Interlock Test Procedure

Procedures for the Commissioning of the Beam Interlock System for the CNGS and SPS-LHC Transfer Lines

Abstract

This document describes the beam commissioning interlock procedures for the transfer lines from the SPS ring to the CNGS target (TT40 and TT41 transfer lines) and from the SPS to the LHC (TT40, TT60, TI2 and TI8 transfer lines). Beam commissioning test procedures are defined for each client system that is connected to the interlock system. Different test phases are defined with and without beam, and with increasing beam intensity.

Prepared by:
J. Wenninger

Checked by:
J.C. Billy
E. Carlier
S. Jackson
L. Jensen
M. Jonker
B. Goddard
M. Meddahi
B. Puccio
R. Schmidt
J. Uythoven
M. Zerlauth

Approved by:
R. Schmidt

Approval List
## History of Changes

<table>
<thead>
<tr>
<th>Rev. No.</th>
<th>Date</th>
<th>Pages</th>
<th>Description of Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>09 June 05</td>
<td></td>
<td>First draft</td>
</tr>
<tr>
<td>0.2</td>
<td>17 Aug 05</td>
<td></td>
<td>Completed test lists, cleaner description of the tests.</td>
</tr>
<tr>
<td>0.3</td>
<td>Dec. 05</td>
<td></td>
<td>Revision to improve naming and structure.</td>
</tr>
<tr>
<td>0.4</td>
<td>Jan. 05</td>
<td></td>
<td>Complete restructuring, prepare for comments.</td>
</tr>
<tr>
<td>0.5</td>
<td>Mar.06</td>
<td></td>
<td>Revision based on general comments.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Timing diagrams added.</td>
</tr>
<tr>
<td>0.6</td>
<td>2006-05-16</td>
<td></td>
<td>Submission for approval.</td>
</tr>
</tbody>
</table>
# Table of Contents

1. **INTRODUCTION** ........................................................................................................................................... 5
2. **PURPOSE** ....................................................................................................................................................... 5
3. **SCOPE** ............................................................................................................................................................ 5
4. **EXTRACTION AND USER-PERMIT TIMING** ..................................................................................................... 6
5. **INTERLOCK TEST CLASSIFICATION** ................................................................................................................ 8
   5.1 **INDIVIDUAL SYSTEM TESTS** .................................................................................................................. 9
   5.2 **HARDWARE COMMISSIONING TESTS** ...................................................................................................... 9
   5.3 **BEAM COMMISSIONING TESTS** ............................................................................................................... 9
6. **CONTROL SYSTEM SERVICES FOR INTERLOCK TESTS** .................................................................................. 9
   6.1 **GENERAL MACHINE TIMING** .................................................................................................................. 10
   6.2 **INTERLOCK SETTINGS** ............................................................................................................................ 11
7. **INTERLOCK COMMISSIONING PHASES** ............................................................................................................ 11
   7.1 **BEAM INTENSITY PHASES** ...................................................................................................................... 12
   7.1.1 **BEAM INTENSITY INCREASE – PHASE VI** ......................................................................................... 12
   7.1.2 **BEAM INTENSITY STEPS** ................................................................................................................ 12
8. **SPECIAL INTERLOCK ISSUES** .......................................................................................................................... 14
   8.1 **LATCHED INTERLOCKS** .......................................................................................................................... 14
   8.2 **INTERLOCK MASKING AND SAFE BEAM FLAG** ....................................................................................... 14
9. **RECOVERY FROM THE TESTS** ........................................................................................................................ 14
10. **STATUS AFTER THE TESTS** ............................................................................................................................ 14
11. **DOCUMENTATION** .......................................................................................................................................... 14
12. **INTERLOCK COMMISSIONING – GENERIC TESTS** .......................................................................................... 15
   12.1 **SAFE BEAM FLAG** .................................................................................................................................... 15
   12.1.1 **MP-TEST:SBF** ....................................................................................................................................... 15
   12.2 **GENERIC TESTS** ...................................................................................................................................... 16
   12.2.1 **MP-TEST:MASK** .................................................................................................................................. 16
   12.2.2 **MP-TEST:TIMING-EVENT-SHIFT** ..................................................................................................... 16
   12.2.3 **MP-TEST:ABSENCE-TIMING-EVENT** ................................................................................................. 16
   12.2.4 **MP-TEST:LATCH** .................................................................................................................................. 17
   12.2.5 **MP-TEST:FE-REBOOT** ...................................................................................................................... 17
13. **INTERLOCK COMMISSIONING – TESTS WITHOUT BEAM** .............................................................................. 18
   13.1 **SYSTEMS AND INTERLOCKS WITHOUT SETTINGS** .................................................................................. 18
   13.1.1 **VACUUM VALVES** .................................................................................................................................. 18
   13.1.2 **PERSONAL PROTECTION DEVICES** .................................................................................................. 18
   13.1.3 **MOBILE TRANSFER LINE BEAM DUMPS** ......................................................................................... 19
   13.1.4 **CNGS NEUTRINO TARGET** ................................................................................................................. 19
   13.1.5 **CNGS HORN** ...................................................................................................................................... 20
   13.1.6 **CNGS HADRON STOP COOLING** ....................................................................................................... 20
   13.1.7 **FAST INTERNAL POWER CONVERTER INTERLOCKS** ...................................................................... 21
   13.1.8 **WARM MAGNET INTERLOCKS** ............................................................................................................ 21
   13.1.9 **EXTRACTION SEPTUM MAGNET INTERLOCK** ..................................................................................... 22
13.1.10  BEAM PROFILE SCREENS ............................................................... 24
13.2  SYSTEMS AND INTERLOCKS WITH SETTINGS ............................... 25
  13.2.1  COLLIMATOR POSITIONS ......................................................... 25
  13.2.2  POWER CURRENT SURVEILLANCE .......................................... 25
  13.2.3  EXTRACTION SEPTUM GIRDER POSITION .................................. 27
  13.2.4  EXTRACTION KICKER ............................................................... 27
14.  INTERLOCK COMMISSIONING – BEAM TESTS .................................. 29
  14.1  BEAM TEST IN THE SPS RING ...................................................... 29
    14.1.1  BEAM INTENSITY ................................................................. 29
    14.1.2  BUMPED BEAM POSITION .................................................. 29
    14.1.3  RADIAL BEAM POSITION .................................................... 31
  14.2  BEAM TEST IN THE TRANSFER LINES ........................................ 33
    14.2.1  BEAM LOSS MONITORING .................................................... 33
    14.2.2  TRANSFER LINE BEAM POSITION ......................................... 34
    14.2.3  FAST MAGNET CURRENT CHANGE MONITOR .......................... 36
15.  REFERENCES .................................................................................. 37
1. INTRODUCTION

In 2006 the SPS will be delivering high intensity beams to the CNGS target and in 2007/2008 to the two LHC rings through the extraction channels located in LSS4 (CNGS and LHC ring 2) and LSS6 (LHC ring 1). The beam intensities of up to \(3.5 \times 10^{13}\) protons per extraction require strict interlocking of the extraction channels and transfer lines, since such intensities exceed by roughly one order of magnitude what can be considered as safe beam intensity, i.e. below damage threshold for tunnel equipment. At 450 GeV the highest intensity for a safe LHC type beam (with nominal emittance of 3.5 mm mrad) corresponds to \(1-2 \times 10^{12}\) protons [1].

The extraction channels and transfer lines are protected by a hardware interlock system that is identical to the LHC beam interlock system [2]. The interlock system gives the possibility to prevent an extraction up to a few microseconds before the arrival of the extraction pre-pulse signal that triggers the extraction kickers. The architecture of the extraction interlock system has been specified in separate documents [3,4].

A number of equipment systems provide client input signals (USER_PERMITs) to the interlock system hardware modules (the Beam Interlock Controllers, BIC). The connection between client system and BIC modules as well the state transition logic for USER_PERMITs must be tested according to pre-defined procedures during the commissioning of the interlock system. The commissioning itself is split into different phases that correspond to operation of the transfer lines and extraction systems without beam, with low intensity beam and finally with nominal beam intensities.

In addition to the hardware interlock system, the transfer lines and extraction channels are also protected by a Software Interlock System (SIS) [5] with slower reaction time. The SIS complements the hardware interlock system by providing early warning for certain fault conditions and by interacting with the General Machine Timing System to stop beam production when extraction is not possible. The SIS also provides a software USER_INPUT (set remotely through a controls network connection) to a subset of the BIC modules that are part of the extraction interlock system. The test procedures for the SIS interlocks are not described in this document and may be the subject of a separate document.

This document describes the beam interlock tests to be performed for the different USER_PERMIT signals that enter the extraction and transfer line interlock system. The different commissioning phases are described.

2. PURPOSE

The purpose of this document is to establish all steps that lead to the commissioning of the transfer line beam interlock systems. This interlock commissioning document lists the procedures to be carried out and describes them in detail.

It is likely that the interlock system and the USER_PERMITs provided by client systems will evolve with time (in particular in the first years of operations). As a consequence this document will have to be updated in the future to reflect those changes.

3. SCOPE

The interlock systems and interlock clients concerned by this specification cover the following SPS machine areas:

- the SPS long straight section LSS4
- the TT40 transfer line common to CNGS and LHC (ring2)
• the TT41 transfer line to the CNGS target, the T40 target zone and the CNGS secondary beam
• the TI8 transfer line to the downstream mobile dump (TED)
• the SPS long straight section LSS6
• the TT60 transfer line
• the TI2 transfer line to the downstream mobile dump (TED)

The last sections of the TI2 and TI8 transfer lines between the last TED and the LHC ring will be described in a separate document.

The main actors concerned by the interlock commissioning procedures are the equipment groups responsible for the individual systems as well the persons responsible for the correct execution and the documentation of all tests.

The following list details the different types of interlock client signals and surveillance tasks. It is important to note that each type of interlock client may provide more than one USER_PERMIT to the interlock system. The client groups are:

1. Power converter current surveillance (maskable USER_PERMIT).
2. Fast Magnet Current change Monitors (FMCM) (maskable USER_PERMIT):
   Observable: current/voltage decay in the electrical circuit.
3. Fast PC interlock signal (maskable USER_PERMIT).
4. Warm magnet interlocks (WIC):
   Observable: magnet temperature.
5. Extraction septum magnet surveillance.
   Observable: magnet temperature and cooling.
   Observable: magnet and powering status.
7. Extraction septum girder position (maskable USER_PERMIT).
8. Bumped beam position at extraction point (maskable USER_PERMIT).
9. Radial beam position in the SPS ring (maskable USER_PERMIT).
11. Beam position in the transfer lines (maskable USER_PERMIT).
15. Vacuum valve position.
16. TCDI collimator positions (maskable USER_PERMIT).
17. CNGS Neutrino target (subset of USER_PERMITs are maskable):
   Observable: target position and movement, target cap shield position.
18. CNGS magnetic horn powering status.
19. CNGS hadron dump cooling status.

The detailed equipment lists are presented for each group in a separate document [8].

4. EXTRACTION AND USER-PERMIT TIMING

The status of all active USER_PERMIT signals connected to the extraction interlock system is used to generate the EXTRACTION_PERMIT signal. This signal is send to the extraction kicker. The kicker is triggered if the EXTRACTION_PERMIT is TRUE [3].
Firing of the extraction kickers proceeds in two steps that are shown in Figure 1. Approximately 15 ms before the time of extraction the Pulse Forming Networks (PFN) are charged from the main capacitor banks. The PFNs are only changed if the EXTRACTION_PERMIT signal is TRUE at this moment. The extraction kickers are triggered by the accurate RF pre-pulse signals provided the EXTRACTION_PERMIT signal is still TRUE when the pre-pulses arrive. For practical reasons the EXTRACTION_PERMIT signal that is provided to the extraction kicker switches shortly from FALSE to TRUE when all conditions are correct for extraction just before the PFNs are charged and just before the moment of extraction.

Most interlock client systems provide a ‘static’ USER_PERMIT: the USER_PERMIT switches rarely between TRUE and FALSE because the state of the system changes slowly or rarely (for example vacuum valves). In addition the transitions are frequently asynchronous with the beam and the SPS cycle.

A significant fraction of the USER_PERMITS, including all permits related to beam observables, are by default in state FALSE. Such USER_PERMITS are designed to switch to TRUE a short moment before extraction (typically following a measurement of a selected parameter) and are automatically reset to FALSE shortly after the moment of extraction. The processes that generate such USER_PERMITS are triggered by machine timing events. In the absence of the timing event, the USER_PERMIT remains FALSE and the extraction is never enabled. Since the EXTRACTION_PERMIT is the result of a logical AND of all relevant USER_PERMITS, it will only be in the state TRUE for a short moment before extraction when all USER_PERMITS are TRUE (when all conditions for extraction are fulfilled). Figure 2 shows examples of USER_PERMITS...
derived from beam and from power converter surveillance processes that only switch to TRUE for a short time interval around extraction.

Figure 2: Timing sequence of some USER_PERMITs that are triggered shortly before extraction in the situation where the extraction is authorized by the interlock system. USER_PERMITs generated by beam instrumentation equipment are typically triggered by timing events distributed between 100 and 50 ms before extraction. The power converter current surveillance USER_PERMIT is triggered twice at around extraction -15 ms and just before the extraction. The resulting EXTRACTION_PERMIT signal sent to the kicker consists of two short (few milliseconds long) pulses: because the extraction permit is the logical AND of all USER_PERMITs, its shape is given by the power converter surveillance USER_PERMIT that provides the USER_PERMIT with the shortest time duration.

The extraction kicker control system is connected to the SPS ring beam interlock system to be able to dump the beam when the EXTRACTION_PERMIT does not follow the nominal timing sequence. The circulating beam in the SPS is dumped whenever:

- the first CNGS batch is not extracted,
- the PFNs have been charged, but the kicker has not been triggered due to an interlock.

5. INTERLOCK TEST CLASSIFICATION

The tests to be performed for each client system are split into 2 categories following a nomenclature similar to that used for LHC Hardware Commissioning (HC): Individual System Tests and Hardware Commissioning Tests. Individual System Tests concern only a single equipment category, while HC Tests involve the interaction of two or more systems.

For the interlock tests, the corresponding 2 categories are:

1. Individual system tests
2. Beam commissioning test

This document covers tests belonging to the second class of tests, although there is some overlap with individual system tests in some cases described below.
5.1 INDIVIDUAL SYSTEM TESTS

The generation of the USER_PERMIT signals for the Beam Interlock Controller (BIC) modules by the clients systems must be failsafe. In case of a system failure (disconnected cable, real-time process abort, front-end computer or PLC failure...) the USER_PERMIT that is delivered by the system must switch to a FALSE state.

It is the responsibility of the system engineers to define and carry out all relevant tests that concern only their system, defined as Individual System Tests in line with the definitions used for LHC Hardware Commissioning.

The definition of the list of Individual System Tests to be carried out on each system is beyond the scope of this specification. Test procedures should be defined for each system, and all tests documented for acceptance.

The Beam Interlock System itself, which includes the BIC modules, CIBU (user) interfaces and all connections, must be tested according the pre-defined procedure as outlined in [5].

5.2 HARDWARE COMMISSIONING TESTS

Interlock tests are considered to belong to the category of hardware commissioning tests if one or more of the following conditions apply:

- The interlock test involves the General Machine Timing.
- The interlock test involves interlock settings, for example tests that involve critical settings that will be managed by the MCS system [7].

Tests belonging to this category may be performed during the SPS machine checkout period.

5.3 BEAM COMMISSIONING TESTS

Interlock tests are considered to belong to the category of beam commissioning tests if one or more of the following conditions apply:

- The interlock test involves USER_PERMIT masking and/or the Safe Beam Flag of the SPS.
- The interlock test requires the presence of beam in the SPS or the concerned transfer line.

Tests that belong to this category can only be performed during the SPS run with the appropriate beams (structure and intensity) and cycles.

6. CONTROL SYSTEM SERVICES FOR INTERLOCK TESTS

The SPS is a fast cycling machine where different beams may be executed in parallel. In the future the composition of the beams within the SPS machine super-cycle is expected to vary a few times per day. Between two super-cycle changes, the beam composition remains stable.

The transfer lines and extraction elements for CNGS and LHC will be pulsed according to the running SPS super-cycle. The super-cycle is itself composed of elementary cycles. Each elementary cycle is associated to a beam type. Super-cycles may be composed of elementary cycles that mix CNGS, Fixed Target (FT) and LHC beams. All cycle dependent interlock settings of a given super-cycle must be available in the front-end computers at the same time like any other machine setting.
6.1 GENERAL MACHINE TIMING

The General Machine Timing of all CERN machines is managed by the Central Beam and Cycle Manager (CBCM). The CBCM is composed of Master Timing Generators (MTG), one MTG being associated to each machine. The MTGs generate the machine timing events that are distributed to a given accelerator of the CERN complex.

The machine timing events distributed by the SPS MTG are used to execute and synchronize all tasks within the SPS equipment that are required to inject, accelerate and eject a given beam in the SPS. Cycle identifiers (the machine ‘USER’) distributed by the timing system are used to select appropriate settings for each SPS cycle within a super-cycle. The settings for all cycles of the running super-cycle must be resident in all SPS equipment, the cycle identifiers being used to select the appropriate subset of settings for each cycle.

The interlock clients of the transfer line interlock systems for LHC and CNGS depend on the machine timing system through:

1. timing events that trigger real-time tasks in front-end systems to survey equipment parameters or record beam observables,
2. cycle identifiers that are used to select the correct interlock reference setting.

The following interlock types that depend directly on the machine timing:

1. Power converter current surveillance.
   - Interlock settings depend on the SPS machine cycle.
   - The USER_PERMIT is generated few milliseconds before extraction by a real-time task which is triggered by a GMT event. This real-time task switches the USER_PERMIT to TRUE for a few milliseconds when no fault condition is detected.

2. Extraction kicker status.
   - Interlock settings depend on the SPS machine cycle.

3. Bumped beam position at extraction point.
   - Interlock settings depend on the SPS machine cycle.
   - The USER_PERMIT is generated few milliseconds before extraction by a real-time task which is triggered by a GMT event. This real-time task switches the USER_PERMIT to TRUE when no fault condition is detected. The USER_PERMIT is reset to FALSE at the end of the SPS cycle.

4. Radial beam position in the SPS ring.
   - Same conditions than for the bumped beam position.

5. Beam loss monitoring.
   - Interlock settings depend on the SPS machine cycle.
   - The USER_PERMIT is switched to TRUE approximately 100 milliseconds before extraction by a real-time task which is triggered by a GMT event. The USER_PERMIT switches to FALSE after extraction when a fault conditions is detected. If no fault condition occurs the USER_PERMIT is reset to FALSE at the end of the SPS cycle.

6. Transfer line beam position monitoring.
   - Interlock settings depend on the SPS machine cycle.
   - The USER_PERMIT is switched to TRUE approximately 100 milliseconds before extraction by a real-time task which is triggered by a GMT event. The USER_PERMIT switches to FALSE after extraction when a fault conditions is detected. If no fault condition occurs the USER_PERMIT is reset to FALSE at the end of the SPS cycle.
7. Beam intensity interlocks.
   - Interlock settings depend on the SPS machine cycle.
   - The dump or extraction inhibit actions are triggered by GMT events at the start of the ramp or before extraction.

   - Extraction pulse for post-mortem freeze.
   - PPS for timestamp accuracy.

For the interlock tests, the GMT timing is required to verify the correct synchronization of the reaction times and delays of interlock signals.

6.2 INTERLOCK SETTINGS

A significant number of systems require interlock settings in the form of reference values, tolerance windows and thresholds. In many cases the settings depend on the SPS cycle and beam type as explained in the previous section. All clients in the list given in section 6.1 must dynamically switch their interlock settings according to the running machine cycle.

A coherent settings management for machine settings and for interlock settings must be developed to ensure consistent downloading of settings from a central repository. Contrary to normal machine settings, the interlock settings must be protected by an adequate access and authorization procedure. Concepts for secure management of critical settings have been developed for the LHC [7]. The same system of critical settings management (MCS) will also be used at the SPS when it will become operational. For the SPS machine run in 2006, management of the interlock settings will be performed by ad-hoc programs (on a system by system basis).

For each new super-cycle that is commissioned and used in the SPS, all interlock settings must be adjusted to the new machine and beam conditions.

A complete test including each setting value must be performed for the first operational cycle associated to a given transfer line, as described in the test procedures of this document.

7. INTERLOCK COMMISSIONING PHASES

The commissioning of the interlock system may be split into the following main phases:

- **Phase I**: Individual System Tests.
- **Phase II**: Commissioning without beam. General Machine Timing and high level application software are not available or not sufficiently operational.
- **Phase III**: Commissioning without beam. General Machine Timing and high level application software are operational. Recording of settings changes (‘trim history’) is available.
- **Phase IV**: Commissioning with low intensity beam in the SPS ring. No beam extraction.
- **Phase V**: Commissioning with low intensity beam in the transfer lines.
- **Phase VI**: Commissioning with high(er) intensity beams following the steps defined below.

All the tests that are described in this document (section 12) are classified according to the different phases in Table 1.

Some of the tests that are described in this document fall into phases I/II. Such tests may be considered to be part of ISTs. The interest of such tests is to be able to...
perform random tests on each system as a cross-check. For the machine protection
system, such tests have a function that is similar to the access system tests that are
performed by the DSO before an accelerator is allowed to begin operation with beam.

7.1 BEAM INTENSITY PHASES

Commissioning of the interlock system must be performed initially with safe beam
intensities of no more than $10^{12}$ protons in phases IV and V.
Whenever the beam intensity or number of bunches is increased significantly the
interlock system must be verified and tested for beam induced EMC – no spurious or
unexpected TRUE-FALSE transitions must occur on any USER_PERMIT - or for
problems with beam instrumentation that is part of the interlock client systems.

7.1.1 BEAM INTENSITY INCREASE – PHASE VI

For each step in beam intensity or in beam structure (number of bunches or batches),
the beam must initially not be extracted from the SPS ring. The beam is prepared for
extraction, including the extraction bump, but the extraction kicker is inhibited. No
interlock or abnormal behaviour of any element must be observed over at least 50
consecutive machine cycles with beam.
In the second stage the beam is extracted. The beam instrumentation and interlock
signals must be carefully analysed to exclude any EMC on interlock client systems.

7.1.2 BEAM INTENSITY STEPS

Intensity steps for the CNGS beam:
- Commissioning beam $\leq 2\times10^{12}$ protons.
- Intermediate beam of $6\times10^{12}$ protons with one batch (PS injection).
- Intermediate beam of $10^{13}$ protons with one batch.
- Intermediate beam of $10^{13}$ protons per batch with 2 batches.
- Nominal beam of $2-3\times10^{13}$ protons with one batch.
- Nominal beam of $2-3\times10^{13}$ protons with 2 batches.

Intensity steps for the LHC beam:
- Commissioning beam $\leq 10^{12}$ protons.
- One nominal PS batch (72 bunches) of $7\times10^{12}$ protons total intensity.
- Two nominal PS batches (2×72 bunches) of $1.4\times10^{13}$ protons total intensity.
- Three nominal PS batches (3×72 bunches) of $2.1\times10^{13}$ protons total intensity.
- Four nominal PS batches (4×72 bunches) of $2.8\times10^{13}$ protons total intensity.
Table 1: Test condition summary for the commissioning tests that are defined in this document.

<table>
<thead>
<tr>
<th>System</th>
<th>Test</th>
<th>Machine Timing</th>
<th>Settings Management</th>
<th>Beam in SPS</th>
<th>Beam in TL</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum valves</td>
<td>VALVE-POS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNGS target</td>
<td>T40-ROT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>I/II</td>
</tr>
<tr>
<td></td>
<td>T40-AIR-COOL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T40-CAP-SHIELDING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T40-TABLE-POS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T40-NOTARGET</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNGS horn</td>
<td>CNGS-HORN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNGS hadron stop</td>
<td>CNGS-HAD-COOL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal protection devices</td>
<td>PPD-STATE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TED dumps</td>
<td>TED-STATE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Septum girder</td>
<td>SEPT-GIRDER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WIC</td>
<td>WIC-DELAY</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>III</td>
</tr>
<tr>
<td>Septum magnet</td>
<td>SEPT-DELAY</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extraction Kicker</td>
<td>MKE-STATUS</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MKE-ETRACK</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MKE-RING-DUMP</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collimators</td>
<td>JAW-POS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Profile monitors</td>
<td>BTV-POS</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power converters</td>
<td>FAST-PCINT-DELAY</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PC-REF</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MBG-MBI-SWITCH</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Current (SPS ring)</td>
<td>BCT-RING</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>IV</td>
</tr>
<tr>
<td></td>
<td>BCT-LSS4</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam position (SPS ring)</td>
<td>EXTR-BP</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>VI</td>
</tr>
<tr>
<td></td>
<td>EXTR-BP-SETTINGS</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SPS-BP-RADIAL</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SPS-BP-RADIAL-SETTING</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam position (CNGS)</td>
<td>CNGS-BP1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>CNGS-BP2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Beam loss</td>
<td>BLM-LOSS</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>VI</td>
</tr>
<tr>
<td>FMCM</td>
<td>FMCM-BP</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
8. SPECIAL INTERLOCK ISSUES

8.1 LATCHED INTERLOCKS

Beam position and beam loss interlocks in the transfer lines will be latched at the level of the client system: the USER_PERMIT will remain FALSE until a manual reset is performed. Interlock latching is used to inhibit the second CNGS extraction when an interlock is generated following the first extraction and more generally to inhibit extractions in the following cycles.

Interlock latching must be tested for two situations:
- Latching of an interlock that is set following the first CNGS extraction to prevent the second extraction.
- Latching of an interlock for subsequent cycles.

8.2 INTERLOCK MASKING AND SAFE BEAM FLAG

Specific tests must be performed for each maskable USER_PERMIT. It must be ensured that the mask is properly applied and removed according to the status of the Safe Beam Flag. The tests are described in detail below.

9. RECOVERY FROM THE TESTS

At the end of the test procedures all machine and interlock settings must be set to their operational values.

10. STATUS AFTER THE TESTS

For a given beam intensity range, as indicated in section 7.1, the beam interlock system for a transfer line group is considered to be commissioned and ready for beam operation up to the maximum beam intensity of the range.

If the beam intensity is increased beyond the operational range, a check procedure as described in section 7.1.1 and 0 must be performed.

11. DOCUMENTATION

Every test described in the following sections must be documented. A template document will be made available. The documentation must include:
- Date and time of the test.
- Name of the persons in charge of the test.
- Identification of the SPS cycle (LSA cycle name) and of the timing user.
- Test description, including:
  - values for settings, tolerances and thresholds.
  - lists of all tested devices in case of complex systems like power converters, beam loss monitors, etc.
  - test of masking – if applicable.
- Timing results: USER_PERMIT transition times as measured by the associated BIC module.
12. INTERLOCK COMMISSIONING – GENERIC TESTS

The key observable for individual system tests is the USER_PERMIT. The state change of this logical signal from TRUE to FALSE (and vice-versa) must follow a defined logic that depends on the state of one or more parameters of the system that generates the USER_PERMIT.

For all tests that are described in this document it is assumed that the USER_PERMIT state transitions are recorded with the BIC history buffer using the BIC surveillance application. This provides the benefit of a precise time-stamping of the state transitions.

12.1 SAFE BEAM FLAG

The Safe Beam Flag (SBF) is a critical flag that is used to allow masking of maskable BIC USER_PERMIT signals whenever the SBF status is TRUE.

12.1.1 MP-TEST:SBF

This test verifies correct generation of the Safe Beam Flag.

Initial conditions: the system to generate and transmit the SBF to all BIC modules that are part of the transfer interlock system is operational.

1. The SPS injection is stopped and no beam is circulating. The SBF must be TRUE.

2. The intensity injected into the SPS is progressively increased (steps to be defined based on the possibilities of the beam that is used for the tests).

3. When the beam intensity in the SPS exceeds the threshold of the Safe Beam, the SBF must switch to FALSE during the SPS ramp (but before the start of the SPS flat top). The SBF must switch back to TRUE at the end of the cycle.

4. The distribution of the SBF is verified for each BIC module. One maskable USER_INPUT that must be in the FALSE state is masked. The mask must be applied during the periods when the SBF is expected to be TRUE, ignore when the SBF is expected to be FALSE.

The time within the SPS (super-) cycle when the SBF switches state must be recorded.
12.2 GENERIC TESTS

Generic tests are not specific to a single equipment class, but they may be applied to a number of systems. Reference to those tests will be made for any system where one or more generic tests must be performed.

12.2.1 MP-TEST: MASK

This test verifies masking of a maskable USER_PERMIT.

Initial conditions: the USER_PERMIT is operational and the USER_PERMIT is forced to FALSE at the moment of extraction. The FALSE state may either be forced by the client system or obtained by a change of interlock reference settings etc.

1. A low intensity beam is injected into to SPS (or no beam is present). The Safe Beam Flag must be TRUE.
2. The USER_PERMIT is masked.
3. The BIC history is used to verify that the USER_PERMIT is effectively masked and that it does not affect the output signal of the associated BIC which must be TRUE.
4. An unsafe intensity beam is injected such that the Safe Beam Flag is FALSE.
5. The BIC history is used to verify that the USER_PERMIT is no longer masked and the output signal of the associated BIC is FALSE.

12.2.2 MP-TEST: TIMING-EVENT-SHIFT

This test verifies that a USER_PERMIT that is activated by a Central (CTIM) or Local (LTIM) timing event reacts correctly to a shift in time of the CTIM/LTIM. Such a USER_PERMIT is by default in state FALSE. Upon reception of a timing event, a real-time task is activated to survey a device parameter and to switch the USER_PERMIT to TRUE if the device parameter is within a defined range.

Initial conditions: the USER_PERMIT is operational and switches from FALSE to TRUE at a given time in the SPS cycle, triggered by a timing event. The time where the transition occurs (measured with respect to the start of the SPS cycle) is recorded.

1. The position of the timing event within the SPS cycle is shifted by a few milliseconds.
2. The BIC history is used to verify that the transition of the USER_PERMIT follows the changes of the timing event.

This test must be performed at least twice, for a positive (later time) and a negative shift (early time) of the timing event.

12.2.3 MP-TEST: ABSENCE-TIMING-EVENT

This test verifies that a USER_PERMIT that is activated by a Central (CTIM) or Local (LTIM) timing event is no longer activated in the absence of the triggering timing event.

Initial conditions: the USER_PERMIT is operational and switches from FALSE to TRUE at a certain time in the SPS cycle, triggered by a timing event.

1. The timing event is de-activated (disabled). This may be done on the event itself (LTIM or CTIM) or by de-activating the master timing event for the fast extraction.
2. The BIC history is used to verify that the USER_PERMIT remains FALSE and no longer switches to TRUE at any time in the cycle.
12.2.4 MP-TEST:LATCH

This test verifies that a USER_PERMIT triggered by a timing event that is configured to be latched following a transition from TRUE to FALSE due to an interlock is remaining in FALSE state until a manual reset is applied to the system.

**Initial conditions:** the USER_PERMIT is operational and provides a USER_PERMIT for extraction.

1. An interlock must be generated (by modifying the interlock reference or threshold or through a system test function).
2. The BIC history is used to verify that the USER_PERMIT remains FALSE and no longer switches to TRUE in the following cycle.
3. The interlock is reset and the cause of the interlock is removed.
4. The BIC history is used to verify that the USER_PERMIT is gained pulsing correctly between the TRUE and FALSE states.

12.2.5 MP-TEST:FE-REBOOT

This test verifies that a front-end system that generates a USER_PERMIT either fails safely after a crate reboot or is restored to the state before reboot, including all interlock settings.

For systems that require interlock settings, this test must be performed when the settings management is operational in order to test the data persistency and consistency.

**Initial conditions:** the front-end system is operational and provides a USER_PERMIT for extraction.

1. The front-end system is rebooted.
2. During the entire time interval where the front-end system is not operational, the USER_PERMIT must remain FALSE.
3. When the front-end system reboot is finished:
   a. The system must provide a correct USER_PERMIT for systems that do not depend on any setting.
   b. The USER_PERMIT must remain FALSE until the correct settings are downloaded in case there is no persistency of the interlock settings.
   c. The system must provide a correct USER_PERMIT for systems that do depend on interlock settings but where appropriate persistency mechanisms are provided.
13. INTERLOCK COMMISSIONING – TESTS WITHOUT BEAM

The tests described in this section must be performed and accepted before the beginning of beam operation. A significant fraction of the tests do not require machine timing nor high level settings management: they are therefore essentially ISTs.

13.1 SYSTEMS AND INTERLOCKS WITHOUT SETTINGS

Tests described in this sub-section do not involve any interlock settings, tolerances or thresholds.

13.1.1 VACUUM VALVES

All transfer line vacuum valves are interlocked. The USER_PERMIT associated to a group of vacuum valves is TRUE only when all valves are out of beam.

The test that is described here may also be performed and documented by the system engineer. Since however it is possible to control each valve independently from the control room, this test can also be performed by persons in charge of the interlock system commissioning.

For each front-end crate the reboot test MP-TEST:FE-REBOOT must be performed.

13.1.1.1 MP-TEST:VALVE-POS

This test verifies the correct functioning of the vacuum valve interlock.

This test must be repeated for each individual valve.

*Initial conditions:* all vacuum valves associated to the same BIC user permit are OPEN, such that the USER_PERMIT=TRUE.

1. A selected valve is closed.
2. The USER_PERMIT state is verified to be FALSE.
3. The selected valve is opened again.
4. The USER_PERMIT state is verified to be TRUE.

13.1.2 PERSONAL PROTECTION DEVICES

The personal protection devices (PPDs) for the transfer lines (TBSEs) and for the CNGS decay tube (CNGS shutter) are interlocked to prevent extraction of the beam when those devices are intercepting the beam. The associated USER_PERMIT must only be TRUE when the devices are on the end-switch associated to the position where the devices are not intercepting the beam.

For each front-end crate the reboot test MP-TEST:FE-REBOOT must be performed.

13.1.2.1 MP-TEST:PPD-STATE

This test verifies the correct functioning of the PPD interlock.

This test must be repeated for each individual PPD.

*Initial conditions:* the selected PPD is OUT of beam, such that USER_PERMIT=TRUE.

1. The selected PPD must be moved to the IN position.
2. The USER_PERMIT state is verified to be FALSE.
3. The selected PPD must be moved to the OUT position.
4. The USER_PERMIT state is verified to be TRUE. The transition time should correspond to the moment when the device reaches its OUT position.
13.1.3 MOBILE TRANSFER LINE BEAM DUMPS

The movable transfer line beam dumps (TEDs) provide two separate interlock signals. One signal provides USER_PERMIT=TRUE when the TED is IN beam (i.e. intercepting the beam), while the other signal provides USER_PERMIT=TRUE when the TED is OUT of beam.

13.1.3.1 MP-TEST:TED-STATE

This test verifies the correct functioning of the two TED interlocks.
This test must be repeated for each individual TED.
1. The selected TED must be moved to the IN beam position.
2. The 'TED-IN' USER_PERMIT must be TRUE. At the same time the 'TED-OUT' USER_PERMIT must be FALSE.
3. The selected TED must be moved to the OUT beam position.
4. The 'TED-OUT' USER_PERMIT must be TRUE. At the same time the 'TED-IN' USER_PERMIT must be FALSE.

In both cases the status of the TED must be monitored in parallel to ensure that the USER_PERMIT state transitions occur at the correct moment (within a few seconds). The total duration of the TED movements is of the order of 30-40 seconds.

13.1.4 CNGS NEUTRINO TARGET

The CNGS neutrino target provides two interlock signals.
A first USER_PERMIT signal is not maskable. It includes the target magazine rotation, the air cooling and the cap shielding. The USER_PERMIT is TRUE when the target is in a valid position, when the air cooling is operational and when the shielding is in place.
The corresponding tests are:
- MP-TEST:T40-ROT
- MP-TEST:T40-AIR-COOL
- MP-TEST:T40-CAP-SHIELDING.

A second USER_PERMIT signal is maskable. The USER_PERMIT is TRUE when the target table is in the correct position and when the target magazine position presents a target rod assembly to the beam. The corresponding tests are:
- MP-TEST:T40-TABLE-POS
- MP-TEST:T40-NOTARGET

Because this USER_PERMIT signal is maskable, test MP-TEST:SBF must be performed for this second USER_PERMIT.
For each front-end crate the reboot test MP-TEST:FE-REBOOT must be performed.

13.1.4.1 MP-TEST:T40-ROT

This test verifies the correction functioning of the target magazine interlock.
Initial conditions: the target is in a correct state and position, such that the USER_PERMIT is TRUE.
1. The target position is rotated.
2. The USER_PERMIT must change to FALSE during the entire duration of the target movement.
3. The USER_PERMIT must be TRUE again when the target is in position.

13.1.4.2 MP-TEST:T40-AIR-COOL

This test verifies the correct functioning of the target air cooling interlock.
Initial conditions: the target cooling is on, such that the USER_PERMIT is TRUE.
1. The air cooling is switched off.
2. The USER_PERMIT must change to FALSE.
3. The air cooling is switched on.
4. The USER_PERMIT must change to TRUE.

13.1.4.3 MP-TEST:T40-CAP-SHIELDING

This test verifies the correct functioning of the target cap shielding interlock.

*Initial conditions:* the target cap shielding is in position, such that the USER_PERMIT is TRUE.
1. The cap shielding is opened.
2. The USER_PERMIT must change to FALSE.
3. The cap shielding set back.
4. The USER_PERMIT must change to TRUE.

13.1.4.4 MP-TEST:T40-TABLE-POS

This test verifies the correct functioning of the target table position interlock.

*Initial conditions:* the target position is in a correct state, such that the USER_PERMIT is TRUE.
1. The target table position is changed.
2. The USER_PERMIT must change to FALSE.
3. The target table position is moved back.
4. The USER_PERMIT must change to TRUE.

13.1.4.5 MP-TEST:T40-NOTARGET

This test verifies the correct functioning of the ‘no-target position’ interlock.

*Initial conditions:* the target position is in a correct state, such that the USER_PERMIT is TRUE.
1. The target is rotated to the ‘no-target position’.
2. The USER_PERMIT must change to FALSE.
3. The target is rotated back.
4. The USER_PERMIT must change to TRUE.

13.1.5 CNGS HORN

The CNGS magnetic horn and reflector provide a USER_PERMIT that is TRUE when both horn and reflectors are both switched on and powered.

For each front-end crate the reboot test **MP-TEST:FE-REBOOT** must be performed.

13.1.5.1 MP-TEST:CNGS-HORN

This test verifies the correct functioning of the horn interlock.

*Initial conditions:* the horn is on, such that the USER_PERMIT is TRUE.
1. The horn is switched off.
2. The USER_PERMIT must change to FALSE.
3. The horn is switched back on.
4. The USER_PERMIT must change to TRUE.

13.1.6 CNGS HADRON STOP COOLING

The CNGS hadron stop cooling circuits are interlocked to prevent an over-heating of the dump blocks if beam hits the blocks with the cooling circuits turned off. The USER_PERMIT is true when all cooling pumps are turned on.

For each front-end crate the reboot test **MP-TEST:FE-REBOOT** must be performed.
13.1.6.1 MP-TEST:CNGS-HAD-COOL

This test verifies the correct functioning of the cooling interlock.

**Initial conditions:** the hadron stop cooling is ON, such that the USER_PERMIT is TRUE.

1. The cooling is stopped.
2. The USER_PERMIT must change to FALSE.
3. The cooling is switched on again.

The USER_PERMIT must change to TRUE.

13.1.7 FAST INTERNAL POWER CONVERTER INTERLOCKS

For power converter that feed electrical circuits with very short time constants or very strong fields, a fast internal power converter status signal is used to inhibit the beam before the power converter is shut off.

The USER_PERMIT is TRUE when the associated power converter is switched on.

The aim of the tests for this class of interlock signals is to verify that the interlock signal is sent out well before the current of the magnet attached to the converter starts to decay.

13.1.7.1 MP-TEST:FAST-PCINT-DELAY

This test verifies the timing of the fast power converter interlock USER_PERMIT signal with respect to the current decay of the current in the magnet string.

**Initial conditions:** no interlock is present, such that the USER_PERMIT is TRUE.

1. An interlock is generated manually. The associated power converter must switch off. The USER_PERMIT must change to FALSE.
2. The power converter current is retrieved for the cycle where the interlock was generated at one millisecond intervals.
3. The time where the converter switched off is estimated from the current function. This time is compared to the transition time of the USER_PERMIT at the associated BIC. The USER_PERMIT must switch from TRUE to FALSE before the current of the circuit decays.

13.1.8 WARM MAGNET INTERLOCKS

The warm magnet interlock system surveys the temperature of the transfer line magnets. In case an abnormal situation is detected (over-heating), the USER_PERMIT is set to FALSE 10 ms before the power interlock is generated to ensure that the beam is stopped before it is affected by the decaying magnetic field.

The test of each individual sensor of this system and the documentation of the tests is the responsibility of the system expert [9,10].

For each front-end crate the reboot test **MP-TEST:FE-REBOOT** must be performed.

An additional test must be performed to verify the correct timing of the interlock signals generated by the WIC.

13.1.8.1 MP-TEST:WIC-DELAY

This test verifies the timing of the USER_PERMIT signal with respect to the power converter interlock.

**Initial conditions:** no interlock is present, such that the USER_PERMIT is TRUE.

1. An interlock is generated manually. The associated power converter must switch off. The USER_PERMIT must change to FALSE.
2. The power converter current is retrieved for the cycle where the interlock was generated at one millisecond intervals.

3. The time where the converter switched off is determined from the current function. This time is compared to the transition time of the USER_PERMIT at the associated BIC. The USER_PERMIT must switch from TRUE to FALSE at least 5 milliseconds before the current of the septum converter decays.

13.1.9 EXTRACTION SEPTUM MAGNET INTERLOCK

The extraction septum magnet state (temperature, cooling...) is surveyed by a PLC that generates an interlock to the associated power converter and BIC whenever the septum magnet state is not correct. When a fault is detected on the septum magnet, the USER_PERMIT is switched to FALSE 10 milliseconds before the power converter interlock in order to stop the beam before the field of the septum is affected.

For each front-end crate the reboot test MP-TEST:FE-REBOOT must be performed.

13.1.9.1 MP-TEST:SEPT-DELAY

This test verifies the correct functioning of the septum magnet interlock that is generated by the septum magnet surveillance PLC. Both occurrence of the interlock and the interlock timing is verified.

Initial conditions: the septum power converter is ON and pulsing, i.e. is operating at a non-zero current. The USER_PERMIT state is TRUE.

1. A septum magnet interlock is generated manually. The power converter must switch off and the USER_PERMIT must change to FALSE.

2. The septum converter current is retrieved for the cycle where the interlock was generated at one millisecond intervals.

3. The time where the converter switched off is determined from the current function. This time is compared to the transition time of the USER_PERMIT at the associated BIC. The USER_PERMIT must switch from TRUE to FALSE at least 5 milliseconds before the current of the septum converter decays.

An example for such a test is shown in Figure 3 and Figure 4.
Figure 3: Example for the test MP-TEST:SEPT-DELAY. Evolution of the current decay of the septum magnet for a manually generated magnet interlock which starts around time 12310 ms.

Figure 4: Example for the test MP-TEST:SEPT-DELAY. The arrival time recorded in the BIC history buffer for a manually generated magnet interlock visible on the line 'PLC MSE septum' is at 12287 ms in super-cycle (SSC) 135912. This time may be compared with the start of the current decay in Figure 3. The time difference is 20 ms.
13.1.10 BEAM PROFILE SCREENS

The beam profile screens (BTVs) in the transfer lines are interlocked to prevent the passage of high intensity beam when the screens are moving from one position to the next or when the thick alumina screens are in beam. The USER_PERMIT is TRUE when the screens are out of the beam or when the very thin OTR screens are intercepting the beam. The USER_PERMIT is FALSE when the screens are moving and when the thick alumina screens are intercepting the beam.

Because the USER_PERMIT signals are maskable, test **MP-TEST:SBF** must be performed for each USER_PERMIT provided by this system.

For each front-end crate the reboot test **MP-TEST:FE-REBOOT** must be performed.

13.1.10.1 MP-TEST:BTV-POS

This test verifies the correct functioning of the BTV position interlock.

This test must be repeated for each individual BTV.

**Initial conditions:** all BTVs corresponding to a given group (associated to one USER_PERMIT) are OUT of beam, such that the USER_PERMIT is TRUE.

1. A selected BTV is cycled through each position.
2. For each position the USER_PERMIT status is verified. The USER_PERMIT must always be TRUE, except for the position corresponding to the alumina screen.

The short transition of the USER_PERMIT signal from TRUE to FALSE and back to TRUE when the BTVs are moving during the beam-out segment of the SPS cycle must be verified in the BIC history buffer.
13.2 SYSTEMS AND INTERLOCKS WITH SETTINGS

This tests described in this section require reference settings, tolerance or thresholds that must be managed in an appropriate way.

For each interlock the tests include changes of every interlock setting to verify the mapping of those betweens between equipment devices and the settings database.

13.2.1 COLLIMATOR POSITIONS

The interlocks of the transfer line collimators of TI2 and TI8 must be tested according to the procedures to be defined within the Collimator Control System.

The USER_PERMIT is TRUE when the collimator jaw positions are within a predefined position range and when the environmental parameters (temperature, cooling...) are normal.

Because the USER_PERMIT signals are maskable, test MP-TEST:SBF must be performed for each USER_PERMIT provided by this system.

For each front-end crate the reboot test MP-TEST:FE-REBOOT must be performed.

13.2.1.1 MP-TEST:JAW-POS

This test verifies the correction functioning of the jaw position interlock. It also verifies the correct association between interlock settings and a motor position.

This test must be repeated for each individual motor and for both directions of movement.

Initial conditions: all jaws are at their nominal positions such that the USER_PERMIT is TRUE.

1. A selected motor position is changed beyond the interlock tolerance window.
2. The USER_PERMIT state is verified to be FALSE.
3. The reference position for the motor is changed sufficiently to remove the interlock.
4. The USER_PERMIT state is verified to be TRUE.
5. The reference position for the motor is restored to its initial value.
6. The USER_PERMIT state is verified to be FALSE.
7. The tolerance window for the motor is changed sufficiently to remove the interlock.
8. The USER_PERMIT state is verified to be TRUE.

13.2.1.2 MP-TEST:COLL-ENVPAR

This test verifies the correction functioning of interlock on environmental parameters like temperature.

Initial conditions: the environmental parameters of the collimator are normal and the USER_PERMIT is TRUE.

1. A selected environmental parameter is simulated to be outside the allowed range.
2. The USER_PERMIT state is verified to be FALSE.

13.2.2 POWER CURRENT SURVEILLANCE

The current of selected power converters is surveyed by the ROCS control system running inside the Mugef crates. The current of the power that is read out through a DCCT by the Mugef system is averaged over N samples separated by 1 millisecond. An interlock is generated if the resulting average differs from the interlock reference value by more than the predefined interlock tolerance. The USER_PERMIT is set to
TRUE before extraction only when all its associated power converters provide a current within a predefined range.

For each power converter interlock, the parameters are:

1. Number of DCCT samples, which is likely to be set to 1 to minimize delays in the system.
2. Reference current.
3. Current tolerance.

The parameters depend on the SPS cycle.

Following an initial complete commissioning, the test must be performed for each new SPS cycle for a sample of 2-3 power converters of each ROCS front-end.

For initial complete commissioning the tests must be performed for 1 and for 5 DCCT samples.

For each front-end crate the reboot test **MP-TEST:FE-REBOOT** must be performed.

The power converter surveillance being triggered by a timing event, the tests:

- **MP-TEST:TIMING-EVENT-SHIFT**
- **MP-TEST:ABSENCE-TIMING-EVENT**

must be performed for each USER_PERMIT provided by this system.

Because the USER_PERMIT signals are maskable, test **MP-TEST:SBF** must be performed for each USER_PERMIT provided by this system.

The tests described below must be repeated for each power converter on at least one cycle.

13.2.2.1 MP-TEST:PC-REF

This test provides the verification that the PC surveillance system is able to trigger an interlock for a selected power converter. This test also verifies the correct association of the interlock reference and tolerances values to the selected power converter.

This test must be repeated for positive and negative current trims.

**Initial conditions:** all power converter interlock references are adjusted to produce USER_PERMIT=TRUE for the ROCS crate of the selected converter.

1. The setting of the power converter is trimmed by a sufficient amount to produce an interlock. The trim must be performed in small steps to validate the tolerance window.
2. The USER_PERMIT state is verified to be FALSE.
3. The interlock reference current is trimmed to agree with the new setting.
4. The USER_PERMIT state is verified to be TRUE.
5. The interlock reference is set back to the initial value. The USER_PERMIT must disappear again.
6. The tolerance window is increased to cover the actual current setting.
7. The USER_PERMIT state is verified to be TRUE.

13.2.2.2 MP-TEST: MBI-MBG-SWITCH

The TT41 main dipole string (MBG) and the TI8 main dipole string (MBI) are powered by a single power converter with mechanic and electronic switches. Dedicated DCCTs located in each circuit (MBG and MBI) are associated to dedicated ROCS channels and surveyed using the same principle as other power converters [8]. A measurement of the current of those dedicated DCCTs ensures that the power converter switch is in the correct position for a given SPS cycle.
The ROCS channel associated to the MBG circuit delivers a signal USER_PERMIT_MBG, the ROCS channel associated to the MBI branch produces a signal USER_PERMIT_MBI. This test verifies the correct functioning of the two USER_PERMITSs.

The USER_PERMIT must only switch to TRUE when the current is flowing through the corresponding circuit and when the measured current is within its tolerance window.

**Initial conditions:** machine and interlock settings are loaded into the ROCS channel associated to the MBG-MBI converter for a CNGS and a LHC cycle. The power converter is pulsing with the switches in position for the CNGS cycle.

1. USER_PERMIT_MBG must be TRUE and USER_PERMIT_MBI must be FALSE.
2. The power converter is switched off to change the setting of the mechanical switch to pulse the MBI circuit (unless the switching is performed automatically by the electronic switches). Both USER_PERMITS must be FALSE while the power converter is off.
3. USER_PERMIT_MBG must now be FALSE while and USER_PERMIT_MBI must be TRUE.

### 13.2.3 EXTRACTION SEPTUM GIRDER POSITION

The extraction septa are installed on movable girders to optimize the extraction channel aperture and to be able to retract the septa from the beam.

The position of the girder is surveyed and the associated USER_PERMIT is TRUE when the girder position is within a predefined position range.

The tests must be repeated for all girder motors.

Because the USER_PERMIT signals are maskable, test **MP-TEST:SBF** must be performed for each USER_PERMIT provided by this system.

#### 13.2.3.1 MP-TEST:SEPT-GIRDER

This test provides a verification of the girder position interlock. At the same time this test verifies the correct functioning of the interlock setting management system.

This test must be performed for both directions of movement, towards the beam and away from the beam.

**Initial conditions:** the girder is at its nominal position and the USER_PERMIT is TRUE.

1. The position of the girder is changed by a sufficient amount to produce an interlock (i.e. larger than the tolerance window).
2. The USER_PERMIT state is verified to be FALSE.
3. The interlock reference is trimmed to agree with the new girder position.
4. The USER_PERMIT state is verified to be TRUE.

### 13.2.4 EXTRACTION KICKER

Besides receiving the extraction permit signal from the master extraction BIC, the extraction kicker is also providing a USER_PERMIT signal that reflects the kicker status. This USER_PERMIT is TRUE only when the kicker is ON and operational and when the energy of the SPS matches the requested kicker voltage.

For each interlock condition that leads to USER_PERMIT=FALSE, the correct transition of the USER_PERMIT must be verified.

#### 13.2.4.1 MP-TEST:MKE-STATUS

This test provides a verification of the MKE extraction kicker status interlock (slow interlock).
Initial conditions:  the kicker state is ON and the USER_PERMIT is TRUE.
1. The kicker status is changed to FAULTY.
2. The USER_PERMIT state is verified to be FALSE.
3. The kicker status is changed to STANDBY.
4. The USER_PERMIT state is verified to be FALSE.
5. The kicker status is changed to ON.
6. The USER_PERMIT state is verified to be TRUE.

13.2.4.2 MP-TEST:MKE-ETRACK

This test verifies the energy tracking / interlocking of the extraction kicker.

Initial conditions:  the kicker state is ON, the energy is within the interlock window and the USER_PERMIT is TRUE.
1. The SPS main momentum is trimmed upwards in steps until it is outside the energy tolerance.
2. The USER_PERMIT state is verified to be FALSE.
3. The SPS momentum is set back to nominal.
4. The USER_PERMIT state is verified to be FALSE.
5. The SPS main momentum is trimmed downwards in steps until it is outside the energy tolerance. This trim applies to the current of the SPS main dipole magnets.
6. The USER_PERMIT state is verified to be FALSE.
7. The SPS momentum is set back to nominal.
8. The USER_PERMIT state is verified to be TRUE.

13.2.4.3 MP-TEST:MKE-RING-DUMP

This test verifies that the extraction kicker is triggering the SPS ring beam dump (for the circulating beam) whenever:
   a) the first CNGS batch is not extracted,
   b) the PFN have been charged, but the kicker has not been triggered due to an interlock.

The test must be repeated for condition a) and b).

Initial conditions:  the kicker state is ON, no interlock is present and the EXTRACTION_PERMIT is TRUE such that the kicker is pulsing normally.
1. An interlock is generated such that EXTRACTION_PERMIT is false and the extraction is inhibited.
2. The MKE must trigger a SPS ring beam dump request a few ms after the nominal extraction time.
14. INTERLOCK COMMISSIONING – BEAM TESTS

14.1 BEAM TEST IN THE SPS RING

Tests described in this section require circulating beam in the SPS ring.

14.1.1 BEAM INTENSITY

Two beam intensity interlocks provide means to limit the beam current to be extracted into the transfer lines.

The first interlock is generated from the SPS ring high intensity DC BCT. The interlock is used to dump the beam at the beginning of the SPS ramp when the beam intensity exceeds a predefined maximum value.

The second interlock is only usable for tests of the LSS4 extraction because it is based on the SPS ion BCT (so called BCT4) that is installed in LSS4. This system provides an interlock for extraction to LHC ring 2/TI8 or to CNGS/TT41 only. The beam intensity is measured some ten’s of milliseconds before extraction and an interlock is produced if the intensity exceeds the predefined threshold. The BCT saturates at an intensity of $7 \times 10^{11}$ charges, which makes it only useful for tests at low intensity.

The USER_PERMIT being triggered by a timing event, the tests:

- **MP-TEST:TIMING-EVENT-SHIFT**
- **MP-TEST:TIMING-EVENT-REMOVAL**

must be performed for each USER_PERMIT provided by this system.

For each front-end crate the reboot test **MP-TEST:FE-REBOOT** must be performed.

14.1.1.1 MP-TEST:BCT-RING

This test verifies the correct functioning of the SPS ring BCT interlock.

*Initial conditions:* the interlock threshold is set above the beam intensity used on the SPS cycle that is used for this test, such that the beam is not dumped.

1. The threshold of the interlock is reduced gradually.
2. As soon as the threshold is below the intensity in the SPS, the beam must be dumped during the SPS ramp. The time of the dump must agree with the expected delay programmed for the timing event.

14.1.1.2 MP-TEST:BCT-LSS4

This test verifies the correct functioning of the LSS4 extraction BCT interlock.

*Initial conditions:* the interlock threshold is set above the beam intensity used on the SPS cycle that is used for this test, such that the USER_PERMIT is TRUE.

1. The threshold of the interlock is reduced gradually.
2. As soon as the threshold is below the intensity in the SPS before extraction, the USER_PERMIT must be FALSE.

14.12 BUMPED BEAM POSITION

The beam position of the circulating SPS beam is surveyed before extraction to ensure a correct extraction trajectory. The corresponding permit is generated by a MOPOS front-end crate. The USER_PERMIT switched to TRUE before extraction only if the beam position is within a predefined position range. The timing sequence of the USER_PERMIT is shown in Figure 5 below. Due to limitations of the acquisition system,
it is presently not possible to survey the beam position at regular intervals of few milliseconds: only a single measurement can be performed just before extraction.

![Diagram of beam position timing](image)

**Figure 5**: Timing of the bumped beam position USER_PERMIT. A real-time task triggered by a timing event just before extraction measures the beam position and switches the USER_PERMIT to TRUE if the position is within tolerance. The timing of the measurement is adjusted to be as close as possible to the moment where the extraction kicker PFNs are charged (see Figure 1). The USER_PERMIT is reset to FALSE at the end of the SPS cycle.

This USER_PERMIT being triggered by a timing event, the tests:

- **MP-TEST:TIMING-EVENT-SHIFT**
- **MP-TEST:TIMING-EVENT-REMOVAL**

must be performed for each USER_PERMIT provided by this system.

Because the USER_PERMIT signals are maskable, test **MP-TEST:SBF** must be performed for each USER_PERMIT provided by this system.

For each front-end crate the reboot test **MP-TEST:FE-REBOOT** must be performed.

### 14.1.2.1 MP-TEST:EXTR-BP

This test verifies the correct functioning of the bumped beam position interlock.

At the same time, the correct association and downloading of interlock settings is also verified.

This test must be repeated for each monitor that is used for the interlock.

**Initial conditions**: the SPS beam is bumped to the nominal position and the interlock reference is set to match the position, such that USER_PERMIT=TRUE.

1. The beam position is changed to move outside the tolerance window of the interlock.
2. The USER_PERMIT state is verified to be FALSE.
3. The interlock reference is adjusted to the new position.
4. The USER_PERMIT state is verified to be TRUE.
5. The interlock reference is set back to the initial value. The USER_PERMIT must disappear again.
6. The tolerance window is increased to cover the actual beam position.
7. The USER_PERMIT state is verified to be TRUE.
14.1.2.2 MP-TEST:EXTR-BP-SETTING

This test verifies the correct functioning of the bumped beam position interlock when the settings of the MOPOS acquisition are incorrect for a given beam (gain too high, gain too low, wrong gate delay).

This test must be repeated for each monitor that is used for the interlock.

Initial conditions: The SPS beam is bumped to the nominal position and the interlock reference is set to match the position, such that USER_PERMIT=TRUE.

1. The gain is increased until the BPM signal is too high to provide accurate and valid data.
2. The USER_PERMIT state is verified to be FALSE.
3. The gain is decreased until the BPM signal is too low to provide accurate and valid data.
4. The USER_PERMIT state is verified to be FALSE.
5. The acquisition gate delay with respect to the revolution frequency signal is displaced until there is no valid data (gate outside of beam).
6. The USER_PERMIT state is verified to be FALSE.

14.1.3 RADIAL BEAM POSITION

The average radial beam position of the circulating SPS beam, which is related directly to the RF frequency setting and to the momentum offset of the beam with respect to the central beam momentum, is surveyed before extraction to ensure a correct extraction trajectory. The corresponding permit is generated by the same MOPOS front-end crate that is also surveying the bumped beam position (section 14.1.2.1). The USER_PERMIT switches to TRUE before extraction only if the beam position is within a predefined position range.

This USER_PERMIT being triggered by a timing event, the tests:

- MP-TEST:TIMING-EVENT-SHIFT
- MP-TEST:TIMING-EVENT-REMOVAL

must be performed for each USER_PERMIT provided by this system.

Because the USER_PERMIT signals are maskable, test MP-TEST:SBF must be performed for each USER_PERMIT provided by this system.

Test MP-TEST:EXTR-BP-SETTING must also be applied to this USER_PERMIT since the acquisition system is identical.

For each front-end crate the reboot test MP-TEST:FE-REBOOT must be performed.

14.1.3.1 MP-TEST:SPS-BP-RADIAL

This test verifies the correct functioning of the radial beam position interlock.

At the same time, the correct association and downloading of interlock settings is also verified.

Initial conditions: The SPS orbit is centred and the interlock reference is set to match the position, such that USER_PERMIT=TRUE.

1. The RF frequency / radial position of the circulating SPS beam at extraction is changed to move outside the tolerance window of the interlock.
2. The USER_PERMIT state is verified to be FALSE.
3. The tolerance window is increased to cover the actual beam position.
4. The USER_PERMIT state is verified to be TRUE.
14.1.3.2 MP-TEST:EXTR-BP-RADIAL-SETTING

This test verifies the correct functioning of the radial beam position interlock when the settings of the MOPOS acquisition are incorrect for a given beam (gain too high, gain too low, wrong gate delay).

Initial conditions: the SPS beam is bumped to the nominal position and the radial beam position is correct, such that USER_PERMIT=TRUE.

1. The gain is increased until the BPM signal is too high to provide accurate and valid data.
2. The USER_PERMIT state is verified to be FALSE.
3. The gain is decreased until the BPM signal is too low to provide accurate and valid data.
4. The USER_PERMIT state is verified to be FALSE.
5. The acquisition gate delay with respect to the revolution frequency signal is displaced until there is no valid data (gate outside of beam).
6. The USER_PERMIT state is verified to be FALSE.
14.2 BEAM TEST IN THE TRANSFER LINES

Test described in this section require beam in the SPS ring and in the transfer line corresponding to the tested equipment.

14.2.1 BEAM LOSS MONITORING

The beam loss monitoring is split over two systems that act either on the circulating beam in the SPS or on the following extractions.

The beam loss monitors (BLMs) in the extraction area that includes the septum magnets are connected to the SPS ring interlock system. Activation of an interlock produces a beam dump of the circulating SPS ring. This interlock protects the extraction elements against failures induced by the circulating beam before extraction.

The beam loss monitors in the transfer lines cannot act directly on the beam that is producing the loss, but only on the following extractions. When the beam loss seen on any monitor in the transfer lines is above threshold, the USER_PERMIT must switch to FALSE. The USER_PERMIT must remain latched in this state until it is reset manually by the operation crews. The timing of the BLM USER_PERMIT is shown in Figure 6.

![Figure 6: Timing of the BLM USER_PERMIT signal for three different cases (CNGS extraction). Top: no BLM interlock. The USER_PERMIT switches to TRUE ≈ 100 ms before extraction and remains TRUE until it is automatically reset at the end of the SPS cycle. Middle: an interlock is generated by the BLM system during the second CNGS extraction. The USER_PERMIT changes to FALSE and remains FALSE until a manual reset is performed by the operation crew. Bottom: an interlock is generated by the BLM system during the first CNGS extraction. The USER_PERMIT changes to FALSE and remains FALSE until a manual reset is performed by the operation crew. In this case the second extraction is inhibited since the BLM USER_PERMIT is FALSE. For LHC beam extraction, the logic is identical, but for a single extraction.](image)

Each individual BLM detector (ionization chamber) is tested in the laboratory. The cabling is tested by replacing the BLM detector with a current source to inject current into the signal cable. Those tests are the responsibility of the system engineer.

Beam loss monitors must be tested with beam: sufficient beam loss must be generated, if necessary by miss-steering a beam of adequate intensity to generate beam losses.

This USER_PERMIT being triggered by a timing event, the tests:

- **MP-TEST:TIMING-EVENT-SHIFT**
- **MP-TEST:TIMING-EVENT-REMOVAL**
must be performed for each USER_PERMIT provided by this system. Because the USER_PERMIT signals are maskable, test MP-TEST:SBF must be performed for each USER_PERMIT provided by this system. The latching and the reset of the beam loss interlock must be verified according to the test MP-TEST:LATCH.

For each front-end crate the reboot test MP-TEST:FE-REBOOT must be performed.

14.2.1.1 MP-TEST:BLM-LOSS

This test verifies the correct functioning of a group of BLMs associated to one USER_PERMIT signal.

This test must be repeated for each individual BLM.

Initial conditions: No beam loss present, the USER_PERMIT is TRUE.

1. With a safe beam, small but measurable beam loss is produced in the region covered by the BLM.
2. The interlock threshold is reduced below the level of the beam loss signal.
3. The USER_PERMIT state is verified to switch to FALSE after the extraction as long as the beam loss is present.

14.2.2 TRANSFER LINE BEAM POSITION

For the CNGS beam the trajectory in the TT41 transfer lines is interlocked. Each position monitor has an associated reference setting and tolerance window. The tolerance window is typically 2-4 mm in most parts of the transfer line, except on the last 3 monitors in front of the target where the tolerance is set to ~0.5 mm. When the position of any monitor in the transfer lines is outside the tolerance range, the USER_PERMIT must switch to FALSE. The USER_PERMIT must remain latched in this state until it is reset manually by the operation crews. The timing of the BPM USER_PERMIT is similar to the BLM USER_PERMIT timing shown in Figure 6.

This USER_PERMIT being triggered by a timing event, the tests:

- MP-TEST:TIMING-EVENT-SHIFT
- MP-TEST:TIMING-EVENT-REMOVAL

must be performed for each USER_PERMIT provided by this system. Because the USER_PERMIT signals are maskable, test MP-TEST:SBF must be performed for each USER_PERMIT provided by this system. The latching and the reset of the beam position interlock must be verified according to the test MP-TEST:LATCH.

For each front-end crate the reboot test MP-TEST:FE-REBOOT must be performed.

14.2.2.1 MP-TEST:CNGS-BP1

This test verifies the individual response of the interlock for each beam position monitor. This test also verifies the correct assignment of monitors and interlock settings.

This test must be repeated for each monitor.

Initial conditions: the trajectory is corrected towards the reference trajectory which corresponds to the interlock reference settings, such that the USER_PERMIT is TRUE.

1. The interlock reference of the selected monitor is changed by a sufficient amount to generate an interlock.
2. The USER_PERMIT state is verified to be FALSE.
3. The trajectory measurement is used to verify that the conditions are indeed such as to generate an interlock.
4. The interlock tolerance window of the selected monitor is increased sufficiently to remove the interlock condition.
5. The USER_PERMIT state is verified to be TRUE.

14.2.2.2 MP-TEST:CNGS-BP2

This test verifies globally the correct functioning of the trajectory position interlock. The test must be performed for at least two correctors with a phase advance difference of 90 degrees (or close to 90 degrees).

Initial conditions: the trajectory is corrected towards the reference trajectory which corresponds to the interlock reference settings, such that the USER_PERMIT is TRUE.
1. A selected corrector of the transfer is used to perturb the trajectory, in steps corresponding to ~1 mm in the major part of the line and to ~0.2 mm near the target (whichever limit is reached first).
2. The perturbation is increased until the excursions reach a critical level where the extraction permit must disappear.
3. The USER_PERMIT state is verified to be FALSE.
4. The trajectory measurement is used to verify that the trajectory excursions are indeed such as to generate an interlock.
14.2.3 FAST MAGNET CURRENT CHANGE MONITOR

To be fully efficient without generating useless spurious interlocks, each Fast Magnet Current Change Monitor (FMCM) unit must be carefully setup and matched to its associated magnet and power converter. The parameter to be adjusted and verified is the interlock level on the current change. The FMCM adjustment and test must be performed and documented by the system expert.

The USER_PERMIT must switch to FALSE whenever the current change rate exceeds the predefined level.

Because the USER_PERMIT signals are maskable, test MP-TEST:SBF must be performed for each USER_PERMIT provided by this system.

14.2.3.1 MP-TEST:FMCM-BP

This test provides a verification of the interlock threshold with the help of a low intensity beam where equipment damage is excluded.

**Initial conditions:** the power converter associated to the selected FMCM is pulsing normally, the FMCM USER_PERMIT is TRUE.

1. The current function of the power converter is trimmed: a steep downward step is programmed into the function at a time slightly after extraction (5-10 ms). The step must be sufficiently large to trigger the FMCM and result in the USER_PERMIT being FALSE (for most power converters in the transfer line, the regular ramp down of the power converter will already be sufficient to perform this test).

2. The transition of the FMCM USER_PERMIT from TRUE to FALSE just after the current step is verified with the BIC history buffer. The current of the power converter is read out at 1 millisecond intervals and used together with the FMCM Post Mortem Data to evaluate the correctness of the FMCM thresholds (warning threshold and the actual beam dump threshold).

3. The extraction timing is advanced in small steps of 1 ms (granularity of the General Machine Timing System events) towards the time of the power converter current step. At each step the trajectory of the beam is recorded in the associated transfer line. This step is repeated until the beam is no longer extracted. For converters with very fast current decay times (for example the extraction septa) smaller time steps must be considered. This may be achieved by modifying the programmed current step.

4. The recorded trajectories are used to evaluate the maximum excursion of the beam due to the ‘failing’ power converter before the FMCM inhibits the beam.
15. REFERENCES

1. V. Kain et al, Material Damage Test with 450 GeV LHC-Type Beam, Proceedings of PAC05, Knoxville, TN.
2. B. Puccio et al, The beam interlock system for the LHC, LHC-CIB-ES-0001-00-10, EDMS No. 567256.
4. B. Goddard et al, Interlocking between SPS, CNGS, LHC transfer lines and LHC injection, LHC-CI-ES-0002 ver.1.0, EDMS No. 602470.
5. J. Wenninger, Software interlock system for the SPS and LHC, in preparation.
9. P. Dahlen, Procedures for the commissioning of the normal conducting magnet interlock system in the TT41 transfer line, CNGS-2006-03 rev.0.2, EMDS No. 699907.
10. M. Zaera-Sanz et al, Procedures for the commissioning of the normal conducting magnet interlock system in the SPS-LHC transfer line TI 8, LHC-D-TP-0001 rev 0.2, EDMS No. 599492.