fortunately the MPS can be broken up into testable components and the outcome of the tests allow to quantify or predict its performance with respect to failures.

The SPS and transfer line BIS is composed of:

- 1 ring beam permit loop,
- 2 extraction interlock systems,
- 16 Beam Interlock Controller (BIC) modules as well as 2 special extraction master BICs,
- 120 BIC inputs.

Approximately 1000 devices/interlocks are connected to the SPS and transfer lines BICs, approximately 50% of the devices/interlocks protect the high energy transfer lines to LHC and CNGS. Approximately 1000 software interlocks are defined in the SPS Software Interlock System (SIS) [3].

The LHC BIS system is composed of:

- 2 ring beam permit loops,
- 2 injection interlock systems,
- 21 BIC modules,
- approximately 180 inputs to the BIS.

Approximately 10000 devices/interlocks are connected to the LHC BICs. Approximately 3800 software interlocks are defined in the LHC SIS.

## BIS CHANGES

In 2009 the following changes will be made to BIS system itself:

- New monitoring firmware for BICs.
- New firmware for the CIBG (generator module) to ease arming sequence and provide diagnostics.
- Modifications in some optical components.
- Automated pre- and post-operation checks (IPOC).
- Automated tests (ready for PIC, work in progress for WIC, BLMs and BTVs).
- CIBU user connections: all LHC clients will be forced to provide redundant signals following the incident of 2008 where a CIBU unit failed blindly [2]

All components will basically be re-commissioned, and one of the goals os to retest all CIBU connections, even if they have not be modified between 2008 and 2009.

### *SPS and Transfer Line BIS Inputs*

The following changes will take place in the SPS and the transfer lines.

- A new turn-by-turn beam position interlock will be added to protect the SPS ring against large beam oscillation in the vertical plane. The horizontal plane will remain protected by the existing analog system (so called '30 mm' interlock). Presently only BLMs provide protection against fast losses and orbit changes in the vertical plane.
- Beam quality interlocks will be implemented for LHC beams before extraction by the RF system (bunch pattern, position, bunch length, bunch intensity spread) and by the SPS fast BCT (bunch intensities and spread).
- A new *beam position before extraction* interlock will be tested. The new system should replace the existing system based on the SPS MOPOS orbit system. It will be much faster and have higher availability (the present system has a $\sim$ 2-3% un-availability).
- Some inputs will be reshuffled between the TI2 and TI8 BICs and the injection BICs.

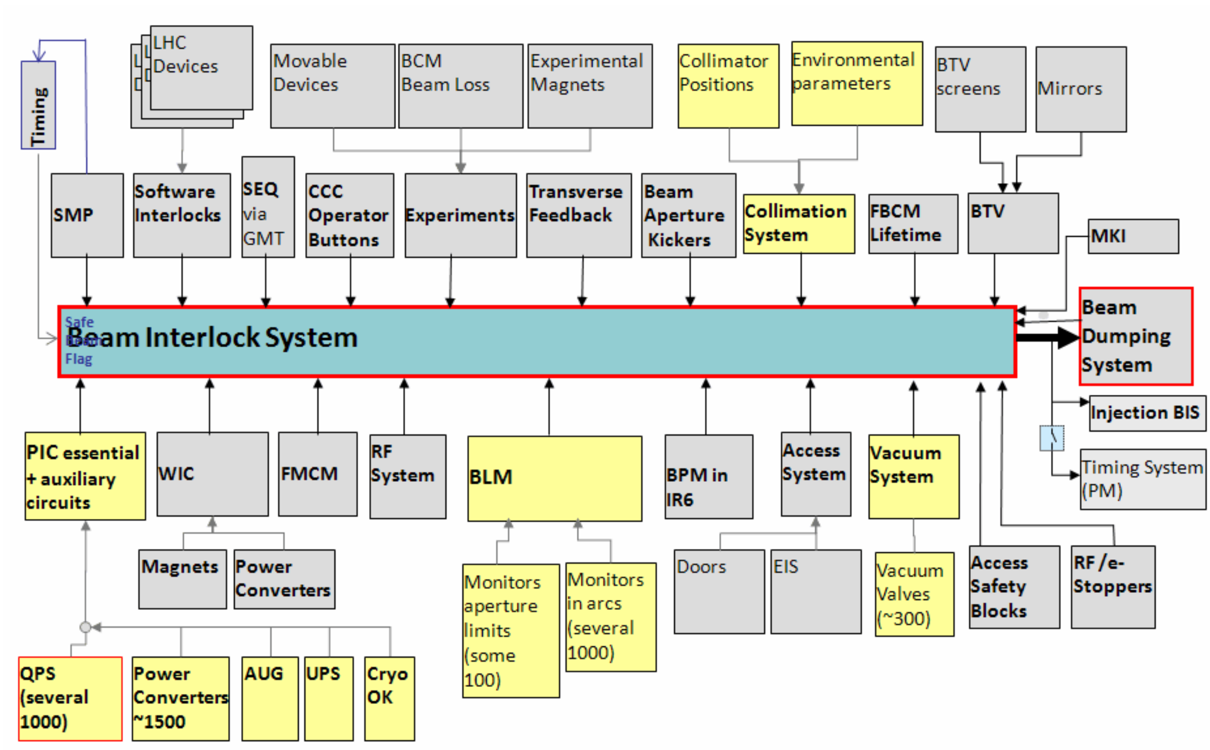


Figure 1: Schema of the LHC Machine Protection System with all its clients.

### *LHC BIS Inputs*

There will be 3 new inputs to the LHC ring BIS for

- the access safety block in IR3 (was coupled to a vacuum input in 2008),
- the electron stopper in IR4 (was coupled to a vacuum input in 2008),
- the fast beam lifetime interlock in IR4.

### *SIS Changes*

The SIS [3] software itself will only see minor changes. But the SIS core process has multiple dependency to standard CO software products (FESA, JAPC, etc) and must follow the trend. For the LHC new tests will be added, for example:

- Powering interlocking with access zones.
- Orbit and COD current surveillance.
- IR6 beam position with respect to the TCDQ and to the secondary collimator.

The core of the interlocks on PC states ($\sim$ 3600 tests) will not be touched to avoid the necessity of complete re-commissioning.

The role of SIS will become more and more important for the LHC because it is the only system where interlocks that perform LHC wide correlations may be implemented 'easily'. SIS plays an important role to fight multiple failures that happen in coincidence. There is no limit to interlock complexity since the logic is implemented in JAVA, but as the logic becomes more complex, the tests also become difficult to perform. The availability of the LHC may also be affected if the interlock logic is not implemented carefully in particular all aspects related to missing data. The response time of SIS is limited to around 1 second.

## PROCEDURES AND DOCUMENTATION

MPS test procedures (LHC-OP-MPS-XXX) were prepared for 2008, but only two documents were formally approved, for injection and for the BIS. The procedures are in the process of being reviewed based on the 2008 commissioning experience. The goal is to have all procedures released by April 2009.

To find a good documentation schema for the diversity of test that have to be performed for each system involved in machine protection has been a moving target. Test results range from simple 'YES/NO' to extensive analysis for beam related tests. In 2008 the documentation was based on a WEB page and EXEL sheets, which is difficult to maintain for such a complex system. As from 2009 a new and more rigorous approach will be started based on MTF/EDMS tuned for MPS needs. At the time of writing the work was in progress.

MPS issue tracking is made since 2008 with the standard

BE-CO software issue tracking tool. Apart from some software development specific overhead this tools is rather adequate for MPS purposes. In 2009 this tool will be reused.

## COMMISSIONING STRATEGY

The general strategy for MPS commissioning is to repeat all tests since there have been a significant number of hardware and software changes.

Systematic testing will be performed since 'sample testing' is considered to be too risky given the required overall SIL level of the MPS. A few systems involved in MP concentrate a large amount of devices: PIC, BLMs, Vacuum, Collimators. Such systems are are tedious and lengthy to test. Automation avoids mistakes due to repetitive work, but requires of course extremely well tested software. Systems that are targeted for automated testing in 2009:

- SPS to LHC transfer line PC and BTV tests are already fully automated since 2007.
- PIC tests are automated since 2008 and will be consolidated for 2009.
- Collimator tests were largely automated in 2008, and improvements are in the pipeline for 2009.
- Automated pre-fill tests of the BLM system will be prepared.
- Preparation for automated tests of the vacuum valve interlocks are ongoing.

In 2008 a reliability run was made for the LBDS, and an availability run for the LHC beam permit loops. Those tests were both important and successful. For 2009 a BLM availability run should be planned for July or August. The exact conditions must still be specified, but in case the beam energy distribution must be operational. This test run is essential in particular because a large fraction of the BLMs in 4 sectors will be dismounted and re-installed. In addition the BLM system was never fully operational to this date. The BLM monitor tests with radioactive source will be also repeated for all monitors.

### *Post-Mortem System*

In 2009 a rather complete (BIS, powering and essential beam instrumentation) Post-Mortem system [4] will be needed to analyze:

- some MPS tests,
- the programmed dumps, since even a dump that is perfectly executed provides information on abort gap population, TCDQ and TCT settings and protection.
- the "natural" failures that will occur. They provide invaluable info on MPS performance and complete the information obtained from tests.

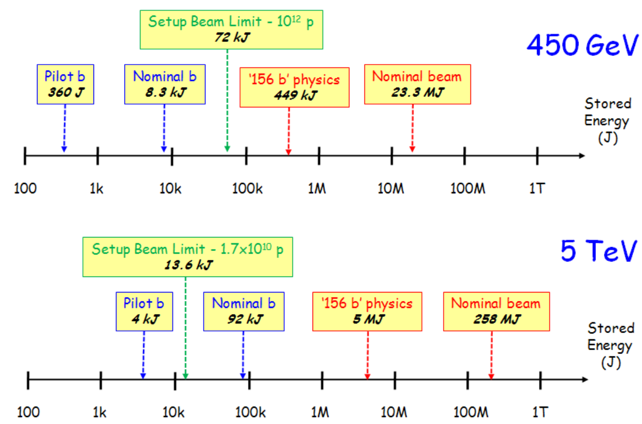


Figure 2: Stored beam energy at 450 GeV and 5 Tev for different beam types. 'b' stands for bunch, '156 b' physics corresponds for early physics with $4 \times 10^{10}$ p/bunch.

The MPS performance must be analyzed for ALL events due to failures, and a *beam dump event database* must be build.

### *Dedicated MPS Machine Periods*

Some MPS components can only be tested when the Beam Energy Tracking System (BETS) of the LDBS is working. Such tests require dedicated periods where eventually at least half of the LHC must be available (also for ramps), namely sectors 45, 56, 67 and 78. Components that require such dedicated periods are:

- The BETS itself for its own internal interlock tests,
- LBDS dry runs,
- The Safe Energy Flag,
- BLM threshold and their dependence on energy,
- Some 'full chain' interlock tests (from source to dump) on a selection of inputs.

It is essential that such test periods are not shifted to the last minute, or even beyond as it happened in 2008.

### *Towards Beam Operation*

In an IDEAL WORLD all MPS test should be performed before beam commissioning is started. But some critical MPS tests require beam, and there is a margin for beam operation without fully tested MPS, provided the energy and intensity is low enough, see Fig. 2. Furthermore, as soon as the full machine is ready for 450 GeV operation, there will be a strong pressure to go ahead and not to first spend a longer period for MPS tests. A strategy must therefore defined to provide LIMITED flexibility for safely interleaving beam and MPS commissioning periods.

| Phase | Energy | Intensity | Comment |
|---|---|---|---|
| MPS-1<br>Probing 450 | 0.45 TeV | $\leq 10^{10}$ | Early commissioning phase<br>Minimal interlock configuration 2008-style<br>All PIC powering interlocks are maskable<br>Experiments protection must be ready! |
| MPS-2<br>Ramp | 0.45-7 TeV | $\leq 10^{10}$ | All interlocks are commissioned<br>Post-mortem recording is operational<br>Beam related MPS tests are passed at 450 GeV<br>Commission in steps of 0.5-1 TeV |
| MPS-3<br>Increasing int.<br>at injection | 0.45 TeV | $\geq 10^{11}$ | All interlocks are commissioned<br>Post-mortem recording is operational<br>Beam related MPS tests are passed at 450 GeV |
| MPS-4<br>Squeeze | | | All interlocks are commissioned<br>Subset of tests must be repeated at every squeeze step |
| MPS-5<br>Unsafe injection | 0.45 TeV | $\geq 10^{11}$ | All injection-related MPS tests passed |

Table 1: MPS commissioning phases.

Guidelines for when to perform MPS tests during beam commissioning should:

- follow the definition of Safe/Setup Beam intensity limit, $I \leq 10^{12} \times (450/E)^{1.7}$, where $E$ is the beam energy in GeV.
- take into account uncertainties on what is safe due to the difficulty of estimating shock damage, plastic deformation or the complex and delicate material mixture of the super-conducting coils.
- follow the ALARA rule: even safe beams should not be lost in the machine too frequently.
- anticipate the next commissioning steps and take into account that time is needed to analyze the test data (Post-Mortem data).

### *Tests with Beam*

Beam tests are an essential part of the MPS commissioning. This is due to the fact that the BLMs and collimators are essential elements for failure protection. The BLMs cover the largest volume in 'failure phase-space': eventually every failure leads to visible beam loss somewhere along the 26.7 km of the LHC. Only beam tests can ensure that the performance of the BLM system is adequate. Some failures must be provoked to verify assumptions on reaction times, loss patterns and BLM thresholds, and ensure that the machine can be protected at higher intensity and energy. The beam tests are done with low intensity, $\sim 10^{10}$ p at 450 GeV which corresponds to less than 1 kJ of stored energy. Such an intensity is a factor 100 below the setup beam limit [5]. The beam tests will be performed, respectively repeated, for higher intensity and energy as required, but only if lower intensity, lower energy tests are passed. Unfortunately one cannot rely on natural occurrence of failures, else their frequency would drive the LHC commissioning!

### *Beam Commissioning Strategy*

The most general strategy of MPS commissioning is the 'probe beam rule'. A probe beam of $2 - 5 \times 10^9$ charges must be used whenever

- new energy ranges are explored,
- new squeeze steps are explored,
- significant changes that affect the aperture are made to the LHC, for example a change of the reference orbit or a beta-beat or optics correction.

For the last category the exact conditions must still be defined. Any action listed above must be performed in collaboration with MPS expert(s).

The different phases for beam and MPS commissioning as proposed today are detailed in Table 1.

## CONCLUSION

The BIS will see minor modifications in 2009, and the SPS will be the usual 'guinea pig'. The general strategy for the MPS is to (re)test everything. MPS beam tests will be essential to asses the system performance and the Post-Mortem system will be required to analyze MPS beam tests and natural failures. Beam instrumentation data integration and the development of first beam PM analysis modules is the top priority for 2009. Coexistence of beam and machine protection commissioning is possible with appropriate coordination (anticipation !). The MPS profits from the natural commissioning evolution in steps of energy, complexity and intensity. A core MPS team must follow beam commissioning on a daily basis and should review the MPS performance at (to be defined) intensity/energy stages in the LHC commissioning.

## ACKNOWLEDGEMENTS

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